Doc 9886, CAEP/7

INTERNATIONAL CIVIL
AVIATION ORGANIZATION

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

SEVENTH MEETING

Montréal, 5–16 February 2007

REPORT

Approved by the Committee on Aviation Environmental Protection and published by decision of the Council.

The views expressed in this report should be taken as advice of a body of experts to the Council but not as representing the views of the Organization.

The Supplement to the report indicates the action taken on the report by the Council.

MONTRÉAL 2007

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INTERNATIONAL CIVIL AVIATION ORGANIZATION

SEVENTH MEETING OF THE
COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

Montreal, 5 to 16 February 2007

SUPPLEMENT NO. 1

1. The Council, at the 15th meeting of its 180th Session on 15 March 2007, took action on the recommendations of the seventh meeting of the Committee on Aviation Environmental Protection (CAEP/7), as set forth hereunder.

2. RECOMMENDATIONS FOR AMENDMENT OF STANDARDS AND RECOMMENDED PRACTICES AND PROCEDURES (RSPP)

2.1 Recommendation 1/1, page 1-8
Recommendation 3/1, page 3-5

2.2 The Council noted that the Air Navigation Commission had made a preliminary review of the above recommendations and agreed that they should be referred to Contracting States and international organizations. Following receipt of comments, the Commission will conduct a detailed review and will then present its recommendations for action to the Council.

3. RECOMMENDATIONS OTHER THAN FOR STANDARDS AND RECOMMENDED PRACTICES AND PROCEDURES

3.1 The Secretary General will arrange for any follow-up action in respect of all approved recommendations as indicated in the action taken hereunder.

Report Reference		Action by Council (C) or Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
1/2	1-9	ANC	**Publication of guidelines related to engine emissions certification** Approved the recommendation and requested the Secretary General to take the necessary action.
1/3	1-17	ANC	**Publication of the report of the independent experts on the 2006 NO_x review and the establishment of medium and long term technology goals for NO_x** Approved the recommendation and requested the Secretary General to take the necessary action.
1/4	1-19	ANC	**Guidance material on airport air quality** Approved the recommendation and requested the Secretary General to take the necessary action.
2/1	2-2	C	**Publication of information on voluntary measures** Approved the recommendation and requested the Secretary General to take the necessary action.
2/2	2-5	C	**Publication of the report on voluntary emissions trading for aviation** Approved the recommendation and requested the Secretary General to take the necessary action.

Report Reference		Action by Council (C) or Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
2/3	2-8	C	**Guidance on emissions trading for aviation** Approved the recommendation as draft guidance and requested the Secretary General to take the necessary action, with the understanding that the President of the Council would develop an introductory text (Foreword) to reflect the views of the ICAO Council on this issue and that reference to the Foreword would be inserted in the CAEP/7 Report.
2/4	2-12	C	**Guidance on local emissions charges** Approved the recommendation and requested the Secretary General to take the necessary action.
2/5	2-12	C	**Policy on local air quality emissions charges** Approved the recommendation with amendments and requested the Secretary General to take the necessary action.
3/2	3-7	ANC	**Amendments to the *Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft* (Doc 9501)** Approved the recommendation and requested the Secretary General to take the necessary action.
3/3	3-14	ANC	**Amendment of the *Airport Planning Manual*, Part 2 – *Land Use and Environmental Control* (Doc 9184)** Approved the recommendation and requested the Secretary General to take the necessary action.

Report Reference		Action by Council (C) or Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
3/4	3-16	C	**Amendment to the *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829)** Approved the recommendation and requested the Secretary General to take the necessary action.
3/5	3-22	ANC	**Publication of a new ICAO manual containing the Recommended Method for Computing Noise Contours around Airports** Approved the recommendation with amendments and requested the Secretary General to take the necessary action.
3/6	3-25	ANC	**Publication of a new ICAO circular on noise and emission effects from *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS) noise abatement departure procedures** Approved the recommendation with amendments and requested the Secretary General to take the necessary action.
4/1	4-25	C	**Future work programme** Approved, in principle, the revised work programme, subject to the views of the Finance Committee on its impact on the Programme Budget for 2008-2009-2010.

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SEVENTH MEETING OF THE
COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP) (2007)

LETTER OF TRANSMITTAL

To: President of the Council

From: Chairman, Committee on Aviation Environmental Protection (CAEP) (2007)

I have the honour to submit the report of the seventh meeting of the Committee on Aviation Environmental Protection (CAEP) which was held in Montréal from 5 to 16 February 2007.

Robert Shuter
Chairman

Montréal, 16 February 2007

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LIST OF RECOMMENDATIONS*

* Recommendations annotated "RSPP" relate to proposals for amendment of Standards, Recommended Practices and Procedures for Air Navigation Services or guidance material in an Annex.

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

SEVENTH MEETING

Montréal, 5 to 16 February 2007

HISTORY OF THE MEETING

1. DURATION

1.1 The seventh meeting of the Committee on Aviation Environmental Protection (CAEP/7) was opened by the President of the Council, in Montréal, at 0930 hours, on 5 February 2007. The meeting ended on 16 February 2007.

2. ATTENDANCE

2.1 The meeting was attended by members and observers nominated by 22 Contracting States and 9 international organizations, as well as by advisers and others as shown in the list below :

Members	Advisers	State
G.A. Omaechevarria	J. Riaboi	Argentina
D.G. Southgate	R. Owen-Jones S. White T. Milczarek	Australia
A.C. Romera	E.S.A de Andrade F. Scatolini J. Barat J.A. da Silveira W.V. Filho	Brazil
R. Shuter	A. Simpson B. Pang J. Hull L. Aalders M. Dorais M. Jones R. Roy S. Donohue S. Mallet T. Lowrey T. McDonald D. McLeay M. Manzo	Canada
P. Langumier	A. Depitre J. B. Rigaudias	France
F. Pleines-Schmidt	I. Bilas	Germany

Members	Advisers	State
	J. Scheelhaase T. Weber	
R. Cecchi	A. Paonessa A. Sbuttoni D. Romano F. Cucuzza F. Sepe G. Gulienetti P. Massoli	Italy
M. Kawakami	K. Nii K. Sakamoto K. Ueki S. Hayashi S. Watanabe T. Kondo T. Nakashima T. Nishimura T. Tanaka Y. Nakamura H. Ishii T. Sasaki	Japan
G. Bekebrede	H. Pulles D. Dijkstra	Netherlands
B. Szuman		Poland
S.A. Volkov	D. Shiyan V. Korovkin Y. Haletskij	Russia Federation
Looi Han Seng	S. Mattar S.Teo	Singapore
A. Iglesias Sastre	A. Benito	Spain
K. Sjölin	A. Gradin K. Keldusild M. Vinikainen M. Tupamaki	Sweden
C. Marthe	U. Ziegler	Switzerland

Members	Advisers	State
M. Capstick	E. Eyers D. Hart D. Lee D. Lister D. Rhodes J. Adam J. Moor M. Cork M. Mann M. Nesbit M. Ralph N. Leeds P. Newton R. Gardner	United Kingdom
C.E. Burleson	J. Draper C. Holsclaw L. Maurice J. Skalecky G. Fleming D. Nelson	United States

Observers	Advisers	State
T. Kråkenes	B. R. Bay C.M. Ringkjøp A. Gaustad	Norway

Observers	Advisers	International Organization
V. Nitsche	E. Fleuti C. Goater M. Hankanen P. Karamanos A. Kwan R. Marchi A. McGinley L. Michaud A. Murray E. Nielsen X. Oh J. Steinhilber	ACI
R. Salvarani	M. Crompton N. Ladefoged J. Barton W. Franken S. Arrowsmith J. Boettcher	EC
R. Gage	P.R. Ingleton G. Visele D. Weir J. Gilley	IBAC

Observers	Advisers	International Organization
A. Joselzon	D. Allyn H. Aylesworth A. Barton J.M. Boiteux J. Bonnet C. Chadourne D. Collin W. Conley F. Couillard S. Davis-Mendelow P. de Saint-Aulaire W. Dodds R. Dubebout C. Etter P. Fonta G. Freire G. Girard C. Grandi M. Huising E. Jacobs E. Jahangir P. Lempereur J. Leverton M. Majjigi R. Muller T. Nakae K. Orth B. Pang K. Renger N. Rizk G.Rollin C. Russell S. Sampath D. Sepulveda B. Solaimani M. Van Boven F. Viscotchi R. Von Wrede J. Yu M. Hurd	ICCAIA
T. Johnson		ICSA

Observers	Advisers	International Organization
A. Hardeman	M. Comber C. Markou B.O. Naes R. Brown D. Jensen K. Morris V. Jones G. Morse T. McGraw Le Thi Mai B. Hawkins N. Young M. Eran Tasker D. Tompkins T. Windmuller K. Brennan	IATA
R. Brons		IFALPA
	S. Pesmajoglou	UNFCCC
H. Puempel		WMO

The meeting was also attended by:

G. M. Aguirre	Representative of Chile on the Council of ICAO
A. Mena	Alternate Representative of Chile on the Council of ICAO
F. Perez	Alternate Representative of Chile on the Council of ICAO
J. Salinas	Alternate Representative of Chile on the Council of ICAO
C. Law	Advisor to the Representative of China on the Council of ICAO
N. Liang	Advisor to the Representative of China on the Council of ICAO
H. Liu	Advisor to the Representative of China on the Council of ICAO
L. Tong	Advisor to the Representative of China on the Council of ICAO
Y. Tsang	Advisor to the Representative of China on the Council of ICAO
Q. Zhan	Advisor to the Representative of China on the Council of ICAO
K. Zhou	Advisor to the Representative of China on the Council of ICAO
S.A.S. Elazab	Representative of Egypt on the Council of ICAO
J. Min	Alternate Representative of Korea on the Council of ICAO
D. Mendez-Mayora	Alternate Representative of Mexico on the Council of ICAO
M. Sayce	Alternate Representative of United Kingdom on the Council of ICAO
M. Ko	Expert invited by the Secretariat
V. Sparrow	Expert invited by the Secretariat
R.C. Miake-Le	Expert invited by the Secretariat

3. OFFICERS AND SECRETARIAT

3.1 Mr. R. Shuter (Canada) was elected Chairman of the meeting and Mr. G. Bekebrede (Netherlands) was elected Vice-Chairman of the meeting. The Secretary of the meeting was Mrs. J. Hupe, assisted by Mr. L. Mortimer, Consultant, Mr. A. Muckle, Mrs. C. Fischer, Ms. C. Alves Rodrigues and Ms. B. Ferrier of Environmental Unit, Air Transport Bureau; Mr. B. Peguillan, Economic Policy and Infrastructure Management Section, Air Transport Bureau; and Mr. C. Mustapha, Economic Analyses and Databases Section, Air Transport Bureau. Also participating during the meeting were Messrs. D. Monaco, E. Lassooij, and H. Defalque of Flight Safety Section, Air Navigation Bureau, Mr. G. Emausson, Air Traffic Management Section, Air Navigation Bureau, Dr. O. Turpeinen, and Mr. N. Halsey, Meteorology Section, Air Navigation Bureau and Mr. B. Verhaegen, Legal Bureau.

4. LANGUAGES

4.1 Interpretation and translation were provided in Arabic, English, French, Russian and Spanish.

5. AGENDA

5.1 The Council approved the following agenda for the meeting:

Agenda Item 1: Review of proposals relating to aircraft engine emissions, including the amendment of Annex 16, Volume II;

Agenda Item 2: Review of market-based options to limit or reduce emissions;

Agenda Item 3: Review of proposals relating to aircraft noise, including the amendment of Annex 16, Volume 1;

Agenda Item 4: Future work.

6. TERMS OF REFERENCE

6.1 To undertake specific studies, as approved by the Council, related to control of aircraft noise and gaseous emissions from aircraft engines.

6.2 In its work the committee shall take into account the following:

a) effectiveness and reliability of certification schemes from the viewpoint of technical feasibility, economic reasonableness and environmental benefit to be achieved;

b) developments in other associated fields, e,g. land use planning, noise abatement operating procedures, emission control through operational practices, etc.;

c) international and national programmes of research into control of aircraft noise and control of gaseous emissions from aircraft engines; and

d) the potential interdependence of measures taken to control noise and to control engine emissions.

7. **WORK PROGRAMME**

7.1 **NOISE**

N.1 **CURRENT TECHNICAL ISSUES**

a) Establish a common position on requirements for the uses of engine de-rate as an operational limitation in an application for noise re-certification.

b) Establish rules and guidance material for possible revision of aeroplane certificated noise levels, in case of new certification demonstration procedures or aircraft modification applications.

c) Recommend:

1) definitions for "average wind speed", cross-wind average wind speed", "gust" and "cross-wind gust" for aircraft noise certification;

2) update of IEC references in Annex and the ETM; and

3) guidance for Differential Global Positioning Systems used in Certification testing.

d) Report on:

1) the progress of adopting the updated atmospheric absorption procedure;

2) the progress in developing acoustical change analysis guidance for small propeller driven aeroplanes under Chapter 10 that have their propeller replaced by a different count propeller;

3) development of guidance on interpolating noise levels between approved noise/mass values; and

4) development of guidance on APU operation during noise certification testing.

e) New environmental technical manual:

1) determine the resources already available and applicable for use in developing the material;

2) investigate all equivalent procedures used in noise certification demonstrations and describe these procedures and their application; and

3) develop explanatory information about Annex 16, Volume I and equivalent procedures.

f) Rotocraft issues

1) study ways to make rotocraft noise reduction schemes more effective in addressing both noise certification and Land Use Planning (LUP) purposes, and to develop guidelines for providing helicopter data for LUP purposes via appropriate process; and

2) study all technical points linked to helicopter noise certification.

g) Workshops:

1) following completion of technical guidelines for aeroplanes re-certification, re-certification workshops will be conducted in different regions to disseminate certificating authorities with experience in aircraft noise-recertification. The goal of workshops will be to promote ICAO/CAEP noise certification rules and methods. Workshops will focus on:

— explanation of noise certification development and harmonization;

— presentation of noise re-certification guidelines (theoretical and practical aspects); and

— exchange of experience with participants

h) Monitor use of noise documentation guidelines:

N.2 FUTURE OF THE NOISE CERTIFICATION SCHEME

a) Review the purpose of certification

b) Review the present Annex 16, Volume I, Chapter 3 demonstration procedures for noise certification with a view to better adapting them to modern aeroplanes and better representing the operational procedures used by such aeroplanes.

c) Investigate the possibility of achieving reductions at each of the reference noise certification points.

d) Variable noise reduction system or technology:

1) develop adapted procedures for noise certification of aeroplanes with specific systems or equipment delivering noise abatement around airports by automatically acting either on the noise sources or the flight path of the aeroplane; and

2) develop guidance and standards for the assessment and demonstration of the noise benefits associated with the operation of those systems/equipment.

e) Monitor research to characterize, quantify, and measure sonic boom signatures, and their acceptability. The eventual goal of this effort is ".. to achieve international agreement on measurement of sonic boom, the definition in quantitative or qualitative terms of the expression 'unacceptable situation for the public' and the establishment of corresponding limits," as stated in Assembly Resolution A33-7, Appendix G.

f) Consider the development of Noise Certification Standards and Recommended Practices that are economically reasonable, technologically practical and appropriate for future civil supersonic vehicles.

N.3 **AIRCRAFT TYPE NOISE CERTIFICATION DATABASE**

a) To complete ICAO certificated NoisedB taking into account the following points:

- certificated noise data will be validated by certificating authorities;
- certificated authority data will be inserted when differing from initial certificated noise data;
- certificated data will be provided for re-certificated aeroplanes; and
- resolution of instances where multiple noise levels assigned to a unique configuration.

b) All technical parameters relevant for determining noise levels will be taken into account in NoisedB.

c) Ensure consistency with the corresponding emissions database. Investigate standardization of data field nomenclature.

d) Study methods to enable the unique identification of acoustic configuration.

N.4 **MONITORING NOISE TECHNOLOGY (TO BE COORDINATED WITH WG/3)**

a) Provide advice and information on mid- and long-term noise reduction technology prospects, by taking into consideration the various national and international research programme goals and milestones.

b) Study the relationships between noise and emissions trade-offs, for aircraft production cases and long-term views (20 years). The study will be conducted for NO_x emissions and for all other relevant emitted gases and smoke. Trade-offs will be evaluated for take-off, approach and flyover conditions. Cumulative effects will be produced.

N.5 **AIRPORT PLANNING AND LAND-USE PLANNING AND MANAGEMENT**

a) Update the *Airport Planning Manual* (Doc 9184) and investigate the possibility of making the *Airport Planning Manual* more readily and cheaply available.

b) Exchange information on best practices by comparing different national systems and the possibility of learning from mistakes and document, for the purposes of developing ICAO guidance, land-use policies and procedures that have been shown to be successful.

c) Update the Balanced Approach guidance material. Further develop the proposed appendices on case studies and on encroachment and explore the issue of community engagement.

d) Monitor and report on evolution of the implementation of environmental measures at airports and by States.

e) Delivery of workshops to promote the Balanced Approach document and the *Airport Planning Manual, Part 2 – Land Use and Environmental Control*.

N.6 **NOISE ABATEMENT OPERATIONAL PROCEDURES**

a) Exchange information and data on the outcome of dedicated research.

b) Review prospects for the optimization of procedures and for the development of advanced procedures in relation to ground and airborne system developments, assessing the corresponding environmental effects (for take-off).

c) Assess noise and emissions reductions accrued from the use of CDAs.

N.7 **MODELLING AND ASSESSMENT**

a) Continue to update, validate and document the MAGENTA tool and its databases to ensure that it provides reliable assessments of regional and global aircraft noise exposure. To provide and update of the evolution of the noise climate by CAEP/7.

b) Perform noise assessment studies that would serve as input into FESG cost benefit studies that would analyse the effectiveness of other elements of noise mitigation. Carefully consider the cost associated with collecting data of this type on a global basis.

c) Maintenance of the necessary registration databases for CAEP analysis.

d) Update the *Recommended Method for computing Noise Contours around Airports* (Circ 205) to reflect current practice and consider for inclusion complementary information currently under development by the Society of Automotive Engineers Aviation Noise Committee and the European Civil Aviation Conference (ECAC).

e) Develop noise/performance database that accompanies Circular 205.

f) Continue work that analyses population/housing developments around airports and report on the degree to which noise protection zones are developed and enforced.

g) Evaluate the use of the models listed in the attachment to this work programme and potential models for the analysis of trade-offs in coordination with FESG.

7.2 **EMISSIONS**

E.1 **ASSESSMENT OF THE EVOLUTION OF THE OVERALL EMISSIONS CONTRIBUTION**

E. 2 RESEARCH

E.2.1 Monitor and foster research to characterize further the air quality and global effects resulting from current and projected future aircraft exhaust emissions, including aviation's contribution relative to other sources. Report on the results of this research, evaluating and highlighting the aviation environmental impacts relative to impacts from other sources.

E.3 SUPPORT TO OTHER UNITED NATIONS BODIES AND INTERNATIONAL ORGANIZATIONS

E.3.1 To continue to cooperate closely with the IPCC and other organizations involved in the definition of aviation's contribution to environmental problems in the atmosphere, and with organizations involved in policy-making in this field, notably with the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC).

E.3.2 Provide clarification and advice as necessary to UNFCCC on aviation emissions data and methodological issues including:

a) facilitate provision of modelled fuel consumption and emissions data arising from the use of validated aviation model for at least 2000 and 2001 (data by country, and, if possible, by airline and aircraft/engine combination);

b) identify areas for improvement of the quality of data reporting, including revised and updated emissions factors; and

c) assess and recommend options for improving the methodologies for estimating and reporting GHG emissions from international aviation.

E.4 LONG-TERM TECHNOLOGY GOALS

E.4.1 Provide assessment of advances in engine and aircraft design technology for subsonic and possible future supersonic aeroplanes and the degree to which these technologies could influence emission levels and fuel consumption; including the potential benefits and trade-offs amongst various emissions and noise, the likely timescale for introductions and appropriate inputs for assessment of the associated economic and environmental costs and benefits.

E.4.2 For the purposes of establishing long-term technology goals for aircraft emissions reductions:

a) implement a CAEP-approved process to set, periodically review and update technology goals and identify environmental benefits, taking into account progress in ongoing R&D efforts toward reducing aircraft emissions, environmental interdependencies and trade-offs, and scientific understanding of the effects of aircraft engine emissions;

b) support and monitor development of methods for understanding the inter-relationship of technology goals targeting individual emissions performance improvements; and

c) develop the inputs appropriate for use of air quality and climate impact models to be used by CAEP to quantify the value of emissions reduction and to estimate the benefit from long-term goals.

E.5 METHODOLOGIES AND STANDARDS

E.5.1 In concert with the ICAO goals for improvement in the environmental performance of aviation and in relation to the emission certification requirements contained in Annex 16, Volume II, noting also the environmental interrelationships and trade-offs, for methodologies and standards.

a) complete, by CAEP/7, validation of an alternate emissions methodology for NO_x that encompasses all phases of flight, other than the current LTO cycle, taking account of the performance of the whole aircraft, and also taking into account potential interdependencies with the existing certification regime;

b) consider and develop, if appropriate, possible certification procedures and standards associated with the alternate emissions methodology for NO_x for possible future incorporation into Annex 16, Volume II;

c) identify the appropriate characterizations of particulates;

d) gather information on the contribution of particulates to local air quality and global climate impact;

e) start to evaluate the feasibility of applying the alternative emissions methodology, encompassing all flight phases, for emissions other than NO_x, such as particulates assuming a suitable metric for particulate matter can be identified;

f) consider the definition and applicability of "technological feasibility" in the emissions standard setting process;

g) review the need for, and if necessary propose a methodology, for revision of the emissions standards for engines intended for supersonic transport aircraft, taking due account of any proposed noise standards revisions relating to supersonic transport aircraft;

h) assess whether it is appropriate to consider, and if so review and make recommendations for modernization of current emissions certification methods;

i) further develop a methodology for characterizing fuel consumption; and

j) to consider, as appropriate, more stringent standards for aircraft engine emissions during the LTO cycle, especially NO_x in light of the technological review process and the CAEP principles of technological feasibility, economic reasonableness and environmental benefits, taking account of the interrelationships between noise and emissions, aiming to complete the process for review at CAEP/8 (in 2010).

E.6 MEASUREMENT AND SAMPLING

E.6.1 Review the appropriateness of current measurement and sampling requirements and procedures for regulated emissions, together with new requirements, particularly for volatile particulate matter, with the aim of making recommendations for incorporation into Annex 16, Volume II.

E.7 AIRPORT AIR QUALITY GUIDANCE

E.7.1 Provide guidance on assessing and quantifying airport source emissions.

E.8 ENVIRONMENTAL TECHNICAL MANUAL

E.8.1 Develop by CAEP/7 an Environmental Technical Manual for emissions, consistent and compatible with the approach taken for noise, including (but not limited to):

a) guidance material resulting from WG/3 AEMTG activities, relating to the assessment of environmental impacts due to emissions; and

b) guidance material for compliance with the Annex 16, Volume II emissions certification requirements.

E.9 FUEL COMPOSITION

E.9.1 Review trends in aviation fuel supply composition to provide an understanding of any emissions effects resulting from changes to refinery processes.

E.10 ICAO EMISSIONS DATABANK

E.10.1 Maintain technical input to the ICAO Engine Emissions Databank to ensure that it reflects current fleet status.

E.11 EMISSIONS – OPERATIONAL ITEMS

a) Build upon the draft ICAO Circular on *Operational Opportunities to Minimize Fuel Use and Reduce Emissions* with a view to expanding the use of the most effective practices industry-wide and to explore their use as a basis for future voluntary agreements.

b) Operational measures workshop – continue to conduct workshop on *Aviation Operational Measures for Fuel and Emissions Reductions* in the remaining ICAO regions.

c) Assess the current and future capabilities of SAGE and AERO2K to model the environmental benefits of regional CNS/ATM implementation plans and their possible application to the work of CAEP. Revise the Global Air Navigation Plan accordingly.

7.3 MARKET-BASED MEASURES

M.1 VOLUNTARY AGREEMENTS

a) Monitor the implementation of any agreements.

b) Periodically report on the status of ongoing agreements (if any)

M.2 EMISSIONS TRADING

a) Support the development of a voluntary emissions trading system provided by interested States and international organizations (also referred to as “Avenue 3”).

b) Develop guidance for use by States as appropriate on incorporating international civil aviation into their emissions trading schemes (“Avenue 1”).

M.3 **CO_2-RELATED EMISSIONS CHARGES**

Undertake further studies and further guidance to the extent technical work is called for by the Council.

M.4 **NOISE CHARGES AND LOCAL AIR QUALITY EMISSIONS CHARGES**

Collect and analyse information on existing charging schemes for noise and emissions affecting local air quality, and explore the scope for harmonization.

7.4 **FESG**

F.1 Review of STRATUS economic input data.

F.2 Review of UNFCCC fuel databases and comparison with ICAO/CAEP data.

F.3 Review of SAGE model in conjunction with WG/2 and WG/3 (and other models as necessary e.g. AERO2K).

F.4 Review and maintain the CAEP forecast (including retirement curves and a range of possible scenarios).

F.5 Review the assumptions used in models employed in the development of previous noise and NOx Standards, and the industry's response to those Standards.

F.6 Provide support to WG/1 on Task N.2 b).

8. WORKING ARRANGEMENTS

8.1 The technical committee met as a single body, with ad hoc drafting groups as required. Discussions in the main meeting were conducted in Arabic, English, French, Russian and Spanish. Some working papers were presented in English only. The report was issued in Arabic, English, French, Russian and Spanish.

9. OPENING REMARKS BY THE PRESIDENT OF THE COUNCIL

On behalf of the Council and the Secretary General of ICAO, I would like to welcome you all to the Seventh Meeting of the Committee on Aviation Environmental Protection (CAEP). CAEP is essential for ICAO to reach its Strategic Objective of minimizing the adverse environmental effects of global civil aviation and to meet its three related goals: limit or reduce the number of people affected by significant aircraft noise, limit or reduce the impact of aircraft engine emissions on local air quality and limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

Over the years, you have consistently provided the Organization with authoritative and credible technical information which is absolutely necessary for discussions in global fora on complex environmental issues with considerable social, economic and political implications. Through your deliberations and recommendations, you and your predecessors have made it possible for ICAO to develop and promote realistic, comprehensive and forward-looking environmental solutions that have been endorsed by the world community. The depth and scope of your technical advice have proven essential in arriving at decisions of a political nature.

During this latest CAEP/7 cycle, which culminates with the present meeting, you laid the foundation for decisions and actions in a number of critical areas. You took a first step in the establishment of the interdependencies modelling framework that will provide, I am sure, much more analytical capability for CAEP to make recommendations in the future. You selected and analyzed candidate models and databases that will enable a comprehensive assessment of options to address the impact of aviation on the environment, including the trade-off of possible measures related to noise and emissions.

You also laid the groundwork for future assessments of the evolution of noise and emissions emanating from aviation operations, thereby forming the basis for the review of our environmental goals. You established a process for formulating a long-term vision for NOx goals, something that industry has been requesting for a long time. You considered novel solutions to address emissions from international aviation, such as the use of emissions trading. You proposed distinct approaches to deal with the impact of aviation on local air quality and on global climate, making it possible to address these issues separately in the CAEP cycle and increase our effectiveness with more focused measures. And you have done all of this while continuing to develop the necessary proposals to ensure that our main Standards and policies remain relevant, while developing measures leading to greater operational efficiency.

As CAEP/7 gets under way, expectations are high, especially in the area of market-based measures to limit or reduce emissions. At its last regular session in 2004, the ICAO Assembly endorsed, through Resolution A35-5, the further development of an open emissions trading system for international civil aviation and requested the Council of ICAO to provide further guidance to States for its implementation. The CAEP Emissions Trading Task Force has prepared the much awaited draft guidance for your review and ultimately for consideration by the next session of the Assembly in September. The guidance will certainly be one of the highlights of this meeting and I am sure that the outcome will prove invaluable in promoting a global consensus on such a critical subject.

Although I consider emissions trading a central issue of this meeting, I hasten to add that all of your deliberations and deliverables will be highly consequential. Together, they could form the basis for an ICAO plan of action encompassing all measures designed to deal effectively with aviation environmental impacts, particularly with emissions. The need for concrete and coordinated action was underscored by findings contained in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change made public last week, in Paris. The Working Group 1 contribution to the Report – titled "Climate Change 2007: the Physical Science Basis" – clearly states that "there is more than a 90 per cent probability that human action has contributed towards recent climate change". Without a doubt, there is a need to act, and more than ever, ICAO is determined to provide the world with the leadership and guidance it is looking for in moving towards a sustainable global air transport system.

The results of CAEP/7 will also be incorporated into the first ICAO Environmental Report which will be published every Assembly year from now on. And they will be watched closely by participants at the ICAO Colloquium on Aviation Emissions in May as well as other environmental meetings in the coming months.

Of course, the impact of CAEP rests ultimately with States and the measures they adopt and enforce. As the officially recognized international body to deal with aviation and the quality of the environment, ICAO depends on the support of States. I would be most grateful if you could convey to your respective States and organizations our sincere appreciation for their cooperation and support in terms of expertise, models and databases that they have made available to CAEP. I would also like to thank our members who have already contributed in a very tangible manner to the creation of the new Environmental

Unit at ICAO, notably by seconding valuable personnel to assume responsibility for major components of our programme.

Ladies and gentlemen, the challenge of CAEP can be seen as reconciling differing legitimate interests and viewpoints in a world that is in constant mutation. One might be allowed to wonder whether the accelerating change that is an integral part of today's modern society is beginning to exceed the capacity of our social institutions to cope. Adapting to change is particularly difficult for institutions dealing with international or global issues that require a concerted, cooperative effort by many countries if they are to succeed. Often the question is not only if we know what needs to be done, or whether we have the technical capability to do it, but whether we can agree on how and when.

What we have accomplished together through CAEP in more than two decades and what I believe we can accomplish in the future demonstrates that we can indeed agree on how and when. The CAEP process can serve as a model of global cooperation in solving seemingly insurmountable problems. As we begin our deliberations, let us be guided by this thought and by the conviction that what we will do in a few short days may have a lasting impact for generations to come. I sincerely thank each and every one of you for having taken this precious time to be with us and to have given so much thought and energy in preparing this meeting.

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GENERAL

Report of the FESG

1. The Rapporteurs of the Forecast and Economic Analysis Support Group (FESG) presented the group's report. The main role of the FESG is to develop and maintain databases necessary to provide the framework for performing economic analysis, forecasting fleet growth and providing support to the other working groups within CAEP and to work with them on data issues that concern more than one working group.

2. Pursuant to the results of the CAEP Steering Group meeting held in Bonn (Germany) in November 2004, the following tasks from the CAEP/7 work programme assigned to the FESG, remained:

— F4 Review and maintain the CAEP forecast (including retirement curves and a range of possible scenarios); and

— F5 Review the assumptions used in models employed in the development of previous noise and NOX-standards and the industry's response to those standards.

At a later stage a new task was assigned to the FESG:

— F7 Conduct an analysis of the cost-effectiveness of local air quality charges.

3. In addition, FESG had a consulting role with Working Group 2 (WG2) on task N.7, which calls on WG2 to "evaluate the use of models listed in the attachment to this work programme and potential models for the analysis of tradeoffs in coordination with FESG."

4. The FESG had established three sub-groups to pursue its tasks. Between November 2004 and February 2007, the FESG held five face-to-face meetings and had also a number of conference call meetings. The results of the Group's work are reported below.

Traffic and fleet forecasts

5. FESG monitored traffic and fleet developments until the end of 2005 and compared them to the CAEP/6 forecast. It was concluded that although the CAEP/6 forecast underestimated the average annual passenger traffic growth for the period 2000-2005, that did not have a significant impact on the overall 2000-2020 forecast period. In light of the difficulty of forecasting aviation in this 2000-2005 time period when the industry went through some difficult times caused by the external shocks of the September 11 terrorist attacks, the SARS outbreak, etc., the CAEP/6 forecast was remarkably consistent with actual experience.

6. In preparation for the work of CAEP/8, FESG had prepared a document outlining the methodology to be used to develop the new air traffic and fleet mix forecasts, including a description of the method for adding a 10-year period to the 20-year forecast time horizon, and to conduct a sensitivity analysis around the forecast.

Discussion and conclusions

7. The meeting approved the use of the methodology outlined by FESG for the development of future forecasts. One member noted that the time horizon for some forecasts developed by other bodies may exceed 30 years and recommended that the FESG considers this issue in its future work. It was noted

however that the longer the time horizon the higher the uncertainty, in particular in the field of technological advances related to aviation.

8. Another member requested clarification on the statement that the original CAEP/6 forecast would under-estimate the 2020 total traffic by about 10 per cent if the actual 2000-2005 is taken into consideration, whereas the traffic recovery on some major route groups had taken longer than predicted. In response, it was explained that there were some differences across route groups in terms of recovery from these external shocks and in terms of traffic growth and that the overall growth was the result of some route groups that have experienced already some more significant growth than initially predicted. He also enquired about the feasibility of including Very Light Jets in the future analyses.

9. The meeting agreed that the timing of the development of future forecasts was critical and should be examined during the discussion of future work under Agenda Item 4.

10. One member suggested that, for the preparation of economic analysis of noise and NOx stringency, performance based values should be used instead of ICAO times in mode. He also suggested that FESG should take advantage of progress made in the field of monetization of benefits in parallel with using cost-effectiveness analysis. It was agreed that these issues would be discussed under a subsequent agenda item.

Liaison activities with other UN bodies

Introduction

11. The meeting reviewed a report by the Secretariat on liaison between ICAO and other UN bodies on environmental matters of interest. It was reported that ICAO had continued to cooperate closely with organizations involved in the assessment of aviation's environmental effects and associated policy-making in the emissions field, notably with the UN Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). Liaison had also continued with a number of other United Nations (UN) bodies including:

a) the United Nations Environment Programme (UNEP);

b) the Montreal Protocol on Substances that Deplete the Ozone Layer;

c) the UN Commission on Sustainable Development (CSD);

d) the UN ECE Convention on Long-range Transboundary Air Pollution;

e) the World Health Organization (WHO);

f) the International Maritime Organization (IMO); and

g) the World Meteorological Organization (WMO).

12. Regular reports on these activities with relevance to the work of CAEP had been provided to the CAEP Steering Group meetings and the current report focussed on developments since the last Steering Group meeting held in June 2006.

The Intergovernmental Panel on Climate Change (IPCC)

13. Following the publication of the IPCC's Special Report on Aviation and the Global Atmosphere (1999), the ICAO Assembly had requested the Council to continue to cooperate closely with the IPCC and other organizations involved in the definition of aviation's contribution to environmental problems in the atmosphere (Assembly Resolution A35-5, Appendix H, Clause 3a). Most of the subsequent cooperation activities had been related to the preparation of the Fourth Assessment Report (AR4) and of the 2006 Guidelines for National Greenhouse Gas Inventories (2006 Guidelines). ICAO had requested IPCC to include in this report an update of the main findings of the Special Report, in particular on the key areas of scientific uncertainty identified, such as the influence of contrails and aerosols on cirrus clouds. Specific aviation issues had been included in the work of two of IPCC's three working groups, namely Working Group I — The Physical Science Basis and Working Group III — Mitigation of Climate Change.

14. The final draft Report was to be considered by IPCC's WG I in January 2007 and by the IPCC in May 2007. It includes a Chapter entitled "Changes in Human and Natural Drivers of Climate" which includes updates on "Aviation Contrails and Cirrus, Land Use, and Other Effects".

15. The WG III report contained analyses of mitigation options for the main sectors in the near-term, addressing cross-sectorial matters, and provided information on long-term mitigation strategies for various stabilization levels, addressing the implications of different short-term strategies for achieving long-term goals. Of particular relevance to aviation was a chapter entitled "Transport and its infrastructure (road, rail, aviation, shipping, including transport fuels)". ICAO experts had submitted substantial comments on this chapter to ensure that it appropriately reflected the work of ICAO.

16. Regarding the 2006 Guidelines, ICAO had cooperated with the IPCC by providing the necessary expertise and support for the development and refinement of a methodology for the calculation of aviation emissions, including an update of its Emission Factor Database regarding aviation emissions. The new guidelines were accepted by the IPCC in April 2006.

The UN framework Convention on Climate Change (UNFCCC)

17. The ICAO Assembly had also requested the Council to continue to cooperate closely with organizations involved in policy-making in the emissions field, notably with the Conference of the Parties of the UNFCCC (Assembly Resolution A35-5 Appendix H, Clause 3a). It had also requested the Council to continue to study policy options to limit or reduce the environmental impact of aircraft engine emissions and to develop concrete proposals and provide advice as soon as possible to the Conference of the Parties (Assembly Resolution A35-5, Appendix H, Clause 3b), and made a similar request regarding on market-based measures (Assembly Resolution A35-5, Appendix I, Clause 1).

18. Since CAEP/6, the main development regarding the UNFCCC had been the entering into force of the Kyoto Protocol (KP) in February 2006. Of main interest to aviation were the activities regarding the methodological issues related to aviation, the implementation of the flexible mechanisms of the Protocol and the negotiations for the post-Kyoto period.

19. Most of the aviation issues had been considered by the UNFCCC's Subsidiary Body for Scientific and Technological Advice (SBSTA) and had focused primarily on consideration of methodological issues related to emissions from fuel used for international aviation. Following a request from the UNFCCC, ICAO had presented a report on the results of an aviation emissions and fuel consumption data comparison exercise using data from aviation models made available to ICAO and inventory information from UNFCCC. Since ICAO presented this report, there had been no further

progress on methodological issues related to emissions from fuel used for international aviation. This lack of progress by the UNFCCC had not helped ICAO in its work of developing measures that address greenhouse gas (GHG) emissions from international aviation. If progress were to be achieved in this area, it was important that it be achieved in a collaborative way in both fora. The UNFCCC would continue its considerations of this matter in May 2007.

20. At the end of 2005, a Conference of the Parties to the Kyoto Protocol had been held. The meeting agreed upon a process for consideration of action beyond 2012 under the UNFCCC, which included the establishment of an open-ended ad-hoc group of Parties to the Kyoto Protocol (AWG) to consider further commitments for Parties for the period beyond 2012.

21. The last Session of the ICAO Assembly had emphasized the importance of ICAO's taking a leadership role on all civil aviation matters related to the environment. As a consequence, the Secretariat had presented a proposal for an aviation dialogue think tank force in CAEP to the last CAEP Steering Group Meeting. The meeting considered that there was no need to establish such a force for the moment but had agreed that there was a need for improved communication of the work already developed by CAEP. In line with the agreement of the SG meeting and further consideration of this subject during the 179th Session of the ICAO Council, the Secretariat was including as a proposal for future work the development of a communication tool dedicated to better describing ICAO's initiatives on aviation emissions for the consideration of CAEP/7 under agenda item 4. The issuing of the ICAO Environmental Report 2007 and the information to be provided at the Colloquium on Aviation Emissions (Montreal, 14 to 16 May 2007) might also contribute to the improved dissemination of information on ICAO's work in this area.

Cooperation with other bodies

22. IMO. AT IMO's invitation, ICAO had provided information to the Air Pollution Working Group of the Marine Environment Protection Committee (MEPC) in October 2006 on its work on aviation emissions. The meeting welcomed the input from the ICAO Secretariat and instructed the IMO Secretariat to report the outcome of the MEPC Session and the outcome of other relevant GHG work within IMO to the ICAO Secretariat and further, to invite ICAO to report on its work in this area to IMO. It was expected that there would be more cooperation in this area between ICAO and IMO in the future.

23. WHO. During the first quarter of 2005, ICAO had been invited to comment on a draft document entitled "Aircraft Noise and Health" prepared by the WHO's Regional Office for Europe. ICAO had provided a substantial response to the WHO-ECE Secretariat. No further developments regarding this publication had been brought to the attention of ICAO.

24. UNEP/CSD. ICAO is currently preparing its contributions to the 15th session of the CSD (CSD/15), which will take place April/May 2007. The 2006/2007 theme – energy for sustainable development, industrial development, air pollution/atmosphere, and climate change – was highly relevant to ICAO. CSD/15 would be held during a "Policy Year" to decide on measures to speed up implementation and mobilize action to overcome obstacles and constraints for implementation of actions and goals in the thematic areas.

25. MONTREAL PROTOCOL. Cooperation had continued between ICAO and the Ozone Secretariat, on the issue of a possible replacement of the current halon-based fire protection systems that could offer an equivalent level of safety to aviation.

Discussion and conclusions

26. The Representative of UNFCCC noted that the meeting was taking place right after the release of the summary for policy makers of Working Group I of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. According to this report, the world faced an average temperature rise of around 3°C this century, if greenhouse gas emissions continued to rise at their current pace and were allowed to double from their pre-industrial level. In addition, the warming during the last 100 years had been 0.74°C, with most of the warming occurring during the last fifty years. The warming per decade for the next twenty years was project to be 0.2°C per decade.

27. These findings, which governments had agreed upon, left no doubt as to the dangers mankind is facing and had to be acted upon without delay. Any notion that we do not know enough to move decisively against climate change had been clearly dispelled. It was politically significant that all the governments had agreed to the conclusions of the scientists, making this assessment a solid foundation for sound decision making. The world urgently needed a new international agreement on stronger emission caps for industrialized countries, incentives for developing countries to limit their emissions, and support for robust adaptation measures.

28. The good news was that the worst predictions of the IPCC were based on scenarios which did not take into account action to combat climate change now or in the future. Both the policies and technologies for preventing such consequences were available and putting them in place was precisely what the Climate Convention and the Kyoto Protocol were designed to do. The economic costs of inaction — for example, permanent displacement of millions of people — would be much higher than the cost of action.

29. The IPCC would complete its assessments of the impacts of climate change and of available preventive measures within the next four months and present its findings at the next UNFCCC meeting scheduled for May 2007 in Bonn. It was believed that it was possible to build on the success of the Kyoto Protocol in using market-based approaches to reduce the costs of action on climate change.

30. It was noted that UNFCCC had still not made progress in its consideration of methodological issues relating to emissions from aircraft (see paragraph 2.3.3 above).

31. The meeting noted the Secretary's report. It was agreed that CAEP should encourage the input of aviation experts from States in both the development and review of the IPCC assessments, although CAEP could not ensure such action.

32. An observer noted that ICAO had submitted substantial comments on the IPCC Working Group III report chapter concerning "Transport and its Infrastructure" and wondered if these comments could be made available to CAEP. The Secretary pointed out that these were expressly the ICAO expert's comments and not CAEP's, but that they could be made available informally.

33. The observer also noted the Secretariat's coordination with IMO and asked if information received from IMO could be shared with CAEP. The Secretary noted that IMO and ICAO had agreed to further strengthen the cooperation between their organizations and this would be reflected in future communications from the Secretary of CAEP to the Group.

34. A member noted that if ICAO wished to demonstrate leadership on the environment it would need to achieve progress across a range of areas and respond to future challenges constructively. In this regard it was interesting that the President of the Council's opening remarks had indicated that a concerted effort was needed if the Organization wished to show it could adapt to accelerating change.

35. A member noted the work of WHO on “Aircraft Noise and Health” and the meeting agreed that CAEP should take additional steps to ensure a proper coordination with WHO on this issue.

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Agenda Item 1: Review of proposals relating to aircraft engine emissions, including the amendment of Annex 16, Volume II

1.1 REPORT OF WG3 – EMISSIONS TECHNICAL

1.1.1 Introduction

1.1.1.1 The Rapporteur of Working Group 3 presented the group's report. Most of the work items had been addressed by the 3 Task Groups (Alternative Emissions Methodologies (AEMTG); Certification (CTG) and Long Term Technology Goals (LTTG)). Ad-Hoc groups had been formed to address specific topics. Liaison with WG1, WG2, FESG and SAE has been via focal points.

1.1.1.2 The group's report addressed briefly all the topics allocated to WG3 at CAEP/6. Items which were the subject of major work were to be reported in separate working papers. These items included:

a) long term technology goals;

b) technological feasibility;

c) emissions standards for SST aircraft;

d) modernization of current emissions certification methods;

e) consideration of more stringent LTO emissions standards;

f) development of an environmental technical manual; and

g) interdependencies.

1.1.1.3 Brief reports on other items on the group's work programme are given in the following paragraphs. Item numbers refer to the work programme developed at CAEP/6.

1.1.2 Research (Item E2)

1.1.2.1 The WG3 Science Focal Points and the recently appointed Local Air Quality Research Focal Point had continued to provide high quality scientific input to WG3 and its Task Groups, particularly for the LTTG Technology Review and in the development of the particulate matter emissions First Order Approximation (FOA).

1.1.3 Support to other UN Bodies and Agencies (Item E3)

1.1.3.1 WG3 had provided specialist technical support through the CAEP Secretary to UNFCCC, specifically on the topic of updating the Intergovernmental Panel on Climate Change / National Greenhouse Gas Inventories Program (IPCC NGGIP) Guidelines.

1.1.4 **Technology advances (Item E4.1)**

1.1.4.1 The manufacturers' organization had continued to provide substantial presentations on technology advances to WG3. These had been focussed mainly on the LTTG review process.

1.1.5 **Validation of the cruise-climb methodology for NO_x that was presented to CAEP/6 (Item E5.1 (A))**

1.1.5.1 The original methodology had been based on a Weighted NO_x Concept (WNC). However, following proposals from WG3, the Steering Group had approved deferring the validation of WNC whilst quantifying, to the extent possible, the potential consequences of relying purely on LTO engine NO_x emissions certification for control of mission emissions of NO_x.

1.1.5.2 Subsequent work on this approach had been presented to a later meeting of the SG, which had accepted the WG's conclusions that:

a) altitude NO_x emissions performance for current engines is controlled by LTO NO_x emission certification; and

b) future engines with potential new technologies, e.g. staged combustion, might behave in a different manner.

In further discussion, the SG had concluded that it was satisfied with the evidence that correlation between LTO NO_x and cruise/climb NOx did exist for today's engine technologies and did not see a reason for continuing to study this item. It agreed that if a new aircraft/engine combination were identified, WG3 would consult the Steering Group for the inclusion of an item in its work programme to undertake this specific new assessment.

1.1.6 **Consideration and development of NO_x cruise-climb certification procedures and standards (Item E5.1 (B))**

1.1.6.1 Work on this item had been deferred pending completion of work on the methodology mentioned above. Given the conclusions of the SG, further work on this item did not appear to be required.

1.1.7 **Appropriate characterisation of particulates (Item E5.1 (C))**

1.1.7.1 This topic incorporated work by an Ad-Hoc group developing a First Order Approximation (FOA) for estimation of total (non-volatile + volatile) particulate matter (PM) as an interim method for airport inventory purposes, development of sampling and measurement techniques by SAE-E31, research activities in various Member States and general scientific understanding. WG3 had approved the current interim approximation methodology for estimating PM emissions from turbo jet aircraft engines for airport-specific LTO cycle emission inventory purposes only. WG3 had recommended this for incorporation into the WG2/TG4 LAQ Guidance Material.

1.1.8 **The contribution of particulates to local air quality and global climate impact (Item E5.1 (D))**

1.1.8.1 Work on this item is covered under paras. 1.1.2 and 1.1.7 above.

1.1.9 Applicability of cruise methodology to emissions other than NO_x (Item E5.1 (E))

1.1.9.1 Work on this had been deferred pending completion of work on the methodology mentioned in para. 1.1.5 above. However, there had been no activity on this item since the direction of work on climb-cruise methodology was reviewed and revised at the 2005 Steering Group meeting.

1.1.10 Further development of methodology for characterizing fuel consumption (Item E5.1 (I))

1.1.10.1 Work on this item had been incorporated into that described in para 1.1.3 above.

1.1.11 Measurement and sampling (Item E6.1)

1.1.11.1 WG3 had continued to work with SAE-E31, not only on the development work on PM emissions sampling and measurement techniques (see para. 1.1.7 above), but also on techniques for measurement and sampling that were applicable for current engine emissions certification. Though new material had not yet been fully developed and approved, it is expected that this would be considered in the future for adoption into Annex 16, Vol. II and/or into the new emissions Environmental Technical Manual (ETM).

1.1.12 Provision of guidance on assessing and quantifying airport source emissions, considering modern operational practices (Item E7.1)

1.1.12.1 WG2 had requested information from WG3 on the availability of emissions data to assist them in the development of guidance material on the assessment and quantification of airport emissions. In its response WG3 had limited itself to providing WG2 with data concerning aircraft engine and related sources. These data sources included turbojet and turbofan engines, turboprop engines, APUs and piston engines, together with the operational practices of start-up, less than 7% idle setting, less than all-engine taxi, reverse thrust and derate or reduced take-off thrust.

1.1.13 Formal publication of the material on the use of LTO emissions certification data for estimation of emissions under operational conditions (Item E8.1 (A))

1.1.13.1 The material approved by CAEP/6 was originally expected to be formalised as a CAEP Circular. However it became clear that this was going to have significant overlap with, and duplication of, documentation being developed by WG2/TG4 relating to Local Air Quality. Therefore the Steering Group had agreed that the material should be incorporated into the WG2 documentation and not provided as a separate document. WG3 had been working with WG2 to achieve this.

1.1.14 Fuel composition (Item E9.1)

1.1.14.1 This topic had been considered under the “modernisation” topic (see para. 1.2.2 of the report on this agenda item).

1.1.15 ICAO Emissions databank (Item E10.1)

1.1.15.1 The data bank continued to be maintained and updated by the UK CAA. The latest version was V15. The website address is www.caa.co.uk/srg/environmental/emissions.

1.1.16 **Intergroup Co-ordination**

1.1.16.1 WG3 had participated in inter-group work with WG1, WG2 and FESG through Rapporteur telecons and attendance at each other's meetings as appropriate, through appointed inter-group Focal Points and by formal document responses. The work had included:

a) **WG3 - WG1:** Technology Interdependencies through the joint TIG (see para.. 1.19 of this report), SST goals and timelines (see para. 3.8.4.1 of this report);

b) **WG3 - WG2:** Responses to requests from TG2 and TG4 (see paras. 1.1.12 and 1.1.13); and

c) **WG3 - FESG:** Responses to requests from IRTG.

1.1.17 **Discussion and conclusions**

1.1.17.1 The meeting noted WG3's report and the status of its activities.

1.1.17.2 A member commented specifically on the topic of applying the cruise-climb methodology for NO_x (see paragraph 1.1.5 above) and the acceptance by the Steering Group of WG3's conclusions. While supporting these conclusions, he wished to emphasise the caveats that surrounded them, particularly that they only applied to past and current aircraft engines in the context of engine technology certification. Application beyond technology certification would require CAEP to review the need to revisit this issue. Furthermore, it should be clarified that the conclusion only applied to the NO_x emissions index for an engine and not to NO_x emissions themselves. LTO EINOx was a constant for a given engine, whereas altitude NO_x emissions were also a function of the airframe, and sector operational factors such as range, aircraft mass and flight profile. In response to a query, the member clarified that in suggesting that any applications beyond technology certification would require further work, he was not referring to fuel flow methodologies for estimating NO_x cruise emissions already in use. Another member noted that, in any case, the recent IPCC report appeared to indicate that CO_2 was the emission of greatest concern and that NO_x emissions at altitude might not be of such importance.

1.2 PROPOSED CHANGES TO ANNEX 16 – *ENVIRONMENTAL PROTECTION*, VOLUME II – *AIRCRAFT ENGINE EMISSIONS*

1.2.1 **Introduction**

1.2.1.1 The Rapporteur of WG3 recalled that, as part of the WG's work programme, it had been asked to: assess whether it is appropriate to consider, and if so, review and make recommendations for modernization of the current emissions certification methods (E.5.1 h)); review the appropriateness of current measurement and sampling requirements and procedures for regulated emissions (E.6.1); and review trends in aviation fuel supply composition to provide an understanding of any emissions effects resulting from changes to refinery processes (E.9.1). The WG3 Certification Task Group (CTG) had consequently addressed these tasks and identified an initial list of seven areas where changes to Annex 16 appeared to be necessary to reflect current certification practices. So far, six of these seven work items had been resolved and agreed at the WG3 level.

1.2.1.2 As a result of this work, amendments to Annex 16, Volume II had been developed, together with guidance material where appropriate. The Rapporteur presented an overview of the proposed amendments. A detailed list of the changes is provided in Appendix A to this part of the report. The meeting was also provided with detailed justification for each change.

1.2.2 **Modernization work items**

1.2.2.1 WG3/CTG had dealt with the following seven items:

Item 1. A review of current gaseous emissions corrections to reference day conditions
Item 2. A review of current fuel specification requirements for naphthalene and aromatic content
Item 3. A clarification of thrust condition to be used to define F_{oo}
Item 4. Amendments to permit the use of alternative sample probe materials to stainless steel
Item 5. A review of improvements in sampling and measuring equipment, e.g. optical smoke meter
Item 6. Consideration of the need to clarify the certification criteria applicable to the modification of currently certificated engines
Item 7. A clarification of the definition of the term "mixing probe".

Work on all items had been completed except for Item 6. The results from Item 5 did not require any amendment to Annex 16 text. The limited use of an optical smoke meter would be addressed in the ETM. The final wording was still to be developed, specifically with regard to the specifications of the optical measurement equipment.

1.2.2.2 Work on Item 6 was still in progress. Currently it was focused on the applicability of Standards for certificated engine types which had been subsequently modified. The issue was complex and any changes needed to be carefully considered. WG3 had started to discuss some basic principles while taking into account current certification practices. This work was expected to continue in the future.

1.2.3 **Description of the proposed changes**

Item 1

1.2.3.1 A number of areas of concern had been raised at CAEP/6, these were:

a) terminology relating to corrections to reference engine conditions and reference atmospheric conditions were not consistent. The Annex did not correctly nor adequately define when measured results should be corrected to the reference atmospheric conditions, and/or corrected to the reference engine conditions;

b) the terms used for the humidity corrections were not clear;

c) several apparently equivalent terms were used to describe thrust setting (e.g. power setting, operating mode, mode setting); and

d) the relationship between fuel flow and combustor inlet temperature (W_f v T_b) was defined in Appendix 3, paragraph 7.2.2 b), and used in 7.2.3 c). However, it was not stated whether measured or corrected W_f values should be used.

1.2.3.2 These issues had been addressed and the following proposals were being made:

a) revise the text to specify clearly the applicable corrections to reference atmospheric conditions and to the reference standard engine, both for smoke and gaseous emissions;

b) introduce a clear distinction between the two different humidity terms used, and eliminate the use of straight brackets in the equations;

c) use the term “LTO operating modes” when referring to the specific LTO cycle points of paragraph 2.1.4.2. For all other cases "Thrust Setting" would be used to refer to non-specific operating conditions; and

d) clarify the appropriate value of fuel flow to be used in emissions rate at each LTO point.

Item 2

1.2.3.3 A Member supported the WG3 proposal at CAEP/6 to broaden the fuel specification in relation to hydrogen content, and proposed similar broadening for fuel aromatic and naphthalene contents. This was because of difficulty in finding fuel that met the specifications in his State.

1.2.3.4 A review of the availability of fuel meeting the specification had indicated that generally available fuels frequently failed to meet a number of the specification limits. However, amending the specification to encompass all available fuels would have an effect on stringency. It was therefore proposed to amend Annex 16 to permit deviations from the specification subject to the application of agreed corrections.

1.2.3.5 The proposed changes to the Annex 16 text, and accompanied by further guidance material on the application and limitations of deviation and correction. The changes proposed would reduce certification costs by enabling manufacturers to use fuels available locally, subject to the application of acceptable corrections to eliminate any effect on the test results. Without this change it was very likely that CAEP would be asked to amend the fuel specification on a regular basis to take account of future variation in fuel supplies.

Item 3

1.2.3.6 The current definition of “rated output” included the expression “maximum power/thrust available for take-off” and was not the correct parameter for this purpose. Firstly, the installed power/thrust was not a certificated parameter, as it included deductions from the rated thrust for installation effects, such as nacelle drag and aircraft power requirements. Secondly, where an engine was approved with additional emergency thrust capability, it was not necessary to carry out the testing at this higher thrust. In practice, the certificated (or uninstalled) rated take-off thrust has always been used for emissions certification. Also, as all engines affected by the Annex were turbo-jet or turbofan engines, the output of these engines was always measured in terms of thrust, and “thrust” should be used instead of “output” throughout the Annex. A new definition had therefore been developed.

Item 4

1.2.3.7 Sampling emissions behind modern gas turbine engines required the use of rakes fabricated of materials capable of withstanding the thermal and structural loads imposed during high power operation. Annex 16, Volume II defined the specifications for rake fabrication, and currently the only material specified was stainless steel. Recent certification tests by some manufacturers of their latest technology engines using the stainless steel rakes specified in Annex 16 had resulted in sampling hardware problems which had led to costly delays to test schedules. To alleviate this problem, rakes made of materials with higher strength had been used in lieu of stainless steel after the manufacturers, working with the authorities, had demonstrated that the accuracy of the emissions measurements had not been compromised.

1.2.3.8 Changes were therefore proposed which would enable manufacturers to make emissions measurement rakes from materials which had adequate temperature capability, provided they were non-reactive. The proposed changes to the Annex 16 would be supported by guidance material on equivalent materials.

Item 7

1.2.3.9 Some aspects of the sampling procedures of Annex 16, Volume II and the appropriate corrections in the English and French language versions are unclear. In one aspect the English and French versions did not have the same technical meaning. The following specific changes to the French text only of Appendix 2, 2.1 and Appendix 3,5.1.1 are required:

a) …

b) *Si une sonde de prélèvement multiple est utilisée, tous les orifices de prélèvement auront le même diamètre.* La sonde sera conçue de telle manière que 80% au moins de la chute de pression à travers la sonde se produise aux orifices.

c) Le nombre de points de prélèvement ne devra pas être inférieur à 12.

d) ….

1.2.3.10 Appropriate changes to the Annex 16 text in English and French were proposed, with supporting guidance material.

Other Changes

1.2.3.11 In the course of the work described above, the need for several other changes in the text had been identified. These included the provision of a link from Annex 16 to the new ETM and clarification that equivalent procedures in the new ETM would meet the intent of variations in the procedures as defined in Appendices 2 and 3 of Annex 16, Volume II. A specific change concerns the Note following 2.2.2 of Appendix 2 which allows the use of copper. Since the use of copper is problematic and the metal is seldom if ever used in engine emissions testing, WG3 recommended that the reference to copper should be removed from this Note.

The proposed amendments are shown in Appendix A to the report on this agenda item.

1.2.4 **Discussions and conclusions**

1.2.4.1 The meeting agreed with WG3's proposals for an updated and more consistent text of Annex 16, Volume II which reflected current certification practice. It noted that the amendment should facilitate certification without affecting stringency.

1.2.4.2 A member suggested that confusion might arise over the use of the terms "equivalent procedure" and "variations in procedure" in the new Note proposed for attachment to paragraphs 2.2.2 and 2.3.2 of the Annex as these expressions meant substantially the same thing. It was explained that these were essentially similar concepts, one used in the Annex and the other in the guidelines that would form a new Environmental Technical Manual (ETM) on emissions and for that reason both had been used

(Secretariat Note: this matter was subsequently resolved during discussions on the proposed new ETM, Volume II — see paragraph 1.3.3.4 of this report.

1.2.5 Recommendation

1.2.5.1 In light of the foregoing discussions the meeting developed the following recommendation:

RSPP **Recommendation 1/1 — Amendment to Annex 16, Volume II — Aircraft Engine Emissions**

That Annex 16, Volume II be amended as indicated in Appendix A to the report on this agenda item.

1.3 PROPOSAL FOR THE *ENVIRONMENTAL TECHNICAL MANUAL* (ETM, DOC 9501), VOLUME II

1.3.1 Introduction

1.3.1.1 The Deputy Rapporteur of WG3 noted that, as part of its work programme, WG3 had been requested to develop a second volume of the *Environmental Technical Manual* (ETM) for emissions, consistent and compatible with the approach taken for noise (Volume I), including but not limited to guidance material in support of Annex 16*,* Volume II. WG3 had consequently agreed on the structure, definitions of guidance material categories and principles to follow in developing the ETM.

1.3.2 Development of the ETM, Volume II

1.3.2.1 Initial focus had been on guidance associated with Annex 16, Volume II, Part III, Chapter 2. *Turbo-jet and Turbofan Engines Intended for Propulsion Only at Subsonic Speeds*. With work completed on Part III, Chapter 2, and a "front end" to the ETM, Volume II developed, the group had begun work on Part III, Appendix 2. *Smoke Emission Evaluation*. A copy of the front end to the ETM, Volume II, Part III, Chapter 2 and Appendix 2, were provided for the meeting's review. During the development of Appendix 2 text, several issues had been identified which need further discussion within CTG and WG3 in order to clarify requirements and for the appropriate disposition of issues. These issues were in addition to those identified in developing the text of Part III, Chapter 2. It was pointed out that discussion of these issues might result in either amendments to Annex 16, Volume II or the need for guidance in the ETM. Work on these issues needed to be continued and would be addressed in the future work programme.

1.3.2.2 In developing the guidance material for Appendix 2, it had been discovered that a non-ICAO document referred to in Section 2.3 j), i.e. American National Standards Institute (ANSI) PH2.17/1977, had been withdrawn and was no longer manufactured by ANSI. There were no plans within ANSI for an equivalent standard to be issued. Discussion with the SAE E-31 Committee, which also refers to ANSI PH2.17, resulted in this issue being considered at their annual meeting, April 5 to 7, but without any resolution. An appropriate replacement, if not the only one, would be ISO 5-4 1995, "Geometric conditions for reflection density". In addition to this problem with the reflectance standard, WG3 had been made aware that SAE E-31 had modified the requirements for reflectance measurement in ARP 1179C to include the use of a green tristimulus filter and traceable secondary diffuse reflectance calibration standards. This was under review by CTG for applicability in Annex 16, Volume II. If it is were determined to be appropriate to the measurement of filter reflectance, the question of adding it as an amendment to the Annex, or more simply as explanatory information in the ETM, would be evaluated and a recommendation made.

1.3.2.3 The need for Annex 16, Volume II to make reference to the emissions ETM in order to ensure the effectiveness of the ETM had been revisited. This need was particularly relevant when dealing with equivalent methods which require the approval of the certificating authority. In addition, the difference in language between Annex 16, Volume II which used the term "variations in the procedure" and the ETM which used "equivalent procedure" could lead to some confusion in interpretation during the certification process. An amendment to overcome this problem had already been proposed.

1.3.3 **Discussion and conclusions**

1.3.3.1 The meeting agreed with the concept of developing a new Volume II of the ETM and endorsed the material developed so far. A concern, however, was how the material would be published. The Secretary explained that since a revised version of Volume I of the ETM was anticipated, and in view of the limited nature of the new material intended for Volume II at present, the plan was to delay formal publication until both volumes could be produced together. However, so that the material developed for Volume II could be used in the interim, it was proposed to publish it as guidelines on the ICAO public website.

1.3.3.2 The meeting agreed with the procedure and noted that the introduction to the guidelines would be amended to clarify its status. It was considered that this procedure would still allow national authorities to incorporate the material in their own regulations by reference to the CAEP/7 report, if they so desired.

1.3.3.3 The text of the guidelines, which will eventually form part of Volume II of the ETM, is shown in Appendix B to the report on this agenda item.

1.3.3.4 A member pointed out that the proposed Annex 16, Volume II amendments previously discussed included (paragraphs 2.2.2 and 2.3.2) a reference to the ETM and this could not be included in the Annex until the document had been formally published. The meeting agreed and the proposed amendment was revised accordingly. It was noted that this action would also remove the terminological difficulty previously reported in 1.2.4.2 above.

1.3.4 **Recommendation**

1.3.4.1 In light of the foregoing discussions, the meeting developed the following recommendation:

Recommendation 1/2 — Publication of guidelines related to engine emissions certification

That the guidelines contained in Appendix B to the report on this agenda item be published on the ICAO public website.

1.4 DEFINITION OF TECHNOLOGICAL FEASIBILITY IN THE CONTEXT OF CONSIDERING REVISED ENGINE EXHAUST EMISSIONS STANDARDS AND TRANSITION GOALS TO STANDARDS

1.4.1 Introduction

1.4.1.1 The Deputy Rapporteur of WG3 presented a paper summarizing the work accomplished by WG3 in assessing the technological basis upon which future engine exhaust emissions Standards should be based, taking into account how such a basis should also be used in the complementary work of establishing technology goals for the reduction of NO_x emissions.

1.4.1.2 Previous attempts had been made to clarify the definition of technological feasibility based upon an understanding of the philosophy adopted during the initial Standard setting undertaken by the ICAO Committee on Aircraft Engine Emissions in 1978 and 1980. During the assessment of NO_x stringency during the preparation for CAEP/6, the text of a working assumption had been agreed, but this text did not make any reference to a goal-setting process.

1.4.1.3 During preparation for this meeting, it had been agreed that further defining technological feasibility, including consideration of goal setting, would best be achieved by introducing the use of a Technology Readiness Level (TRL) scale. Such a scale had consequently been agreed by WG3. It had originally been developed by NASA as a general tool characterizing the level of development of new technologies across a wide range of applications including space vehicles, aircraft systems, aircraft engines and engine components. It had been slightly modified with the input of the European Commission. It had been recognized that goal setting would involve some degree of judgment on the performance outcome that was likely through the TRL development process. However the TRL scale would provide a consistent measure of technological development that aligned well with the objectives of identifying transition from long term goals to mid term goals, and for considering future Standards based upon achievement of mid term goals.

1.4.1.4 WG3 had further agreed that TRL8 was the point at which technologies could be deemed to be technologically feasible in the context of ICAO Standard setting. Technologies demonstrated up to and including TRL7 would be appropriate for consideration in a goal-setting process with long term goals encompassing the range of TRL2-5 and mid term goals encompassing the range of TRL6-7.

1.4.1.5 A revised definition of technological feasibility taking into account both the goal-setting and Standard setting processes, had also been developed. The definition acknowledged that a Standard would typically apply some 3-4 years (short term) after CAEP agreement, therefore referencing TRL8 ("flight qualified through test and demonstration") draws in technologies already proven, and either already certificated or about to be certificated with entry into service shortly thereafter. TRL9 took into account only engines already in service and ignored the known introduction of further engine technology developments prior to the effective date for a new Standard. Introduction of the goal-setting reference acknowledged the basis for transition from goals to consideration of Standards and provided a logical link between short, mid and long-term timescales.

1.4.2 Discussion and conclusions

1.4.2.1 The meeting noted the work done by WG3 on this topic and endorsed the use of the technical readiness scale as proposed. It also approved the definition of “technological feasibility”. The scale is illustrated in Appendix C to the report on this agenda item.

1.4.2.2 An observer noted that the definition of technological feasibility included the expression "a sufficient range of newly certificated aircraft" and he questioned what was precisely meant by this expression. He was informed that WG3 had not been able to be any more precise and this could be a matter of judgement in a cost-benefit analysis.

1.4.2.3 Other members noted that in view of the normal timescales for the applicability of new Annex 16 applicability provisions (usually three or four years), there was an implication that a regular review of technology would need to be undertaken. It was agreed that use of the scale would be an integral part of the goal setting process and that Technical Readiness Level (TRL) 8 should be accepted as defining feasibility in the context of Standard setting. Mid-term goals were consistent with TRL 6 and 7 and long-term goals with TRL 2 to 5.

1.4.2.4 It was also agreed that a similar process should be used in determining technical feasibility in the case of noise provisions.

1.4.2.5 It was also noted that the development of standards based on TRL 8 needed to be part of an overall package incorporating long term goals (see para 1.7 of the report on this agenda item).

1.4.2.6 It was questioned whether the right hand side bars shown in Appendix C should be included since the division between research institution and manufacturer could well vary from State to State. However, it was agreed that the only issue was where the manufacturer might become involved in the process and in any case the bars were only illustrative in nature. It was agreed not to change the diagram.

1.5 EFFECTS OF AIRCRAFT EMISSIONS ON LOCAL AIR QUALITY

1.5.1 The Focal Point on Local Air Quality gave a report on the latest scientific consensus on the effects of aircraft emissions on local air quality in the vicinity of airports.

1.5.2 In respect of local air quality, the main concern was the effect on human health from particulate matter, ozone and oxides of nitrogen (NO_x). A new concern was that surrounding hazardous air pollutants (HAPs). Annex 16, Volume II already imposed limits on NO_x, unburned hydrocarbons (UHC) and smoke (particulate matter) but interaction between these emissions and the role of HAPs was not well understood. There may well be trade-offs involved in the reduction of these emissions, as there were between CO_2 and NO_x production and also with noise concerns. When considering local air quality, ambient pollutant levels were a factor and the effect of different emissions could vary with location.

1.5.3 NO_x continued to be an issue. It was a participant in ozone formation and also contributed to the acidification of fog and rain. Aviation was not the only low altitude producer of NO_x, but the relative contribution from aviation could become greater as other sources reduced NO_x emissions. In some locations, NO_2 was a specific health concern and the ratios of NO_2 to NO in NO_x could become an issue.

1.5.4 While UHC were controlled by the Annex provisions, they were interrelated with HAPs and more detailed characterization of UHCs may be required in the future.

1.5.5 Much research was in progress in the area of particulate matter (PM). Although smoke emissions were regulated, the emphasis of the current Standard was to reduce the visibility of the smoke; it was not aimed at reducing invisible particulates. Some fine particulate matter had been identified as being injurious to human health and this fraction needed to be better understood. It was well understood that the sulphur in aviation fuel contributed directly to the emission of gaseous sulphates and sulphur dioxide. However, how these compounds contributed to secondary fine particles was less well understood.

1.5.6 **Discussion and conclusions**

1.5.6.1 The meeting noted this information with interest. A member commented that there appeared to be a lack of consensus in the scientific community in this area at present. The Focal Point considered that while there was general agreement on what was being emitted by aircraft engines, the response of health authorities on health impacts to the data so far available had not yet been forthcoming. It was agreed that the question of health impacts was not currently within CAEP's purview, but a member suggested that CAEP may need to consider the impacts in the future as it considers environmental goals. The RFP noted that, since such information might not be forthcoming for a long time, it might be wise for CAEP to take some kind of proactive stance, as it had done for smoke in the past.

1.5.6.2 It was generally agreed that no specific action could be taken at this time, but that thought should be given to what process might be used to deal with this matter, if necessary, in the future. Meanwhile, further information from health authorities and on measurement techniques was eagerly awaited.

1.6 **PRESENTATION BY THE WORLD METEOROLOGICAL ORGANIZATION**

1.6.1 The Representative of the World Meteorological Organization (WMO) made a presentation to the meeting. He briefly described his Organization's purposes and functions and stressed its long standing and close cooperation with ICAO on aviation-related meteorology matters. WMO was also closely involved with environmental issues through its World Climate Programme and other initiatives.

1.6.2 Concerning aviation and climate change, he acknowledged that although global climate change was a reality, more research was needed to understand its consequences. Aviation was only a part of the problem; small in some cases and more significant in others. He stressed that climate change was more than global warming, causing increased storm activity and rainfall, but also increased desertification. It was already understood that aviation was contributing more than CO_2 to climate change.

1.6.3 He mentioned that operational measures taken to mitigate the effects of aviation on the environment could make more use of meteorological information, for example by avoiding holding procedures at destination airports which had marginal weather conditions forecast at departure.

1.6.4 A specific area of uncertainty was in the area of contrail and cirrus cloud formation. These phenomena had only a moderate affect on global warming by day because of their radiation reflecting characteristics, but were more instrumental in causing warming at night. The atmospheric layers involved were very thin and could be avoided and less traffic by night would help alleviate the problem. A potentially positive aspect was the environmental monitoring that aircraft could undertake.

1.6.5 It was also appropriate that aviation authorities should begin to consider adaptation measures to help cope with the effects of climate change. Such effects could include:

a) the effects of climate change on populations, migration and tourism;

b) the effects on daily operations of severe local weather situations which were becoming more violent and frequent; and

c) the role of aviation in emergency relief and rescue operations.

1.6.6 The meeting noted the presentation with interest. It was, however, appreciated that some of the assertions were the opinion of the presenter. In particular, a member noted that suggestions for operational modifications to avoid contrails/cirrus were premature and inconsistent with the recently released Fourth Assessment Report by IPCC's WG1, which noted a low level of scientific understanding of contrails/cirrus.

1.7 REPORT OF THE INDEPENDENT EXPERTS ON THE 2006 NO_X REVIEW AND THE ESTABLISHMENT OF MEDIUM AND LONG TERM TECHNOLOGY GOALS FOR NO_X

1.7.1 Introduction

1.7.1.1 At CAEP/6, WG3 had been requested to assess the prospects for NO_x emissions reductions from technology developments that might be possible over the next 20 years. The Steering Group had subsequently agreed in October 2005 that the review should be focused on NO_x, that it should be seen as a pilot project, and that it should take into account any impact on other areas such as noise, CO_2 etc. as a second step, once CAEP had gained confidence in the process. The Steering Group also approved the commissioning of a group of independent experts to carry out the review and to record results as technology goals for both the medium and long term (10 and 20 years respectively). This review had been carried out in March, 2006, under the direction of the LTTG whose rapporteur gave an overview of the activity.

1.7.2 Overview

1.7.2.1 It was noted that the objective was an assessment of the industry's ability to reduce NO_x emissions at source. It had been agreed that an independent review process was needed and that it should involve the use of the accepted certification parameters. This was the first goal setting review of its kind undertaken by CAEP.

1.7.2.2 The objective was to inform CAEP on possible future emissions reduction trends over the long term, as required for policy-making purposes, not least to be able to consider future possibilities for emissions improvements/standards.

1.7.2.3 The independent experts, six in number, had been provided by States. Basic information to assist their review had been provided in the following areas:

a) relationship between goal setting and standard setting;

b) an atmospheric science review; and

c) a review of current and developmental technology.

Brief summaries of the information provided to experts under these headings was presented to the meetings as described in the following paragraphs.

1.7.3 **Relationship between goal setting and standard setting**

1.7.3.1 This information was basically that already described in paragraph 1.4 of the report on this agenda item.

1.7.4 **Atmospheric science review**

1.7.4.1 This review was intended to provide an overview of the latest scientific consensus on the effect of aviation emissions on the atmosphere for both local air quality and climate change. This was to provide a framework for future questions to help assess the environmental benefits of technology improvements in trade-off studies. The aspect of trade-offs was only beginning to be studied by the scientific community. The science review was limited to emissions, although there might also be trade-offs with noise involved.

1.7.4.2 The basic trade-off question was, if technology improvements resulted in decreasing one emission species at the expense of others, how does one determine whether the trade-off is beneficial in environmental terms? The emissions of interest were detailed, as were the steps to be followed in trying to answer this basic question in a particular case.

1.7.4.3 It was noted that LTO emissions dominated impacts on local air quality and non-LTO emissions dominated impacts on climate change. However, there was a lack of dialogue between the separate scientific communities addressing these two aspects. Partly because of this, in the global science community there was more emphasis on quantifying impacts, whereas in local air quality the emphasis was on emissions inventories to compare aviation with non-aviation sources.

1.7.4.4 The importance of the metric chosen to assess trade-offs in the global impact area was stressed and illustrated.

1.7.5 **Technology review**

1.7.5.1 The information provided by manufacturers on current combustor technology and technology under development was described. The basic purpose and function of a combustor was illustrated and the extreme temperature and pressure condition were noted, as was the physically small space in which combustion occurred and the very short time scale involved. Many requirements, often conflicting, had to be met by any design. These included:

a) minimal fuel consumption;

b) a wide range of thrust requirements, rapid acceleration/deceleration in varying ambient conditions (e.g. rain and hail);

c) ground starting and altitude relight capabilities;

d) combustor and turbine durability; and

e) low weight and cost.

There was also always the overriding requirement for safety.

1.7.5.2 The optimum fuel/air ratio for combustion efficiency resulted in the highest combustion temperatures. NO_x production was temperature dependent and therefore also highest at the optimum fuel air ratio. NO_x production was also dependent on residence time at high temperature. NO_x production could be reduced, at the possible expense of fuel consumption and/or the production of other emissions, by burning a rich mixture or burning a lean mixture of fuel and air.

1.7.5.3 Recent engine certification results covering ten engine families with a wide range of thrusts and pressure ratios showed all engines meeting CAEP/6 requirements, with a range of margins of compliance. All these combustors used the rich mixture approach. In the middle term, new technology combustors using both rich and lean approaches were at the TRL5 and 6 stage and were showing considerable promise. However, it was emphasized that significant additional effort was required to translate these technologies into production engines.

1.7.6 **Report of the independent experts**

1.7.6.1 The chairman of the group of independent experts presented the group's report to the meeting. He thanked all those who had provided the information necessary for the group to complete its task. He believed the group had produced a balanced report. He noted that there had been no previous experience of such an exercise and that the group had had to "learn by doing". Any future similar reviews should be easier as a consequence. He also noted that no attempt had been made to undertake cost-benefit analyses because of lack of time and of agreed models and scenarios.

1.7.6.2 From the background information supplied to it, the group had noted the difference between goals and standards and that it was only concerned with goal setting. According to the IPCC 1999 Special Report, aviation was estimated to produce 2% of global anthropogenic CO_2, but 3.5% of radioactive forcing. However, these contributions were growing and were estimated to be 5% (CO_2) by 2050. Some climate impacts were very long term (e.g. CO_2 more then 100 years). NO_x remained important but other pollutants needed to be considered.

1.7.6.3 Concerning the science aspects of local air quality, the group noted that there was not much information available. Significant LAQ pressure already existed (e.g. EU directives). NO_x appeared to be the most significant aviation emission but UHC and particulates would need future study. Source attribution was an issue but aircraft contribution appeared to be significant within 1 km of the airport, and relatively small 2 to 3 km away. It appeared that pressure to reduce aircraft NO_x further would continue at least into the mid-term. For the long term (20 years), more work was needed, including perhaps cost-benefit analyses of trade-offs.

1.7.6.4 Concerning the science aspects of global climate change, the group noted continuing uncertainties regarding the impact of cirrus clouds and particulates. It noted that NO_x was only exceeded in concern by CO_2. Climate response time was noted to be a particular factor; in the short term NO_x appeared to be more significant then CO_2, at around 50 years NO_x and CO_2 were about equally significant, but over the long term (100+ years) CO_2 was much more important.

1.7.6.5 The group noted some global trade-off considerations, e.g. reduced NO_x resulted in increased CO_2, CO and HC minimizing noise could result in a 1.5% NO_x penalty for one example of aircraft/engine combination. It also noted that the airworthiness requirement for engine relight capability at 30,000 ft might be challenging for lean burn combustor concepts and a relaxation of this requirement to 25,000 ft could perhaps be examined. Overall the group concluded that for local air quality there was insufficient cost and benefit information to guide robust conclusions; in the global climate case it did not appear desirable to trade NO_x and CO_2 since it was important to reduce both.

1.7.6.6 Concerning technology, the group noted that there had been successive increases in NO_x stringency in the past and recently certificated engines were between 5% and 20% below the CAEP/6 limits. Combustors under development were predicted to be up to 40% below the CAEP/6 levels. The group did not think that alternative fuels would be a significant factor in the medium or even possibly long term and in any case had limited potential for NO_x reduction.

1.7.6.7 In developing goals the group, while acknowledging the environmental pressure to reduce NO_x, did not consider that the environmental need was sufficiently quantified to inform judgement on the level of goals to be recommended. It therefore based its proposals on predicted technical capability for NO_x emissions reduction. It had agreed that goals would be based on leading edge technology and more aggressive than best available current technology. This approach did raise issues however over such points as the well known steep NO_x rise which can accompany engine development within a family; competition; small engine problems; and thrust alleviation. Also the allowance previously made for higher pressure ratios should be re-examined. These, however, were all considered to be stringency and not goal-setting issues.

1.7.6.8 Inevitably there were uncertainties involved in such an exercise as this and goal bands rather than single lines had therefore been developed. The band width was greater for the long-term goal than for the mid-term and it was thought that the mid-band values represented a 50% probability of achievement.'

1.7.6.9 The goals which the group had developed were:

2016, medium term (MT), CAEP/6 levels – 45%, ±2.5% (of CAEP/6) at a PR of 30

2026, long term (LT), CAEP/6 levels – 60%, ±5% (of CAEP/6) at a PR of 30

In summary the Chairman of the group of independent experts commented that the difference between CAEP/6 levels and the MT and LT goals emphasized the difference between stringency and goals. Despite continuing scientific uncertainty, it was clear that technology should address both NO_x and CO_2 in the future, noting CO_2 had the greater long term impact. It was the opinion of the IEs that significant R&D investment during the 1990s should ensure sufficient technology to support the MT NO_x goal substantially below CAEP/6 with a relatively narrow band of uncertainty. Meeting the challenging LT Goals would require technology breakthroughs, and the achievement uncertainty was significantly greater. The recommended goals were based on technology capability driven by qualitative environmental need: future reviews should quantify the environmental need. Little opportunity had been found to trade one emission against another. It was considered inadvisable to trade lower NO_x against increased CO_2 and other possible trades would require a better quantifying process and appropriate assessment tools. It was also noted that absolute levels of NO_x production were becoming very low and that achieving the LT goals and any further future reductions would be subject to the law of diminishing returns.

1.7.7 **Discussion and conclusions**

1.7.7.1 The meeting congratulated the group on its ground-breaking efforts. It noted that this was an initial review, limited to NO_x and it noted the conclusions and recommendations of the group's report. A member asked if settling the goals had been difficult. The Chairman of the Group of independent experts responded that the Group had given the matter full consideration and discussion, but as the goals were evidence-based, consensus had been achieved with relative ease. The meeting approved the report for future use within CAEP, although there was some uncertainty about how it would be used. It agreed that the report should be made publicly available, however it was noted that it was not an ICAO report of a normal type. It was the view of a group of independent experts and could not be edited by ICAO. It was agreed that it should be published on the ICAO public website in English only, as soon as possible, with a suitable indication that it was the work of independent experts and not an ICAO report. Also, it was agreed that all the presentations relating to the LTTG review would be made available on the ICAO public website.

1.7.8 **Recommendation**

1.7.8.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 1/3 — Publication of the report of the independent experts on the 2006 NO_x review and the establishment of medium and long term technology goals for NO_x**
>
> That the report of the independent experts be published by ICAO, in the English language only, as soon as possible.

1.8 REPORT OF WORKING GROUP 2

1.8.1 **Introduction**

1.8.1.1 The Co-Rapporteurs of WG2 presented the Group's report on activities since CAEP/6. The detailed work of the Group had been undertaken by four Task Groups as follows:

a) Task Group 1 (TG1): Land use planning and noise management;

b) Task Group 2 (TG2): Modelling and assessment;

c) Task Group 3 (TG3): Operational measures; and

d) Task Group 4 (TG4): Airport air quality.

Ad hoc activity on Operation Benefits Outreach (OBO) had also been undertaken.

1.8.1.2 Many of WG2's tasks were relevant to CAEP/2 work on noise as well as emissions. For convenience, the work of TG2 and TG4 would be reported under this agenda item and the work of TG1 and TG3 would be reported under Agenda Item 3.

1.8.2 **Task Group 2**

1.8.2.1 Major tasks of TG2 have been in the areas of model evaluation and the databases necessary for providing the information need to run the models. The group has also been studying the issue of goal assessment. The group has also been investigating the suitability of the available models for use in assessing interdependency (of noise and emissions alleviation activities) issues and has conducted a preliminary review of a sample problem. All these issues had been addressed in more detailed working papers.

1.8.3 Task Group 4

1.8.3.1 The principal effort of this group had been the development of guidance information to assist States in implementing the best global practices for improving air quality in the vicinity of airports. This subject is also dealt with in more detail in a later part of the report on this agenda item.

1.8.4 Discussion

1.8.4.1 The meeting noted the report and also that more specific reports on the main items would be dealt with in detail separately.

1.9 GUIDANCE MATERIAL ON AIRPORT AIR QUALITY ASSESSMENT

1.9.1 Introduction

1.9.1.1 The WG2/TG4 Focal Point presented the Group's report on its work of developing airport air quality assessment guidance information to assist States in implementing best practices

1.9.2 Progress Report

1.9.2.1 The Task Group's work programme utilized a two phase approach spanning CAEP/7 and at least CAEP/8. For the first phase, TG4 was delivering (1) the framework for the entire guidance document and (2) text for the following guidance document sections: Introduction, Regulatory Frameworks and Drivers, Emissions Inventory, and Emissions Temporal and Spatial Distribution. For the second phase up to CAEP/8, the original work plan envisaged delivering text for the remaining guidance document sections: Dispersion Modelling, Airport Air Quality Measurements, Mitigation Options, and Interrelationships.

1.9.2.2 The guidance was based upon a tiered approach that allowed users to draw upon methodologies with increasing levels of accuracy (and broadly commensurate complexity) according to their need and available data. The methodology tiers were 'simple', 'advanced' and 'sophisticated'. In the aircraft engine section of the inventory chapter, detailed guidance was provided for the 'simple' and 'advanced' approaches since they relied upon existing published information and were relatively straightforward to implement. The 'sophisticated' method employed refined data and methods to more accurately calculate aircraft emissions. An overview of the 'sophisticated' approach for aircraft engines was contained in the material developed so far and detailed guidance was proposed to be produced in the next CAEP round as it relied, in part, upon the production of data and methodologies that were either under active consideration by WG3 or have yet to be addressed by them.

1.9.2.3 The guidance was fairly detailed and some sections were self-standing; others referenced sources of information required to produce an inventory. There were a number of weblinks to organisations holding relevant technical information. Whilst the majority of the inventory guidance related to undertaking assessments of present day airport emissions, it also included some information that would assist those seeking to conduct assessments of future emissions from an airport.

1.9.3 Proposed future work

1.9.3.1 As discussed above, the second phase of the guidance was the key future work item. It was proposed that future drafting work on the guidance should be prioritised as follows:

a) *Target completion by CAEP/8:* Aircraft source emissions inventorying, 'sophisticated' approach, Dispersion modelling, and Airport Air Quality Measurement; and

b) *Most likely after CAEP/8:* Mitigation, and Interrelationships.

1.9.3.2 Future parts of the guidance material would be more complex than those developed to date. This work would require the addition of further technical and scientific expertise to the group and the expansion of work with external organisations. Completion of the next stages of the guidance would be dependent upon States and observer organisation committing significant resources to the work. Because of the scale and complexity of the future work, it was anticipated that some later chapters of the guidance would not be finalised before CAEP/8.

1.9.3.3 A number of specific areas were identified where TG4 would need new inputs from other CAEP sub-bodies, from States and other organization before it could complete the work.

1.9.4 Discussions and conclusions

1.9.4.1 The meeting noted with satisfaction the material that had been produced and agreed that it should be published on the ICAO public website as an interim measure; when completed it could be recommended that it be published as a formal ICAO document.

1.9.4.2 The Representative of WMO mentioned that his organization had done much work on dispersion modelling which it would no doubt be pleased to pass to ICAO. It was agreed to take up this offer. A member also noted that the future work would require additional expertise. He considered that the requirements should be more specific and should be revisited as part of future work.

1.9.5 Recommendation

1.9.5.1 In light of the foregoing discussions, the meeting developed the following recommendation:

Recommendation 1/4 — Guidance material on airport air quality

That the material developed so far as part of an Airport Air Quality Guidance Manual be published on the ICAO public website as an interim measure.

1.10 THE IMPORTANCE OF LOCAL MICRO-CLIMATE CONDITIONS IN LOCAL AIR QUALITY

1.10.1 Introduction

1.10.1.1 A member pointed out that experience had demonstrated that local weather conditions played a fundamental role in pollutant dispersion at airports, especially those located at low latitudes. The existence of favorable meteorological conditions in this respect could exempt airports from the need to make comprehensive and expensive inventories of air pollutants. CAEP was therefore invited to introduce a set of minimum prevailing meteorological conditions for preparing an inventory.

1.10.2 Discussion and conclusions

1.10.2.1 Other members expressed support for this idea. However, it was pointed out that the material developed by WG2 (see paragraph 1.9 above) was only guidance material and not regulatory in nature. Airports would need to be treated on a case-by-case basis and meteorological data was one of multiple factors to be taken into account when assessing LAQ. If States wished to establish their own criteria for conducting an LAQ analysis, they were free to do so. However, it was not appropriate for CAEP to establish meteorological criteria. The meeting consequently took no action on the proposal.

1.11 ADVANCED AIRCRAFT EMISSION CALCULATION METHODOLOGY

1.11.1 Introduction

1.11.1.1 A member and an observer noted the first elements of the air quality guidance material that had been developed to assist States and interested parties in assessing the air quality at and around airports. It was understood that this guidance material would be a living document and that further chapters would be developed. It was also expected that existing elements would be periodically revisited to include the latest knowledge and expertise.

1.11.1.2 The emissions inventory in the version presented to the meeting provided only basic (simple) guidance for some important emission sources. This limited the usefulness of the material and support was offered to overcome this shortcoming. Many airports already considered more sources to a smaller or larger degree and were already developing practices that supersede the current status of the guidance material.

1.11.2 Aircraft engine emission calculations

1.11.2.1 The proposed material suggested a “simple method” with a look-up table of an invariable emission mass for various aircraft types and emission species. It also described a “sophisticated method” that involved various stakeholders and complex databases and procedures that would probably be beyond the normal capabilities of individual airports, because they involved the use of non-public proprietary information. Lying between these two, the currently suggested “advanced method” used the ICAO certification LTO cycle (i.e. four modes) for individual aircraft-engine combinations, using, if available, actual taxi times. It was noted, however, that the ICAO certification LTO cycle had not been developed with the intention of creating emission inventories.

1.11.2.2 The departure and arrival phases of an actual operational flight cycle for a commercial aircraft were more complex than the four modal phases typically used for ICAO certification purposes. Actual cycles employed various aircraft engine thrust settings and times in mode settings. Factors that affect those settings included, but were not limited to, aircraft type, airport and runway layout characteristics, operational procedures and local meteorological conditions.

1.11.2.3 There was evidence that engine ignition and start-up phase contributed HC emissions in the same order of magnitude as the whole ICAO Certification LTO cycle. This was very significant and therefore should not be excluded from inventories.

1.11.2.4 Moreover, in the proposed version of the “advanced method”, aircraft engine emissions in the ICAO LTO cycle are calculated using, to a large degree, the ICAO Engine Emission Certification data directly. The LTO times in mode and thrust in mode (thus fuel flow and emission indices) do not reflect actual aircraft operation or performance. Studies have shown that this method can overestimate aircraft NOx emissions by 20% to 30%.

1.11.2.5 The “advanced method” was only advanced in terms of aircraft/engine combination determination, but still quite simple for the emission calculation. What was needed therefore was a truly “advanced method” that took into account the aircraft performance but still at a level where airports or individual assessors would be able to do the calculations.

1.11.3 **Advanced aircraft emission calculation method**

1.11.3.1 A truly advanced aircraft emission calculation method would need to take into account the performance of aircraft operating at a specific location at the specific time. Such performance based calculations should be based on data that is easily and publicly available. A prototype of an advanced aircraft engine emission calculation method (ADAECAM) was being developed that relied on data and information that is non-sensitive, non-proprietary and publicly available. Many airports had such data available on a regular basis through other operational airport databases. Thus only a limited effort would be necessary to obtain all the parameters needed to perform this advanced emission calculation at an airport.

1.11.3.2 The methodology under development included the full LTO-cycle from engine start-up to engine shut down within the LTO perimeter (below 3,000 ft) for a number of pollutants, including PM. Within the performance module, the method used data that are aircraft related (take-off weight, based on trip length), airport related (local meteorological conditions) and engine related (ICAO emission factors). The methodology, validation and examples could be fully documented and presented to the proper CAEP working groups. CAEP was therefore invited to note that an advanced aircraft emission calculation method was under development and would be available for further use within the current and future CAEP work.

1.11.4 **Discussion and conclusions**

1.11.4.1 The meeting noted the offer with interest. The Rapporteur of the Task Group agreed that performance modelling was important, but had not been included so far because a consensus on the subject had not been reached. The group would, however, be pleased to receive any input on this subject that would be provided.

1.12 EMERGING ISSUES FROM THE PROJECT FOR SUSTAINABLE DEVELOPMENT AT LONDON HEATHROW AIRPORT

1.12.1 **Introduction**

1.12.1.1 A member informed the meeting of interesting lessons that were emerging from a project underway in his State. He noted that the proposed guidance material highlighted a number of emerging issues related to air quality around airports. It was suggested that the information available could help the Task Group in its future development of the guidance material.

1.12.2 **Discussion**

1.12.2.1 The meeting noted the information with interest and requested the Task Group to include consideration of it in its future development of the guidance material. It was also agreed to request other States to provide similar information where it was available, as it would not be advisable to develop guidance on one case.

1.13 ENVIRONMENTAL GOALS ASSESSMENT

1.13.1 **Introduction**

1.13.1.1 The WG2/TG2 Focal Point introduced a report on this subject. It noted that, as far as emissions were concerned, it was CAEP's goal to limit or reduce the impact of aviation emissions on local air quality and limit or reduce the impact of aviation greenhouse gas emissions on the global climate. To assist in this task, at the October 2005 Steering Group Meeting, two members had agreed to prepare a joint paper which would present a proposed methodology for measuring progress towards meeting these goals. As a result of its experience with various environmental models, EUROCONTROL was also asked to contribute. It had been noted that there was no accepted metric or modelling system for reporting the impact on local air quality (LAQ) and of greenhouse gas (GHG) emissions from aircraft, as there was for noise.

1.13.1.2 WG2 had begun to explore various approaches to measuring impacts of LAQ and GHG emissions. A proposal had been developed which had been presented and agreed to by the June 2006 Steering Group Meeting. More discussion was required and would probably persist into the CAEP/8 preparation cycle. Therefore, the LAQ and GHG environmental goals assessment for this meeting had been restricted to quantifying aircraft emissions trends.

1.13.2 **LAQ and GHG emissions**

1.13.2.1 WG2 had been requested at CAEP/6 to evaluate several specific models and databases and the Working Group had added other models to the list. The evaluation of these models could not be completed in time to support goals assessments at this meeting. As an interim measure, it had been agreed at the 2006 Steering Group Meeting to use existing GHG models, offered under the model evaluation process by CAEP Member States. This would provide the information required for assessment of progress towards the emissions environmental goals. Consequently, results were being presented from four models: AEDT/SAGE, AERO2k, AEM and FAST. In carrying out the modelling of emissions, the aircraft replacement data used had been derived from a 2006 version of the WG3 In-Production database. Consequently, projections of future technology developments had not been included in the assessment. WG2 had not been able to identify any simple means of taking technology advances into account in time to conduct sensitivity assessments for CAEP/7. However, WG2 was aware that other work had been carried out assuming improved fuel efficiency and emissions rates for future aircraft operations, achieved through technology, operational or Air Traffic Management (ATM) improvements. In such cases, equivalent fuel and emissions results based on similar fleet forecasts and timescales were generally lower than those used in WG2's assessment.

1.13.2.2 Since the GHG models computed emissions and fuel burn from aircraft operating gate-to-gate, they effectively also provided LAQ data, in addition to data for the en-route portion of flight. Consequently, for the purposes of this initial LAQ/GHG analysis, the results from the four models were presented for the complete flight. As a result, there was no need to separately model the LAQ emissions using a model such as AEDT/EDMS.

1.13.3 **Discussion and conclusions**

1.13.3.1 It was noted that the results produced showed trends, but did not indicate whether the CAEP goals had been met, in part due to the lack of a methodology for calculating emissions and impacts where necessary. This was acknowledged, but it was pointed out that this was the first attempt and a goals assessment could not be accomplished yet. Some members also noted that the increases in fuel consumption in the various regions did not appear to be credible — particularly fuel consumption in Europe appeared to be increasing more quickly than in Asia, which seemed unlikely. It was also suggested that the assessment would be more useful if the timescales were aligned with those used by IPCC in its studies. Although a change in this respect might introduce discontinuities, the results would be more valuable in the long term.

1.13.3.2 There was considerable discussion on how the information could be used. It was noted that this information had been specifically requested by the 35th Session of the Assembly and that some response to the next Session was therefore essential. If the information were to be made public, it would need to have caveats attached, i.e. that it was a first attempt at an assessment; there was no agreed metric for an emissions impact assessment; and technology and operational improvements had not been incorporated. It could therefore only be considered as illustrating trends. Some members feared that, even with these caveats attached, the information might be misinterpreted.

1.13.3.3 The meeting agreed that the Secretary would have to communicate the results of the assessments to the Assembly but that the fact it was only a preliminary trend assessment and that there were several other caveats attached should be made clear. After further discussion the meeting agreed to endorse the work that had led to the preliminary trend information presented and, recognizing the limitations of the data produced to date, endorsed the recommendations on potential improvements to the methodology for CAEP/8 goals assessment.

1.14 **STATUS REPORT ON MODEL EVALUATIONS**

1.14.1 **Introduction**

1.14.1.1 The WG2/TG2 Focal Point introduced a report on work done to evaluate the models used to investigate various aspects of noise and engine emissions as requested at CAEP/6.

1.14.1.2 Evaluation teams had been established in the areas of noise, local air quality, greenhouse gases and economics. A framework had been developed to ensure consistency in the evaluation process across all modelling areas. The report briefly described the evaluation framework, and presented the current status of the evaluation.

1.14.1.3 A list of the models examined, and the States or Organizations providing them, is contained in Appendix D to the report on this agenda item.

1.14.2 **Evaluation Framework**

1.14.2.1 Tables had been designed to present each model's degree of readiness relative to minimum CAEP modelling capabilities, namely: (1) anticipated CAEP/8 modelling requirements; (2) common issues across tools in summary format; and (3) issues unique to a specific tool. A single summary table compared model readiness in regard to each of the specific requirements. The degree of model readiness in regard to each of the specific requirements was presented according to the following qualitative definitions: (1) "does not appear to meet requirement; thus, tool change is needed"; (2)

"appears to need adaptation to meet the requirement"; (3) "insufficient information to make a judgment"; (4) "appears to meet requirement with minor or no change to the tool"; and (5) "not relevant to this type of tool".

1.14.2.2 A related, expanded set of the summary tables was also presented including detailed supporting explanation for the degree of readiness assigned. A version of this table had been prepared for each model submitted for evaluation.

1.14.2.3 A further set of tables presented a comparison of key elements of each model submitted, with a specific focus on differences for each modelling area, i.e., differences in input databases and methodologies. The intent of this table was to highlight differences in specific model capabilities. By doing so, related strengths and weaknesses of one model versus another should be more apparent. This approach might also help illustrate reasons for differences in model output.

1.14.3 **Considerations for CAEP**

1.14.3.1 It had been anticipated that the model evaluation process would not lead to the identification of a single acceptable model in each of the areas. It was thought more likely that some models would have particular strengths where others had weaknesses and vice versa. The goal of the evaluation process had been to establish a presentation framework that would allow Working Groups to identify for CAEP/7 models capable of answering a specific question identified for study under the CAEP/8 Work Programme.

1.14.3.2 There would be instances where more than one model would be capable of addressing a specific CAEP question. The Steering Group has already agreed that, in general, there were advantages in pursuing the use of multiple models and that the most important issue was the correct assessment and interpretation of the results.

1.14.4 **Noise-specific CAEP consideration**

1.14.4.1 It was recalled that the Steering Group meeting had already agreed that the DOC29-compliant version of the Model for Assessing the Global Emissions of Noise from Transport Aircraft (MAGENTA) should, in principle, be adopted as the CAEP noise assessment tool during CAEP/8 subject to completion of the model evaluation task. The main factors supporting this position were that: (1) the model was developed under CAEP guidance and supervision; (2) the model is currently the only one submitted that provides the data coverage necessary for assessing noise exposure worldwide, and (3) the tool currently has the funding support necessary to continue the development, update, and expansion of both its software and data coverage, which are important for the ongoing support of the CAEP efforts. Other noise models evaluated will nevertheless be vital in providing the supplementary checks that ensure the correctness of the MAGENTA results provided to CAEP.

1.14.5 **General Results of Model Evaluations**

1.14.5.1 The following conclusions had been reached from the studies:

a) all candidate models in each area had been found to be potentially suitable for use in one or more of the current and likely future policy issues developed by CAEP;

b) where models needed adaptation or major change to meet CAEP requirements, there did not appear to be any reason why such adaptations and changes could not be made, should the model submitters wish to do so;

c) in some cases, the suitability of individual models would depend on yet-to-be-defined details of the CAEP requirement;

d) sensitivity tests had been proposed to understand differences between models; and

e) two types of sample problems had also been proposed to answer specific domain-level questions, as well as a system-level sample problem across all areas that included technology considerations.

In regard to these general conclusions, it was cautioned that the results presented should be considered accurate at present. However, it was expected that the results of running further sample problems would identify areas for possible improvement and that the model development would continue in most cases. Model evaluations should also therefore continue, and the results presented could be expected to evolve also.

1.14.6 **Discussion and conclusions**

1.14.6.1 The meeting endorsed the evaluations of the models that had been undertaken and noted that the evaluations might be revised in the light of future information becoming available. It was considered that no major changes to the models was likely, but small adjustments and refinements could probably be incorporated before final decisions on the models to be used were made at the next Steering Group Meeting. The picture would become clearer once the tasks to be performed by the models in preparation for CAEP/8 had been determined, which should be done as soon as possible. It was cautioned, however, that extra tasks could be added by the next session of the Assembly, and that the list of assessments that would require modelling would need to be decided at the Steering Group meeting.

1.14.6.2 A member considered that the general view might be overly optimistic and it would be helpful to identify specific areas requiring improvement. He also believed that, for example, health and welfare aspects needed to be added to the models and was not sure of the time required to develop these capabilities. He considered health and welfare considerations needed to be added for tradeoff studies, even for technically driven changes; CAEP's goals were impact-based and evaluation of impacts on health and welfare were therefore necessary. Other members did not agree about adding health and welfare considerations. These might be relevant in some cases, but not all; in any case they appeared implicit in the case of noise contour based evaluations. It was also suggested that health and welfare concerns had already been included by States in their national guidelines. It was also considered that health and welfare were subjective issues and there was concern about relying too much on such an approach. However, a member noted that a common currency for impacts was necessary for considering trade-offs, even if this was difficult.

1.14.6.3 The meeting also endorsed the need to carry out sensitivity tests to improve understanding of the differences between the models. It was also agreed that, subject to completion of the model evaluation, the ECAC Doc 29-compliant version of MAGENTA would be the primary model for conducting noise analyses for CAEP/8.

1.14.6.4 It was generally agreed that the evaluations needed to be rigorous for all the models, since the results would no doubt be sensitive to rigour and accuracy. It was stressed, however, that the evaluation process did not amount to a formal vetting of the models.

1.15 SAMPLE MODELLING PROBLEM

1.15.1 Introduction

1.15.1.1 The WG2/TG2 Focal Point introduced a report on a sample problem exercise undertaken to investigate tradeoffs between noise and emissions using existing models. It was noted that, with model evaluations progressing, and substantial progress being made towards developing common databases, the foundation had been established within CAEP for a modelling system which would be capable of evaluating interdependencies between noise, emissions and economics in time for CAEP/8 analyses.

1.15.1.2 It was expected that the trade-off capabilities of a system would only be fully revealed by applying a common set of equivalent inputs to the proposed modelling systems and addressing a specific problem. This process might identify required improvements in a modelling system's core modules and databases, improvements in the framework that integrates the modelling system (e.g., common assumptions), improvements in the input assumptions which describe the problem/policy, challenges in incorporating the databases in a consistent manner, and the future challenge in establishing a "common currency" for the evaluation of the output given in varying noise/emissions metrics. Depending on specific sample problem results and additional development of trade-off capability required for the CAEP/8 work programme, there could be a wide range of additional resources necessary. To this end, the case of reduced thrust had been agreed upon as a suitable sample problem.

1.15.1.3 This report indicated the participating models and organizations and summarized the lessons learned in conducting the sample problem, with specific focus on trade-off modelling in preparation for the CAEP/8 Work Programme. It did not present specific results but identified differences in the trade-off capabilities of the participating models.

1.15.2 Trade-Off Modelling Capabilities and Lessons Learned

1.15.2.1 For noise the participating organizations (and models) were: Anotec Consulting (Sondeo); UKCAA (ANCON); and USFAA (AEDT/MAGENTA).

1.15.2.2 For emissions calculations, the participating organizations (and models) were: Cambridge Environmental Research Consultants (ADMS); EUROCONTROL (ALAQS); Janicke Consulting (LASPORT); and USFAA (AEDT/SAGE). Due to time pressures, and to ensure consistency, the AEDT performance module was used to compute a set of full power and 10% reduced thrust profiles to be used by all modellers participating in the sample problem. Due to time and modelling constraints with all models, no attempt was made to represent actual operational levels of reduced thrust. Unlike with noise, the study did not consider emissions impact assessment beyond emissions inventory. Future work was expected to consider suitable metrics for assessing emissions impacts.

1.15.2.3 The results of the study were presented in an example format. Because of the sample problem definition (a fixed 10% reduced thrust) and issues with the input data the results did not represent the actual comparative tradeoffs of reduced thrust takeoff that would be seen in operational service. The presentation was an initial attempt at visualizing the trade-offs associated with fuel burn, NOx and noise in a single chart.

1.15.3 Discussion and conclusions

1.15.3.1 The meeting noted the results of the exercise with interest and endorsed the lessons learned. It was noted that data from one of the models had been used as input for other models and it was thought that, to some extent this invalidated the independency of the exercise. This was accepted and it was agreed that for future use, all models would need to be capable of performing the complete analysis task.

1.15.3.2 The meeting endorsed the need for the CAEP/8 work programme to address the matter of emissions impact modelling including the development of suitable metrics.

1.15.3.3 The meeting noted the format in which the results of the study had been illustrated and also noted that all members and observers were invited to provide comments as input for developing a framework for presenting modelling results.

1.15.3.4 The meeting agreed that TG2 should perform more such sample problems as part of the model evaluation process. The Focal Point indicated that TG2 considered the sample problems, sensitivity analyses and verification and validation, including comparison to "gold Standard" data where available, as constituting a full vetting process. It was again stressed that this was not a model vetting procedure as generally understood. It was noted that CAEP was still examining the models to identify their strengths and weaknesses prior to possibly agreeing them in the future at a Steering Group meeting.

1.16 HARMONIZED GLOBAL AIRCRAFT MOVEMENTS AND AIRPORTS DATABASE

1.16.1 Introduction

1.16.1.1 The WG2/TG2 Focal Point introduced a report on the harmonization of aircraft movements databases and airports databases.

1.16.1.2 CAEP analyses such as those performed with the Model for Assessing Global Emissions of Noise from Transport Aircraft (MAGENTA), or the analyses used to develop the CAEP/6 NOx stringency assessment used different movements databases to develop the baseline fleet to which the FESG forecast was applied.

1.16.1.3 It was recognized that different modelling assumptions would probably result in discrepancies in the assessment of trade-offs in future work. TG2 consequently established a subgroup whose mandate was to make recommendations for improvements to the modelling assumptions that would be used in the planned future analysis of tradeoffs. One of the first actions of this group had been the harmonization of a global movements database. The subgroup's activity was subsequently expanded to include a harmonized global airports database.

1.16.1.4 United States FAA/Volpe and EUROCONTROL had already developed global movements databases, but because of different development strategies and objectives, early comparisons of numbers of operations did not show good correlation. These organizations had therefore agreed to pursue a harmonization programme of the two databases.

1.16.1.5 In both databases, radar data for North America (ETMS) and Europe (ETFMS) was used to define a large proportion of global civil flight operations (approximately 75-80%). For the rest of the world, timetable data from the International Official Airline Guide (IOAG) was currently used. However, it was known that this approach missed a significant number of unscheduled flights around world. Following earlier attempts to obtain radar data from regions of the world other than North America and Europe, selected ICAO States had been requested to supply additional radar data where there were considered to be significant gaps in world traffic data.

1.16.2 Global Aircraft Movements Database Harmonization

1.16.2.1 A set of ground rules had been established to help facilitate the harmonization. It was agreed that the focus would be on commercial aviation, excluding flights categorized as general aviation or military. In cases where both radar and schedule-based data existed for a given flight, it had been decided that radar-based data would take precedence.

1.16.2.2 Since ETMS and ETFMS coverage overlapped geographically, a methodology needed to be developed to merge trajectories from the two radar-based datasets. EUROCONTROL had developed a methodology for this merging which was being studied by FAA/Volpe. Comparative work between the two databases was well advanced and a harmonized movements database was expected to be completed early in the CAEP/8 work programme.

1.16.2.3 A final area which required further investigation and possible harmonization was trajectory development for IOAG-based movements and work was continuing in this area.

1.16.2.4 One of the challenges in using radar data was that sometimes the data were incomplete, particularly for the initial departure phases (push back, taxiing, takeoff, climb out) where the availability of data was often dependent on when the transponder was switched on. This meant that it was often necessary to complete the trajectory for these initial phases. Work on comparing the approaches taken by FAA/Volpe and EUROCONTROL to this problem had not yet started.

1.16.2.5 It was suggested that the WG2/FESG Common Movements database be used as the baseline for conducting the updated FESG forecast. This would ensure consistency between WG2 and FESG.

1.16.3 Collection of Radar Data

1.16.3.1 Analysis so far of additional data received in response to ICAO's request had indicated that, in most cases, further coordination with the States involved would be necessary in order to ensure the future provision of appropriate data. This was expected to take place during the early phases of the CAEP/8 work programme. Review of data had also shown, however, that when appropriate detailed flight information from radar sources could be provided, a significant number of flights were sometimes added and additional flight details about flight trajectories could improve the precision within the database.

1.16.4 Global Airports Database

1.16.4.1 To date, the global airports database had been assembled by merging the U.S. databases with similar databases maintained by EUROCONTROL's Experimental Centre.

1.16.4.2 The current version of the airports database included the following elements: latitude, longitude, name, city, country and time zone. The database also provided linkages between ICAO, IATA and ETMS airport codes, which were critical for interpreting data from sources around the world. Another key element of the database was that it described the country and ICAO region relationship, which would facilitate the reporting of model results by ICAO region in support of the CAEP/8 work programme.

1.16.4.3 The database currently held details of approximately 31,000 airports and was essentially complete, although some additional enhancements may be required as a result of the development of the movements database. It was also expected that some annual maintenance of this database would be required.

1.16.5 **Discussion and conclusions**

1.16.5.1 The meeting endorsed the progress that had been made in creating the harmonized databases. One observer expressed concern, however, that merging radar-based data and timetable-based data might skew the results and a sensitivity study on this point might be needed. In response it was pointed out that IOAG-based data alone would also be skewed because, for example, it did not reflect the very heavy summer charter traffic in Europe. Nevertheless, some sensitivity studies were already in progress. It was questioned whether the anticipated date for completion of this work, i.e. late 2007/early 2008 would fit with FESG's work schedule for developing the updated forecast. In response it was predicted that the airport database would be ready and the timetable-based part of the movements data, which is all that is needed by FESG to prepare the updated forecast, would also be ready but the comprehensive trajectory information might not be ready until early 2008.

1.16.5.2 The meeting encouraged States not covered by ETMS/ETFMS to submit radar data if they had not done so already.

1.16.5.3 A member understood that an issue of data confidentiality existed which was hampering the efforts of modellers and enquired whether any progress had been made in resolving the matter. Another member responded that the problem had regrettably resisted all efforts at resolution for several years.

1.17 **CAEP POLICY MODELLING IN EUROPE**

1.17.1 **Introduction**

1.17.1.1 On behalf of a number of members and an observer, a member presented a paper outlining modelling being carried out in Europe which supported CAEP's work.

1.17.1.2 Candidate models had been submitted by a number of European States and other European bodies for evaluation and use within the CAEP process. These included SONDEO and ANCON for modelling noise, AEM, AERO2k, AERO-MS and FAST for modelling greenhouse gas emissions and ADMS, ALAQS and LASPORT for Local Air Quality Modelling. The AERO-MS model had also been previously evaluated and used within FESG for assessment of economic policy options. Additionally, other models were becoming available or were undergoing development within European States and these might also be submitted for evaluation and use within CAEP at a later date.

1.17.1.3 Individual States, the EC and other bodies within Europe had funded the development of these models. This support would continue and would facilitate future developments appropriate for modeling the effects of aviation activity and development to inform CAEP policy decisions.

1.17.2 **Next steps**

1.17.2.1 The participating European organisations would develop these plans further and present them to CAEP. These plans would not conflict with the work carried out to date by WG2. The developed models will complement the AEDT/APMT/EDS modelling capability offered by the US. Together, these modelling approaches would provide CAEP with necessary insights into policy decision making which have not previously been available.

1.17.2.2 To support this initiative, it was also important that, common databases were developed and made available to all CAEP modellers. Key amongst these was the Common Operations Database, the Campbell-Hill database (or equivalent) and global access to the MAGENTA airport data. Moreover, any common databases supplied needed transparency where assumptions have been made, or where data are incorporated (e.g. FESG forecasts).

1.17.2.3 It is also considered to be fundamental that the CAEP approach to modelling remained flexible and non-prescriptive, whenever practicable, thereby permitting the various approaches used in the European and US models to be used.

1.17.3 **Discussion and conclusions**

1.17.3.1 A member agreed that it was useful to have other models available and welcomed the modular approach envisaged. However, it was regrettable that there was a lack of access and transparency with many of the models. It was suggested that the level of transparency used in developing US/Canadian models should be the norm for all models. The member presenting the paper responded that the comments were appreciated but since the models were the property of individual States or organizations, no collective response to the criticisms could be given.

1.17.3.2 The meeting noted the information provided and agreed the benefits of having alternative models. It agreed on the need for common databases and confirmed the requirement to provide CAEP modelling capability based on flexible approaches for modelling future policy options. It also encouraged transparency and collaboration in model development.

1.18 CAEP INTERDEPENDENCIES FRAMEWORK AND COORDINATION

1.18.1 **Introduction**

1.18.1.1 The Rapporteurs of all three working groups and FESG presented a joint report on interdependencies between the various elements of CAEP/s work. It was recalled that CAEP/6 had acknowledged the importance of taking an integrated approach to aviation environmental issues, where appropriate. It had agreed that the working groups should follow progress on the development of new tools and metrics for addressing interdependencies, and that a paper should be prepared for CAEP/7 reviewing developments on how to address the trade-offs between the environmental problems and their solutions. It was also recognised that the comparison of trade-offs between various environmental impacts (e.g. noise/emissions) would require a more complex analysis system than that used for previous CAEP work.

1.18.1.2 In pursuing this task the working groups had spent time reviewing the historical body of previous CAEP analysis and identifying the inter-group coordination and liaison required. After this review and discussion, the work had been divided into two parts: a) identification of the sub-systems and components required to meet CAEP's analysis needs; and b) identification of software or procedures that could "assemble" these sub-systems in a way that would allow for the assessment of trade-offs.

1.18.2 **Sub-Systems And Components**

1.18.2.1 Sub-system analysis tasks were identified as local air quality, greenhouse gas emissions, noise, and economics. Candidate models that could be used by CAEP in its modelling efforts in these areas had been evaluated as reported in paragraph 1.14 of the report on this agenda item.

1.18.2.2 Components which supported specific analysis tasks were identified as (a) the application of the FESG forecast, (b) WG1-WG3 technology interdependency rules, (c) fuel flow estimation and fuel-flow-based methods for calculating EIs, based on the ICAO Engine Emissions Databank and (d) the application of the Aircraft Noise and Performance database in a computational module that is compliant with ECAC Doc. 29.

1.18.2.3 The application of the FESG forecast had also led to the recognition of the need for a CAEP Analysis Commonality task which would ensure that modelling factors (e.g. inputs, rules, assumptions) would be consistent. This was essential to ensure consistency between environmental benefit models when considering trade-offs, and also between benefit and cost models. Relevant work on databases is reported in paragraph 1.16 of the report on this agenda item.

1.18.3 **Assembly of Sub-systems**

1.18.3.1 WG2 had demonstrated a basic modelling capability and the results of its application to a sample problem are presented in paragraph 1.15 of the report on this agenda item.

1.18.3.2 Further iterative work was expected to develop the capacity to assess the trade-offs in an integrated way. These verification studies (e.g. additional sample problems, model comparative studies and model sensitivity tests) would be used to identify modelling “gaps” and demonstrate system capability as models moved towards a common set of inputs, rules and assumptions.

1.18.4 **Discussion and Conclusions**

1.18.4.1 The meeting endorsed the work done so far on this subject. However, it considered that the recommendations for future activities might involve a change of CAEP’s structure and it therefore agreed to return to them during its discussions on future work (Agenda Item 4).

1.19 NOISE-EMISSIONS TECHNOLOGY INTERDEPENDENCIES GROUP: PROGRESS REPORT

1.19.1 **Introduction**

1.19.1.1 The Rapporteurs of WG1 and WG3 reported on the work of the WG1-WG3 ad-hoc group set up in February 2005 to consider how technology assessments had been performed during previous noise and emissions stringency increases, as well as future steps and processes for analyzing technology interdependencies. A report from this ad-hoc group had been approved by both Working Groups, and the Steering Group, which subsequently created the WG1-WG3 Technology Interdependencies Group (TIG) under the responsibility of both WG1 and WG3 Rapporteurs. The role of the TIG was to coordinate the work, the detail of which was carried out by WG1/TTG and WG3/CTG, and to provide input into the SG which had been approved by both WG1 and WG3.

1.19.2 **Linking of ICAO Noise and Emissions Certification Databases**

1.19.2.1 The TIG had created a linking group, consisting of both WG1 and WG3 members, to perform this task. The group had initially created two “master lists” of unique engine type designations from NoisedB (March 2005) and the Engine Emissions Databank (Issue 14 – 1st June 2005). This review had proved useful in identifying missing datasheets from the Emissions Databank and corrections to engine designations in NoisedB. Engine type matches had been made and the linking group expected to use these matches to create the final linking database between the ICAO certification databases once NoisedB had been formally approved. An aeroplane maximum take off mass (MTOM) only affected its noise certification characteristics since emissions certification was performed at the engine level. Therefore the same engine type on different aeroplane mass variants would have different noise certification levels while the emissions levels would stay the same. The working groups had agreed that this did not reflect real life, and a statement on the use and limitations of the linking database had therefore been prepared to address these concerns.

1.19.3 **Technological Responses to a Stringency Option**

1.19.3.1 This issue had been recognised as a significant challenge facing both WG1 and WG3. Historically, noise and emissions had been considered separately and had used different assessment techniques. One possible tool for modelling technology response, which was currently in development, was the FAA Environmental Design Space (EDS). Changes in engine cycle parameters (e.g. Overall Pressure Ratio and Fan Pressure Ratio) affected the trade-off between factors such as NOx and fuel burn. Similarly, the infusion of current technology (e.g. chevron nozzle, new materials) could be assessed in terms of its impact on engine cycle, which in turn could be translated into noise, emissions and performance metrics. An expert-driven process was also being developed to extend the tool's capability to enable forecasting of the effects of introducing future technology.

1.19.3.2 In addition to the current research projects within the United States, the European industry had offered the Technology Evaluator process as a further means of evaluating technology response to stringency options. Evaluator currently only considered noise and CO_2 for technologies at Technology Readiness Levels (TRL) between 3 and 6 but could be extended to TRL 8 and include a NOx emissions element.

1.19.3.3 The TIG agreed that there was a need to keep in mind what policy options CAEP may ask WG1 and WG3 to assess during CAEP/8, and with what assumptions, in order to steer the development of models. It had also encouraged the continued development of the EDS and Technology Evaluator tools, and had left the door open for other models. Finally, the TIG had acknowledged the deadline provided by WG2 for identifying the form of the technology inputs for CAEP/8 policy assessment as the end of 2007.

1.19.4 **Review of the Campbell-Hill (C-H) Database**

1.19.4.1 Following a request from WG2, WG1 and WG3 had reviewed the new and modified entries in an updated version of the C-H Database (end of year 2004). The C-H Database identified, on an aircraft registration-specific basis, the commercial aircraft (passenger and cargo/freight) in the existing fleet worldwide. IATA had provided the C-H Database to CAEP since CAEP/5. The UK CAA, US FAA, Schiphol Airport and Delta Air Lines had provided feedback as part of the review of the noise certification levels contained in the new C-H Database. This information suggested that there were discrepancies and, it had been agreed that the identified differences would be corrected by C-H.

1.19.4.2 Some concerns had been expressed, from both a noise and emissions perspective, regarding the engine designations, certificated masses and associated noise certification levels in C-H. It had been agreed that if the C-H Database were to be used for future CAEP environmental goals and stringency assessments, there would be a need for the completion of the emissions review and a better understanding of the modeling sensitivities to the process and assumptions used in collating the C-H data. At the Steering Group Meeting in June 2006, it had been agreed to progress this immediately in order to determine whether any changes are needed, and for any identified improvements to be ready for CAEP/8. This work had now been commenced with the assistance of IATA, which was developing a common format airline survey to elicit responses from its members. Furthermore, C-H was now collaborating with engine manufacturers to create a comprehensive list of engine types and emissions/noise options, and would incorporate those data in the appropriate spreadsheet fields to be provided to operators. Operators would be asked to confirm or correct engine designations and combustor options for each aircraft in their fleets, and appropriate UIDs would then be entered.

1.19.4.3 The final product needed for CAEP/8 work was a database that reflected the global fleet at the end of 2006, which would be synchronous with an updated FESG fleet forecast. As operators' 2006 fleet plans were already set, it had been agreed to perform a single survey, based on the C-H Database (year end 2004) where operators would be asked the following:

- Whether the aircraft shown in the year-end 2004 database were still in their fleet, and to identify deletions.
- For aircraft still in the fleet, to confirm/correct the information outlined above.
- To identify additional aircraft added to their fleet since 1 January 2005, and for those additions, to provide the information outlined above.
- Whether the operator planned other deletions or additions in the remainder of 2006, and to identify upcoming deletions and additions.

The target date for completion of reviews was 30 March 2007. This would allow results to be presented at Spring 2007 working group meetings.

1.19.5 **Discussion and Conclusions**

1.19.5.1 The meeting noted the work done so far on this subject. A Member commented that work on the US/FAA EDS is ongoing and had included international participation, but emphasised that it would be helpful to have similar information on, and participation in, the technology evaluator. The meeting considered that future activities would be dependent on any decisions it might take on the general subject of interdependencies within CAEP (see 1.18 of the report on this agenda item). It therefore deferred further consideration of this matter until its discussion of future work under Agenda Item 4.

1.19.5.2 An Observer proposed that IATA should participate in the TIG.

1.20 INDUSTRY RESPONSE TO STRINGENCY STANDARDS AND REVIEW OF PREVIOUS MODELLING ASSUMPTIONS

1.20.1.1 The FESG had conducted a detailed review of assumptions used in models to assess the economic impact of previous noise and NOx stringency standards, and the industry response to those standards.

1.20.1.2 The review had shown the progress made by manufacturers in bringing in-production engines that did not meet the CAEP/5 noise and CAEP/6 NOx standards into compliance with that standard. Because sufficient time had not elapsed since the adoption of the CAEP/5 noise and the CAEP/6 NOx standards for complete responses to be observed, a full evaluation of the industry response to these standards had not been possible. However some initial findings of industry responses had been reported. Key modelling methods and assumptions used for economic analysis of noise and NOx stringency had been reviewed, and recommendations for their future had been made. The review found the key modelling methods and assumptions discussed are appropriate for the economic analysis of NOx and noise stringency, either individually or in combination.

1.20.2 **Discussion and Conclusions**

1.20.2.1 One member requested clarifications regarding the level of confidence placed on the cost estimates provided by the manufacturers for the development of economic analyses and whether they had gone through any validation process. He also enquired about the evidence for using a 2% fuel burn penalty for past analyses and how this estimate will be updated. He also requested clarification on the timing and the manner in which industry responses to CAEP/5 noise and CAEP/6 NOx standards would be monitored.

1.20.2.2 In response and in relation to the confidence placed on the cost estimates and their validation, it was mentioned that the manufacturers' data is proprietary and that the private sector is bound by competitive and legal issues which prevent it from sharing cost data. New models using public data were being developed and they may offer a solution to this limitation. As for the 2% fuel burn penalty estimate, it corresponded to the initial commercialization of the dual annular combustor in a lower thrust high by-pass ratio engine as a surrogate for unproven technology. Recalling the WG3 Long-Term Technology Goals presentation, a fuel burn penalty could apply to future staged combustors. FESG will work with WG3 to update the estimate should the need arise in any future stringency analysis. The reporting on the monitoring of industry responses to CAEP/5 noise and CAEP/6 NOx standards would be provided during future Steering Group meetings and also at CAEP/8.

1.20.2.3 Another member enquired about whether the impact of airport and airspace capacity constraints on airline revenues has been taken into consideration in economic analyses. In response, it was noted that, in past economic analyses of stringencies, the focus had been on direct costs and benefits of the stringency option. Nevertheless, capacity constraints may be significant in economic analyses. For future analyses, the assumption of unconstrained airspace and airport capacity should be maintained for the core analysis and a sensitivity analysis should be undertaken to take into consideration the effects of capacity constraints.

1.20.2.4 The meeting agreed that FESG should develop, in cooperation with Working Group 2, appropriate sensitivity tests to assess the impact of air traffic system and airport congestion and delay on the economic analyses of noise and emissions stringencies.

1.20.2.5 A member suggested that, for the future development of economic analysis of noise and NOx stringency options, more representative performance-based values should be used instead of ICAO times in mode since it had been proven that using the latter had led to an over-estimate of the total NOx emitted by about 20 per cent. In response, it was noted that for economic assessment of policy options, the key principle is to develop appropriate modelling methods and assumptions to isolate the effect of the policy variable, and to exclude the effect of all other variables that may further influence the result. The meeting was reminded that uncertainty in estimating future performance-based values could introduce a variation that could influence the modelling results. ICAO stringency was based on an invariable standard time in mode and thrust level schema for certification purposes and following this method in the economic analysis isolated the effect of the stringency option.

1.20.2.6 It was agreed that the CAEP should produce for the first Steering Group meeting a parallel sensitivity analysis using performance values along with the ICAO times in mode.

1.20.2.7 A member suggested that FESG should take advantage of progress made in the field of monetization of benefits in parallel to using cost-effectiveness analysis. One member expressed his doubts on the ability to attach a value or a price to benefits or impacts. While he recognized that this approach may be feasible at a national level, its extension to the regional and global levels would not be a simple task. Another member suggested that it would improve the ability to evaluate trades between various environmental impacts without considering monetization and that this could be done using ranges instead of point estimates in the monetization. Another member suggested that for the monetization results to be credible, there was a need for some sort of scientific evidence (of the damage impact) which could be translated into a benefit which could then be monetized.

1.20.2.8 The meeting recommended that FESG should carry out a "sample problem" approach for cost-benefit analysis for assessment of stringency options using ranges of estimates of monetized values. This should assist in understanding the challenges involved. In the meantime, cost-effectiveness analysis should be used for conducting economic analyses of stringency options.

1.20.2.9 After discussion, the meeting accepted the recommendations for future analyses based on the findings of the report on the industry response to previous stringency measures after taking the results of this discussion into consideration. It was noted, however, that assumptions would be open to future review based on the results of future sample problems and model assessments.

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APPENDIX A

PROPOSED AMENDMENT TO

INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION

ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME II
AIRCRAFT ENGINE EMISSIONS

1. The text of the amendment is arranged to show deleted text with a line through it and new text highlighted with grey shading, as shown below:

1. ~~Text to be deleted is shown with a line through it.~~	text to be deleted
2. New text to be inserted is highlighted with grey shading.	new text to be inserted
3. ~~Text to be deleted is shown with a line through it~~ followed by the replacement text which is highlighted with grey shading.	new text to replace existing text

TEXT OF PROPOSED AMENDMENT TO THE

**INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES**

ENVIRONMENTAL PROTECTION

**ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION**

**VOLUME II
AIRCRAFT ENGINE EMISSIONS**

. . .

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

. . .

Rated ~~output~~ thrust. For engine emissions purposes, the maximum ~~power/thrust available for take-off~~ take-off thrust approved by the certificating authority for use under normal operating conditions at ISA sea level static conditions, and without the use of water injection ~~as approved by the certificating authority~~. Thrust is expressed in kilonewtons.

. . .

Take-off phase. The operating phase defined by the time during which the engine is operated at the rated ~~output~~ thrust.

. . .

CHAPTER 2. SYMBOLS

. . .

F_{oo} Rated ~~output (see definition)~~ thrust

F^*_{oo} Rated ~~output~~ thrust with afterburning applied

. . .

PART III. EMISSIONS CERTIFICATION

CHAPTER 1. ADMINISTRATION

. . .

1.3 The document attesting emissions certification for each individual engine shall include at least the following information which is applicable to the engine type:

. . .

d) rated ~~output~~ thrust;

. . .

CHAPTER 2. TURBO-JET AND TURBOFAN ENGINES INTENDED FOR PROPULSION ONLY AT SUBSONIC SPEEDS

. . .

2.1.4.2 *Thrust settings*

The engine shall be tested at sufficient ~~power~~ thrust settings to define the gaseous and smoke emissions of the engine so that mass emission rates and Smoke Numbers ~~corrected to the reference ambient conditions~~ can be determined at the following specific percentages of rated ~~output~~ thrust as agreed by the certificating authority:

LTO Operating mode	*Thrust setting*
Take-off	100 per cent F_{oo}
Climb	85 per cent F_{oo}
Approach	30 per cent F_{oo}
Taxi/ground idle	7 per cent F_{oo}

. . .

2.1.4.4 *Fuel specifications*

The fuel used during tests shall meet the specifications of Appendix 4, unless a deviation and any necessary corrections have been agreed by the certificating authority. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

. . .

~~2.1.6~~2.5.3 When test conditions differ from the reference atmospheric conditions in ~~2.1.4~~ 2.1.4.1 the gaseous emission test results shall be corrected to the reference atmospheric conditions by the methods given in Appendix 3.

. . .

2.2.2 Regulatory Smoke Number

The Smoke Number at any of the four LTO Operating Modes thrust setting when measured and computed in accordance with the procedures of Appendix 2 and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the level determined from the following formula:

Regulatory Smoke Number = $83.6\,(F_{oo})^{-0.274}$
or a value of 50,
whichever is lower

2.3 Gaseous emissions

2.3.1 Applicability

The provisions of 2.3.2 shall apply to engines whose rated ~~output~~ thrust is greater than 26.7 kN and whose date of manufacture is on or after 1 January 1986 and as further specified for oxides of nitrogen.

2.3.2 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 and converted to characteristic levels by the procedures of Appendix 6 shall not exceed the regulatory levels determined from the following formulas:

. . .

d) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December 2007:

. . .

3) for engines with a pressure ratio of 82.6 or more:

$$D_p / F_{oo} = 32 + (1.6 * \pi_{oo})$$

~~*Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.*~~

2.4.1 General information

The following information shall be provided for each engine type for which emissions certification is sought:

a) engine identification;

b) rated ~~output~~ thrust (in kilonewtons);

. . .

2.4.3 Derived information

. . .

2.4.3.2 The characteristic Smoke Number and gaseous pollutant emission levels shall be provided for each engine type for which emissions certification is sought.

~~*Note.— The characteristic level of the Smoke Number or gaseous pollutant emissions is the mean of the values of all the engines tested, measured and corrected to the reference standard engine and reference ambient conditions, divided by the coefficient corresponding to the number of engines tested, as shown in Appendix 6.*~~

. . .

APPENDIX 2. SMOKE EMISSION EVALUATION

. . .

2. MEASUREMENT OF SMOKE EMISSIONS

2.1 Sampling probe for smoke emissions

a) The probe material with which the exhaust emission sample is in contact shall be ~~made of~~ stainless steel or any other non-reactive material. ~~If a mixing probe is used, all sampling orifices shall be of equal diameter.~~

b) If a probe with multiple sampling orifices is used, all sampling orifices shall be of equal diameter. The probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.

c) The number of ~~sampling orifices~~ locations sampled shall not be less than 12.

d) The sampling plane shall be as close to the engine exhaust nozzle exit plane as permitted by considerations of engine performance but in any case shall be within 0.5 nozzle diameters of the exit plane.

e) The applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed ~~power~~ thrust setting.

2.2 Sampling line for smoke emissions

. . .

2.2.2 Sampling lines shall be as "straight through" as possible. Any necessary bends shall have radii which are greater than 10 times the inside diameter of the lines. The material of the lines shall be such as to discourage build up of particulate matter or static electricity.

Note.— Stainless steel~~, copper~~ or carbon loaded grounded polytetrafluoroethylene (PTFE) meet these requirements.

2.3 Smoke analysis system

. . .

f) *temperature control*: the ~~incoming~~ analyser internal sample line through to the filter holder shall be maintained at a temperature between 60°C and 175°C with a stability of ±15°C;

Note.— The objective is to prevent water condensation prior to reaching the filter holder and within it.

. . .

j) *reflectometer*: the measurements of the reflectance of the filter material shall be by an instrument conforming to the ~~American National Standards Institute (ANSI)~~ International Standards Organization, Standard No. ~~PH2.17/1977~~ ISO 5.4 for ~~diffuser~~ diffuse reflection density. The diameter of the reflectometer light beam on the filter paper shall not exceed D/2 nor be less than D/10 where D is the diameter of filter stained spot as defined in Figure 2-1.

Replace Figure 2-1. Smoke analysis system as follows:

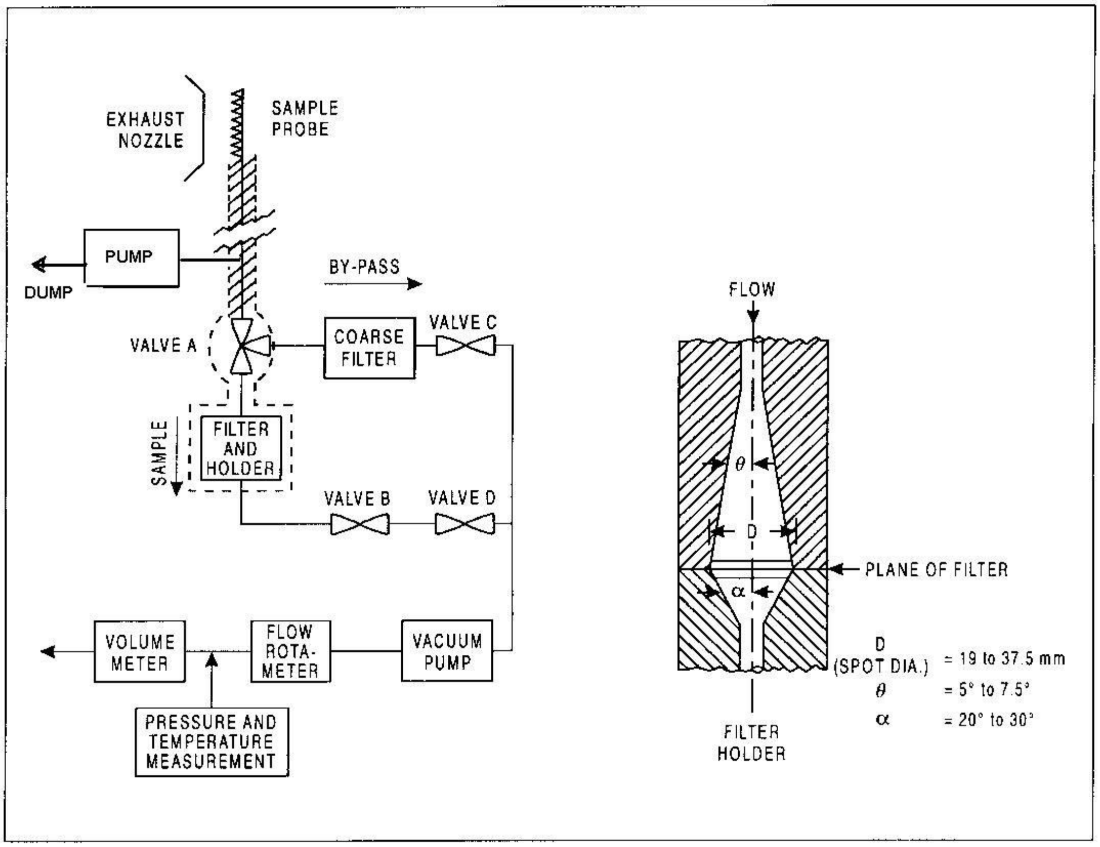

Figure 2-1. Smoke analysis system

2.5 Smoke measurement procedures

2.5.1 Engine operation

. . .

2.5.1.2 The tests shall be made at the ~~power~~ thrust settings approved by the certificating authority. The engine shall be stabilized at each setting.

2.5.2 Leakage and cleanliness checks

. . .

a) *leakage check*: isolate probe and close off end of sample line, perform leakage test as specified in 2.3 ~~g)~~ h) with the exceptions that valve A is opened and set to "bypass", valve D is closed and that the leakage limit is 2 L. Restore probe and line interconnection;

. . .

2.5.3 Smoke measurement

. . .

b) set valve A to "bypass", close valve D and clamp clean filter into holder. Continue to draw exhaust sample in the bypass setting for at least five minutes while the engine is at or near to the ~~requisite operating mode~~ required operating condition, valve C being set to give a flow rate of 14 ±0.5 L/min;

. . .

APPENDIX 3. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS

. . .

3. DATA REQUIRED

3.1 Gaseous emissions

Concentrations of the following emissions shall be determined:

a) Hydrocarbons (HC): a combined estimate of all hydro-carbon compounds present in the exhaust gas.

b) Carbon monoxide (CO).

c) Carbon dioxide (CO_2).

Note.— CO_2 is not ~~considered a pollutant~~ a regulated engine emission but its concentration is required for calculation and check purposes.

. . .

5. DESCRIPTION OF COMPONENT PARTS

. . .

5.1 Sampling system

5.1.1 Sampling probe

a) The probe material with which the exhaust emission sample is in contact shall be ~~made of~~ stainless steel~~. If a mixing probe is used, all sampling orifices shall be of equal diameter~~ or any other non-reactive metal;

b) ~~the~~ if a probe with multiple sample orifices is used, all sampling orifices shall be of equal diameter. The probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices;

c) the number of ~~sampling orifices~~ locations sampled shall not be less than 12;

. . .

e) the applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed ~~power~~ thrust setting.

. . .

6. GENERAL TEST PROCEDURES

6.1 Engine operation

. . .

6.1.2 The emissions tests shall be made at the ~~power~~ thrust settings prescribed by the certificating authority. The engine shall be stabilized at each setting.

. . .

6.3 Operation

. . .

6.3.2 The following procedure shall be adopted for operational measurements:

. . .

c) when the engine has been stabilized at the ~~requisite operating mode~~ required thrust setting, continue to run it and observe pollutant concentrations until a stabilized reading is obtained, which shall be recorded;

. . .

7. CALCULATIONS

7.1 Gaseous emissions

7.1.1 General

The analytical measurements made shall be the concentrations of the various ~~classes of pollutant, as detected at their respective analysers for the several engine operation modes, and these values shall be reported. In addition, other parameters shall be computed and reported, as follows**.~~gaseous emissions, as detected at their respective analysers for a range of combustor inlet temperatures (T_B) encompassing the four LTO operating modes. Using the calculations of 7.1.2, or the alternative methods defined in Attachment E to this appendix, the measured emissions indices (EI) for each gaseous emission shall be established. To account for deviations from reference atmospheric conditions, the corrections of 7.1.3 shall be applied. Note that these corrections may also be used to account for deviations of the tested engine from the reference standard engine where appropriate (see Appendix 6, paragraph 1 f)). Using combustor inlet temperature (T_B) as a correlating parameter, the emissions indices and fuel flow corresponding to operation at the four LTO operating modes of a reference standard engine under reference day conditions shall then be established using the procedures of 7.2.

7.1.2 Basic parameters

where

$$\cancel{P_0/m = \frac{2Z - (n/m)}{4(1 + h - [TZ/2])}}$$

$$P_0/m = \frac{2Z - (n/m)}{4(1 + h_{vol} - [TZ/2])}$$

and

$$\cancel{Z = \frac{2 - [CO] - ([2/x] - [y/2x])\,[HC] + [NO_2]}{[CO_2] + [CO] + [HC]}}$$

$$Z = \frac{2 - [CO] - ([2/x] - [y/2x])\,[HC] + [NO_2]}{[CO_2] + [CO] + [HC]}$$

. . .

η efficiency of NO_2/NO converter

h_{vol} humidity of ambient air, vol water/vol dry air

. . .

7.1.3 Correction of emission indices to reference conditions

Corrections shall be made to the measured engine emission indices for all pollutants in all relevant engine ~~operating~~ modes to account for deviations from the reference atmospheric conditions (ISA at sea level) of the actual test inlet air conditions of temperature and pressure. These corrections may also be used to account for deviations of the tested engine from the reference standard engine where appropriate (see Appendix 6, paragraph 1 f)). The reference value for humidity shall be 0.00634 kg water/kg dry air.

Thus, EI corrected = $K \times$ EI measured,

where the generalized expression for K is:

~~$K = (P_{Bref}/P_B)^a \times (FAR_{ref}/FAR_B)^b \times \exp(|T_{Bref} - T_B|/c) \times \exp(d|h - 0.00634|)$~~

$$K = (P_{Bref}/P_B)^a \times (FAR_{ref}/FAR_B)^b \times \exp([T_{Bref} - T_B]/c) \times \exp(d[h_{mass} - 0.00634])$$

. . .

h_{mass} Ambient air humidity, kg water/kg dry air

. . .

7.1.4 Using the recommended curve fitting technique of paragraph 7.2 to relate emission indices to combustor inlet temperature effectively eliminates the exp $((T_{Bref} - T_B)/c)$ term from the generalized equation and for most cases the (FAR_{ref}/FAR_B) term may be considered unity. For the emissions indices of CO and HC many testing facilities have determined that the humidity term is sufficiently close to unity to be eliminated from the expression and that the exponent of the (P_{Bref}/P_B) term is close to unity.

. . .

~~EI(NO_x) corrected = EI derived from~~
~~$EI(NO_x)\ (P_{Bref}/P_B)^{0.5}\ \exp\ (19\ |h - 0.00634|)$ v. T_B curve~~

EI(NO_x) corrected = EI derived from
$EI(NO_x)\ (P_{Bref}/P_B)^{0.5\ \exp}\ (19\ [h_{mass} - 0.00634])$ v. T_{Bcurve}

. . .

7.2 Control parameter functions (D_p, F_{oo}, π)

7.2.1 Definitions

. . .

F_{oo} ~~The maximum thrust available for take off under normal operating conditions at ISA sea level static conditions, without the use of water injection, as approved by the applicable certificating~~

~~authority.~~Rated thrust (see definition)

F_n Thrust at LTO operating mode, n. (kN)

W_f Fuel mass flow rate of the reference standard engine under ISA sea level conditions. (kg/s)

W_{f_n} Fuel mass flow rate of the reference standard engine under ISA sea level conditions at LTO operating mode, n.

π The ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane when the engine is developing take-off thrust rating at ISA sea level static conditions.

7.2.2 The emission indices (EI) for each pollutant, corrected ~~for pressure and humidity (as appropriate)~~ to ~~the~~ reference ~~ambient~~ atmospheric conditions ~~as indicated in 7.1.4~~ and, if necessary, to the reference standard engine, EI (corrected), shall be obtained for ~~the required~~ each LTO ~~engine~~ operating mode ~~settings (n) of idle, approach, climb-out and take-off, at each of the equivalent corrected thrust conditions~~. A minimum of three test points shall be required to define the idle mode. The following relationships shall be determined under reference atmospheric conditions for each ~~pollutant~~ gaseous emission:

a) between EI (corrected) and T_B ; and

b) between W_f ~~(engine fuel mass flow rate)~~ and T_B ; and

c) between ~~F_n (corrected to ISA sea level conditions)~~ F and T_B ~~(corrected to ISA sea level conditions)~~;

Note 1.— These are illustrated, for example, by Figure 3-2 a), b) and c).

Note 2.— The relationships b) and c) may be established directly from engine test data, or may be derived from a validated engine performance model.

~~When the engine being tested is not a "reference" engine, the data may be corrected to "reference" engine conditions using the relationships b) and c) obtained from a reference engine. A reference engine is defined as an engine substantially configured to the description of the engine to be certificated and accepted by the certificating authority to be representative of the engine type for which certification is sought.~~A reference engine is defined as an engine substantially configured to the production standard of the engine type and with fully representative operating and performance characteristics.

The manufacturer shall also supply to the certificating authority all of the necessary engine performance data to substantiate these relationships and for ISA sea level ambient conditions:

d) ~~maximum~~ rated thrust (F_{oo}); and

e) engine pressure ratio (π) at maximum rated thrust.

Note.— These are illustrated by Figure 3-2 d).

7.2.3 The estimation of EI (corrected) for each ~~pollutant at each of the required engine mode settings, corrected to the reference ambient conditions,~~gaseous emission at the four LTO operating modes shall comply with the following general procedure:

a) ~~at each mode ISA thrust condition F_n,~~ determine the ~~equivalent~~ combustor inlet temperature (T_B) (Figure 3-2 c)) at the values of F_n corresponding to the four LTO operating modes, $_n$, under reference atmospheric conditions ;

b) from the EI (corrected)/T_B characteristic (Figure 3-2 a)), determine the EI_n value corresponding to T_B;

c) from the W_f /T_B characteristic (Figure 3-2 b)), determine the W_{f_n} value corresponding to T_B;

. . .

ATTACHMENT E TO APPENDIX 3. THE CALCULATION OF THE EMISSIONS PARAMETERS — BASIS, MEASUREMENT CORRECTIONS AND ALTERNATIVE NUMERICAL METHOD

Editorial Note.— Replace straight brackets and use *vol*.– index for humidity.

1. SYMBOLS

. . .

h_{vol} humidity of ambient air, vol water/vol dry air

. . .

2. BASIS OF CALCULATION OF EI AND AFR PARAMETERS

2.1 It is assumed that the balance between the original fuel and air mixture and the resultant state of the exhaust emissions as sampled can be represented by the following equation:

CmHn + P0[R(O2) + S(N2) + T(CO2) + h_{vol} (H2O)]

= P1(CO2) + P2(N2) + P3(O2) + P4(H2O)

+ P5(CO) + P6(CxHy) + P7(NO2) + P8(NO)

from which the required parameters can, by definition, be expressed as

. . .

2.3 The ambient air humidity, h_{vol}, is as measured at each test condition. It is recommended that, in the absence of contrary evidence as to the characterization (x, y) of the exhaust hydrocarbon, values of x = 1 and y = 4 are assigned.

2.4 Determination of the remaining unknowns requires the solution of the following set of linear simultaneous equations, where (1) to (4) derive from the fundamental atomic conservation relationships and (5) to (9) represent the gaseous product concentration relationships.

m + TP0 = P1 + P5 + xP6 .... (1)

$$n + 2h_{vol}P0 = 2P4 + yP6 \quad (2)$$

$$(2R + 2T + h_{vol})P0 = 2P1 + 2P3 + P4 + P5 + 2P7 + P8 \quad (3)$$

. . .

3. ANALYTICAL FORMULATIONS

. . .

3.2 Equation for conversion of dry concentration measurements to wet basis

Concentration wet = $K \times$ concentration dry; that is,

$$[\quad] = K[\quad]_d$$

The following expression for K applies when CO and CO_2 are determined on a "dry" basis:

$$\cancel{K =} \quad \frac{\cancel{\left\{4 + (n/m)\,T + (\,|n/m|\,T - 2h)\left([NO_2] - (2[HC]/x)\right)\right.}}{\cancel{(2 + h)\left\{2 + (n/m)\,(1 + h_d)\left([CO_2]_d + [CO]_d\right)\right\}}}$$

$$\frac{\cancel{\left.+ (2 + h)\,(|y/x| - |n/m|)\,[HC]\right\}\,(1 + h_d)}}{\cancel{-(|n/m|T - 2h)\left(1 - |1 + h_d|[CO]_d\right)}}$$

$$K = \quad \frac{\left\{4 + (n/m)\,T + ([n/m]T - 2h_{vol})\left([NO_2] - (2[HC]/x)\right)\right.}{(2 + h)\left\{2 + (n/m)\,(1 + h_d)\left([CO_2]_d + [CO]_d\right)\right\}}$$

$$\frac{\left.+ (2 + h_{vol})\,([y/x] - [n/m])\,[HC]\right\}\,(1 + h_d)}{-([n/m]T - 2h)\left(1 - [1 + h_d]\,[CO]_d\right)}$$

. . .

3.4 Equation for estimation of sample water content

Water concentration in sample

$$\cancel{[H_2O] =} \quad \frac{\cancel{(|n/2m| + h|P_o/m|)\,([CO_2] + [CO] + [HC])}}{\cancel{1 + T(P_o/m)}} \; \cancel{-\,(y/2_x)\,[HC]}$$

$$[H_2O] = \quad \frac{([n/2m] + h_{vol}[P_o/m])\,([CO_2] + [CO] + [HC])}{1 + T(P_o/m)} - (y/2_x)\,[HC]$$

where

$$\cancel{P_0/m = \frac{2Z - (n/m)}{4(1 + h - |TZ/2|)}}$$

$$P_0/m = \frac{2Z - (n/m)}{4(1 + h_{vol} - [TZ/2])}$$

and

$$\cancel{Z = \frac{2 - [CO] - (|2/x| - |y/2x|)\,[HC] + [NO_2]}{[CO_2] + [CO] + [HC]}}$$

$$Z = \frac{2 - [CO] - ([2/x] - [y/2x])\,[HC] + [NO_2]}{[CO_2] + [CO] + [HC]}$$

It should be noted that this estimate is a function of the various analyses concentration readings, which may them-selves require water interference correction. For better accuracy an iterative procedure is required in these cases with successive recalculation of the water concentration until the requisite stability is obtained. The use of the alternative, numerical solution methodology (4) avoids this difficulty.

. . .

APPENDIX 6. COMPLIANCE PROCEDURE FOR GASEOUS EMISSIONS AND SMOKE

. . .

2. COMPLIANCE PROCEDURES

The certificating authority shall award a certificate of compliance if the mean of the values measured and corrected (to the reference standard engine and reference ~~ambient~~ atmospheric conditions) for all the engines tested, when converted to a characteristic level using the appropriate factor which is determined by the number of engines tested (*i*) as shown in the table below, does not exceed the regulatory level.

Note.— The characteristic level of the Smoke Number or gaseous ~~pollutant~~ emissions is the mean of the values of all the engines tested, ~~measured~~ and, for gaseous emissions only, appropriately corrected to the reference standard engine and reference ~~ambient conditions~~ atmospheric conditions, divided by the coefficient corresponding to the number of engines tested, as shown in the table below.

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English only

APPENDIX B

GUIDELINES ON THE USE OF PROCEDURES IN THE EMISSIONS CERTIFICATION OF AIRCRAFT ENGINES
(for publication on the ICAO website)

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2.1 Sampling probe for smoke emissions
2.2 Sampling line for smoke emissions
2.3 Smoke analysis system
2.4 Fuel specifications
2.5 Smoke measurement procedures
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2.5.2 Leakage and cleanliness checks
2.5.3 Smoke measurement
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5. Description of Component Parts

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7.1.3 Correction of emissions indices to reference conditions [Reserved]
7.2 Control parameter functions [Reserved]
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NOMENCLATURE [Reserved]

Symbols and Units

Symbols and abbreviations employed in these guidelines are consistent with those contained in Annex 16 – *Environmental Protection*, Volume II – *Aircraft Engine Emissions* (Second Edition, July 1993).

SECTION 1. - INTRODUCTION

1.1 PURPOSE

1.1.1 The aim of this document is to promote uniformity in the implementation of Annex 16 – *Environmental Protection***,** Volume II – *Aircraft Engine Emissions*, by providing guidance to certificating authorities and applicants regarding the intended meaning and stringency of the current Annex 16, Volume II emissions Standards and those specific procedures that are deemed acceptable in demonstrating compliance to these Standards.

1.1.2 This document also provides guidance in the wider application of equivalent procedures that have been accepted as a technical means for demonstrating compliance with the emissions certification requirements of Annex 16, Volume II. Such equivalent procedures are referred to in Annex 16, Volume II, but are not dealt with in the same detail as in the appendices which describe the emissions evaluation methods for compliance with the relevant chapters of Annex 16, Volume II.

1.1.3 Annex 16, Volume II procedures must be used unless an equivalent procedure is approved by the certificating authority. Procedures presented in these guidelines should not be considered as limited only to those described herein, as these guidelines will be expanded as new procedures are developed. Also, their presentation does not infer limitation of their application or commitment by certificating authorities to their further use.

1.1.4 References to Annex 16, Volume II relate to Amendment 5.

1.2 FRAMEWORK

1.2.1 The basic framework of this document is a replication of the Annex 16, Volume II structure in order to ensure easy reference between the annex and these guidelines. References in the table of contents are only made to a part of the requirements when there is associated guidance material, otherwise the relevant paragraph has been "reserved" for future use. There is minimal repetition of the requirement text in order to simplify the ETM content, lower maintenance costs and reduce the danger of inconsistencies between Volume II and the ETM following future revisions.

1.2.2 The first section provides general information while the second section contains guidance material to Annex 16, Volume II. The format of the guidance material includes three types of information described as explanatory information, equivalent procedures and technical procedures. The definitions of these three types of information are as follows:

Explanatory Information

— Explains Annex 16 emissions Standards language.

— States current policies of regulatory authorities regarding compliance with Annex 16 emissions Standards.

— Provides awareness of critical issues for approval of applicants' compliance methodology proposals.

Equivalent Procedures

An equivalent procedure is a test or analysis procedure which, while differing from one specified in Annex 16, Volume II, in the technical judgement of the certificating authority yields effectively the same emissions levels as the specified procedure.

The use of equivalent procedures may be requested by applicants for many reasons, including:

a) to make use of previously acquired certification test data for the engine type; and

b) to minimize the costs of demonstrating compliance with the requirements of Annex 16, Volume II by keeping engine test time, test bed usage, and equipment and personnel costs to a minimum.

Technical Procedures

A technical procedure is a test or analysis procedure not defined in detail in Annex 16 emissions Standards but which certificating authorities have approved as being acceptable for compliance with the general provisions specified in the emissions Standards.

1.3 EMISSIONS COMPLIANCE DEMONSTRATION PLAN

1.3.1 Prior to undertaking an emissions certification demonstration, the applicant is normally required to submit to the certificating authority an emissions compliance demonstration plan. This plan contains the method by which the applicant proposes to show compliance with the emissions requirements. Approval of this plan and the proposed use of any equivalent procedure remains with the certificating authority. The determination of equivalency for any procedure or group of procedures must be based upon the consideration of all pertinent facts relating to the application.

1.3.2 Emissions compliance demonstration plans should include the following types of information:

a) introduction
   - description of the engine emissions certification basis, i.e. the applicable Annex 16, Volume II amendment and chapter;

b) engine description
   - type, model number and specific details of the basic configuration to be certified;

c) engine emissions certification methodology
- test concepts, equivalent procedures and technical procedures;

d) test description
- test methods to comply with the emissions Standards;

e) measurement system
- description of measurement and sampling system components and procedures, including calibration procedures, that are intended to be used to demonstrate compliance with the emissions Standards; and

f) data evaluation procedures
- emissions evaluation and adjustment procedures (including equivalent and technical procedures such as those provided in these guidelines) to be used in compliance with the provisions of Annex 16, Volume II appropriate to the engine type being certificated.

1.4 EMISSIONS CERTIFICATION REPORTS

1.4.1 Following completion of an emissions certification demonstration test, an applicant is normally required to submit an emissions certification report. This report provides a complete description of the test process and the test results with respect to compliance with the provisions of Annex 16, Volume II.

1.4.2 These reports should include the following types of information:

a) basis for test approval
- the approved emissions certification compliance plan for the engine type and model being certificated;

b) description of tests
- actual configurations tested and non-conforming items (with justification that they are not significant to emissions, or if significant, can be dealt with by an approved method), test methodology (including equivalent procedures and technical procedures), tests conducted, test data validity, and data analysis and adjustment procedures used;

c) test results
- data to demonstrate compliance with the provisions of Annex 16, Volume II regarding maximum emissions levels for the engine type being certificated; and

d) references.

SECTION 2 – GUIDANCE MATERIAL

PART III – EMISSIONS CERTIFICATION

CHAPTER 2. Turbo-jet and turbofan engines intended for propulsion only at subsonic speeds

2.1 General

2.1.1 Applicability

The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbo-jet and turbofan engines.

Explanatory Information

This sentence anticipates the introduction of future engine technologies. The emissions Standards in Chapter 2 would also be applicable to future engine types not categorized as a turbo-jet or turbofan but intended for use in international air transport services. The provision above is not applicable to turbo-prop engines.

2.1.2 Emissions involved [Reserved]

2.1.3 Units of measurement

Explanatory Information

Smoke level is determined indirectly, by means of the loss of reflectance of a filter used to trap smoke particles from a prescribed mass of exhaust per unit area of filter. The result is a dimensionless smoke number "SN" which acts as a surrogate for, or indicator of, plume opacity. These smoke sampling and measurement procedures standardized in Annex 16, Appendix 2 are derived from SAE Aerospace Recommended Practice (ARP) 1179, Aircraft Gas Turbine Exhaust Smoke Measurement.

The smoke measurement standard was developed for engines that generated smoke at considerably higher levels than are seen today. This affects the relative accuracy of the method. The measurement is considered (by the SAE E-31 Committee that developed the method) to be no more accurate than ±3 SN. At smoke levels of SN 50-60 this represents an accuracy of 6 to 5 per cent. At regulatory standards of 30 and below, relative accuracy becomes 10 to 20 per cent or more.

2.1.4 Reference conditions

2.1.4.1 Atmospheric conditions

Explanatory Information

The reference atmospheric conditions to which the gaseous emissions (HC, CO and NOx) are to be corrected are the reference day conditions, as follows: Temperature = 15°C, Humidity = 0.00634 kg H_2O/kg of dry air, Pressure = 101.325 kPa.

2.1.4.2 Thrust settings [Reserved]

2.1.4.3 Reference emissions landing and take-off (LTO) cycle

Explanatory Information

The exhaust emissions test is designed to measure hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen concentrations, and to determine mass emissions through calculations during a simulated aircraft landing-takeoff cycle (LTO). The LTO cycle is based on times in mode data during high activity periods at major airports for four modes of engine operation: taxi/idle, takeoff, climbout, and approach. The mass emissions for these modes are combined to yield the reported emissions certification levels.

2.1.4.4 Fuel specifications

Explanatory Information

Aircraft gas turbine engines use a variety of fuels. The specific fuel type and composition can and often do have a significant effect on engine emissions. Hence, it is an important factor when comparing emissions levels from one engine with those from another. It is particularly important in evaluating engine emission levels relative to a regulation that was based, in part, on an assumed fuel specification. The fuel specification defined in Appendix 4 is typical of Jet A aviation fuel. The requirement for emissions certification testing with a fuel that meets a particular specification provides a fixed point of reference for the engine. It provides for some degree of control over the effect of fuel composition on smoke formation and emission. It also helps in the assessment of the effects of changing technology.

2.1.5 Test Conditions [Reserved]

2.2 Smoke

2.2.1 Applicability [Reserved]

2.2.2 Regulatory Smoke Number [Reserved]

2.3 Gaseous Emissions

2.3.1 Applicability [Reserved]

2.3.2 Regulatory levels [Reserved]

2.4 Information Required

2.4.1 General information [Reserved]

2.4.2 Test information [Reserved]

2.4.3 Derived information

Explanatory Information

The "Maximum Smoke Number" is formally defined as the greatest value of SN measured at any of the four thrust levels defined in 2.1.4.2. However, if a higher smoke number is measured at any other test condition between 7 and 100 per cent of rated thrust during emissions certification tests, it is recommended that the higher value be reported as the "Maximum Smoke Number".

APPENDIX 2. Smoke Emission Evaluation

Explanatory Information

The procedure for evaluating smoke emissions is an indirect measure of smoke plume visibility which is obtained by using a filter to trap smoke particles contained in a predetermined mass of exhaust gas and measuring the loss of reflectance, i.e., degree of staining, of this filter relative to the absolute reflectance of the filter when clean or free of stain. The uncertainty of the smoke emission evaluation is estimated to be within ±3 SN (smoke numbers).

1. Introduction and Definitions [Reserved]

2. Measurement of Smoke Emissions

   2.1 Sampling probe for smoke emissions

   a) *The probe shall be made of stainless steel or any other non reactive metal. If a probe with multiple sampling orifices is used, all sampling orifices shall be of equal diameter.*

Equivalent Procedures

Stainless steel is the preferred probe material but other non-reacting materials may be more suitable under specific circumstances, e.g. engine exhaust temperatures which exceed the physical specification limits of stainless steel. Inconel 625 and Nimonic 75 alloys have previously been accepted as a non-reactive probe material. Other materials may be suitable but need to be approved by the certificating authority.

   b) *The probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.*

Explanatory Information

Smoke particles are submicron in size which, for sampling from gas turbine engines, precludes the need for isokinetic sampling. Nevertheless, good practice would suggest sampling as close to isokinetically as possible. Taking an 80 per cent pressure drop at the probe orifices is a reasonable compromise. Further information on probe design is provided within the section on Appendix 3, paragraph 5.1.1.

   c) *The number of locations sampled shall not be less than 12.* [Reserved]

   d) *The sampling plane shall be as close to the engine exhaust nozzle exit plane as permitted by considerations of engine performance but in any case shall be within 0.5 nozzle diameters of the exit plane.* [Reserved]

   e) *The applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed power setting.*

Explanatory Information

Smoke measurements can be performed by means of a single point probe which is traversed through the sampling plane in sufficient detail to provide a representative sample. This measurement can also be made using a multi-orifice probe which has been demonstrated to provide a representative sample by comparison with those of the single point traverse. Work sponsored by the SAE E-31 Committee has shown that the best agreement between a detailed traverse, used to establish the mean value of smoke emissions in the sampling plane, and a multi-point sampling probe is achieved when this probes sampling orifices are located on centres of equal area. The most common configuration is that of a cruciform with the individual orifices equally distributed and located on centres of equal area.

   2.2 Sampling line for smoke emissions

Explanatory Information

If carbon-loaded grounded polytetrafluoroethylene (PTFE) is used special care must be taken to allow sufficient cooling of the exhaust sample from the probe to the PTFE line to prevent damaging the PTFE line and possibly compromising the sample.

2.3 Smoke analysis system

a) *sample size measuremen*t: [Reserved]
b) *sample flow rate measurement*: [Reserved]
c) *filter and holder*: [Reserved]
d) *valves*: [Reserved]
e) *vacuum pump*: [Reserved]
f) *temperature control*: [Reserved]
g) If it is desired to draw a higher sample flow rate through the probe than through the filter holder, an optional flow splitter may be located between the probe and valve A (Figure 2-1), to dump excess flow. The dump line shall be as close as possible to probe off-take and shall not affect the ability of the sampling system to maintain the required 80 per cent pressure drop across the probe assembly. The dump flow may also be sent to the CO_2 analyser or complete emissions analysis system.

Explanatory Information

Achieving an 80 per cent pressure drop across the probe assembly can result in an unacceptably high sample flow rate through the filter holder due to the pressure drop taken across the filter. In these instances, a flow splitter may be required.

h) If a flow splitter is used, a test shall be conducted to demonstrate that the flow splitter does not change the smoke level passing to the filter holder. This may be accomplished by reversing the outlet lines from the flow splitter and showing that, within the accuracy of the method, the smoke level does not change.

Explanatory Information

Smoke from gas turbine engines, although consisting of sub-micron particles, can be particularly sensitive to flow splitter design or other flow elements in the sampling stream due to inertial separation at very high flow velocities. This test addresses these concerns and ensures that the splitter design does not adversely impact the smoke emissions evaluation.

i) *leak performance*: [Reserved]
j) *reflectometer*: [Reserved]

2.4 Fuel specifications [Reserved]

2.5 Smoke measurement procedures

2.5.1 Engine operation [Reserved]

2.5.2 Leakage and cleanliness checks

Explanatory Information

Leakage checks are to ensure clean air does not leak into the system thereby diluting the sample and lowering the smoke number. Cleanliness checks ensure that the sampling system is acceptably clean and the collecting filter will not be contaminated. If the probe cannot be removed from the sampling stream during engine start-up, the probe and lines should be back pressured with a suitably clean gas, such as dry nitrogen, to minimize contamination problems.

2.5.3 Smoke measurement

Explanatory Information

It is common practice, while sampling for smoke, to also measure levels of CO_2 as an operational check of the sampling system. The engine fuel-air ratio is calculated from the measured CO_2 and compared to the fuel-air ratio obtained from engine performance data. These should be in agreement within ±10 per cent at engine power above idle and within ±15 per cent at idle.

Paragraphs a) through d) provide for adjusting and setting the sample flow rate through the filter holder. To duplicate the pressure drop through the filter holder during actual sampling conditions a clean filter is clamped into the holder. This filter should be removed and discarded before clamping a clean filter into the holder as described in d).

3. Calculation of Smoke Number from Measured Data

Explanatory Information

The absolute reflectance of each clean filter should be determined as well as that of the stained filter. Work performed by Dieck, et al, "Aircraft Gas Turbine Smoke Measurement Uncertainty Using the SAE/EPA Method", Journal of Aircraft, Vol. 15, No. 4, April 1978, concluded that "The major instrument-related source of error in SAE/EPA smoke measurement is clean-filter reflectance precision. It is a direct result of the variability in filter reflectance about the average value used". The backing material should be flat and provide equal pressure across the surface of the filter.

4. Reporting of Data to the Certificating Authority [Reserved]

APPENDIX 3: Instrumentation and Measurement Techniques for Gaseous Emissions

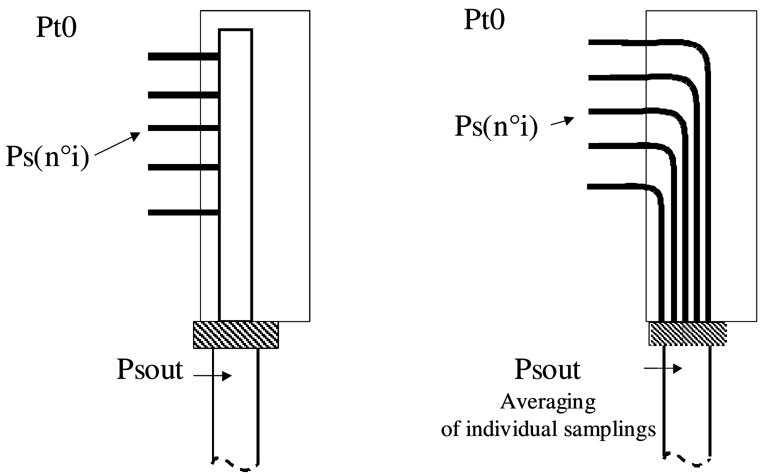
1. Introduction [Reserved]
2. Definitions [Reserved]
3. Data Required [Reserved]
4. General Arrangement of the System [Reserved]
5. Description of Component Parts
   - 5.1 Sampling system
     - 5.1.1 Sampling probe

Explanatory Information

A mixing probe design could include either several sampling orifices leading into a single plenum or several sampling orifices leading into individual sample lines which are mixed external to the probe. The sampling orifices should be equal in size and located on centres of equal area for all mixing probes. If a multi-armed probe is used, then there should be an equal number of orifices on each arm. Considerations for probe design leading to these criteria can be found in "Gas/Turbine Emission Probe Factors", SAE Aerospace Information Report AIR4068A, 1996.

The pressure drop refers to the <u>dynamic head</u> not the total pressure and is needed to ensure that each orifice takes a flow rate that is proportional to the dynamic head present at the sampling orifice. Thus when the samples taken by the individual sampling orifices are mixed together within the probe, the total sample is representative of the mass flux of emissions through the engine exhaust sampling plane.

$$\frac{P_{t0} - p_{s(n^o i)}}{P_{t0} - p_{sout}} \geq 0.8$$



Multi-hole mixing probe
(Mixing in the probe)

Multi-hole non mixing probe
Mixing at the probe exit (before entering the line)

5.1.2 Sampling lines [Reserved]
5.1.3 HC Analyser [Reserved]
5.1.4 CO and CO2 analysers [Reserved]
5.1.5 NOx analysers [Reserved]
5.1.6 Smoke analysis system [Reserved]

6. General Test Procedures
   6.1 Engine operation [Reserved]
   6.2 Major instrument calibration [Reserved]
   6.3 Operation [Reserved]
   6.4 Carbon balance check [Reserved]
7. Calculations
   7.1 Gaseous emissions [Reserved]
      7.1.1 General [Reserved]
      7.1.2 Basic Parameters [Reserved]
      7.1.3 Correction of emissions indices to reference conditions [Reserved]
   7.2 Control parameter functions [Reserved]
   7.3 Exceptions to the proposed procedures [Reserved]

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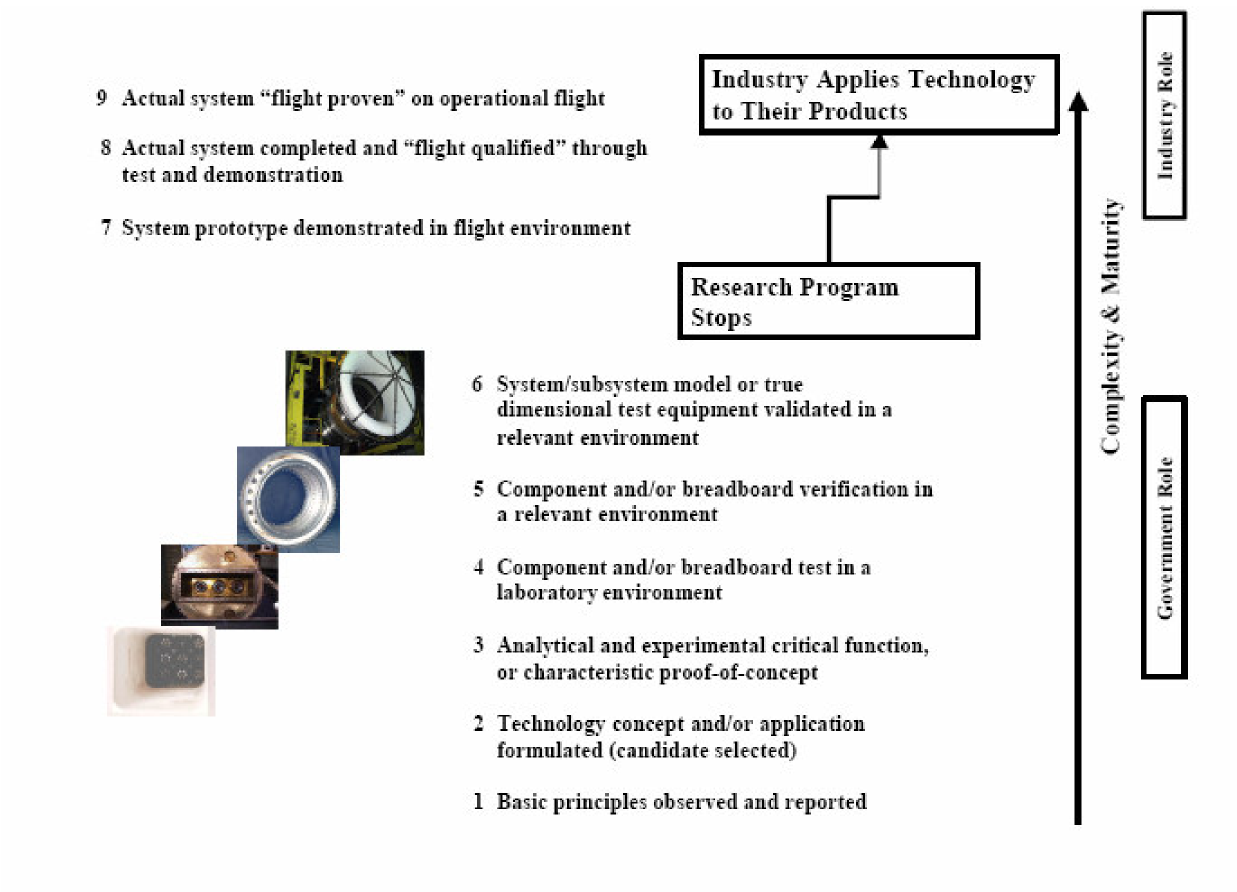
English only
APPENDIX C

TECHNOLOGY READINESS LEVEL SCALE

The technology readiness level (TRL) scale system is widely agreed between research organizations and industry in the ICAO/CAEP process. The purpose of this Appendix is to describe the analyses and tests necessary to meet a given TRL level for a low emission combustor technology. The TRL Scale shown in Figure 1 was originally developed by NASA as a general tool to characterize the level of development of new technologies across a wide range of applications including space vehicles, aircraft systems, aircraft engines and engine components. It has been slightly modified with the input of the European Commission. The definition of terms is rather general, as required to fit a wide range of technologies.



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English only

APPENDIX D

MODELS EVALUATED
(see para. 1.14)

1. NOISE

Aviation Environmental Design Tool/Model for Assessing the Global Emissions of Noise from Transport Aircraft (AEDT/MAGENTA)
US FAA

Aircraft Noise CONtour model (ANCON)
UK CAA

EuropeaN Harmonised Aircraft Noise Contour Modelling Environment (ENHANCE)
EUROCONTROL

Japanese Civil Aviation Bureau Model (JCAB Model)
Japan

SONDEO
Anotec Consulting

2. LOCAL AIR QUALITY

Aviation Environmental Design Tool/Emissions and Dispersion Modeling System (AEDT/EDMS)
US FAA

LASat for airPORTS (LASPORT)
Janicke Consulting

Airport Local Air Quality Studies (ALAQS)
EUROCONTROL

Atmospheric Dispersion Modelling System (ADMS)
Cambridge Environmental Research Consultants

3. **GREENHOUSE GASES**

Aviation Environmental Design Tool/System for Assessing Aviation Global Emissions (AEDT/SAGE)
US FAA

Advanced Emission Model (AEM)
EUROCONTROL

AERO2k
UK/EC

FAST
Manchester Metropolitan University – MMU

4. **ECONOMICS**

Aviation Portfolio Management Tool (APMT)
US FAA

Campbell-Hill Noise Cost Model (Noise Cost)
Campbell-Hill

NO_x Cost
FESG

AERO Modelling System (AEROMS)
Netherlands

— END —

Agenda Item 2: Review of market-based options to limit or reduce emissions

2.1 INTRODUCTION

2.1.1 The use of market-based measures as a means of limiting or reducing the environmental impact of aircraft engine emissions had been on CAEP's work programme since CAEP/5. Work had focussed on three areas: voluntary measures, emissions trading and emission-related levies. With respect to the first area, guidance material and a template voluntary agreement had been produced during the CAEP/6 process and subsequently endorsed by the Council and the Assembly (A35-5, Appendix I, Resolving Clause 2. a) refers) (see also section 2.2 below). With respect to emissions trading, work on the development of specific guidance, as requested by Assembly Resolution A35-5, Appendix I, Resolving Clause 2. c), had been undertaken during the CAEP/7 process and is reported upon in section 2.3 below.

2.1.2 Work on the use of emission-related levies had initially been addressed according to the directions given in Assembly Resolution A35-5, Appendix I, Resolving Clause 2. b), which requested ICAO to develop guidance on both greenhouse gas (GHG) and local air quality (LAQ) emissions charges. Clause 2 b) also pertained to a request for the Council to study the effectiveness of emissions charges related to local air quality. During the course of the CAEP/7 process, various difficulties, including some of a legal and policy nature, had been encountered, which led to the establishment of a Council Special Group on Legal Aspects of Emissions Charges. Based on the results of the work of this Special Group, the CAEP Steering Group (SG) had decided to address the charges issue in two different ways: one related to local air quality emissions charges, the other to global (GHG) emissions charges. The SG had noted that there was a greater potential for developing guidance for local air quality charges than for GHG emissions charges; it had consequently agreed that CAEP should concentrate its efforts and resources in areas where progress was more likely to be achieved, i.e. on developing guidance on aviation related LAQ charges and emissions trading.

2.1.3 As a consequence of this decision, CAEP's work on emission charges, including a study of the effectiveness of emissions charges related to LAQ, as reported below (see section 2.4), only addressed the charges that might be imposed on those emissions that affect local air quality. Climate change issues are therefore only covered under market-based measures at this stage through guidance provided on emissions trading.

2.2 VOLUNTARY MEASURES

2.2.1 Introduction

2.2.1.1 Regarding voluntary measures, CAEP had already developed a template for voluntary agreements between the aviation sector and public sector organizations, which was available on the ICAO website.

2.2.1.2 It was thought that many kinds of voluntary activities, including voluntary agreements, might be undertaken in the world. It was expected that collecting and providing feedback of the information on various voluntary activities to the aviation community would help and encourage the implementation of such activities. Consequently, the Focal Point on Voluntary Measures (FPVM) called on CAEP members and observers to provide information on voluntary activities, with the cooperation of the CAEP Secretariat, as a first step. As a result, information on five activities had been collected for the CAEP Steering Group Meeting in June 2006. Among this information, there had been new information on two activities, although the information had been released to the public on the Internet. Therefore, the CAEP Steering Group agreed to request that a State Letter be sent to all States soliciting information on voluntary activities undertaken not only by States but also airlines, airports, etc.

2.2.2 **Collected Information**

2.2.2.1 State Letter AN 1/17-06/77 calling for States to provide information was subsequently sent to all States on 3 October 2006. Ten States had replied to the State Letter as of 7 December 2006. Some of their replies indicated that no voluntary activities relating to global warming had taken place in the aviation sector in their States. The information submitted by other States and information collected prior to CAEP/7-SG/3 was provided to the meeting. The FPVM welcomed additional submissions at any time, in order to ensure that a wide range of information could be disseminated.

2.2.3 **Discussion and conclusions**

2.2.3.1 The meeting noted with appreciation the efforts made by the Focal Point on Voluntary Measures to collect relevant information. It also noted the information provided as a result of the questionnaire sent to Member States.

2.2.3.2 The meeting endorsed the idea of releasing the collected information to the public through the ICAO public website and of updating the information through the following three means:

a) to state on the ICAO website that additional or further information concerning new and/or improved voluntary activities was welcome at any time;

b) to request that each contact point update information concerning their voluntary activities on an annual basis; and

c) to issue a State Letter, once every three years, requesting all Member States and international organizations to submit information on new voluntary activities undertaken by entities in their States or constituency.

2.2.4 **Recommendation**

2.2.4.1 In light of the foregoing discussion, the meeting developed the following recommendation:

Recommendation 2/1 — Publication of information on voluntary measures

That the information gathered from Member States and international organizations on voluntary measures be published on the ICAO public website and updated, as requested.

2.3 **EMISSIONS TRADING**

2.3.1 Consistent with Assembly Resolution A35-5, Appendix I, Resolving Clause 2. c), CAEP's work on developing guidance for emissions trading schemes had focussed on two approaches: one addressed the development of a voluntary trading system that States and international organizations might propose; the other considered the integration of emissions from international aviation into States' emissions trading schemes consistent with the UNFCCC process. Under both approaches guidelines for an open emissions trading system had been designed so as to ensure that the structural and legal basis for aviation's participation in such a system were properly addressed, including, for example, key elements such as reporting, monitoring and compliance.

2.3.2 Voluntary Emissions Trading

2.3.2.1 With respect to voluntary emissions trading systems (VETS), a report had been developed by CAEP's Emissions Trading Task Force (ETTF). It described the general nature of various types of voluntary emissions trading schemes, it presented and summarized a number of practical experiences currently implemented throughout the world, and discussed the possible future development of such schemes involving aviation.

Description of voluntary emissions trading

2.3.2.2 The VETS report defined a voluntary trading scheme as any scheme in which participation was not made mandatory by a State. Schemes that involved some kind of government incentive for companies to participate would therefore also fall under this definition.

2.3.2.3 For the purpose of this report, voluntary emissions trading for international aviation was considered to be one of the following:

a) A group of airlines decided to create its own Emissions Trading Scheme (ETS);For example, airline alliance partners could set up an ETS among themselves.

b) The airline sector created a new ETS together with other sectors; For example, members of a national air transport association could join the national electricity companies and agricultural sector to establish and participate in a national emissions trading scheme.

c) An airline/a group of airlines decided to unilaterally join an existing ETS:

    1) run by its own government

    2) run by other government(s)

    3) run by a commercial entity.

Under these scenarios, the money paid by those buying allowances helps to finance the development and/or implementation of CO_2 control measures by others who are selling the allowances. In addition to these options, more direct mechanisms may also be considered, for example:

d) An airline/a group of airlines decided to compensate for carbon emissions by using an offset mechanism:

    1) run by the airline(s) itself (possibly as an option for passengers/customers)

    2) run by an independent service provider.

In this case, money would usually be paid into a fund that sponsors specific projects to reduce or avoid emissions from sources or remove emissions from the atmosphere through so-called sink projects. An example would be an airline that set aside a small amount per ticket sold to fund climate mitigation projects. Such offset programmes, if only triggered by passengers or customers, may not result in the reduction of a predefined quantity of emissions.

Key considerations

2.3.2.4 A number of considerations were key in designing a workable and credible voluntary trading scheme. These included, but were not limited to, the following:

a) Environmental results;

b) Flexibility;

c) Administrative & transaction;

d) Transparency;

e) Overall cost and cost-effectiveness;

f) Competitiveness;

g) Interactions with other mitigation options; and

h) Political acceptability.

Existing Voluntary Emissions Trading Schemes

2.3.2.5 At the present time there are only a handful of examples around the world of voluntary emissions trading schemes for greenhouse gases. Only one of these trading schemes has included the activities of an airline operator. Other types of schemes involve voluntary financial contributions by airline passengers to fund carbon dioxide emissions offset projects. While the overall contribution of these schemes to global emissions reduction is small at present, the potential exists for this contribution to multiply over time if more schemes are developed.

2.3.2.6 The various experiences described in the VETS report included the following**:** The UK Emissions Trading Scheme (UK ETS); Japan's Voluntary Emissions Trading Scheme; The Chicago Climate Exchange (CCX); the European Climate Exchange (ECX); the Montreal Climate Exchange (MCeX) and the Asia Carbon Exchange (ACX-Change). Those schemes would therefore seem to be the only types of schemes that currently have any potential for providing an existing voluntary emissions trading facility for aviation to join.

Future development of voluntary emissions trading schemes for aviation

2.3.2.7 In the future, there would be four ways for airlines to become involved in a voluntary emissions trading scheme: by participating in an existing voluntary scheme; by developing a carbon offset facility (open to action by customers or organized by the airline itself); by developing a voluntary agreement as a precursor to an emissions trading system; or by establishing an airline-only emissions trading scheme. The role that ICAO might play into the development of such schemes was also described in the report.

Discussion and conclusions

2.3.2.8 A question was raised relating to obligations of participants in voluntary schemes compared to those of participants in mandatory schemes. It was probable that participants in a voluntary scheme would enter into some form of contract and agree to be bound by its terms. The difference compared with a mandatory scheme would be that participants would enter into the scheme on a voluntary basis, with full knowledge of the obligations and implications, instead of having these imposed on them.

2.3.2.9 One Member noted that voluntary initiatives were interesting experiences, but that they may not achieve as much as was initially expected. In his view, they therefore did not constitute a complete solution.

2.3.2.10 The meeting agreed to endorse the report on the voluntary emissions trading system. It also agreed that the report should be made available to the public through the ICAO public website.

Recommendation

2.3.2.11 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 2/2 — Publication of the report on voluntary emissions trading for aviation**
>
> That the report on voluntary emissions trading for aviation as contained in Appendix A to the report on this agenda item be published on the ICAO public website.

2.3.3 **Integrated emissions trading**

2.3.3.1 With respect to integrating international aviation into States' emissions trading systems, guidance had been prepared by CAEP's ETTF. This guidance material identified a range of emissions trading issues and was based on expertise from a wide range of aviation, climate change and emissions trading experts from various parts of the world. The scope of this guidance material extended exclusively to international civil aircraft operations and did not include State aircraft, which included military, customs and police services. The guidance focused on those aspects of emissions trading that required consideration with respect to aviation-specific issues; it identified options and offered potential solutions where possible. It addressed the aviation-specific options for the various elements of trading systems, such as accountable entities, emissions sources and species (gases) to be covered, trading units, base year and targets, allowance distribution, monitoring and reporting, and geographic scope. Since most emissions trading schemes defined emissions sources in terms of fixed ground based installations, the guidance addressed how emissions sources could be defined for aviation.

2.3.3.2 This material was not of a regulatory nature. It was recognised that it may not provide the level of detail necessary to assist ICAO Contracting States in addressing every issue that might arise, given that there may be unique legal, technical or political situations for particular States. It was therefore advised that ICAO Contracting States should use this guidance as supporting material, to be shaped and applied to specific circumstances. It should also be noted that, given the limited practical experience that currently exists in emissions trading, this guidance may need to be revised as the world of emissions trading and aviation developed over time.

2.3.3.3 One issue that was particularly difficult to address during the development of the guidance had been that of the geographic scope. The central point of disagreement regarding geographic scope had been whether Contracting States could integrate international aviation emissions from aircraft operators of other Contracting States into their emissions trading schemes without the explicit agreement of these other States (mutual agreement). At CAEP's request, the Council had considered this issue on several occasions and had issued guidance in November 2006 (C-DEC 179/11), as follows:

> "requested that CAEP, in completing its draft guidance, adopt the same principle used in the drafting of other key elements of this guidance, by including the different options to geographic scope describing their advantages and disadvantages and start to address the integration of foreign aircraft operators under a mutually agreed basis, and continue to analyze further options; and urged Contracting States to refrain from unilateral action to implement an emissions trading system for international aviation before the Council reports to the Assembly on its work to implement Assembly Resolution A35-5".

Discussion and Conclusions

2.3.3.4 The meeting noted that drafting guidance on emissions trading was a difficult exercise since this was a new area, with little or no experience to build upon, in particular with respect to aviation participation in such schemes. For this reason, and for the quality and clarity of the guidance, it commended the ETTF for the excellent work it had done.

2.3.3.5 There was consensus among Members and Observers to endorse the guidance as proposed.

2.3.3.6 However, different views were expressed on the possible implementation of emissions trading schemes, as reflected below.

2.3.3.7 One observer commended ICAO's leadership in developing this guidance, but noted with concern that the language on the issue of geographical scope derived from the Council decision was being given different interpretations, while, in his view, the intent of the Council was that States work through mutual agreement to include foreign aircraft operators in emissions trading schemes. In his view, an open emissions trading system was superior to a system of charges and taxes in terms of cost-effectiveness and should be used to the exclusion of such levies. Finally, emissions trading should be considered in a context of other measures, such as voluntary actions, aircraft technology improvements, improved airspace utilization, and realization of the potential of alternative fuels.

2.3.3.8 Several members and a Council Representative observer to the meeting were of the view that the mutual agreement approach was the only workable solution in a multilateral context to deal with the issue of applying an emissions trading system to foreign operators. They thought that this was a fundamental principle that should be endorsed by ICAO, and that there was no alternative to it, since any alternative would result in forcing airlines into a system without the consent of their States. They also insisted that different measures should not be applied to tackle the same problems (e.g. emissions trading and taxes).

2.3.3.9 Some members feared that the inclusion of non-Annex 1 countries of the United Nations Framework Convention on Climate Change (UNFCCC) in an imposed emissions trading scheme would not take into account the principle of common but differentiated responsibilities (Article 3.1 of the UNFCC). One member considered that the only way to include non-Annex 1 countries in emissions trading schemes was through the Clean Development Mechanism (CDM), one of the flexible mechanisms of the Kyoto Protocol. A member suggested that the establishment of an international fund would be a good solution to help developing States purchase new technology that could reduce their emissions.

2.3.3.10 Summarizing the above, some members and observers believed that even with agreement on the guidance document, there remained significant technical complexities and legal issues in implementing market-based measures in international aviation. This reflected the large diversity of States' economic development status, the nature of their aviation industries, and differing views on international legal obligations. They were of the opinion that the only way such market-based measures could be used successfully in a workable, legal and cost-effective manner to address emissions rested on the principle of mutual consent between States in application of such measures.

2.3.3.11 One member remarked that the guidance was a first step in the use of market-based measures, as opposed to a full-scale approach. With a gradual progression, there would be the possibility of learning by doing.

2.3.3.12 An observer considered that the guidance as proposed would ensure that all options on geographic scope were covered rather than an exclusive reliance on the mutual agreement approach. He emphasized that all other options should continue to be analysed, consistent with the advice given by the Council. He added that his organization was fully committed to reducing GHG emissions through a number of other measures, such as technological improvements, research and development, greater air traffic management efficiency, to complement emissions trading. He also emphasized efforts to create a global carbon market, and the numerous projects underway using the Clean Development Mechanism and the Joint Implementation projects. His views were supported by some members, one of them noting that it was very important that the guidance document reflect alternatives to the mutual agreement.

2.3.3.13 One member considered that the guidance on emissions trading was a first step on a long path where difficulties would probably arise. In his view, the current initiative taken in his region to start implementing an emissions trading system which included aviation, was going in the right direction, and the measures taken to that effect were reasonable and rational and would enhance the orderly development of aviation, since they were giving consideration to the particular needs of developing countries.

2.3.3.14 One observer remarked that it was desirable to apply an emissions trading system in the context of the widest possible geographical scope if it was to be environmentally efficient. He recalled the debate earlier in the meeting which had highlighted rising trends in CO_2 and other greenhouse gas emissions. Against that background, a mutual agreement approach was not the best solution; it would furthermore provide for unequal treatment of aircraft operators. He pointed out that the geographic scope would only be a problem until other regions had implemented their trading schemes. He considered that when global coverage of trading schemes was achieved, geographic scope would cease to be an issue.

2.3.3.15 One member supported other members and observers who had agreed that the option described as the "alternative to mutual agreement" must be included in the guidance, as it provided for a fair and non-discriminatory approach. Inclusion of aviation in an emissions trading scheme on this basis should not be seen as an anti-aviation measure but should form part of the sector's sustainable development. He said that nothing in the *Convention on International Civil Aviation* or in Assembly Resolution A35-5 requires that participation of foreign aircraft operators in integrated trading schemes be subject to the agreement of the States of those aircraft operators.

2.3.3.16 One observer suggested that the present focus on CO_2 should not discourage the inclusion of other GHG in the emissions trading schemes; he also recommended that the possibility of granting carbon credits to operators who reduce their emissions of other GHG should be studied. Another observer suggested that the proposed guidance material would benefit significantly from further review, notably with regard to establishing the inclusion threshold, the implications for non-uniform inclusion thresholds, the description of operators and the correction of the definition of business aviation contained in the glossary.

2.3.3.17 In concluding its discussions, the meeting agreed to recommend to the Council[1] that it adopt the guidance on emissions trading for aviation that had been prepared by ETTF.

Recommendation 2/3 — Guidance on emissions trading for aviation

That the Council adopt the guidance on the use of emissions trading for aviation as contained in Appendix B to the report on this agenda item and publish it prior to the next Assembly.

2.3.4 **Web-based resource on Emissions Trading**

2.3.4.1 Complementary to the VETS report and the guidance on emissions trading for aviation, initial consideration had been given to the establishment of a web-based resource collecting relevant information on emissions trading experiences. The objective of this resource would be to (a) provide background information on emissions trading schemes to complement the aviation-specific design elements in the relevant ICAO guidance, and (b) help to facilitate a broader understanding of emissions trading within the ICAO community, including the opportunities for voluntary trading initiatives.

2.3.4.2 Some examples of information that could be included in an ICAO public website on trading were developed and presented to the meeting. These included a general introduction to the homepage; relevant ICAO documents; possible links to reference material on emissions trading; integrated schemes and practical experiences; voluntary trading schemes; and stakeholder and other reports.

2.3.4.3 While recognizing that the ICAO public website was an important resource for disseminating information in an increasingly electronic and global world, a member expressed concerns on how and what information should be distributed via the website, in particular with the need to provide a clear distinction between ICAO agreed material and information from other sources. He suggested that a protocol be developed on how CAEP should use of the ICAO public website to better disseminate information.

2.3.4.4 The meeting agreed on the importance of the ICAO public website as a means to disseminate information and while recognizing that the management of the ICAO public website was a matter for ICAO, not CAEP, the meeting agreed that there should be disclaimers placed at appropriate locations every time that a link lead to another website, the content of which were not under ICAO's control. In that respect, use should be made of the existing ICAO guidelines. A proposal to develop a protocol for the use of the ICAO public website was not supported by the meeting. It was noted that this meeting had already developed various recommendations to publish material on the website and it was decided that the Secretariat should continue to manage this resource in accordance with the guidelines in

[1] During the review of this report (CAEP/7), the Council (C-DEC 180/15) requested that a foreward be developed by the President of the Council to reflect the views of the Council on this issue. The President's foreword would, among other things, indicate that the inclusion of international civil aviation in emissions trading schemes should be on the basis of mutual agreement.

force and with resources available. The Secretary invited States and International Organizations to share information on their experiences with the management of their websites.

2.3.5 Proposed European Legislation to Extend the EU Emission Trading Scheme to Aviation

2.3.5.1 The European Commission presented to the meeting the latest status of the legislation to bring aviation within the EU Emission Trading Scheme. It summarized the main features of the proposal and explained the next steps in the European legislative process.

2.3.5.2 In September 2005, the European Commission adopted a Communication on reducing the climate change impact of aviation. Although aviation's share of overall greenhouse gas emissions was still modest (about 3%), it was felt that the rapid growth in emissions in the sector undermined progress to reduce emissions made in other sectors and that the combined effect of existing aviation measures would not be sufficient to offset the growth in aviation emissions. The Communication concluded that including aviation in the EU Emission Trading Scheme (EU ETS) would be the most cost-efficient and environmentally effective way.

2.3.5.3 The legislative proposal to extend the EU ETS to aviation was adopted by the Commission in December 2006; it was accompanied by a detailed impact assessment. Consistent with decisions taken at ICAO level an open emissions trading regime was the approach proposed by the Commission.

2.3.5.4 The meeting took note of the information provided by the EC Observer but decided not to open discussion on this subject matter.

2.4 EMISSIONS CHARGES

2.4.1 Guidance on Aircraft Emissions Charges Related to Local Air Quality

Background

2.4.1.1 The 35th Session of the ICAO Assembly had requested that the ICAO Council develop further guidance on emissions levies related to local air quality (LAQ), while recognizing the continued validity of the Council's Resolution of 9 December 1996 on Environmental Charges and Taxes.

2.4.1.2 At its October 2005 meeting in Montreal, the CAEP Steering Group had established a new Emissions Charges Task Force to develop guidance for Contracting States on emissions charges related to LAQ, organizing its work along the following lines:

a) taking account of past experience from States and guidance that had been developed by ICAO in the field of noise charges;

b) taking inspiration from the concept of the balanced approach used in the noise field; and

c) taking account of the CAEP Action Plan on Aircraft Engine Emissions.

Overview of the Guidance

2.4.1.3 The guidance was composed of five chapters, which are briefly discussed below.

2.4.1.4 Chapter 1 is entitled "Scope of Guidance and Application of Existing ICAO Policies on Charges to Emissions Charges Related to Local Air Quality." Key among the components of this Chapter is information on the request by the Assembly to develop further guidance on emissions charges related to LAQ. As the title of the Chapter suggests, the scope of the guidance is also addressed. The CAEP Steering Group had confirmed that the ECTF interpretation, that the guidance was to focus only on emissions charges, was appropriate. In light of this, the guidance assumed (and acknowledged) that a State (or its delegate) that had chosen to proceed with a local emissions charge on aircraft would have undertaken an analysis to confirm that such a charge was an appropriate policy measure to address the air quality situation. In addition, this Chapter contained information that made the distinction between a local emissions charge and a tax, as well as a discussion of the application of ICAO's existing policies on charges in the context of LAQ. These policies pertained to the cost-basis for charges, cost-effective measures, no fiscal aims, minimizing competitive distortions, transparency, taking stakeholders' views into account, developing country considerations and non-discrimination, among others.

2.4.1.5 Chapter 2 addressed the "Process for Implementing Local Emissions Charges." First, it acknowledged that implementing charging policies with due regard to ICAO policies and guidance was the responsibility of ICAO Contracting States, although they may delegate this responsibility to appropriate authorities. At the same time, the guidance noted that Appendix I of Assembly Resolution A35-5 recognized in the context of market-based measures that Contracting States have legal obligations, existing agreements, current laws and established policies. Second, the guidance noted that local emissions charging schemes should be tailored to the specific characteristics of the airport air quality situation of concern by means of an airport-by-airport approach. Nonetheless, it recognized that a general framework may be implemented at State level in order to set up a common methodology for the implementation of the scheme. Third, Chapter 2 noted that ICAO urges States to institute or oversee an inclusive and transparent process when adopting and implementing local emissions charges and provides an overview of the steps in such a process (similar to the process in the balanced approach guidance on aircraft noise). The detail of this step-by-step approach was given in the remaining chapters of the guidance.

2.4.1.6 Chapter 3 was entitled "Local Air Quality Assessment". To develop the content for this Chapter, the ECTF had been coordinating with Task Group 4 of Working Group 2 (WG2-TG4), which was preparing guidance on LAQ assessment in the airport vicinity. The ECTF guidance identified and summarized the relevant steps in such an assessment. It cross-referred to the WG2-TG4 guidance where possible to avoid duplicating this work.

2.4.1.7 Chapter 4 was entitled "Designing a Local Emissions Charges Scheme". Specifically, this Chapter addressed the steps a State (or its delegate) might take in designing a specific emissions charging scheme once the LAQ situation and the aircraft contribution to adverse impact had been determined. First, to enhance consistency, the guidance recommended use of an aircraft emissions classification scheme incorporating a recognized means of quantifying the amount of emissions emitted by each aircraft during a landing and takeoff (LTO) cycle. Second, the guidance addressed how the cost-basis may be established for a specific charge, reflecting the damage, mitigation and/or prevention costs to address the environmental impact of aircraft engine emissions, to the extent that such costs are properly identified and directly attributed to air transport. Third, this Chapter discussed the use of funds from LAQ charges levied on aircraft. Finally, it provided guidance on how the charging level might be set and the ways in which the various charges might be collected.

2.4.1.8 Chapter 5 pertained to the administration of emissions charges, particularly with respect to consultation with relevant stakeholders and States regarding the various facets of emission charges ranging from their consideration for adoption, implementation, and post implementation activities. Specifically, the guidance recommended the use of open fora to allow stakeholders a chance to actively participate in the emissions charges process. Further, it suggested that ICAO be kept informed of LAQ charges and that those levying such charges keep records regarding the collection of charges and the use of funds generated. A key benefit of these actions would be enhanced mutual trust from transparency.

Discussion and Conclusions

2.4.1.9 Some Members reminded the meeting of the specific characteristics of developing countries, according to which it would be unfair to impose heavy financial burdens on their economies in view of their limited contribution to global pollution. They also emphasized the importance of ICAO playing a central role in setting up a uniform system to apply to aviation emissions, while noting that any imposition of charges or taxes should respect the provisions contained in Articles 15 and 24 of the Chicago Convention. Finally, priority should be given to adopting a framework to put all emission-related measures in context. The last point was supported by an observer who emphasized the need for a framework for emissions measures that addresses the relative role of different measures in aircraft local air quality emissions management.

2.4.1.10 This observer was also of the opinion that emissions charges were not appropriate since it had not been demonstrated that local emission charges were cost effective. The observer also shared the concern that having guidance solely on charges drew the attention to this particular type of measure instead of putting it in perspective vis-à-vis other possible measures. Furthermore, the guidance, in his view, was not fully consistent with ICAO policies as contained in *ICAO's Policies on Charges for Airports and Air Navigation Service* (Doc 9082), which stated that charges should only cover the use of airports and air navigation services. He also requested that a paragraph in the proposed guidance material dealing with "internalisation of external costs" be deleted.

2.4.1.11 A number of opposing views were expressed on this request, since some Members maintained that the proposed guidance reflected the consensus that had been reached in the ECTF group that had developed the guidance. In order to avoid too long a discussion on this subject, the meeting decided to establish a small drafting group who after discussion developed a compromise solution according to which the sentence in paragraph 4.3.3 of the proposed guidance starting with "In line with the cost basis discussion …" until "local air quality problem" in alinea b) would be deleted and replaced with: "Local emissions charges can address the costs mentioned in paragraph 4.3.1 above in line with the policies and principles described in chapter 1". The meeting adopted this proposal.

2.4.1.12 Turning to the appendix where the proposed policy text to be inserted in Doc 9082 was presented, a Member proposed that the first paragraph of 1 i) be amended by inserting "directly attributable" before "damage caused by the aircraft"; he also suggested that the whole process should be entirely transparent to all stakeholders involved and proposed to add at the end of the last sentence of paragraph 1 viii) the following words: "to be made available to all users", the two proposals were accepted by the meeting.

2.4.1.13 The meeting agreed to recommend to the ICAO Council that it adopt the guidance elaborated by the ECTF group, subject to amendments made during the meeting, and that it adopt the proposed text for insertion into ICAO Doc 9082, subject to amendments made during the meeting as well. It also confirmed the ECTF recommendation with respect to the publication of the guidance material in a stand-alone document, and policy text in Doc 9082.

Recommendation 2/4 — Guidance on local emissions charges

That the Council adopt the guidance on local air quality emissions charges as contained in Appendix C to the report on this agenda item and publish it prior to the next Assembly.

Recommendation 2/5 — Policy on local air quality emissions charges

That the policy text relating to local air quality emissions charges as contained in Appendix D to the report on this agenda item be inserted appropriately in ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082) as soon as possible.

2.4.2 Cost-Effectiveness of Local Air Quality Charges Study

Background and Overview of Study

2.4.2.1 The Council had tasked the FESG to study the effectiveness of emission levies related to local air quality. The focus adopted had been on NO_x emissions at two airports - Zurich in Switzerland and Stockholm in Sweden – which had had aircraft emission charges in place since the late 1990s. Local emission dispersion, health effects, and relative importance of air transport emissions, had been outside the scope of the analysis**.** The analysis had not considered the relative contributions of the different sources of emission nor the political and legal obligations in place justifying the introduction of the charge.

2.4.2.2 Due to time constraints, the FESG had had to limit the scope of the analysis limited to NO_x emissions from aviation only, excluding all other emissions at the airport or its vicinity. The analytical framework developed by the FESG for this type of analysis had also had to be adjusted due to the data limitations.

2.4.2.3 Ideally, the analytical framework should allow determination of the change (reduction) in NO_x emissions and isolate the reductions attributable to the introduction of the charge; establish the costs of mitigation measures introduced by airlines in response to the charge, by airports funded out of the revenues from the charge and for the administration of the charge; and establish the relative cost-effectiveness of the charge. Once again, the analytical approach had had to accommodate practical limitations (e.g. data). The terms and conditions of the charges introduced had been important in defining the data needed and requested.

2.4.2.4 The costs to airlines (individually and as a whole) of the charge had to be based on the relationship between the change in emissions volumes, the changes in operations (at the airports with emission charges), and the charge itself. Changes in the volumes of emissions at the airports with the charge, compared with changes at other airports without a charge, with due considerations to the "time" factor, were relevant to the relationship question, as well as the "revenue neutrality" feature of the charges at the two airports.

2.4.3 **Conclusions of the FESG Study**

2.4.3.1 Aviation contribution to the air quality problems around airports, in general, was relatively limited and depended on the size of the area considered. The following conclusions had been drawn from the analysis conducted.

a) Depending on the size of the catchment area considered, aviation, in general, had a relatively limited contribution to the air quality problems around airports. However in countries like Sweden and Switzerland, there were political forces and/or legal rulings that weighed in the decision to include aviation into emission reduction targets;

b) The impact of the charge on NO_x emissions directly attributable to the charge was found to be, at best, marginal. The shift observed to aircraft with better NO_x technology at Zurich and Stockholm airports, had also been observed at other comparable airports in Europe;

c) An analysis of direct operating cost figures from one airline for different aircraft types showed that the level of the charge applied at the two airports had not been high enough to create an incentive for the operators to change their operations and/or their fleet purchase plans. How much higher the charge would have had to be and/or at how many airports within a broad region of the globe it would have had to be applied to have an influence on airlines behaviour, was not assessed;

d) Studying the changes in costs due to the charge for the different aircraft/engine combinations in Zurich had shown winners (use of aircraft with landing fees less than before the introduction of the charge) and losers (use of aircraft with landing fees higher than before the introduction of the charge). The analysis showed that operators serving Zurich, as a whole, had benefited from an overall net airport charge/fee reduction since the second year of the introduction of the NO_x charge. Due to some Swedish data limitations, the same assessment had not been possible for Stockholm;

e) Assessment of the impact of the charge on developing country airlines showed that the number of movements by these airlines had been relatively small. Only developing country operators with minimal operations at these airports operated older aircraft and faced increased landing fees; those with more significant operations, like developed country operators, had operated more modern and less emitting aircraft. Consequently the effect of the charge on developing country carriers had been marginal;

f) The additional NO_x-reduction measures at Zurich airport that were said to have been paid out from the proceeds of the NO_x charge, had been assessed on their possible additional NO_x emission reduction benefits. Although some of these measures had fallen within the ICAO definition of being cost-related, they had not been generating additional NO_x reductions. For one measure, the information available had permitted some minimal assessment of its cost-effectiveness. The costs of this measure had been paid out of the revenues of the NO_x charge, although the overall proceeds of the charge had been negative. However judging the measure by itself its effectiveness in terms of costs had been low, although still within the range of other NO_x reduction measures.

2.4.3.2 Overall, the FESG analytical work on the cost-effectiveness of the NO_x charges has shown that the impact on NO_x emissions directly attributable to the charge had been marginal at Zurich and Stockholm airports, while at the same time the overall additional costs to the airlines from the introduction of the charge at Zurich were negative. In light of the limitations of the analysis conducted, a definite inference on the cost/effectiveness of local air quality charges could not be made.

2.4.4 **Discussion and Conclusions**

2.4.4.1 Members and observers congratulated the FESG for completing the analysis despite the numerous constraints and difficulties encountered.

2.4.4.2 One member noted that the report had concluded that the impact of the NO_x emission charges was marginal and enquired about how this conclusion could be drawn from an analysis which focussed mainly on one airport (Zurich airport). In response, it was noted that the reason for focussing on one of the airports was that the data provided by the two airports had different levels of detail and that the FESG thought that the conclusion was valid for both airports.

2.4.4.3 With respect to the analysis of the impact on developing countries, one member mentioned that he found the conclusion according to which the introduction of the NO_x emission charges did not have an impact on air carriers from developing countries was too strong a statement. He suggested that the analysis could have been enhanced, for instance, by the comparison of the share of developing countries in the revenues from the NOx emission charges to their share in the total number of aircraft movements. He also suggested that if the main impediment to the analysis was data confidentiality, then its results could be improved significantly if operators were willing to share confidential data. It was agreed to invite operators to study the possibility of sharing the necessary confidential data in this regard.

2.4.4.4 One observer noted that the results of this analysis should not come as a surprise to anyone since they were consistent with those of other studies showing that emission charges in general were not cost-effective. He suggested that this was the right time for CAEP also to come to this conclusion.

2.4.4.5 One observer noted that the results of this study should be considered while keeping in mind that it only covered two airports and that the study might capture the global scope of effectiveness but that the local specifics were lost. He added that two important local elements were not included in the analysis. The first element was related to the non-emission benefits such as political acceptance since the approval of the airport infrastructure extension at Zurich was conditional on the introduction of the charge. The second element related to the benefits resulting from the avoided NO_x emissions. He suggested that Swissair, the air carrier based at Zurich airport at the time, anticipating strong air traffic growth, had launched a programme to replace its MD80 aircraft fleet with less polluting aircraft and invested heavily in new technology which had resulted in the avoidance of 10% of the total NO_x emissions at the airport. These two major benefits were not factored in. In reaction, one member noted that the 35th Session of the ICAO Assembly had requested the conduct of a cost-effectiveness analysis and not a political-effectiveness analysis and that political factors were rightly excluded.

2.4.4.6 One member noted that the results of the analysis were not affirmative and that it did not cover all aspects related to emission charges. In particular, manufacturers design changes in response to the possibility of such charges were not covered in the FESG study while the LTTG report showed that manufacturers are responding to increasing environmental concerns. In response, it was noted that before including any factor in the cost-effectiveness analysis, the causality aspect had to be proven and that the FESG did not find any evidence of causality between the introduction of the NO_x emission charges and a possible airlines' behaviour response.

2.4.4.7 A member noted that while the reason mentioned in previous meetings for the introduction of the emissions charges was to provide an incentive to change the fleet mix, this report showed that this link could not be found. In reaction, another member noted that while the analysis did not find a link between the introduction of the NO_x emission charges and the change in the fleet mix, that did not mean that there was no link. He suggested endorsing the report while recognising that it had several caveats.

2.4.4.8 One member asked whether the analysis took into consideration the requirement that a particular charge or fee should be commensurate with the service rendered as stated in Article 15 of the Chicago Convention and other international conventions. It was noted that the analysis has considered ICAO's policy on charges. It was also noted that this question related more to the guidance material on emission charges than to the cost-effectiveness analysis.

2.4.4.9 Two members noted that this report proved how difficult it was to study the internalisation of external costs and that this should be reflected in the report to ICAO Council.

2.4.4.10 After discussion, the meeting accepted the conclusions drawn from the analysis on the cost-effectiveness of local air quality charges while recognizing that there were limitations in the data available.

2.5 ACI POLICY PAPER ON CLIMATE CHANGE

2.5.1 Airports Council International presented a policy paper on climate change issues to the meeting, in which it stressed that aviation should address its climate change impacts at a global level. To that effect a long-term strategy is necessary. ACI supports both the initiatives that airports can take to reduce greenhouse gas emissions within their direct control and recognises that in certain regions, due to political and public pressures, a more active action may be taken, such as emissions trading. ACI supports regional solutions to climate change impacts as an interim step to a global solution and also supports airport specific solutions.

2.5.2 The meeting took note of this position paper.

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REPORT

ON

VOLUNTARY EMISSIONS TRADING FOR AVIATION

ICAO CAEP

EMISSIONS TRADING TASK FORCE (ETTF)

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CHAPTER 1 VOLUNTARY EMISSIONS TRADING CONCEPTS

1.1 Introduction

1.1.1 Discussions in ICAO CAEP

In evaluating alternative approaches to addressing aviation's impact on the global climate, ICAO CAEP concluded that, relative to other market-based measures, an emissions-trading system would be a cost-effective measure to limit or reduce CO_2 emitted by civil aviation in the long term, provided that the system is an open one across economic sectors.[1]

The 33rd ICAO Assembly (2001) endorsed the "development of an open emissions trading system for international aviation" and "requested the Council to develop as a matter of priority the guidelines for open emissions trading for international aviation, focusing on establishing the structural and legal basis for aviation's participation in an open trading system, and including key elements such as reporting, monitoring, and compliance, while providing flexibility to the maximum extent possible consistent with the UNFCCC process."

Subsequently, at its 35th Assembly (2004), ICAO endorsed the "further development of an open emissions trading system for international aviation" and requested the Council, in its further work on this subject, to focus on two approaches, namely to "support the development of a voluntary trading system that interested Contracting States and international organizations might propose" and to "provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process".

Under both approaches, the Council was instructed to ensure that the guidelines for an open emissions trading system address the structural and legal basis for aviation's participation in an open emissions trading system, including for example key elements such as reporting, monitoring and compliance.

This report has been developed for CAEP by the Emissions Trading Task Force in response to the request to the Council to support the development of a voluntary trading system that interested Contracting States and international organisations might propose.

1.1.2 Aviation's role in the global economy

Aviation plays a vital role in facilitating economic growth, particularly in developing countries. It provides the only worldwide transportation network, and transports about 2 billion passengers annually, as well as 40% of interregional exports of goods (by value). According to industry sources[2], its global economic impact is estimated at US$ 2,960 billion (equivalent to 8% of world Gross Domestic Product (GDP)) while generating a total of 29 million jobs globally.

The demand for air transport has increased steadily over the years. Passenger numbers have grown by 45% over the last decade and have more than doubled since the mid-1980s. Freight traffic has increased even more rapidly, by over 80% on a tonne-kilometre performed basis over the last decade and almost three-fold since the mid-1980s.

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[1] "Market-Based Measures:" Report from Working Group 5 to the fifth meeting of the Committee on Aviation Environmental Protection. CAEP/5-IP/22. 5/01/01.

[2] ATAG (2005) Economic Benefits of Air Transport

1.1.3 **Climate impact**

Inclusion of aviation in an emissions trading system would require a decision regarding aviation emissions to be covered by the scheme.

The primary direct greenhouse gas emissions of aircraft are carbon dioxide (CO_2) and water vapour (H_2O). Other emissions are oxides of nitrogen (NO_x), particles containing sulphur oxides (SO_x) and soot. The total amount of aviation fuel burned, as well as the total emissions of carbon dioxide, NOx, and water vapour by aircraft, are well known relative to other parameters such as aerosols. These gases and particles alter the concentration of ozone (O_3) and methane (CH_4), may trigger formation of condensation trails (contrails), and may increase cirrus cloudiness – all of which may contribute to climate change.

According to estimates produced in the IPCC aviation report (1999), the overall radiative forcing from aircraft effects (excluding that from changes in cirrus clouds) in 1992 was a factor of 2.7 larger than the forcing by aircraft carbon dioxide alone.[3] The IPCC concluded that there were varying levels of scientific understanding (e.g. ranging from "very poor" in the case of cirrus to "good" for CO_2[4]) associated with these effects. Further research into such non-CO_2 effects is ongoing, and IPCC is expected to provide an update in its fourth assessment report due in 2007. These radiative forcings represent the best estimate of the effects of aviation on climate for the reported year, i.e. 1992. However, for aviation's past, present or future emissions, the radiative forcing index should not be used to derive relationships between emissions and marginal changes in climate, as the Global Warming Potential (GWP) is intended to do.

The Global Warming Potential (GWP) metric was developed by the IPCC, to compare the climate impacts of changes on emissions of long lived well mixed gases to that of CO_2 over a specific time horizon. It is used by the UNFCCC process in establishing emissions equivalencies for emissions reduction targets and activities. CO_2 impacts from aviation are the longest lived and most well defined and are readily defined in terms of GWP. Formulating GWPs from non-CO_2 effects from aviation has conceptual difficulties and the IPCC (1999) stated that such GWPs were not adequate to describe the climate impacts of aviation (see IPCC, 1999 Chapter 6 section 6.2.2).

For further information on emissions from the aviation sector please refer to the most current IPCC Assessment Report and the IPCC Special Report on Aviation and the Global Atmosphere.

1.1.4 **International regulatory framework**

The United Nations Framework Convention on Climate Change (UNFCCC), adopted at the Rio Earth Summit in 1992, aims to stabilize greenhouse gas concentrations in the global atmosphere. Under the UNFCCC, industrialized countries (named "Annex I Parties") shall adopt national policies and take corresponding measures on the mitigation of climate change by limiting its greenhouse gas emissions.

The UNFCCC is supplemented by the Kyoto Protocol of December 1997 which requires participating Annex I Parties to reduce their overall emissions of greenhouse gases by at least 5% below 1990 levels in the period 2008-2012, in accordance with the quantified emissions limitation/reduction commitments (QELRCs) as assigned to each of them individually in Annex B of the Protocol.

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[3] The so-called RFI or radiative forcing index, is defined by the IPCC 1999 report as the sum of all the forcings divided by the CO_2 forcing (chapter 6 paragraph 6.2.3)

[4] For further details see the 1999 IPCC Special report on Aviation and the Global Atmosphere and the 2001 IPCC Third Assessment Report (TAR).

Parties' commitments under the Kyoto Protocol include emissions from domestic aviation, but emissions from international flights are not currently included. Article 2.2 of the Protocol states that "[T]he Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases (…) from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively".

Although non-Annex I Parties have no quantified obligations under the Kyoto Protocol, all Parties to the UNFCCC are called upon to take mitigation and adaptation measures, within the confines of their respective capabilities [5].

Voluntary participation in emissions trading schemes is equally relevant to Annex I and non-Annex I Parties and may be considered as a cost-effective complement to technology transfer and other mechanisms to reduce fuel consumption and increase resource efficiency.

1.2 Voluntary emissions trading explained

1.2.1 Rationale behind emissions trading

Emissions trading is a market-based policy tool that can be used to promote economic efficiency in achieving environmental goals. By harnessing market forces, emissions trading regimes can create incentives for economic agents to discover and implement cost-effective approaches to complying with environmental targets.

The basic argument for using emissions trading as an environmental policy tool relates to the potential costs saving a trading system can generate relative to a conventional command and control approach. In particular, when regulated entities are allowed to buy and sell emission instruments, market forces can create an incentive for firms with relatively low-cost emission reduction options to reduce their emissions by more than needed to satisfy their regulatory requirements.

These entities are then able to sell surplus emission instruments to other regulated firms that are faced with relatively high-cost emission control options. The opportunity to sell surplus emission instruments can create incentives for cost-effective compliance with environmental targets. As a result, incorporating an emissions trading system into an environmental policy can mean that the same level of environmental protection can be achieved at a lower overall cost. Care must be taken, however, that the savings in mitigation costs across all participants are large enough to more than offset the combined administrative and transactions costs.

1.2.2 Description of voluntary emissions trading

Various interpretations exist as to what is meant by voluntary emissions trading and specifically what is meant by the term 'voluntary'. According to the Organisation for Economic Co-operation and Development (OECD), for example, there are many different examples of voluntary initiatives, ranging from unilateral actions at the company level to negotiated agreements between governments and sectors [6]. The OECD also points to different ways in which voluntary programmes can be combined with other measures such as taxes (most commonly involving some exemption), subsidies or standards. In practice, many voluntary agreements are in fact combined with some sort of incentive measure.

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[5] See Article 4 UNFCCC

[6] See OECD (2003) *Voluntary approaches for environmental policy- effectiveness, efficiency and usage in policy mixes*, and OECD (1999) *Voluntary Approaches for environment policy: an assessment*, OECD, Paris

This report defines a voluntary trading scheme as any scheme in which participation is not made mandatory by a State. Schemes that involve some kind of government incentive for companies to participate therefore also fall under this definition.

For the purpose of this report, voluntary emissions trading for international aviation is considered to be one of the following:

1. a group of airlines decides to create its own ETS;

For example, airline alliance partners set up an ETS among themselves. This would be a sectoral trading system that could be designed in a way that would allow participants to purchase offsets outside the scheme in order to keep costs down.

2. the airline sector creates a new ETS together with other sectors

For example, members of a national air transport association get together with the national electricity companies and agricultural sector to establish and participate in a national emissions trading scheme.

3. an airline/a group of airlines decides to unilaterally join an existing ETS

a) run by own government
b) run by other government(s)
c) run by a commercial entity

For example, as part of national efforts to drive technology efficiency and reduce emissions, a group of national airlines choose to participate in a trading scheme a) administered by its own government; or b) run in a neighboring State; or c) run by an independent trading platform.

Under these scenarios, the money paid by those buying allowances helps to finance the development and/or implementation of CO_2 control measures by others who are selling the allowances. In addition to these options, more direct mechanisms may also be considered, for example:

4. an airline/a group of airlines decides to compensate for carbon emissions by using an offset mechanism

a) run by the airline(s) itself (possibly as an option for passengers/customers)
b) run by an independent service provider.

In this case, money is usually paid into a fund that sponsors specific projects to reduce or avoid emissions from sources or remove emissions from the atmosphere through so-called sink projects. An example would be an airline that sets aside a small amount per ticket sold to fund climate mitigation projects. Such offset programmes, if only triggered by passengers or customers, may not result in the reduction of a predefined quantity of emissions.

1.2.3 Key considerations

A number of considerations are key in designing a workable and credible voluntary trading scheme. These include:

- ***Environmental results***—how stringent are the environmental targets, with what degree of certainty are these results achieved, how likely are entities to participate and how broad is the emissions coverage under the agreement, and what factors might undermine achieving the environmental results [7].

- ***Flexibility***—does the approach offer sufficient flexibility to ensure environmental benefits while allowing for economic growth within the sector and does it enable participants to take those actions that will most effectively reduce emissions and to encourage innovation in emissions reduction;

- ***Administrative & transaction costs***—how costly will requirements of the system be for the central administrative body and other entities (incl. the government) to administer and enforce, and how expensive will it be for entities to participate in the broad range of activities (such as monitoring and verification, reporting, and trading).

- ***Transparency***—how complex will the administration of the scheme be, how complex will it be for entities to participate in the scheme (incl. monitoring, verification, reporting and trading) and how transparent will the scheme be for third party stakeholders;

- ***Overall cost and cost-effectiveness***—does the option have adverse effects on the cost-effectiveness (i.e., the cost per tonne of CO_2 reduced) of control, or on overall control costs (i.e., the total costs of abatement plus purchase/sale of emission allowances and/or credits) for the aviation sector (domestic or international).

- ***Competitiveness***—how will the design of a trading scheme affect the competitive positions of participants and non-participants within the aviation sector, and between aviation and other transportation modes.

- ***Interactions with other mitigation options***—what types of issues arise regarding compatibility or conflicts with other policy instruments (standards, taxes, charges, other trading schemes, etc.) that exist or are being considered to address greenhouse gas emissions from aviation. Measures should not detract from other efforts to improve overall environmental performance.

- ***Political acceptability***—how will the trading scheme be viewed by the relevant stakeholders, including airlines and other industry actors that have an influence on aviation emissions but are not direct participants in the agreement (e.g. engine manufacturers, air traffic controllers), governmental and non-governmental bodies, etc.

1.2.4 Opportunities for airlines created by voluntary emissions trading

There are a number of reasons why voluntary emissions trading schemes may provide a helpful option for addressing aviation emissions, particularly from international flights.

1.2.4.1 Flexibility

Voluntary trading schemes are not necessarily constrained by the framework of international agreements. This could allow early action under a voluntary framework while discussions on a possible mandatory approach are ongoing. It could also allow action that is broadly inclusive.

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[7] OECD assessment of voluntary initiatives in environmental policy concludes that their environmental effectiveness and economic efficiency is generally low compared to other approaches, but when measured against other criteria (so called 'soft' criteria) such as awareness raising they have been seen to have a very important role**.** See *supra* note 7

1.2.4.2 **Cost containment**
Successful voluntary measures can help to minimise costs, especially compared with the perceived cost of regulatory actions. As the action that needs to be taken to achieve a reduction target becomes more costly – approaching the cost of potential "command and control" regulations – the incentive to pursue voluntary trading diminishes. Therefore, successful voluntary measures should be cost-effective and have low administrative and transactions costs.
1.2.4.3 **Competitiveness**
Voluntary trading has potential to attract broad geographic participation by States and airlines. If the system attracts broad geographic participation, and since airlines are unlikely to join if they anticipate doing so will significantly hamper their ability to compete, competitive impacts are likely to be small.

1.2.4.4 **Learning by doing**
For companies not involved in mandatory trading schemes, a key benefit of voluntary trading might derive from "learning-by-doing" and from "institutional capacity building" within the airline sector. Starting out with a voluntary trading regime offers the important advantage of allowing participants the opportunity to develop skills and learn trading strategies that may be useful as emissions trading develops in the future. Voluntary emissions trading can be a step toward demonstrating to governments and the public that global warming concerns are being addressed responsibly.

The next chapter describes some examples of voluntary emissions trading schemes for greenhouse gases in which aviation participates or could participate.

CHAPTER 2 EXISTING VOLUNTARY EMISSIONS TRADING SCHEMES

At the present time there are only a handful of examples around the world of voluntary emissions trading schemes for greenhouse gases. Only one of these trading schemes has included the activities of an airline operator. Other types of schemes involve voluntary financial contributions by airline passengers to fund carbon dioxide emissions offset projects. While the overall contribution of these schemes to global emissions reduction is small at present, the potential exists for this contribution to multiply over time if more schemes are developed.

This chapter summarises the key elements of the following voluntary schemes:

- United Kingdom Emissions Trading Scheme;
- Japanese Voluntary Emissions Trading Scheme;
- Chicago Climate Exchange (with reference to the European Climate Exchange and the Montreal Climate Exchange);
- Asia Carbon Exchange; and
- Voluntary Carbon Offset Schemes.

2.1 UK Emissions Trading Scheme (UK ETS)

2.1.1 **Overview**
The UK ETS for greenhouse gases was launched by the Government in April 2002 as part of a wider range of measures in the UK designed to reduce greenhouse gas emissions under the UK Climate Change Programme. At the launch, it was claimed to be the world's first economy-wide greenhouse gas trading system.

A range of organisations, including British Airways as the only airline operator (domestic operations only), voluntarily undertook to reduce their emission of carbon dioxide equivalent (CO_2e) to below set targets. In return, these organisations receive incentive payments totalling £215 million from the Government. Over the lifetime of the scheme (2002-2006), almost 12 million tonnes of CO_2e emissions releases will have been avoided. Options for the future of the scheme beyond 2006 are currently being considered by the Government.

The scheme is also open to the companies with Climate Change Agreements with the Government. These negotiated agreements set energy-related targets and companies meeting their targets receive an 80% discount from the Climate Change Levy, a tax on the business use of energy. These companies can use the scheme either to buy allowances to meet their targets, or to sell any over-achievement of these targets. In addition, anyone can open an account on the registry to buy and sell allowances.

It was reported that over the first three years (2002 - 2004), the scheme delivered emissions reductions totalling 5.9 million tonnes of CO_2e.

2.1.2 Participants and incentives

Entry into the scheme is voluntary and open to all individuals or organisations in the UK. There are two principal types of participants - Direct Participants and Agreement Participants.

Direct Participants are organisations that agreed to take on voluntary targets for a five-year period, 2002-2006, in exchange for financial incentives provided by the Government. Thirty-three such organisations, including British Airways, committed to reduce their annual emissions against 1998-2000 levels by 3.96 million tonnes of CO_2e by the end of the scheme in 2006. In addition to fulfilling the total annual reduction target by 2006, Direct Participants had to comply with interim targets for years 2002-2005. Each year, the reduction target was increased by one-fifth of the overall (2006) target. As a result, the original commitment made by Direct Participants equates to delivering 11.88 (that is, (1/5+2/5+3/5+4/5+5/5) x 3.96) million tonnes of CO_2e worth of cumulative emissions releases avoided over the lifetime of the scheme.

As an incentive, the Direct Participants receive a total of £215 million in payments from the Government over 5 years or approximately £43 million (£30 million after tax) per year. The level of incentive payment and the associated targets for each Direct Participant were set through a competitive bidding process.

Agreement Participants are those 6000 companies which already had emission or energy targets set through Climate Change Agreements with the Government. Companies meeting these targets receive an 80 per cent discount from the Climate Change Levy, which is a tax on the business use of energy. These companies can use the scheme either to buy allowances to meet their targets, or to sell any over-achievement of these targets.

In addition to these participants, the UK ETS allows other parties to participate in the scheme as traders without compliance commitments.

2.1.3 Identifying emissions sources and calculating a Baseline

The Baseline for each Direct Participant was calculated on the basis of historic emission levels and was generally the average annual emissions in the three years up to and including 2000.

The Baseline was made up of emissions from individual sources, which Direct Participants had to list by way of an approved protocol. The total emissions calculated using the approved protocol formed the Baseline expressed in tonnes of carbon dioxide equivalent (tCO_2e). Emissions included both direct emissions such as those from fossil fuel combustion or other industrial processes, and indirect emissions associated with energy use.

The Scheme makes provision for adjustments to the Baseline to take account of changes in the structure or operations of a Direct Participant.

2.1.4 Allocation of allowances

For Direct Participants, a 'descending clock' auction was used to allocate the incentive money and the associated targets for emission reductions. Auction participants bid amounts of emission reductions in response to prices for tCO_2e announced by the Department for the Environment, Food & Rural Affairs (DEFRA), starting at a nominal £100. Companies submitted new bids in response to successively lower prices for tCO_2e until the total incentive payment implied was no more than the incentive budget of £215 million. This process gave a final price of £53.73 per tCO_2e reduction in 2006.

Because participants are required to make progressively larger reductions in each year of the Scheme, the 2006 reductions relative to the Baseline represent one-third of the cumulative total reductions from 2002-2006. The final price of £53.73 therefore corresponds to £17.79 per tCO_2e of cumulative reductions over the life of the Scheme, or £12.45 per reduction tCO_2e net of the maximum corporation tax due on the incentive payments.

The thirty-three Direct Participants pledged emissions reductions totalling 3.96 million tCO_2e in 2006, which is equivalent to 11.88 million tCO_2e of cumulative emissions releases avoided in total over the life of the Scheme. The 2006 target corresponded to a 13 per cent reduction from verified baseline emissions.

Direct Participants are subject to a 'cap and trade' emissions trading system. They are allocated allowances equal to the target for each year, provided they have been in compliance in the previous year. At the end of each compliance year, Direct Participants must reconcile their verified emissions against their allowances and undertake any further trading necessary to meet their target.

Companies entering the Scheme through the Climate Change Agreements participate in a 'baseline and credit' trading system. They do not receive allowances up front. At the end of each year in which they have targets, they receive allowances if they have beaten their target, or they are able to buy additional allowances if they have not beaten their target.

2.1.5 Trading of allowances

A computerised registry is the centralised means of managing all transactions. Anyone wanting to hold, buy or sell allowances or credits must have an account in the registry. The registry records all allowance holdings and tracks allowances from their initial allocation through all transfers of ownership until final cancellation or retirement.

Anyone holding an account in the registry is allowed to buy and sell allowances. Participants in the scheme are able to trade directly between themselves or through third party brokers.

2.1.6 Reporting, verification and compliance

At the end of each compliance period (calendar years for Direct Participants and every two years for Agreement Participants), target holders must report their emissions over that period. All target holders must ensure that they either hold sufficient allowances to cover their verified emissions (for Direct Participants), or that they hold sufficient allowances to cover any emissions or energy use in excess of their target (for Agreement Participants).

A three-month reconciliation period is allowed following each compliance period to enable participants to continue trading if required before a final deadline. After this, the Government checks the total holdings in each participant's account and all allowances needed to cover emissions over the preceding year are retired. Any allowances that remain can be banked for future use or sold.

Penalty provisions apply for non-compliance which are intended to be sufficiently strong to ensure the scheme operates effectively but not disproportionate for a voluntary scheme. For Direct Participants penalties can include financial penalties, non-payment of the financial incentive and a reduction in the number of allowances for the next compliance period. There is also the option for the Government to publicly list those Direct Participants who fail to hold sufficient allowances at the end of the reconciliation period. For Agreement Participants, the penalty is the removal of the 80 per cent discount on the Climate Change Levy.

2.1.7 **Results**

To date, British Airways has operated successfully within the UK ETS, meeting the reporting and verification requirements of the scheme, and keeping within its agreed emissions cap. Successful participation has been greatly helped by agreeing a protocol with the UK government, which deals with the key issues of monitoring and measuring emissions from mobile sources.

British Airways reports that participation in the UK ETS has brought valuable experience of operating with an emissions trading scheme. In addition to making cuts in CO_2 emissions and associated energy costs, the scheme has led to improvement in data accuracy and energy management information in a number of areas of operation.

The airline also cites a number of strategic benefits from participation in the scheme:

- Exposure to the concept within the business by taking into account the price of carbon in network planning decisions within its domestic network and integrating emissions trading into fuel hedging and financial management activities;

- Gaining experience of the processes and strategic implications, including the reporting of verifiable emissions data and credit trading; and

- Demonstration that emissions trading is a deliverable and practical policy tool for managing air transport emissions.

2.2 **Japan's Voluntary Emissions Trading Scheme**

2.2.1 **Overview**

In May 2005, the Ministry of the Environment launched Japan's Voluntary Emissions Trading Scheme (JVETS). Under the scheme, the Ministry subsidises the installation of emissions reduction equipment for selected participants who make a commitment to specific reductions in their CO_2 emissions. The scheme also allows these participants to trade CO_2 emission quotas to meet their reduction targets. The total emissions reductions for fiscal year (FY) 2006 are forecast to be almost 0.28 million tCO_2, while the total reduction over the officially-recognised service life of the subsidised equipment is calculated at about 3.8 million tCO_2.

The main purpose of the scheme is to achieve a cost-effective and substantial reduction in greenhouse gas emissions and to accumulate knowledge and experience relating to domestic CO_2 emissions trading.

A graphic illustration of the scheme is provided in Appendix A to this report.

2.2.2 **Participants and incentives**

An open invitation was made to private companies and other appropriate groups in Japan to participate in the JVETS. Of the 38 entities that applied, 34 companies and corporate groups were selected to participate based on the cost effectiveness of their emissions reduction proposals. In return for adopting specific emissions reduction targets, these 34 participants became eligible for Government subsidies for the installation of the emissions reduction equipment. Subsidies were only available for new facilities to improve energy efficiency or to promote renewable energy leading to greenhouse emissions reduction. The subsidies were capped at one third of the cost involved for each participant. The total Government budget for the subsidies is about 2.6 billion yen (about US$23.6 million).

The scheme provides for trading by the participants as required to meet their emissions reduction targets. There is also provision for 'trading participants' who will be able to operate trading accounts but who will not be eligible for subsidies or the allocation of allowances. Eight companies were selected as trading participants.

2.2.3 **Calculating baseline emissions and emission reductions**
The calculation of baseline emissions for each participant is based on their average annual CO_2 emissions between 2002 and 2004. For the 34 participants involved this equates to a total of over 1.3 million tCO_2. The total emissions reductions promised by the individual companies for FY2006 is almost 0.28 million tCO_2, or 21 per cent of their average annual CO_2 emissions in the base years. The total reduction over the officially recognised service life of the subsidised equipment is calculated at about 3.8 million tCO_2.

Participants received subsidies for new facilities and their installation during FY2005. The new facilities were to be set-up before the end of FY2005 (end March 2006) and the calculation of base year emissions also had to be completed by October 2005.

Base year emissions for all participants were verified by a Ministry accredited verification entity.

2.2.4 **Allocation of allowances**
The Ministry of the Environment allocated emissions quotas based on the results of the base years verification process. The allocations for each participant was the average emissions for the base years minus the estimated or pledged emission amount for FY2006.

2.2.5 **Trading allowances**
Throughout FY2006, participants will implement their CO_2 reduction projects using the newly installed equipment. Participants will be able to trade their allowance throughout FY2006 which finishes at the end of March 2007. At that time, actual greenhouse gas emissions will be calculated and verified. A final trading period of about one week will be allowed for participants to trade allowances again if necessary. By June 2007, participants will need to retire allowances in the registry.

2.2.6 **Reporting, verification and compliance**
At the completion of FY2006, participants will have the period April to June 2007 to calculate their actual emissions for FY2006 and to submit the results to the third party entity for verification. The Ministry of the Environment will fund the cost of verification.

Participants will be non-compliant if they cannot retire sufficient allowances corresponding to the actual amount of their emissions. In the case of non-compliance, the participant must return the subsidy received to the Ministry for the Environment.

2.2.7 **Results**
The total emissions reductions for FY2006 are forecast to be 276,380 tCO_2, while the total reduction over the officially recognised service life of the subsidised equipment is calculated at about 3.8 million tCO_2. Final results for FY2006 were not available at the time of this report.

2.2.8 Remarks

The Ministry of the Environment selected 61 companies and corporate groups as subsidised participants for the second period of JVETS. The total emissions reductions are estimated to be 229,405 tCO_2 for FY2007 while the total reduction over the officially recognised service life of the subsidised equipment is calculated as 2.8 million tCO_2.

2.3 Chicago Climate Exchange (CCX)

2.3.1 Overview

The Chicago Climate Exchange (CCX) is a voluntary, legally binding, greenhouse gas emissions registry, reduction and trading system for emission sources and offset projects in the United States, Canada, Mexico, Brazil and worldwide. The development of the CCX was initiated through a feasibility study funded by a grant from the Chicago-based Joyce Foundation. A subsequent grant was given to initiate research on market implementation.

CCX is a self-regulatory, rules-based exchange designed and governed by CCX members. Members make a voluntary but legally binding commitment to reduce their emissions of greenhouse gases. By the end of Phase I (December 2006) all Members will have reduced direct emissions by four per cent below the average of their 1998-2001 baseline. Phase II, which extends the CCX reduction program through to 2010 will require all members to reduce greenhouse gas emissions by six per cent below the baseline.

Continuous electronic trading of greenhouse gas emission allowances and offsets began on 12 December 2003. CCX reduction commitments and trading apply for years 2003-2010. With a total emission baseline of about 231 million tCO_2e for 2006, the CCX program aims to achieve a total emissions reduction of over 9 million tCO_2e (4 per cent) by the end of Phase I in December 2006. Actual emissions reductions by the end of the 2004 compliance year were over 32 million tCO_2e, which was substantially better than the target for that year.

The CCX market price in October 2006 for CO_2 was about US$4 per tonne. The price has risen from around US$0.98 in December 2003 and reached a high of US$5 in April 2006.

2.3.2 Participants and incentives

Membership of the CCX is open to a wide range of participants. There are four classes of CCX membership, which together are referred to as CCX Registry Account Holders. The classes are:

a) CCX Members include corporations, municipalities and other entities that have direct GHG emissions from facilities in the United States, Canada or Mexico.

b) CCX Associate Members are entities that have insignificant or no direct GHG emissions and comply with CCX rules by offsetting all indirect emissions associated with a selection of business related activities.

c) CCX Participant Members include Offset Providers and Liquidity Providers.

    (i) Offset Providers are entities such as project owners, project implementers and registered aggregators that sell Exchange Offsets produced by qualifying CCX-registered Offset Projects.

    (ii) Liquidity Providers are entities or individuals who trade or engage in market-making activities on the Exchange for purposes other than compliance with the

CCX emissions reductions schedule.

d) CCX Exchange Participants are entities that establish a CCX Registry Account for the purpose of acquiring and retiring CCX Carbon Financial Instruments (CFIs) the CCX tradable commodity.

As at 12 September 2006 CCX membership totalled 142. No airline operators or aircraft manufacturers were included in the membership. While Rolls-Royce is a member, this is in the context of its manufacturing activities and not in the context of aircraft engine emissions.

There are no Government funded incentives to participate in the CCX. The CCX promotes the benefits of membership as being:

1. First-mover advantage.
2. Helping to build a transparent and credible first step solution.
3. Ease and security of trade execution.
4. Helping to shape environmental policy for the 21st century.
5. Global exposure.

2.3.3 Identifying emissions sources, calculating baselines and setting emission reduction targets

Emissions of the following greenhouse gases from facilities owned by CCX members are included in the scheme as applicable: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

Emissions of all non-CO_2 greenhouse gases are converted to metric tonnes CO_2 equivalent using the one hundred year Global Warming Potential (GWP) values established by the Intergovernmental Panel on Climate Change.

The unit of emissions measurement, reporting, price quotation and trading is metric tons of carbon dioxide equivalent or tCO_2e. Each CCX Carbon Financial Instrument represents one hundred tCO_2e.

CCX emitting Members make a voluntary but legally binding commitment to reduce direct emissions below an emissions baseline. An emissions baseline is calculated by taking the average of emissions inventories from a specific timeframe, or ‘baseline period’. Baselines are adjusted to reflect acquisition or disposal of facilities.

Phase I Members: By the end of Phase I (December 2006) all Members will have reduced direct emissions by 4 per cent below a baseline period of 1998-2001. Members that participate in Phase II will reduce emissions by an additional 2 per cent below baseline by 2010 to achieve the Phase II reduction target of 6 per cent below baseline. CCX Members were issued greenhouse gas emission allowances at the inception of the program for the four-year period (2003-2006) in an amount reflecting the CCX emission reduction schedule below:

Phase I	**CCX Emission Reduction Target**
2003	1 per cent below Member’s baseline
2004	2 per cent below Member’s baseline
2005	3 per cent below Member’s baseline
2006	4 per cent below Member’s baseline
Phase II	**CCX Emission Reduction Target**

2007	4.25 per cent below Member’s baseline
2008	4.5 per cent below Member’s baseline
2009	5 per cent below Members baseline
2010	6 per cent below Members baseline

Phase II Member joining in 2006: New Phase II Members’ emission baseline is the annual average of emissions from facilities included in the baseline period 1998-2001. If data is insufficient, new Phase II Members may use a year 2000 baseline. The Phase II reduction target is 6 per cent below baseline by 2010. CCX Phase II Members will be issued greenhouse gas emission allowances in an amount reflecting the CCX emission reduction schedule below:

Phase II	**CCX Emission Reduction Target**
2006	1.2 per cent below Member’s baseline
2007	2.4 per cent below Member’s baseline
2008	3.6 per cent below Member’s baseline
2009	4.8 per cent below Member’s baseline
2010	6 per cent below Member’s baseline

2.3.4 **Emission offsets**

Eligible projects can be recorded in the CCX Registry and are issued Exchange Offsets on the basis of mitigation tonnage realized during 2003-2006. Exchange Emission Offsets are issued after mitigation occurs and required documentation is presented to the CCX. Project eligibility, project baselines, quantification, and monitoring and verification protocols are specified in the CCX Rulebook.

The initial categories of eligible offset projects are:

- Methane destruction;
- Agricultural practices;
- Forestry practices;
- Other greenhouse gas emission mitigation in Brazil;
- Renewable energy; and
- Clean Development Mechanism Eligible Projects.

2.3.5 **Allocation of allowances and offsets**

The tradable Carbon Financial Instruments employed in CCX are Exchange Allowances (XA's) and Exchange Offsets (XO's). Exchange Allowances are issued to Exchange Members and Associate Members in accordance with each Member's Emission Baseline and Emission Reduction Schedule, subject to provisions outlined in the CCX Rulebook. They are also issued on the basis of forest carbon sequestration and reductions in electricity use. Exchange Offsets are generated by qualifying mitigation projects and registered with CCX by Exchange Participant Members.

Each CCX Carbon Financial Instrument resides in the CCX Registry in a manner that designates the Instrument's annual vintage. Each Carbon Financial Instrument is recognized as equivalent when surrendered for compliance. Carbon Financial Instruments may be used for compliance in their designated vintage year or banked for use in later years, subject to provisions outlined in the CCX Rulebook. CCX Carbon Financial Instruments may not be used for compliance in years that precede the vintage of an Instrument.

2.3.6 **Trading of allowances and offsets**

The CCX Trading System has three component parts:

1. *The CCX Trading Platform* is an internet-accessible marketplace that is used to execute trades among CCX Registry Account Holders. The system utilizes SUN java technology to bring live and active content to a screen. The Platform features a price transparent marketplace that displays order size, market depth and a market ticker. The system supports both exchange-cleared trades which preserve anonymity, and bilateral trades that are established through private negotiations off-system.

2. *The Clearing and Settlement Platform* receives information daily from the CCX Trading Platform on all trade activity. It processes all transaction information, nets out positions, and produces payment instructions for settlement of trades. Daily statements are provided to members when trading occurs. All corresponding changes are automatically updated in a Registry Account Holders' holdings of Carbon Financial Instruments in the CCX Registry.

3. *The CCX Registry* is an electronic database that serves as the official holder of record and transfer mechanism for Carbon Financial Instruments owned by Registry Account Holders.

The three components are integrated to provide Registry Account Holders with real-time data to support trading, assist in managing member emissions baselines, reduction targets and compliance status.

2.3.7 **Reporting, verification and compliance**

CCX has contracted with the National Association of Security Dealers (NASD) to provide regulatory services. NASD assists in the registration, market oversight, and compliance procedures for CCX members. NASD audits a representative sampling of each member's emission baseline and annual true-up, and reviews offset projects verification procedures. NASD utilises its state-of-the-art market surveillance technologies to monitor CCX trading activity. To ensure environmental integrity, offset verification services are provided by CCX-approved verifiers and are required for all exchange offset projects.

2.3.8 **Results**

As of September 2006, results had only been released for the first two emission reduction compliance periods (calendar years 2003 and 2004). This showed that the direct emission reduction achieved in the first year was some 21.6 million tCO_2e or 8.7 per cent better than the emissions objective, while the reduction achieved in the second year was some 32.3 million tCO_2e or 13.8 per cent better than the emissions objective. All CCX Members with direct emissions reduction commitments were in compliance.

2.4 **European Climate Exchange (ECX)**

2.4.1 **Overview**

The European Climate Exchange (ECX) was established in 2004 and is a wholly-owned subsidiary of the Chicago Climate Exchange. It manages the sales and marketing for ECX Carbon Financial Instruments (ECX CFIs) listed on the Intercontinental Exchange (ICE) Futures electronic platform. Each ECX CFI is based on emission allowances issued under the EU's Emissions Trading Scheme. There is no information available at this time as to whether the ECX has the potential to also support a voluntary emissions trading scheme involving aviation, but given the link with the CCX, voluntary trading could be a matter that interested airlines or other parties could explore with the ECX. ECX daily prices per tonne of CO_2 have ranged from €20 or US$25 (April 2005) to €30 or US$37 (April 2006). The ECX market price in

September 2006 for CO_2 was about €16 or US$20 per tonne. In October 2006 the ECX traded its first emission option, giving buyers and sellers the ability to hedge price risks.

2.5 Montreal Climate Exchange (MCeX)

2.5.1 Overview

The Montreal Climate Exchange (MCeX) was established in July 2006 as a partnership arrangement between the Montreal Exchange (MX) and the Chicago Climate Exchange (CCX). It is intended to accelerate the development of a structured environmental market in Canada. The MX brings to the new climate exchange its expertise in leading-edge trading systems, clearing, market regulation and financial risk management. The CCX contribution is its extensive experience in operating climate exchanges in North America and Europe.

The mission of the MCeX is to offer price transparency, environmental integrity, low cost, wide access and reliability to those sectors of the Canadian economy involved in air quality and climate change concerns. Further details on the nature of the intended trading were not available at the time of writing (August 2006), but given the link with the CCX, it could be expected to include some form of voluntary emissions trading.

2.6 Asia Carbon Exchange (ACX-Change)

2.6.1 Overview

The Asia Carbon Exchange (ACX-Change) was launched in August 2006 and is a fully owned subsidiary of the Asia Carbon Group, which is headquartered in the Netherlands. The ACX-Change is a Clean Development Mechanism (CDM) focused exchange. It claims to be uniquely positioned as a global platform for sellers and buyers of Certified Emission Reductions (CERs), having a presence in both Annex 1 and non-Annex 1 countries. It gives sellers of CERs an exposure to a large number of potential buyers while giving buyers a broad range of CER sources with varied risk/benefit profiles to choose. There is no indication as to whether this trading platform could be used to support a voluntary emissions trading system involving aviation.

2.7 Voluntary Carbon Offset Schemes

2.7.1 Context

For a number of years now, consumers have been able to offset the emissions from their flights via the facility provided by independent carbon offset providers. These organizations sponsor projects, which aim to reduce carbon emissions. Initially the focus was on reforestation (tree-planting), but emphasis has now shifted towards renewable energy supply and energy conservation in countries not covered by the Kyoto protocol (hence avoiding double-counting of emissions reductions).

There is increasing interest among private and corporate airline customers in the climate change impact of air travel. Within the UK, the aviation industry, as part of its Sustainable Aviation strategy, made a commitment in 2005 to “evaluate carbon offset initiatives” as a practical, short-term measure with the aim of informing passenger understanding of the impact of air travel. The UK Government has committed to offset the emissions from central government official air travel from April 2006.

2.7.2 British Airways’ offset scheme

In September 2005 British Airways launched a voluntary carbon offset scheme which operates via its website. The scheme is aimed at raising passenger understanding of the climate impacts of air travel. Alongside the opportunity to offset emissions, customers are provided with information about how the airline is seeking to reduce its climate change impact.

Passengers are able to offset the CO_2 emissions created during their flights by making a voluntary contribution to an organisation called Climate Care. The money raised is used by Climate Care to invest in projects that avoid, reduce or absorb carbon dioxide emissions through renewable energy, energy efficiency and forest restoration. The voluntary contribution is calculated on an emissions cost of approximately £7.50 per tCO_2, using actual fuel consumption and load factors from the British Airways' aircraft fleet. This translates to a contribution of £5.00 per passenger on a return flight from London to Madrid and £13.30 for a return flight from London to Johannesburg. On longer routes, such as a return flight between London and Sydney, the contribution is £28.83.

Climate Care's work is scrutinised by an Environmental Steering Committee, which includes environmentalists and NGOs including WWF and Forum for the Future. To ensure that the projects achieve the CO_2 emission reductions that they claim, the Committee requires them to meet three criteria for each project. These are:

- that a third party report be obtained;
- that the CO_2 reductions be monitored on an on-going basis; and
- that any shortfall is made up in other projects.

For more details of the scheme and offset projects, see www.ba.com/offsetyouremissions.

CHAPTER 3 FUTURE DEVELOPMENT OF VOLUNTARY EMISSIONS TRADING SCHEMES INVOLVING AVIATION

3.1 Introduction

As can be seen from Chapter 2 of this report, voluntary emissions trading schemes are becoming established in a number of countries – including the two largest economies of the world, United States and Japan. Aviation participation is confined so far to the UK Emissions Trading Scheme, and even there, it involves domestic aviation services only. However, there is scope for more airlines to become involved in some form of voluntary emissions trading. While there are a number of possible options for achieving this, as identified in Section 1.2.2, this chapter considers four broad ways in which this might be done:

- through participation in an existing voluntary emissions trading scheme;
- through the development of carbon offsets;
- through the development of voluntary agreements as a precursor to an emissions trading system; and
- through the establishment of an aviation-only voluntary emissions trading scheme.

3.2 Participation in an existing voluntary emissions trading scheme

The extent of significant voluntary emissions trading schemes worldwide is generally as described in Chapter 2. On this measure, there would presently appear to be few opportunities available for airlines to participate in existing voluntary schemes. Furthermore, some of these schemes are either not open to new participants, are limited to certain countries, or do not appear to be readily adaptable for participation by airlines. These existing voluntary schemes may nevertheless be a first step towards voluntary emissions trading and might be expanded in the future.

The UK Emissions Trading Scheme *(UK ETS)* is a 5 year pilot scheme that ended in December 2006, so it is not possible for other airlines (or organisations of any type) to join the scheme

Japan's Voluntary Emissions Trading Scheme *(JVETS)* is based on the provision of government subsidies to participants for the installation of emissions reduction equipment. It is difficult to see how this approach could be applied to airline operations given the technology constraints with aircraft engines. It is most unlikely that new aircraft engines or even replacement aircraft could be justified within the current structure of the scheme. However, there may be opportunities for certain airline ground operations to qualify for participation in a voluntary scheme of this type, for example, replacement of auxiliary power unit operation by fixed airport power supply.

The Chicago Climate Exchange *(CCX)* and similar schemes would therefore seem to be the only types of existing schemes that have any potential for providing a voluntary emissions trading facility for aviation. Even here there are significant implications for airlines that may wish to participate particularly in relation to the emissions reductions targets specified by the CCX.

It is likely that new voluntary emissions trading schemes for ground sources will be developed in the future. The adaptability of future schemes for aviation is a matter that cannot be assessed in advance. When considering the possible integration of aviation into such voluntary schemes, it could be expected that the aviation specific issues that arise would generally be similar to those applying to the integration of aviation into mandatory emissions trading schemes. Entities considering participation in a voluntary trading scheme should therefore refer to the *ICAO Guidance on Aviation Emissions Trading* for a detailed discussion of relevant issues.

3.3 **Development of carbon offsets**

Some airlines may face a position where no suitable voluntary emissions trading scheme exists in their country or region. Alternatively, they may prefer to initially become involved in a more basic scheme rather than a relatively complex trading scheme involving other airlines or sectors. In these circumstances, airlines may consider carbon offsets as a market-based mechanism for reducing emissions. Carbon offset providers are active in Europe, North America and in many other regions around the world.

There are two approaches that might be considered.

1. An airline provides a capability for its customers to voluntary offset their emissions.

This could be similar to the British Airways' offset scheme described in Section 2.7.2 of this report. The key feature of this approach is that the airline actively promotes the scheme as part of the ticket booking system rather than just leaving it to passengers to find a carbon offset provider through their own initiative. It would be the airline's responsibility to:

- select the most appropriate carbon offset provider;
- determine the voluntary contribution rate per ton of CO_2 emissions based on fuel consumption performance;
- facilitate calculation, arrange collection and on-forwarding of customer contributions to the offset provider; and
- promote the environmental benefits of the scheme.

Some of the main advantages of this type of scheme are its simplicity, short lead time for implementation and independence from other airlines or industry sectors. A key disadvantage is that there is no predetermined amount of emissions reduction over a specific period or the course of the scheme. This could be addressed by the following approach.

*2. **An airline decides to offset some or all of its emissions, using its own resources.***

In many respects, the steps in establishing this scheme would be similar to the scheme above except that responsibility for funding the offsets would fall on the airline itself rather than on individual passengers. The financial implications for the airline would be directly dependent on the amount of emissions that the airline chose to offset. The main benefit of this type of scheme is that the amount of emissions reductions for a defined period could be predetermined by the airline, and associated offset projects could be more substantial and better planned because of income predictability.

3.4 Development of voluntary agreements as a precursor to an emissions trading system

ICAO has created a Template for Voluntary Measures that may be used by airlines and/or governments as a starting point for the development of voluntary agreements to achieve emissions reductions. For example, such agreements might be based upon the establishment of a future fuel efficiency target for aircraft operators. To provide a basis for emissions trading such an agreement should include an enforceable commitment to achieve emissions reductions that are below an appropriate baseline.

To the extent that voluntary trading would be part of a voluntary agreement between government and industry partners, the ICAO Template for Voluntary Measures may be a useful reference document. It should however be noted that the ICAO Template was not designed with voluntary emissions trading schemes in mind and would have to be adapted for this purpose. The ICAO Template is available from ICAO at http://www.icao.int/icao/en/env/Caep_Template.pdf .

3.5 Establishment of a voluntary emissions trading scheme for aviation

One approach might involve the establishment by a group of airlines of a new voluntary emissions trading scheme for international aviation. This option would have more chance of being realised if it had the support of government(s). Given the greater worldwide focus by governments on solutions to climate change issues, the likelihood of such government support could be expected to increase over time.

This section will not attempt to address all of the issues involved in establishing a new emissions trading scheme but will only focus on aviation specific issues. In doing so, it is recognised that many of the aviation issues would be common to participation in either a voluntary scheme or a mandatory scheme. For other aviation issues, there would be specific differences between voluntary and mandatory schemes.

3.5.1 Commonalities between voluntary and mandatory emissions trading schemes

The *ICAO Guidance on Aviation Emissions Trading* discusses the aviation specific issues relevant to the inclusion of international aviation in mandatory emissions trading scheme. This section draws on the guidance provided in that document to identify issues whose consideration in voluntary or mandatory schemes would be similar.

3.5.1.1 Accountable entities

Given that the voluntary emissions trading scheme considered in this section is assumed to be established by a group of airlines, then it follows that the accountable entities would be aircraft operators.

Accountable entities participating in a voluntary emissions trading scheme will be required, individually or jointly, to hold at the end of a trading period the necessary number of allowances (or credits) covering all relevant emissions, based on measured or modelled (calculated) emissions of their operations under the scope of the scheme.

3.5.1.2 **Emission sources**
The relevant sources of emissions that are to be controlled by the aircraft operator need to be defined. It is preferable that for international aviation the emission source be defined as all civil flights by the aircraft operator within the geographic scope of the scheme. Depending on the number and type of aircraft operators seeking to join the scheme, to lower the administrative burden it may be necessary to make exceptions by establishing an inclusion threshold based on aggregate air transport activity, aggregate emissions (measured in CO_2) or aircraft weight.

3.5.1.3 **Emissions species**
While participants are free to choose which emissions species to include in the scheme, there are several factors that could lead airlines to only include their CO_2 emissions. CO_2 emissions are the largest and most certain of the greenhouse gas emissions from the aviation sector. While non-CO_2 gases are potentially significant, there currently exists a high degree of scientific uncertainty associated with most of them. A CO_2 based scheme is most likely to be compatible with other trading schemes and so increase the potential for future trading between schemes. This would not preclude the inclusion of other aircraft emissions that contribute to climate change in the longer run.

3.5.1.4 **International and domestic emissions**
As States may take action to address international or domestic emissions in the future, any voluntary emissions trading scheme should take the precaution of distinguishing between international and domestic aviation emissions.

The IPCC definition of international and domestic emissions should be used for the purposes of accounting for greenhouse gas emissions from civil aviation. This approach is internationally accepted and will help ensure consistency between the various approaches of States and participants in voluntary schemes.

3.5.1.5 **Distribution of allowances**
Distribution of allowances could occur through grandfathering, auctioning or benchmarking. Grandfathering and auctioning do not raise specific issues that are significantly different for aviation than for other sectors. If benchmarking is being considered for distributing emissions allowances within the scheme, then recognition should be given to previous investment in new technology. Incentives should also be provided to operate the most emissions efficient aircraft in the most efficient way in the future.

3.5.1.6 **Monitoring, reporting and verification**
To ensure the integrity of the trading system clear procedures should be defined for monitoring, reporting and verification of emissions data. These procedures are primarily needed to help accountable entities identify and correct data and/or calculation errors. To avoid misrepresentation of actual emissions, verification procedures are important to ensure equitable treatment of all participants and to publicly demonstrate that obligations are fulfilled. Scheme participants would be responsible for the accurate and timely reporting of emissions data.

3.5.2 **Differences between voluntary and mandatory emissions trading schemes**
There are a number of issues that would clearly be different in a voluntary scheme compared with a mandatory scheme. One overarching consideration is whether the voluntary scheme would be accepted for trading by other emissions trading systems. Additional considerations are as follows:

3.5.2.1 **Participation**
By definition, there would be no compulsion to participate in a voluntary emissions trading scheme. In

order to widen the scope of the scheme, increase the potential environmental benefits and the economic efficiency, and minimise competitive effects, airlines could consider joint participation, for example, as part of an airline association or airline alliance. New entrant airlines would not be obliged to participate in a voluntary scheme but should be able to join if they wished. Once emissions reductions commitments were made, there would need to be an enforceable obligation for participants to meet their targets.

3.5.2.2 **Incentives**
Governments may see benefits in providing financial support or incentives for the establishment or ongoing administration of a voluntary trading initiative. A voluntary scheme with incentives may encourage wider industry participation leading to additional environmental benefit. Incentives may also facilitate quicker implementation.

3.5.2.3 **Targets and timelines**
Participants could decide amongst themselves the stringency and the timing of the emissions reduction targets that would apply under the scheme. Targets would need to be set at a level that would give credibility to the scheme as an effective emissions reduction initiative. Conceivably, airline trade bodies could facilitate the negotiation and definition of relevant targets and timelines.

3.5.2.4 **Types of trading systems**
There is more flexibility in designing a voluntary trading scheme. Besides having the choice between adopting a capped system with allowances or some form of baseline and credit system, participants could opt for meeting their reduction targets separately and individually or for example jointly under a "bubble" agreement. The latter approach may combine a semi-open trading system with a clearinghouse function managed by a central administrator [8].

3.5.2.5 **Trading unit**
The participants in a voluntary scheme can decide amongst themselves the nature of the trading unit (or "allowance") to be used in the scheme. The allowance could represent an absolute amount of emissions (e.g. 1 tonne of CO_2) or, alternatively, an amount of emissions related to some measure of output (e.g. grammes of CO_2 per ATK, RTK, ASK, or RSK).

To avoid the drawbacks of a 'closed' trading system, the scheme could be designed in a way that would allow participants to purchase offsets outside the scheme in order to keep costs down. However, selling scheme allowances into other trading schemes would depend on whether those other schemes accept these.

3.6 How voluntary emissions trading for aviation could develop

Looking at how voluntary emissions trading measures involving aviation have developed to date may provide some insight as to how new measures may develop into the future.

It would seem that carbon offset schemes have potential for early expansion. They can be implemented unilaterally by an individual airline and do not require any form of support from governments or other industry partners. Such schemes could be used as a positive marketing tool by airlines. Initial schemes could be based on carbon offset decisions by individual customers. They could then evolve into a defined reduction scheme where the airline predetermines the amount of emissions reduction to be achieved.

Carbon offset schemes or voluntary agreements, depending on their nature, could be seen as a first step towards wider voluntary emissions trading although it is recognised that this is not a prerequisite. With

[8] The role of administrator could be filled for instance by a governmental agency, an industry body or an independent entity.

more airlines having experience with carbon offset schemes and/or voluntary agreements, it might then be easier for them to turn their attention to a voluntary trading scheme as a group than it might be at the present time.

Government support would appear to be an important ingredient in a voluntary emissions trading scheme although not essential. With the back-up of a well established carbon offset scheme and/or voluntary agreements, airlines may find that government support for a trading scheme is more forthcoming.

The establishment of an airline-only emissions trading scheme would be within the capability of a group of airlines. The limitations of a closed trading system could be overcome by the ability to purchase offsets from other sectors. The level of sophistication and degree of integration with other sectors could then evolve over time.

3.7 Role of ICAO

While the possibility exists in theory, ICAO would not normally be directly involved in setting up voluntary emissions trading schemes. There are however roles that ICAO could pursue to encourage and support the development of voluntary schemes that interested Contracting States and international organisations might propose, for example by

- Providing a forum to develop and review voluntary emissions trading schemes;
- Providing technical information to support such schemes;
- Encouraging consistency between such schemes;
- Encouraging the use and recognition of such schemes; and
- Facilitating or assisting in the verification of aviation emissions data.

3.8 Further information

Further information can be found in the draft *ICAO Guidance on Aviation Emissions Trading* where the various design options are discussed in more depth and a number of recommendations are provided.

3.8.1 Finally, more general background information on emissions trading is available from the ICAO web site at (*insert link*).

GLOSSARY

The terms contained herein are not intended to be universal definitions, but rather to clarify concepts as used in this document.

Accountable Entity
A physical or legal person which, in a given emissions trading scheme, is responsible for emissions from international aviation under the scheme.

Allocation
Method for initial distribution of allowances among States for a commitment period.

Allowance (Emission allowance)
An allowance is a tradable emission permit that can be used for compliance purpose in an emissions trading system. An allowance grants the holder the right to emit a specific quantity of pollution once (e.g. one tonne of CO_2).

Annex B Parties or Countries
Annex B countries are the 39 emissions-capped industrialised countries and economies in transition listed in Annex B of the Kyoto Protocol.

Annex I Parties or Countries
Annex I countries are the 36 industrialised countries and economies in transition listed in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC).

Anthropogenic greenhouse-gas emissions
Greenhouse-gas emissions resulting from human activities.

ATK
Available Tonne Kilometres - a measure of an airlines total capacity (both passenger and cargo).

ASK
Available Seat Kilometres – a measure of an airlines passenger carrying capacity.

Auctioning
Auctioning is an initial distribution method in which allowances are sold in an auction.

Baseline
Total amount of allowances distributed to a sector or an accountable entity.

Benchmarking
An initial distribution method in which allowances are allocated free of charge based on a specific benchmark, for example emissions per unit of output.

Bubble
A bubble is a regulatory concept whereby two or more emission sources are treated as if they were a single emission source.

Buyer
A legally recognised entity (individual, corporation, not-for-profit organisation or government, etc.) who acquires credits, reductions or allowances from another legally recognised entity through a purchase,

lease, trade, or other means of transfer.

Cap and Trade
The Cap and Trade system involves trading of emission allowances, where the total amount of allowances is strictly limited or 'capped' by a regulatory authority. Allowances are created to account for the total allowed emissions. At the end of each compliance period each entity must surrender sufficient allowances to cover its emissions during that period. Trading occurs when an entity can reduce units of emission at a lower cost than another entity and then sells the allowance. A Cap and Trade system is generally based on those entities included in the cap.

Carbon Dioxide (CO_2)
A naturally occurring gas that is also a by-product of burning fossil fuels and biomass, land use changes and other industrial processes. Carbon dioxide is the reference gas against which the global warming potential of other greenhouse gases is measured.

Carbon Dioxide Equivalent (CO_2e)
The universal unit of measurement used to indicate the global warming potential (GWP) of a greenhouse gas.

Certified Emission Reductions (CERs)
A Kyoto Protocol unit equal to 1 metric tonne of CO_2 equivalent. CERs are issued for emission reductions from CDM project activities.

CH_4
Methane – a greenhouse gas.

Cirrus cloud
A type of cloud composed of ice crystals and shaped like hair like filaments. May partly be aviation induced.

Clean Development Mechanism (CDM)
A mechanism under the Kyoto Protocol through which developed countries may finance greenhouse-gas emission reduction or removal projects in developing countries, and receive credits for doing so which they may apply towards meeting mandatory limits on their own emissions.

Climate Change
A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods (Source: UNFCCC).

Closed emissions trading
An emissions trading scheme that is designed to limit or reduce emissions within one sector only without providing access to allowances or credits outside the scheme.

Contrails
The condensation trail left behind jet aircraft. Contrails only form when hot humid air from jet exhaust mixes with ambient air of low vapour pressure temperature.

Credit
A term most commonly used in relation to emission reductions that have been achieved below a predefined, agreed baseline. Once the reduction has been verified by an accredited entity, the authority

issues a credit. The credit grants the holder the right to emit a specific quantity of pollution once (e.g. one tonne of CO_2).

Distribution
Method for apportioning allowances among accountable entities.

Domestic flights
Emissions from civil domestic passenger and freight traffic that departs and arrives in the same country (commercial, private, agriculture, etc.), including take-offs and landings for these flight stages.

Domestic operations
Domestic flights and other aviation activities by an airline relating to those flights.

Emissions Trading
Emissions Trading is a market-based system that, in principle, can allow accountable entities the flexibility to select the most cost-effective solutions to achieve established environmental goals. With emissions trading, entities can meet established emission goals by: (a) reducing emissions from a discrete emissions unit within an entity's boundaries; (b) reducing emissions from another place within the entity; or (c) securing emission reductions from the marketplace. Emissions trading can encourage the implementation of cost-effective emission reduction strategies and provide incentives to emitters to develop the means by which emissions can inexpensively be reduced. Under the Kyoto Protocol, "emissions trading" is one of the three Kyoto mechanisms, by which an Annex I Party may transfer Kyoto Protocol units to or acquire units from another Annex I Party. An Annex I Party must meet specific eligibility requirements to participate in emissions trading.

Fiscal Year (FY)
A fiscal year (or financial year) is a 12 month period used for calculating ("yearly") financial reports in business and other organisations. The specific 12 month period varies between countries,

Fossil Fuels
Carbon-based fuels that include coal, petroleum, natural gas and oil.

Geographic scope
Refers to the geographic coverage of aviation emissions under the trading scheme, i.e. specification of the countries, routes and type of flights/aircraft to be included.

Global Warming Potential (GWP)
Global Warming Potentials (GWP) are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme CO_2 over a period of time (100 years). Carbon dioxide has been designated a GWP of 1; Methane, for instance, has a GWP of 23.

Grandfathering
Method for the initial distribution of allowances free of charge to entities in an emission trading scheme according to historical emissions.

Greenhouse gases (GHGs)
The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent --but very powerful -- greenhouse gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Greenhouse gas reduction or Emissions reduction
A reduction in emissions intended to slow down the process of global warming and climate change. Greenhouse gas reductions are often measured in tonnes of carbon-dioxide-equivalent (**CO_2e**), which is calculated according to the GWP of a gas.

H_2O
Water (vapour).

HC
Hydrocarbons.

Hydrofluorocarbons (HFC)
A group of greenhouse gases subject to limitations under the terms of the Kyoto protocol.

Intergovernmental Panel on Climate Change (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) has been established by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. It is open to all Members of the UN and of the WMO.

Kyoto Protocol
An international agreement standing on its own, and requiring separate ratification by governments, but linked to the UNFCCC. The Kyoto Protocol, among other things, sets binding targets for the reduction of greenhouse-gas emissions by industrialized countries.

Methane (CH_4)
A greenhouse gas.

Nitrogen oxides (NO_X)
Generic term for oxides of nitrogen (NO, NO_2, NO_3).

Nitrous oxide (N_2O)
A greenhouse gas.

Non-Annex I Parties or Countries
Countries not included in Annex I of the United Nations Framework Convention on Climate Change UNFCCC.

O_3
Ozone.

OECD
The Organisation for Economic Co-operation and Development.

Offsets
An emissions reduction achieved by undertaking a greenhouse gas emission reduction project.

Open emissions trading
An emissions trading system where allowances can be traded in and outside the given scheme or sector.

E.g., within an emissions trading scheme for aviation, participants would be allowed to buy allowances from sectors outside the aviation emissions trading scheme.

Perfluorocarbons (PFC)
A group of greenhouse gases.

Radiative forcing (RF)
A change in average net radiation (in Wm-2) at the top of the troposphere resulting from a change in either solar or infrared radiation due to change in atmospheric greenhouse gas concentrations; perturbance of the balance between incoming solar radiation and outgoing infrared radiation.

RSK
Revenue Seat Kilometres.

RTK
Revenue Tonne Kilometres.

Seller
A legally recognised entity (individual, corporation, not-for-profit organisation, government, etc.) who sells reductions, credits or allowances to another legally recognised entity through a sale, lease, trade, or other means of transfer.

Soot
Substance emitted by aircraft; may have both warming and cooling climate impacts.

Sulphate
Substance emitted by aircraft; which may have a cooling impact.

Sulphur hexafluoride (SF_6)
A greenhouse gas.

Surrender
The handing in of allowances for emissions by the accountable entity in order to fulfil the obligations under the emissions trading scheme.

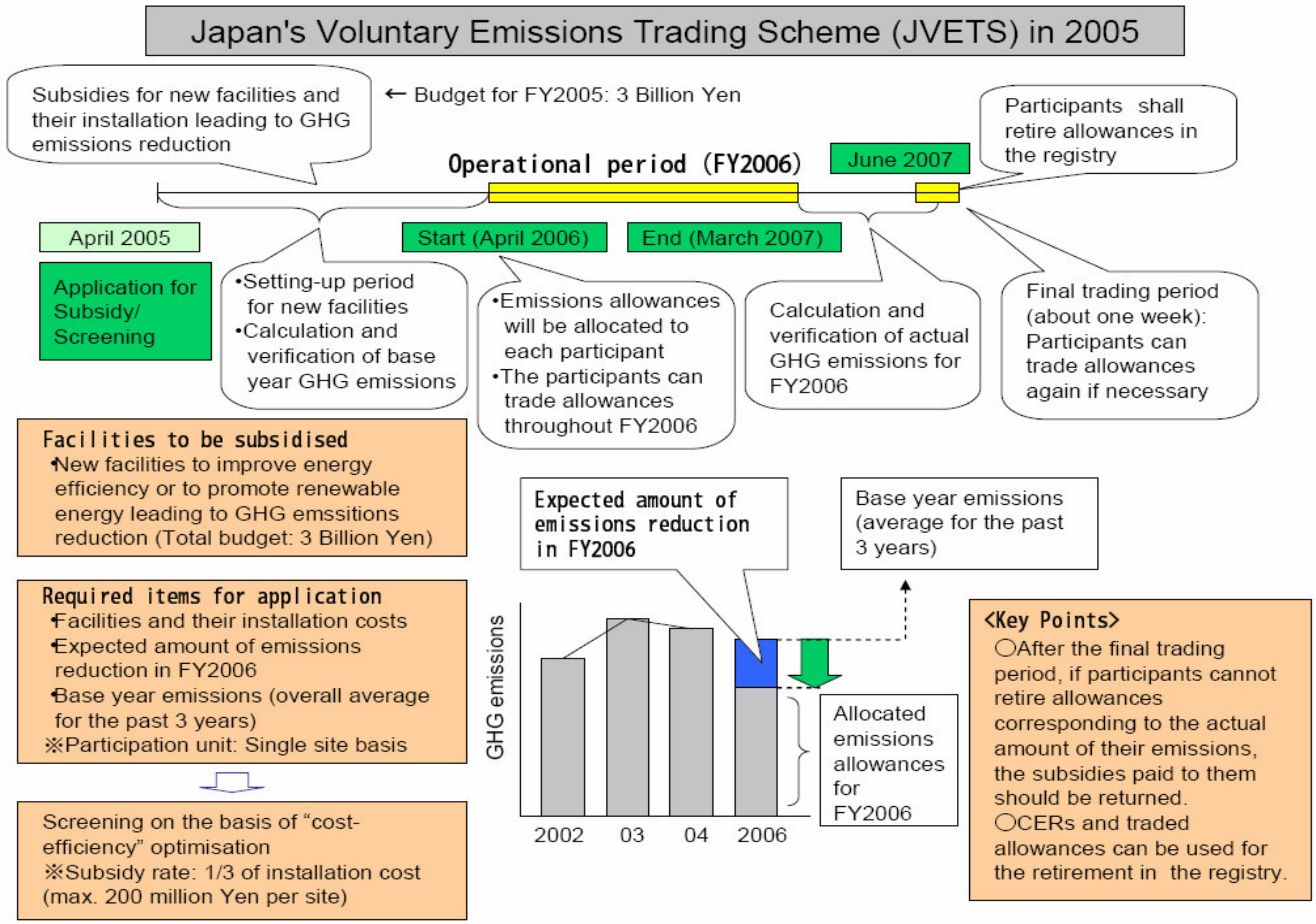
United Nations Framework Convention on Climate Change (UNFCCC)
The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases. The Convention enjoys near universal membership, with 189 countries having ratified. Under the Convention, governments gather and share information on greenhouse gas emissions, national policies and best practices, launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries and cooperate in preparing for adaptation to the impacts of climate change.

Verification
Verification provides independent assurance that emissions reporting has been realised in an accurate manner. The verifiers are accredited. The level of assurance provided will depend on the scope of the verification which is usually agreed by the transacting parties and may include: adequacy of measuring and monitoring systems for emission reduction credits, reviewing the operations of the underlying emission reductions project etc.

Voluntary Action/Commitment
Actions taken by an entity that reduces greenhouse gas emissions in the absence of any regulatory requirements compelling it to do so.

Water vapour
H_2O.

APPENDIX A


Japan's Voluntary Emissions Trading Scheme (JVETS) in 2005
Subsidies for new facilities and their installation leading to GHG emissions reduction
← Budget for FY2005: 3 Billion Yen
Participants shall retire allowances in the registry
Operational period (FY2006)
June 2007
April 2005
Application for Subsidy/ Screening
•Setting-up period for new facilities
•Calculation and verification of base year GHG emissions
Start (April 2006)
End (March 2007)
•Emissions allowances will be allocated to each participant
•The participants can trade allowances throughout FY2006
Calculation and verification of actual GHG emissions for FY2006
Final trading period (about one week): Participants can trade allowances again if necessary
Facilities to be subsidised
•New facilities to improve energy efficiency or to promote renewable energy leading to GHG emssitions reduction (Total budget: 3 Billion Yen)
Required items for application
•Facilities and their installation costs
•Expected amount of emissions reduction in FY2006
•Base year emissions (overall average for the past 3 years)
※Participation unit: Single site basis
Screening on the basis of "cost-efficiency" optimisation
※Subsidy rate: 1/3 of installation cost (max. 200 million Yen per site)
Expected amount of emissions reduction in FY2006
Base year emissions (average for the past 3 years)
GHG emissions
Allocated emissions allowances for FY2006
2002
03
04
2006
<Key Points>
○After the final trading period, if participants cannot retire allowances corresponding to the actual amount of their emissions, the subsidies paid to them should be returned.
○CERs and traded allowances can be used for the retirement in the registry.

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English only

APPENDIX B

[LOGO]

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GUIDANCE ON THE USE OF EMISSIONS TRADING FOR AVIATION

Approved by the Secretary General
and published under his authority

First Edition – xxxx

International Civil Aviation Organization

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CHAPTER 1 GENERAL

Introduction

1.1.1 The 35th Session of the ICAO Assembly in October 2004 unanimously adopted Resolution A35-5 on both aircraft noise and aircraft engine emissions[1]. The Assembly adopted the environmental goal of limiting or reducing the impact of aviation greenhouse gas emissions on the global climate and endorsed "the further development of an open emissions trading system for international aviation".

1.1.2 In this context, the Assembly further requested the ICAO Council to prepare "guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process (and that it) address the structural and legal basis for aviation's participation in an open emissions trading system, including key elements such as reporting, monitoring and compliance." This document has been prepared in response to that request.

1.1.3 It should be noted that this guidance is not of a regulatory nature. Rather it provides States with advice and information that they may need or find helpful. It cannot, and does not purport to, cover every conceivable issue that might arise: indeed ICAO recognises that contracting States have their own legal obligations, existing agreements, current laws and established policies. States should therefore consider how best to apply this guidance to their specific circumstances. The scope of this guidance material extends exclusively to international civil aircraft operations and does not include State aircraft, which covers military, customs and police services.

ICAO Resolution A35-5

1.1.4 Appendix I of ICAO Assembly Resolution A35-5 addresses market-based measures regarding aircraft engine emissions, which includes emissions trading. Relevant to emissions trading, the ICAO Assembly noted the following points:

- that "market-based measures are policy tools that are designed to achieve environmental goals at a lower cost and in a more flexible manner than traditional regulatory measures";

- that "Principle 16 of the Rio Declaration on Environment and Development (1992) states that 'National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment'"; and

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[1] **ICAO Assembly Resolution A35-5 "**Consolidated Statement of continuing ICAO policies and practices related to environmental protection", available **at** ***http://www.icao.int/cgi/goto_m.pl?icao/en/assembl/a35/documentation.htm***

- that "whereas the Kyoto Protocol treats international and domestic emissions from the aviation sector differently, the potential advantages of harmonizing treatment of the two categories of emissions have been noted".

1.1.5 Assembly Resolution 35-5 further "encourages Contracting States and the Council, taking into account the interests of all parties concerned, including potential impacts on the developing world, to evaluate the costs and benefits of the various measures, including existing measures, with the goal of addressing aircraft engine emissions in the most cost-effective manner and …with Contracting States striving to take action in a consistent manner to both domestic and international aviation emissions."

Background, Purpose and Scope.

1.1.6 Aviation plays a key role in the world economy, providing the ability to move people and products all over the globe - quickly and safely. Though there has been a history of increased fuel and performance efficiency, the nature of aviation limits the technology options available to directly reduce emissions. It is those technology limitations, along with the projected rate of growth in the aviation industry, that have contributed to ICAO's consideration of market-based options such as emissions trading as one possible approach to address aviation emissions.

1.1.7 An open emissions trading approach is considered preferable to a closed emissions trading approach. It provides for trading both within and between sectors . Because of the high relative costs of aviation technology and the lack of substitute energy sources, allowance prices for the open trading system would be substantially lower than under a closed trading system which is designed to limit emissions within one sector only without providing access to allowances or credits outside the scheme. Open emissions trading offers the economic advantage of achieving reductions in a more cost-effective way than closed emissions trading.

1.1.8 As noted above, this document was prepared at the request of the ICAO Assembly to provide ICAO Contracting States with advice and practical information they might be able to use when incorporating emissions from international aviation into emissions trading schemes. The inherent mobility of international aviation, however, challenges the ability to readily incorporate its emissions into traditional emissions trading mechanisms. To facilitate this process, the guidance focuses on those aspects of emissions trading that require consideration with respect to aviation-specific issues; it identifies options and offers potential solutions where possible.

1.1.9 The guidance does not describe or explain generic emissions trading mechanisms, design options or processes. However, to help facilitate broader understanding, relevant background information on emissions trading is available at the ICAO website (*www.icao.int*). Definitions of terms used in the guidance can be found in the Glossary.

1.1.10 The guidance addresses the aviation-specific options for the various elements of trading systems, such as accountable entities, emissions sources and species (gases) to be covered, trading units, base year and targets, allowance distribution, monitoring and reporting, and geographical scope. Since most emissions trading schemes define emissions sources in terms of fixed ground based installations, the guidance addresses how emissions sources could be defined for aviation.

1.1.11 The guidance notes that emissions from international aviation are excluded from the national totals reported by Parties to the UNFCCC and provides options for including those emissions in trading schemes.

1.1.12 Many issues considered in this guidance will be interdependent on, or require knowledge of, other design criteria. It is unlikely that a full assessment of a trading scheme can be made until all of the elements have been taken into account. The order in which the design elements are presented in the guidance does not imply any specific hierarchy in their relative importance.

1.1.13 It is recognised that this guidance material may not provide the level of detail necessary to assist ICAO Contracting States in addressing every issue that might arise, given that there may be unique legal, technical or political situations for particular States. It is therefore advised that ICAO Contracting States use this guidance material as supporting material, to be shaped and applied to specific circumstances.

1.1.14 Given the limited practical experience with issues related to the aviation sector that currently exists in emissions trading, it is recognized that this guidance material may need to be revised as the world of emissions trading develops over time.

CHAPTER 2 OPERATIONAL BOUNDARIES

2.1 Accountable entities

2.1.1 This section provides guidance on the definition of accountable entities for the international aviation sector, describes the advantages and disadvantages of the several options available and establishes recommendations on the most suitable choice.

2.1.2 In the context of this guidance material, an accountable entity is a physical or legal person which, in a given emissions trading scheme, is responsible for emissions from international aviation under the scheme. A proper identification of the accountable entities is crucial for addressing aviation emissions in an effective and transparent manner.

Assessment of options

2.1.3 Paragraphs 2.1.5 to 2.1.19 provide more information associated with each possible choice of accountable entity, i.e. aircraft operators, fuel suppliers, air navigation service providers, airport operators and aircraft manufacturers. Each of these options is associated with particular advantages and disadvantages in terms of environmental effectiveness, possible distortions in competition and administrative and legal feasibility.

2.1.4 Each option is likely to lead to cost increases for the accountable entities, either the cost of action to reduce emissions, the cost of acquiring allowances, or the costs relating to the administration of the trading scheme. This section compares the options in terms of how well those costs translate into price signals that will drive emissions reductions.

Aircraft operators

2.1.5 Under this option, aircraft operators will be required to hold the necessary number of allowances covering all relevant emissions of their aircraft engaged in international transport.

2.1.6 An important advantage of this option is that aircraft operators can in principle provide all the relevant data required to participate in a trading system. They also have a substantial degree of control over technical and operational measures to improve efficiencies in order to reduce engine emissions. Environmental benefit may accrue because of an added incentive for operators to further minimize fuel consumption.

2.1.7 Administrative difficulties might arise due to the number of aircraft operators included in the trading scheme. This can be solved by introducing a *de minimis* inclusion threshold. This is further addressed in section 2.2.

2.1.8 Another possible disadvantage would be the inappropriate burden placed on aircraft operators related to emissions resulting from Air navigation Systems (ANS) inefficiencies such as delays, holdings and the use of non-optimized routes.

Fuel suppliers

2.1.9 If fuel suppliers are selected as accountable entities, they will have the obligation to hold the required allowances on the basis of the carbon content of the fuel sold to aircraft operators. The selection of fuel suppliers as accountable entities would provide an indirect incentive for emissions reductions as aircraft operators – and their customers – can be expected to respond to higher fuel prices. The relatively small number of fuel suppliers may also be an advantage.

2.1.10 Drawbacks of choosing fuel suppliers as accountable entities include the fact that it may be difficult for fuel suppliers to accurately distinguish between international and domestic aviation and fuel tankering practices by operators might increase.

Air navigation services providers

2.1.11 Under this option, air navigation services providers (ANSPs) will be obliged to hold allowances covering emissions from all international flights operated within the airspace under their control.

2.1.12 Choosing ANSPs as the accountable entities may create additional incentives for these entities to reduce delays and holdings and to provide the shortest routes for operators to fly. The way in which the costs are passed on is critical if the additional costs imposed on operators are to truly reflect the actual emissions. Defining appropriate mechanisms for providing correct price signals could be challenging, particularly where ANSPs operate as monopolies.

Airport operators

2.1.13 Under this approach, airport operators within the territory of the State will have to hold allowances to cover the emissions produced by the international flights arriving at or departing from their airports.

2.1.14 In terms of integrating aviation into an emissions trading scheme, this option would manage emissions in a way similar to that for stationary sources. However, airports do not have direct access to all relevant data, and defining appropriate mechanisms for providing correct price signals could be challenging. For example an increase in landing fees is generally less effective than measures directly related to fuel use.

2.1.15 This option would require aircraft operators to monitor and report their emissions to the 4airport operators. Aircraft operators would therefore be actively involved even though they are not obliged to surrender allowances themselves. The rules under which aircraft operators would have to report emissions to airport operators might have to be defined centrally within each trading scheme and not left to the discretion of the airports.

Aircraft manufacturers

2.1.16 Under this option, aircraft manufacturers will be required to hold the relevant number of allowances when they deliver an aircraft to their customers. In this case the emissions produced by an aircraft would have to be calculated up-front.

2.1.17 This option would assign to each individual aircraft of a given aircraft type a specific amount of emission "credits" reflecting the desired amount of emissions during its projected useful life. In theory, this could provide manufacturers with an added incentive to develop aircraft with superior emissions characteristics

2.1.18 A drawback is that this may lead to higher production costs for manufacturers, translating into higher product prices for operators. Once an aircraft is sold there would be no further incentive under the emissions trading scheme to reduce the emissions resulting from the operation of the aircraft.

2.1.19 The assignment of a pre-defined amount of emissions credits to individual aircraft of the same aircraft type, may result in the unequal treatment of aircraft operators who would pay for identical amounts of credits irrespective of the actual amount of emissions the aircraft would produce during their lifetime.

Table 1: *Advantages and disadvantages of options for accountable entities.*

Aircraft Operator	**Advantages** a) Can provide all the relevant data to participate in a trading system. b) Substantial degree of control over technical and operational measures to reduce engine emissions. **Disadvantages** a) ANS inefficiencies may place inappropriate burden on aircraft operators. b) Depending on the number of aircraft operators covered by the trading scheme, administrative difficulties might arise.
Fuel Suppliers	**Advantages** a) Relatively small number of fuel suppliers to include in the scheme. **Disadvantages** a) May be difficult to accurately distinguish between the fuel provided to international and domestic aviation. b) Unintended incentives for operators to increase tankering practices.
Air Navigation Services Providers	**Advantages** a) Additional incentive to reduce delays and holdings and to provide the shortest routes. **Disadvantages** a) Creating correct price signals could be challenging, particularly where ANSPs operate as monopolies.
Airport Operators	**Advantages** a) Closer to the concept of conventional emission trading schemes, since it would be managed in a way similar to that for stationary installations. **Disadvantages** a) Creating correct price signals could be challenging. b) To gain access to the necessary data transfer of sensitive or confidential data between two private entities would be required.
Aircraft Manufacturers	**Advantages** a) Additional incentive to develop aircraft with superior engine characteristics, specifically fuel efficiency. **Disadvantages** a) No continuing incentives to improve operational efficiencies b) Could result in unequal treatment among aircraft operators.

Guidance

2.1.20 To the extent that international aviation is to be covered within an Emission Trading System, the preferred option is to select aircraft operators as accountable entities, for the reasons described in this section.

2.1.21 For the purposes of the remainder of this document it is assumed throughout that the aircraft operator will be the accountable entity.

Determination of aircraft operator

2.1.22 The method for identifying the aircraft operator for emissions trading purposes would need to be sufficiently precise to enable aircraft operators and regulators to identify the entity responsible for emissions from any given flight whilst retaining flexibility to take into account the numerous types of commercial arrangements common in the aviation sector. Examples of such commercial arrangements include wet and dry leasing, code-sharing and the use of subcontractor airlines to operate portions of an airline network.

2.1.23 Indicators of who is the operator should be clearly specified and could include:

- the ICAO designator used in the flight plan; or
- the holder of an Air Operators Certificate (AOC) in which the aircraft is listed.

2.1.24 In order to ensure that it is always possible to identify an aircraft operator responsible for the emissions from a flight, there should be a clear default position. This could be achieved by providing that if the operator is unknown the owner of the aircraft would be considered to be the operator unless he can demonstrate that another person was the operator.

2.1.25 The administrative issues which arise in relation to the identification of the aircraft operator responsible for emissions from a particular flight have some similarities with those related to the identification of the aircraft operator for the purpose of billing en-route air navigation charges. States may already have systems in place for that purpose which have proved to be workable and are understood by aircraft operators. In order to avoid additional administrative burden for operators and regulators, States may, therefore, wish to consider taking a similar approach to identifying the aircraft operators responsible in an emissions trading system.

Commercial arrangements

Contractual provisions

2.1.26 Potentially accountable entities may want to shift the burden of the responsibility for aviation emissions to another such entity. Such agreements between potentially accountable entities on who is responsible for emissions from the flight should be communicated to the relevant regulatory authority responsible for the administration of the trading scheme.

2.1.27 In the context of an emissions trading scheme for international aviation, leasing and code-share arrangements can create complexities with regard to assigning responsibility for surrendering emissions allowances and the monitoring and verification of emissions in order to avoid double-counting or omissions. The treatment of these arrangements must be addressed in order to unambiguously delineate responsibility for the emissions from each flight.

Leasing arrangements

2.1.28 In the case of a "*dry lease*" arrangement the responsibility for emissions would rest with the lessee as the aircraft operator.

2.1.29 In the case of a "*wet lease*" arrangement responsibility for emissions might rest with the lessee, notwithstanding the fact that the lessee is not the AOC holder.

Code share arrangements

2.1.30 Under code sharing arrangements, one specific operator actually operates the aircraft, but this same flight is shared with one or more different carriers.

2.1.31 Responsibility for emissions would rest with the operator that actually operates the flight.

Guidance

2.1.32 The method for identifying the responsible aircraft operator would need to be sufficiently precise to enable aircraft operators and regulators to identify the entity responsible for emissions from any given flight whilst retaining flexibility to take into account the numerous types of commercial arrangements common in the aviation sector. Examples of relevant indicators could be the AOC under which the aircraft is operated or the ICAO designator used in respect of the flight.

2.1.33 To ensure that it is always possible to identify an aircraft operator responsible for the emissions from a given flight, there should be a clear default position to determine the final responsibility on objective grounds in case of disputes between the commercial entities involved in operating the flight.

2.2 Emissions sources

Background

2.2.1 This section considers the following two issues:

1) the level at which obligations under an emissions trading scheme should be applied in the aviation sector; and

2) whether the scheme should include a *de minimis* threshold.

Specific considerations

2.2.2 Current emissions trading schemes apply obligations separately to each fixed ground based installation. This means that operators receive a separate allocation of allowances for each installation and are required to monitor and report emissions and surrender allowances separately for each installation. As aircraft are mobile sources of emissions and aircraft operators continually change routes, frequencies, and the aircraft fleets that fly those routes, this installation-based approach is deemed unsuitable for aviation.

2.2.3 Applying obligations at the level of an aircraft would result in a large number of separate sources and would increase the administrative burden of the scheme for aircraft operators and regulators. This would also be the case if the obligations under the scheme were applied at the level of flight routes. It is therefore recommended that the obligations under the scheme should be applied on the basis of the total aggregated emissions from all covered flights performed by each aircraft operator included in the scheme.

Thresholds and Exclusions

2.2.4 In order to determine a basis for inclusion in emissions trading, two aspects can be identified, namely the *type* of activity (i.e. commercial or general aviation) and the *volume* of activity (e.g. number of flights, available tonne-kilometres or amount of emissions).

2.2.5 Further, a definition of threshold may be considered in order to establish an adequate balance between emissions coverage on the one hand, and administrative burden on the other. Key principles for defining a threshold are simplicity and avoidance of perverse incentives.

2.2.6 While it is recognized that it is sometimes desirable to exclude certain types of air transport activity from an emissions trading scheme, any exemptions would require a strong justification.

2.2.7 Generally, a *de minimis* threshold can be based on aircraft weight, number of operations or aggregate air transport activity.

2.2.8 In designing an inclusion threshold, care needs to be taken to minimise the incentive for aircraft operators to deliberately avoid inclusion in the scheme by operating just below the threshold. To minimise such avoidance, the inclusion threshold needs to be set at a level at which the potential economic benefits from operating beneath the threshold are either totally or mostly counter-balanced by the economic inefficiency resulting from operating at this level. Regular review and possible adjustment of the inclusion threshold would provide a further disincentive for aircraft operators to avoid inclusion.

Weight-based threshold

2.2.9 An example of a weight threshold in international legislation exists in ICAO Annex 16, Volume I (Aircraft Noise). It uses a limit of 8,618 kg to distinguish aircraft covered by Chapters 3 and 4 from those covered under Chapters 6 and 10. The same limit has also been used in charging systems for local emissions. For the purpose of technical regulations, ICAO Manual on the Regulation of International Air Transport (Doc 9626) makes a distinction between large and small aircraft, using a limit of 5,700 kg.

2.2.10 Because small aircraft tend to fly shorter distances and consume less fuel per distance, their overall emissions contribution, relative to the number of operations, also tends to be small. The exclusion of small aircraft may therefore not significantly affect the environmental effectiveness of an emissions trading scheme.

2.2.11 An additional argument for setting a weight level is that the fleet mix for small aircraft is very diverse, and ex ante emission calculations are relatively unreliable.

Operations-based threshold

2.2.12 Setting a threshold based on the number of operations does not take account of the contribution of the operation to CO_2 emissions. The number of operations may be small, but the contribution to CO_2 emissions could be significant.

Activity-based threshold

2.2.13 An inclusion threshold may be based on the total activity of an operator. One possibility is to define the threshold based on the total CO_2 emissions. Another possibility is to define the threshold in terms of the Available Tonne Kilometres (ATK) associated with each source.

2.2.14 If a source were defined as all flights by an operator within the geographical scope, inclusion in the scheme would be determined by comparing the operator's actual activity within the scope with the inclusion threshold value. Care must be taken to prevent the creation of multiple separate sources that each fall below the inclusion threshold.

Guidance

2.2.15 It is therefore recommended that the obligations under the scheme should be applied on the basis of the total aggregated emissions from all covered flights performed by each aircraft operator included in the scheme.

2.2.16 It is recommended, however, that aircraft operators ensure appropriate systems for data collection and management prior to implementation of aviation into an emissions trading scheme.

2.2.17 States should seek to include all types of civil air transport operations in emissions trading, without exception, recognizing that small operations or small aircraft may automatically be excluded on the basis of an inclusion threshold.

2.2.18 States should consider applying an inclusion threshold based on aggregate air transport activity, aggregate CO_2 emissions and/or aircraft weight.

2.3 *Emissions species*

2.3.1 Inclusion of aviation in an emissions trading system would require a decision regarding aviation emissions to be covered by the scheme.

2.3.2 The primary direct greenhouse gas emissions of aircraft are carbon dioxide (CO_2) and water vapour (H_2O). Other emissions are oxides of nitrogen (NO_x), particles containing sulphur oxides (SO_x) and soot. The total amount of aviation fuel burned, as well as the total emissions of carbon dioxide, NO_x, and water vapour by aircraft, are well known relative to other parameters such as aerosols. These gases and particles alter the concentration of ozone (O_3) and methane (CH_4), may trigger formation of condensation trails (contrails), and may increase cirrus cloudiness – all of which may contribute to climate change.

2.3.3 According to estimates produced in the IPCC aviation report (1999), the overall radiative forcing from aircraft effects (excluding that from changes in cirrus clouds) in 1992 was a factor of 2.7 larger than the forcing by aircraft carbon dioxide alone.[2] The IPCC concluded that there were varying levels of scientific understanding (e.g. ranging from "very poor" in the case of cirrus to "good" for CO_2) [3] associated with these effects. Further research into such non-CO_2 effects is ongoing, and IPCC is expected to provide an update in its fourth assessment report due in 2007. These radiative forcings represent the best estimate of the effects of aviation on climate for the reported year, i.e. 1992. However, for aviation's past, present or future emissions, the radiative forcing index should not be used to derive relationships between emissions and marginal changes in climate, as the Global Warming Potential (GWP) is intended to do.

2.3.4 The Global Warming Potential (GWP) metric was developed by the IPCC to compare the climate impacts of changes on emissions of long lived well mixed gases to that of CO_2 over a specific time horizon. It is used by the UNFCCC process in establishing emissions equivalencies for emissions reduction targets and activities. CO_2 impacts from aviation are the longest lived and most well defined and are readily defined in terms of GWP. Formulating GWPs from non-CO_2 effects from aviation has conceptual difficulties and the IPCC (1999) stated that such GWPs were not adequate to describe the climate impacts of aviation (see IPCC, 1999 Chapter 6 section 6.2.2).

2.3.5 For further information on emissions from the aviation sector please refer to the most current IPCC Assessment Report and the IPCC Special Report on Aviation and the Global Atmosphere.

Guidance

2.3.6 CO_2 emissions from aviation are the largest and most certain sources of GHG emissions from the aviation sector; other non-CO_2 effects are potentially significant but there still exists a high degree of scientific uncertainty associated with them.

2.3.7 Given these uncertainties, it is recommended starting with an emissions trading scheme that includes CO_2 alone.

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[2] The so-called RFI or radiative forcing index, is defined by the 1999 IPCC Special Report on "Aviation and the Global Atmosphere" as the sum of all the forcings divided by the CO_2 forcing (chapter 6 paragraph 6.2.3)

[3] For further details see the 1999 IPCC Special Report on "Aviation and the Global Atmosphere" and the IPCC Third Assessment Report: Climate Change 2001.

2.3.8 This does not preclude States from considering the inclusion of other aircraft emissions that contribute to climate change in a trading scheme, as scientific understanding evolves about the effects of non-CO_2 aircraft emissions.

CHAPTER 3 REGULATORY CONSIDERATIONS

3.1 International & domestic emissions

3.1.1 The UNFCCC framework addresses greenhouse gas emissions differently, depending on whether they are generated by domestic or international operations. ICAO has developed, and is continuing to develop, approaches to address greenhouse gas emissions from international aviation. For countries with commitments under Annex B of the Kyoto Protocol, greenhouse gas emissions from domestic aviation are included in their Kyoto targets.

3.1.2 Consistent with their Kyoto obligations, some countries listed in Annex B to the Kyoto Protocol are developing policies and measures to address emissions from the domestic operations of their air carriers. This difference between the approaches for addressing domestic and international emissions makes it important to distinguish between international and domestic operations.

3.1.3 The need to define "international" versus "domestic" operations in the context of emissions trading is a unique situation for the international aviation (and international maritime) industries. Stationary sources, such as power plants, manufacturing facilities and the like, which are subject to greenhouse gas emissions reduction targets by virtue of their State's policies, are completely resident within the States imposing those targets on their industries.

3.1.4 In contrast, aircraft (and ships) that travel internationally may be registered in States that are not subject to greenhouse gas emission reduction targets and/or may travel to and from States that may or may not be subject to such targets. Moreover, to the extent that States that have agreed to emission targets under the Kyoto Protocol, only the domestic portion of aviation and maritime operations, as defined in the UNFCCC framework, are subject to the State targets in the first Kyoto commitment period (2008-2012).

3.1.5 The Intergovernmental Panel on Climate Change produced its *2006 Guidelines for National Greenhouse Gas Inventories* at its 25th session. These guidelines represent the state of the art technical guidance of experts in the aviation, maritime, and inventory fields.

3.1.6 The guidelines clarify how countries differentiate between emissions from domestic and international flights. Emissions from international aviation (International Bunkers) are defined as " Emissions from flights that depart in one country and arrive in a different country, including take-offs and landings for these flight stages" (partial quote)[4].

3.1.7 Emissions from domestic aviation are defined as "Emissions from civil domestic passenger and freight traffic that departs and arrives in the same country (commercial, private, agriculture, etc.), including take-offs and landings for these flight stages" (partial quote)[5] [6].

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[4] The IPCC definition adds the following about military operations: "Emissions from international military aviation can be included as a separate sub-category of international aviation provided that the same definitional distinction is applied and data are available to support the definition." This is of no relevance to the discussion in this document.

[5] The IPCC definition adds the following about military operations: "Emissions from military flights are excluded as these are reported under 1 A 5 b." This is of no relevance to the discussion in this document.

[6] Note that this may include journeys of considerable length between two airports in a country (e.g. San Francisco to Honolulu).

3.1.8 ICAO's standard definition of "international" versus "domestic" flights is slightly different than the definition in the IPCC guidelines, in that the ICAO definition of a "domestic flight" does not include flights purely within one State that is not the principal place of business of the airline operator, while the IPCC guidelines do consider such flights as "domestic." For purposes of emission trading, however, the IPCC guidelines definition is preferred, as States' reporting obligations for greenhouse gas emissions are based on the IPCC definition.

Guidance

3.1.9 States should use the IPCC 2006 Guidelines definition of international and domestic emissions for the purposes of accounting GHG emissions as applied to civil aviation. It is important that States apply this definition for purposes of any carriers included in the emissions trading scheme. The IPCC approach is internationally accepted and will help ensure consistency between the various approaches of States addressing domestic and/or international greenhouse gas emissions.

3.2 Geographic scope

Background

3.2.1 This section provides guidance to States in making decisions relating to the geographic scope of efforts to incorporate emissions from international aviation into their emissions trading schemes. As the basis for the discussion in this section, it is assumed that the accountable entities would be the aircraft operators (See Chapter 2.1)

3.2.2 On the issue of providing guidance to States on geographic scope the Council "requested that CAEP, in completing its draft guidance, adopt the same principle used in the drafting of other key elements of this guidance, by including the different options to geographic scope describing their advantages and disadvantages and start to address the integration of foreign aircraft operators under a mutually agreed basis, and continue to analyze further options."

3.2.3 The ICAO Council, in the Summary of Decisions C-DEC 179/11 of 29/11/06, paragraph 2 f), in providing advice on progressing the matter of geographic scope, also "urged Contracting States to refrain from unilateral action to implement an emissions trading scheme for international aviation before the Council reports to the Assembly on its work to implement Assembly Resolution A35-5". Resolution 35-5 also urges States to refrain from unilateral environmental measures that would adversely affect the orderly development of international civil aviation.

3.2.4 Including emissions from stationary sources is geographically simple, because emissions physically occur within the territory of a given State. However, this is not the case for emissions from non-stationary sources, such as from international aviation, which by definition are not geographically contained wholly within one State. This adds complexity to the inclusion of international aviation in an emissions trading scheme.

3.2.5 The UNFCCC Secretariat, in advice to the 179th ICAO Council, confirmed that the UNFCCC and the Kyoto Protocol confer no guidance in relation to emissions trading schemes not provided for in either of these agreements. The Kyoto Protocol does not provide for inclusion of international aviation emissions from either Annex I or non-Annex I Parties. Article 2.2 of the Kyoto Protocol states that Parties "included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation…bunker fuels, working through the International Civil Aviation Organization".
Options for including foreign aircraft operators

3.2.6 A key issue for international aviation emissions trading is how States might integrate emissions from aircraft operators of other States in a given emissions trading scheme. Generally there are two approaches States could take to the integration of emissions from foreign aircraft operators into an emissions trading scheme:

1) Mutual agreement; or

2) Alternative to mutual agreement.

Mutual agreement

3.2.7 Under this approach, a State or group of States operating an emissions trading scheme would seek to include foreign aircraft operators in the scheme through mutual agreement between the State(s) responsible for administering the scheme and the State in which the aircraft operator is based.

3.2.8 The scheme would only include flights operated by aircraft operators registered in the State(s) participating in the scheme. Aircraft operators from other states could only be obliged to participate in the scheme on the basis of bilateral or multilateral agreements.

Advantages

3.2.9 An advantage of mutual agreement is that it provides for certainty in relation to the participation of the covered foreign aircraft operators and facilitates the enforcement of obligations under the scheme.

3.2.10 A benefit of this type of approach would be equitable treatment in the sense that all carriers operating on a given route within the jurisdiction and geographic scope of the scheme would be subject to the same obligations.

3.2.11 This approach has the advantage of clear political acceptability in that explicit State by State consensus would minimize the risk of disputes between States.

Disadvantages

3.2.12 If a State wanted to include all airlines operating on a given route, the mutual agreement approach would have the disadvantage of requiring that State to negotiate agreements with all States whose carriers operate on that route. This could be time-consuming and may increase the risk of a fragmented approach.

3.2.13 The potential for State(s) to not accede to the inclusion of its carriers could result in the non-equal application of the scheme and competitive distortion between carriers on the same route.

3.2.14 There could be additional complications such as avoidance behaviour if airlines change leasing or code-share arrangements.

Alternative to mutual agreement

3.2.15 Under this approach, a State or group of States operating an emissions trading scheme would seek to mandate the inclusion of foreign aircraft operators in a given emissions trading scheme in the absence of specific mutual agreement.

3.2.16 Operators would be included in the scheme if they operate on the routes or within the airspace covered by the scheme without distinction as to nationality.

Advantages

3.2.17 Under this approach all carriers operating on the same route would be subject to the same rules regardless of their nationality. Also, competitive distortions could be avoided, as long as all operators have equivalent obligations.

3.2.18 This approach could provide for non-discriminatory treatment of carriers of other States.

Disadvantages

3.2.19 The approach has the disadvantage that it may be disputed, with potential consequential delays and/or lack of uniformity.

3.2.20 This approach could also encourage aircraft operators to avoid the scheme, which could also potentially lead to competitive distortion, trade disruptions and an increase in emissions.

3.2.21 The application of this approach, which may be appropriate for a State or group of States, may not be appropriate for other States given the divergent approaches and circumstances of different States.

Options for the architecture of geographic coverage

3.2.22 Once the matter of participation by foreign aircraft operators has been addressed, there are the following architectural elements for a State to consider in deciding how to delimit the geographic scope in an emissions trading scheme:

- Routes: those that delimit the geographic scope to incorporate emissions from flights operated on selected routes. Including decisions regarding whether to incur obligations on departure and/or arrival.

- Airspace: those that use nationality of airspace as a criteria for delimiting geographical scope.

3.2.23 There are multiple considerations in choosing among the options for designating geographic scope such as administrative burden, total emissions covered, accuracy or equity in treating the source of emissions and potential compatibility with schemes adopted by other States. As States seek to include international flights within their respective trading schemes, and different States might do so at different times, it is preferable to have a common means of designating coverage so duplication is avoided and the potential for compatibility is enhanced.

Routes

3.2.24 This option corresponds to delimiting the scope of the scheme to incorporate emissions from flights operated on selected routes. State(s) participating in an emissions trading scheme will need to decide which international routes are covered by the scheme. It is not necessary to cover all routes to and from a country.

3.2.25 State(s) would need to decide whether to include in the scheme emissions from flights arriving or departing on predetermined routes. A combination of the two could also be formed, corresponding to 50% of emissions from all arriving flights and 50% of all departing flights (an apportionment would be necessary to avoid duplication). Given that most routes are generally operated with the same frequencies in both directions, the three variants are more or less equivalent in emissions coverage.

Advantages

3.2.26 A benefit of not initially including all routes would be the increased ease of implementation and administration.

3.2.27 An advantage of using solely the country of departure or arrival would be that should additional States cover international aviation emissions in their schemes over time, this would avoid duplication and would promote compatibility.

Disadvantages

3.2.28 A disadvantage to not including all routes would be the potential for inducing competitive distortion. To avoid competitive distortion, it would be desirable to include routes to locations that are geographically proximate.

3.2.29 The "50% & 50%" option would require for each flight an additional data report (of trip fuel and/or emissions) and essentially double the number of flights to be accounted for in a given scheme. This could create an additional administrative burden.

3.2.30 Another potential disadvantage is that it could encourage carriers to shift operations to neighboring states not participating in the scheme, causing market distortions and potentially add to flight distance and emissions.

Airspace

3.2.31 Under this approach only emissions within the national airspace of the State (or States) administering the scheme would be included.

Advantages

3.2.32 This option is similar to how emissions from stationary sources are handled.

3.2.33 It treats carriers on the same routes over a designated airspace equally, reducing possibility of market distortion.

3.2.34 It also averts political sensitivities of including emissions from operators outside of the airspace of the emissions trading scheme.

Disadvantages

3.2.35 Options defined solely on the basis of national airspace are inherently limited in their coverage as emissions over the high seas will never be included and have the complication that they would automatically include overflights, unless these were somehow exempted. This could create significant administrative problems and enforcement difficulties.

3.2.36 Also, delimitation of geographical scope based on national airspace appears impracticable. The inclusion of overflights is already complex to administer and the inclusion of other measures to complete the coverage is increasingly complex with the added risk of double counting emissions.

Guidance

3.2.37 States that wish to incorporate emissions from international aviation into their emissions trading schemes consistent with ICAO AR35-5 should consider that the ICAO Council C-DEC 179/11:

"requested that CAEP, in completing its draft guidance, adopt the same principle used in the drafting of other key elements of this guidance, by including the different options to geographic scope describing their advantages and disadvantages and start to address the integration of foreign aircraft operators under a mutually agreed basis, and continue to analyze further options"; and

"urged Contracting States to refrain from unilateral action to implement an emissions trading system for international aviation before the Council reports to the Assembly on its work to implement Assembly Resolution A35-5".

CHAPTER 4 TRADING UNITS

4.1 Including aviation in existing trading schemes

4.1.1 Emissions trading relates to the trading of emission allowances. An allowance grants permission to emit a certain quantity of a substance into the air. These allowances can be defined by the regulator of the scheme. One allowance is generally defined as a permit to emit one tonne of CO_2-equivalent.

4.1.2 Emissions from international aviation are not included in the targets set by the Kyoto Protocol. Therefore unlike other sectors who might be involved in emissions trading, emissions from international aviation are not covered by Assigned Amount Units (AAUs).

4.1.3 Trading between companies is not directly affected by the presence or absence of AAUs. But trading between countries under the Kyoto Protocol uses AAUs as its currency. Some existing trading schemes (such as the EU emissions trading scheme) deal with this by backing a transfer of allowances in the scheme with a transfer of AAUs between trading registries in different countries, but this is not possible for international aviation where there are no AAUs.

4.1.4 The key issue is that inclusion of aviation in existing trading schemes should not undermine the Kyoto accounting system. In that context it should be clear which trading allowances are backed by AAUs and which are not. This clarity will allow those sectors who have to surrender AAU backed allowances as part of their obligations under a scheme to do so, and would also allow States to be clear about the extent to which they had met their Kyoto obligations. This chapter sets out a range of possible ways to do this. Most of the solutions here would also be appropriate for a State that had not ratified Kyoto but wanted to include aviation in a trading scheme consistent with the United Nations Framework Convention on Climate Change.

4.1.5 Because the international regulatory framework for addressing greenhouse gas emissions for the period post-2012 is currently unknown, the options for solutions presented in this chapter focus on the first Kyoto Protocol commitment period (2008-2012).

Options

4.1.6 The options fall into two categories. The first two options suggest ways to introduce aviation into a trading scheme using only AAU’s, which would allow full trading between aviation and other sectors. Options 3 to 6 consider emission trading with a combination of AAU’s and separately defined aviation allowances, and any trading restrictions that might be necessary.

4.1.7 In options 1 and 3 to 6 a baseline is used. There is more detail on setting baselines in chapter 5.

AAU's only

Option 1. Borrowing of AAU's by the aviation sector

4.1.8 Under this option, AAU's allocated under the Kyoto Protocol to cover non-aviation sectors that are currently not in use could be borrowed temporarily by aviation. Aviation would be allocated such AAUs and take on an obligation to surrender these allowances to cover their emissions. When the allowances were surrendered, rather than being cancelled, they would become available again for use by States to cover emissions from the sectors they were originally supposed to cover.

4.1.9 This would give aviation entities (aircraft operators) allowances that are fully fungible in the trading market, so that the aviation sector would be free to buy and sell AAUs within the sector and to trade with other sectors without any restrictions.

4.1.10 States may want to assess the risk that not all the allowances distributed to aviation are surrendered back to them e.g. if emissions are lower than the total amount of allowances distributed. If this occurs States would have to buy extra Kyoto units or, if still possible, take extra reduction measures in order to restore the balance between emissions and Kyoto units.

Option 2. No allocation of allowances to the aviation sector

4.1.11 In this option the aviation trading entity would have to buy all the allowances required for compliance from the market. This would increase the demand for Kyoto units, and might put pressure on the price of these instruments. This option would also put a higher financial burden on the aviation sector than the other possible solutions. States considering this option may want to assess these effects.

AAU's and Aviation Allowances

4.1.12 Under options 3 to 6 separate aviation allowances are created and brought into circulation. Because international aviation emissions are not included in the national Kyoto targets, aviation allowances cannot be treated as AAU's and cannot be counted against such targets. Special accounting arrangements can avoid this situation, as described under options 3 through 6.

Option 3. Buy allowances to cover emissions above a non-tradable baseline

4.1.13 This option requires establishment of a non-tradable emissions baseline for aviation trading entities. Aviation allowances would be distributed to the aviation entities for emissions up to the baseline. They would not be able to trade these allowances, but could use them for compliance. If emissions reach levels above the baseline, additional Kyoto units would need to be purchased.

4.1.14 If aviation trading entities meet their obligations by buying and surrendering Kyoto units in addition to the aviation units initially distributed, States would have to cancel AAU's relating to the Kyoto units surrendered to avoid double counting.

4.1.15 The use of a non-tradable baseline means that the flexibility and efficiency of this system is limited. The system is however relatively simple and does not require a separate registry to trade aviation allowances. States may want to consider these two aspects.

Option 4. Buy allowances to cover emissions above a tradable baseline

4.1.16 As in option 3, this option requires establishment of a baseline for aviation trading entities. The difference is that under this option, the aviation allowances distributed to the aviation entities would be tradable within the aviation sector. If emissions reach levels above this baseline, additional Kyoto units should be acquired. The option differs from option 3 because of the tradability of the baseline, thus offering more flexibility.

4.1.17 Under this approach, aviation would effectively participate in two separate schemes: the Kyoto system and a specific aviation system. Kyoto units are valid under the Kyoto Protocol and can be used to cover aviation emissions. In contrast, the aviation allowances would not be valid to cover Kyoto obligations and therefore may not have a market value outside the aviation sector.

4.1.18 The existence in the same trading system of two kinds of allowances with different validity and price, could result in economic inefficiencies. States should weigh this inefficiency against the complexity of setting up a registry to accommodate trading of aviation allowances.

Option 5. Gateway

4.1.19 In this option aviation allowances are distributed up to a baseline, and are tradable within the aviation sector. Additional allowances could be purchased from other sectors through a gateway mechanism. Aviation entities would be able to sell allowances to other sectors as long as there was no net transfer of aviation allowances to other sectors. If trading were going to breach this condition, the gateway would close. This option offers more flexibility than options 3 and 4, as it would limit trading only in those cases where aviation is a net seller. States considering this option will want to bear in mind that aviation is expected to be a net buyer of allowances in an emissions trading scheme, so the gateway may not need to close.

4.1.20 In practice, AAU’s that are transferred from the Kyoto system to the aviation sector would be separated from the associated allowances and put in a dedicated account, while the allowances would be distributed to the aviation entities. If an aviation entity intended to sell an allowance to a Kyoto covered sector, this transaction could only be completed if there are sufficient AAU’s available in the dedicated account. If that is the case, the aviation allowance would be coupled to an AAU and thus be valid for Kyoto covered sectors.

4.1.21 To guarantee integrity of the combined Kyoto Protocol and the aviation system, at the end of the trading period all the AAU’s remaining in that specific account should be cancelled.

Option 6. Clearinghouse

4.1.22 In this option the aviation sector first uses any excess allowances amongst its entities before it buys Kyoto units to cover the remaining shortfall. Instead of individual aviation entities taking action, as in the options 3, 4 and 5, in this option a clearinghouse would assume responsibility for settling supply and demand of allowances among the aviation entities.

4.1.23 If certain aviation entities, due to emission reductions, hold excess allowances, the clearinghouse would buy the surplus and sell it to aviation entities that have a shortage.

4.1.24 If the emissions of aviation as a whole were low in a certain year, the excess allowances could be banked in the clearinghouse and (without a transfer of money) withdrawn in times of growth. If the aviation sector as a whole requires more allowances from other sectors, the clearinghouse would buy AAU’s from these other sectors.

4.1.25 This option would avoid the possibility of aviation allowances flowing back into the Kyoto market.

Summary

4.1.26 Table 2 summarises the most important aspects of the options described in this chapter. While all options are considered feasible, different States may favour different options depending on their own specific circumstances and policy preferences. For example, States that can achieve their Kyoto target relatively easily might favour option 1. States that estimate the complexity of constructing a gateway as a relatively minor problem might favour that option.

4.1.27 In all options the financial burden for the aviation sector depends in most cases on the baseline level and AAU price. In option 2 there is no baseline level, so the burden only depends on the AAU price. The AAU price may be influenced by the inclusion of aviation.

Table 2: *Summary of key aspects*

Option	Description	Tradable aviation allowances?	Interaction with AAU's possible?	Financial burden on aviation sector?	Risk Kyoto Target	Point of attention
1	Borrowing	No	Full	Depending on baseline level and AAU price	Some	Might risk Kyoto target
2	No allocation	No	Full	Maximum, but depending on AAU price	No	May influence AAU price
3	Non-tradable baseline	No	Limited	Depending on baseline level and AAU price	No	Simple, limited economic flexibility
4	Tradable baseline	Yes	Some limitation	Depending on baseline level and AAU price	No	Average complicated, some economic efficiency
5	Gateway	Yes	Up to a Maximum	Depending on baseline level and AAU price	No	Complicated, maximum economic efficiency
6	Clearing house	Yes	Up to a Maximum	Depending on baseline level and AAU price	No	Complicated, maximum economic efficiency

Guidance

4.1.28 States will need to make a choice about which option to pursue taking into account economic efficiency, environmental integrity, and equity and competitiveness issues. They may take into consideration that more economically efficient options, which offer the maximum flexibility to the aviation sector, will tend to be more complex to administer.

4.1.29 States are advised to put in place an accounting arrangement that ensures that emissions from international aviation are counted separately and not – whether deliberately or inadvertently – against the specific reduction targets that States may have under the Kyoto Protocol.

CHAPTER 5 TRADING SYSTEM ELEMENTS

5.1 Types of trading system

5.1.1 Two families of tradable allowance systems are generally distinguished: cap and trade systems, and credit systems.

5.1.2 Under cap and trade systems (also referred to as tradable quota or allowance systems) entities must obtain and hold emission allowances sufficient to cover actual emissions during a stated compliance period.

5.1.3 Under credit systems (also referred to as baseline and credit) a baseline is used representing an implicit authorization of emissions for the compliance period. Emission reduction credits result when the actual performance—e.g. the actual emission level—is lower than the allowed performance.

5.1.4 A variant of a basic cap and trade system or a credit system could be a hybrid approach combining trading with a maximum price for allowances/credits (price- capped system).

5.1.5 The relationship between the base year (or base years) for setting the baseline as well as the setting of targets or caps for the aviation sector in any trading system are specific aviation-related issues to be considered.

5.1.6 However, for the aviation sector it would in any case be highly desirable to maintain a certain compatibility of the chosen system with other existing systems in order to allow the sector to take advantage of allowances from other sectors and from other greenhouse gas reduction mechanisms such as CDM or JI (see 5.1.18).

Cap and trade systems

5.1.7 Allowance caps - whether for the overall system or a specific sector - can be of a number of different types such as hard caps or ceilings on emissions, a rising or falling emissions path over time, formula-based caps or caps or paths that are revised as circumstances warrant.

5.1.8 An important issue in choosing whether to use a sector-wide cap for aviation and in defining the type and level of such a cap is the variability of emissions and how well emissions — and costs — can be projected for the period during which the cap is binding.

5.1.9 If the sector-wide cap is too strict, then the sector as a whole may find meeting the cap to be financially onerous. In an open system, costs to participants will be limited by the selling price of the tradable instruments (allowances) in the market, e.g. Kyoto instruments (AAUs).

5.1.10 If, however, the sector cap is set too loosely, then it will not constrain emissions from the sector, and so the system may not provide an overall environmental benefit.

Credit systems

5.1.11 Two basic types of credit systems can be envisioned for aviation, namely a 'binding credit system' and a 'credit generation system'.

5.1.12 Under a binding credit system (also known as a 'target system'), all participants are required to meet emission limits. They have an emissions target (essentially a baseline) that they commit to achieving, and can sell emission reductions generated below the target. There are no allowances distributed initially to the entities, however.

5.1.13 Under a credit generation system, participants can voluntarily choose to generate emission reductions by reducing emissions below a fixed baseline, but are not required to limit emissions to the baseline. Only those participants that can reduce emissions at low costs would seek to generate credits within such a system. For this type of system to work, a market for credits must exist outside the system – e.g., entities with allowances requirements under another trading regime would be allowed to buy and use aviation-generated credits for compliance.

System variants and other trading mechanisms

Price-capped systems

5.1.14 In a price-capped system a State sets a limit on the total allowances and a limit on their market price. When the market price is below the limit, the system works as any trading system, giving incentive to pursue abatement opportunities. When the market price reaches the limit, instead of covering their emissions by surrendering allowances, accountable entities can cover their emissions by paying the price cap per allowance they are short of. This approach does not guarantee a particular level of net greenhouse gas emissions but it provides operators with cost certainty.

Dual target systems

5.1.15 Basically a dual target system is a variant of a credit system. In principle a dual target system could work in a baseline and credit system as well as in a cap and trade system.

5.1.16 Under such a system, participating entities face two targets. The higher target is binding in order to ensure the achievement of a minimum environmental goal. If emissions are above the higher target, participants have to purchase allowances or credits on the market in order to be compliant. If emissions are reduced below the lower target, the entity can generate tradable credits or allowances for sale. If emissions fall in the area between the two targets, the entity does not have to buy credits or allowances and it also does not generate tradable allowances.

5.1.17 This option might be of interest to the aviation sector as it tries to balance environmental and economic uncertainty. So far it has not been tested. Predictions about the administrative costs and related efficiency for monitoring and verification of compliance are not possible.

Project based mechanisms: Clean Development Mechanism and Joint Implementation

5.1.18 Under a system which is open for project based mechanisms such as Clean Development Mechanisms (CDM) or Joint Implementation (JI) under the Kyoto Protocol, participating entities would still be subject to whatever allowance caps or credit limits the system requires, and would at the same time have access to credits from project-based mechanisms. In addition, however, participating entities would be allowed to purchase emission reduction credits generated by entities that are not subject to absolute emission targets. This would be an addition to the system, with its associated set of rules and requirements, to accompany the basic cap system.

Absolute and relative trading systems

5.1.19 From a methodological perspective, there are two choices for the units in which a cap or a baseline can be specified by the member states. The first method is to specify the cap or baseline in absolute terms (e.g., tons of CO_2) in each year to be considered.

5.1.20 The second method is a relative approach where the cap or baseline is specified in terms of a rate, such as carbon intensity (e.g., CO_2 per tonne kilometre), relative to an output variable that is linked to economic activity (e.g. aircraft kilometres, passenger or freight kilometres, payload kilometres).

5.1.21 The application of this method implies the development of an appropriate intensity and corresponding output measure. One feasible option would be the creation of a relative system based on fuel used (CO_2-emitted) per RTK (revenue tonne-kilometre).

5.1.22 Under this approach, it should, however, be recognized that the amount of CO_2-emitted per RTK may differ widely depending on the specific circumstances of different operators, varying by distance, fleet characteristics and load factor. For example, if such as system was introduced and a fixed target was agreed, operators of most shorter haul flights would have to buy credits while operators of the longer haul flights would be able to sell credits.

5.1.23 As a variant to the examples mentioned above it would e.g. also be possible to impose individual targets (expressed as a percentage of the individual baseline) per city pair. In this case an individual baseline would have to be defined for each city pair by aircraft type serving these cities, which would make this alternative rather cumbersome.

Advantages and Disadvantages of absolute and relative trading systems

5.1.24 The absolute approach provides greater environmental certainty, since emissions are capped, at least at the entity level. Both absolute and relative caps or baselines can allow for reasonable growth of emissions in line with existing plans.

5.1.25 From an administrative point of view the absolute approach is easier to design and monitor, since it requires only one piece of data (emissions) instead of two (a rate and output measure). However, depending on the rules governing its specification, the absolute emissions cap or baseline may require more review on a case-by-case basis than the relative cap or baseline.

Flexibility and stringency

5.1.26 The generally observed high degree of variability and the associated unpredictability in the aviation sector would suggest that emissions are difficult to predict on an entity level. States may wish to consider ways to increase flexibility while maintaining established rules, such as:

- Revisiting the distribution when output or other variables change;
- Banking and borrowing (to even out allowance requirements over time);
- Setting a multi-year budget period (such as the 5 year period under the Kyoto Protocol);
- Using a credit system with a relative baseline or

- Using a dual target system.

5.1.27 The key advantage of a credit or a dual target system is their ability to provide more flexibility than a cap and trade system. Depending on how baselines are set for participants, a credit or dual target system may be able to provide the necessary flexibility to enable compensation within the system for economic growth and contraction, without imposing severe cost burdens on the participants or allowing a detrimental effect on environmental quality. The integration of this type of system into an existing cap and trade may however prove to be difficult.

Compatibility with project based mechanisms

5.1.28 When considering the inclusion of the aviation sector into an existing trading system the compatibility of the system with project based mechanisms such as CDM or JI under the Kyoto Protocol, could be a key decision element as it may offer an important source of additional credits for a sector expected to be a net buyer. Aviation currently has no options to switch to other types of fuel and it has already reached a significant level of fuel efficiency. This and the predicted growth-rates of the sector will lead to a situation where the aviation sector will most likely not be able to meet stringent caps or baselines through reduction activities within the sector. Thus the availability of allowances at a reasonable price and/or the availability of such offsets (CDM, JI, etc.) for aviation are of utmost importance to the sector.

Guidance

5.1.29 States may use 3 different approaches to generate a baseline or a cap.

1. Set the baseline or the cap with reference to historic emissions in a year or a set of years, or a set percentage below that historic level.

2. Use the baseline or cap to define an emissions performance standard—such as emissions per unit of output (e.g. RTK's or ATK's) —against which emission reductions can be measured.

3. An emission baseline or a cap can be viewed as a projection of what would, or could, have occurred, not what actually happened.

5.1.30 Choosing the assumptions for constructing a baseline (or an appropriate level for a target or a cap) by the States for a sector requires weighing a number of potentially competing considerations. Such considerations include the environmental effects of current and forecast emission rates and levels, as well as the effects on emissions of actions that have already been taken to reduce emissions, which may be taken into account either on a sector-wide basis or an individual-entity basis.

5.1.31 In determining allowance requirements, States should consider the potential contribution of air navigation service providers to levels of emissions generated by aircraft operators: e.g. terminal area holding patterns, indirect routing and en route delays. Considering data on average system delays caused by air traffic would be an appropriate mechanism.

5.1.32 Considerations also include factors governing emissions reductions—the cost of further reducing aviation related emissions, available technologies and the potential for emission reductions within the sector or the individual entity.

5.1.33 Other factors include projected rates of growth in the industry and variability in growth over time, the likely cost of allowance or credit purchases in an open system, and profitability in the industry and impacts on competitiveness, i.e. the ability of the aviation industry to remain viable and competitive. Many of these factors are uncertain, further complicating the process of setting an equitable cap or baseline.

5.2 Distribution of emission allowances through benchmarking

5.2.1 Participation in an emissions trading scheme requires trading entities (aircraft operators) to hold emissions allowances in order to cover their emissions and to be able to trade. Accountable entities may receive their allowances at the start of the trading period either from auctioning or by being distributed a given amount by the authority. Auctioning or grandfathering allowances from historic emission do not bear aviation specific issues. This section therefore focuses on benchmarking as a distribution method applied to aviation.

5.2.2 Under a benchmarking approach allowances are distributed according to a specific formula based on a benchmark parameter that reflects the amount of emissions in relation to a level of activity representative of the sector.

5.2.3 In order to design a cost-effective and efficient distribution system based upon benchmarking particular attention has to be paid to the following points:

- Technical feasibility / verifiability
- Standardization / simplicity
- Transparency
- Minimizations of perverse incentives
- Provision of incentives for best practice and clean technology
- Network and operational efficiencies
- Avoidance of excessive distributional impacts between operators

5.2.4 In addition it has to be considered that benchmarking and grandfathering approaches do not have the same data requirements. While a grandfathered distribution system would require historic emissions data, a benchmarked distribution system requires the collection of appropriate activity data.

5.2.5 Although the air transport sector has a number of common characteristics, such as the use of a homogeneous fuel type, it provides a wide range of services as reflected in the large variation in operators' business models. For benchmarking to be used successfully as a method for distributing emissions allowances, the activity parameter will need to avoid unintended distributional effects between different business models as much as possible.

Basic design options

Definition

5.2.6 In order to determine how the fuel (or energy) efficiency performance of an operator compares with that of other operators in the sector, a benchmark parameter must be defined. This can be achieved in different ways, for example by comparing the operator's performance against a sector average, a percentile value, or a theoretically "best achievable" level. In this respect two operators producing the same amount of activity will receive the same amount of permits but the one with the better performance (i.e. lower energy consumption) will have to surrender fewer permits than its competitor at the end of the trading period.

5.2.7 A benchmark parameter is typically defined in terms of emissions per unit of output, ‘activity’ or as a technology factor applied to historic emissions. Activity levels in air transport can be expressed by way of different variables, such as the number of operations, flight distance, capacity offered, or payload transported

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5.2.8 The combination of these variables for a particular operator will reflect its geographic location and the product characteristics in the markets in which it operates..

Choice of reference year

5.2.9 Distribution of allowances will be proportional to the production of a chosen reference year. The most recent year of available data could be considered an appropriate reference year. However, in the airline industry, it may be preferable to include several consecutive years in the base period, as this would level out the effects of economic cycles, short-term differences in investment cycles and unusual events.

Potential benchmarking methods

5.2.10 A range of potential benchmarking methodologies and parameters can be considered.

5.2.11 One possibility would be to define the benchmark parameter as an average value of emissions per payload kilometre, using Revenue Tonne-Kilometres (RTK) as a measure for an entity’s accountable activity, according to the following formula:

$$A_i = \frac{(\sum^{n} E_i - T)}{\sum^{n} RTK_i} * RTK_i$$

in which

A_i	= Amount of emission allowances distributed to each entity for the commitment period
n	= Total number of entities
$\sum RTK_i$	= Total revenue tonne kilometre of all flights considered in the trading scheme in the reference period
RTKi	= Revenue tonne kilometres performed under the scheme by entity i in the reference period
$\sum E_i$	= Total emissions of all flight considered in the commitment period
E_i	= Emissions considered for entity i in the commitment period
T	= Emission reduction target

5.2.12 Another possibility would be to characterize the activity level in terms of transport capacity. In this case, the benchmark parameter could be expressed as an average value of emissions per unit of available capacity, using Available Tonne Kilometers (ATK) as a measure, using basically the same formula by substituting ATK for RTK.

5.2.13 Also other benchmarking methodologies are possible, such as using technology factors expressed in terms of specific fuel consumption and applied to historic emissions.

5.2.14 Any benchmarking approach should try to minimise undesirable effects for operators that are active in the same market. For instance, emissions per RTK tend to be lower for long haul flights than for short haul flights because of the higher fuel efficiency achieved during cruise. On the other hand, on very long haul flights efficiency may be lower due to the fact that more fuel is burned in order to carry the extra fuel needed for the longer flight.

5.2.15 Therefore, an approach based on traditional airline activity measures such as RTK, may lead to different reduction burdens for short-, middle- and long-haul flights. An approach using categories of aircraft families or ranges or using a standardized measure based on transport capacity (e.g. a standardized ATK based upon a common calculation methodology) could be used to avoid unintended distributional effects between different business models as much as possible.

Guidance

5.2.16 For benchmarking to be used successfully as a method for distributing emissions allowances, the benchmark parameter should be designed to reward previous investments in new technology and provide incentives to operate the most emissions efficient aircraft in the most efficient way into the future, whilst avoiding unintended distributional effects between different business models as much as possible.

5.3 Treatment of new entrants and changes in operation

5.3.1 States may consider how to treat new entrants and changes in operation. The treatment of new entrants and changes in operation is relevant to emissions trading schemes where allowances are distributed free of charge on the basis of a grandfathering or benchmarking method. There may be a greater need to make provision for new entrants if the allocation periods are long.

5.3.2 One option would be not to make any special provision for new entrants or changes in operation. Operators could simply be required to buy allowances on the market. Alternatively States may decide to create a reserve of allowances for allocation to new entrants and/or changes in operation. States considering whether to create some sort of new entrant reserve will need to consider the administrative complexity of developing and implementing such a reserve.

5.3.3 If it were decided to make some form of special provision, it would be necessary to define the terms new entrants and/or changes in operation. In the context of aviation, a new entrant could be defined as any aircraft operator (as defined in Chapter 2.1 of this guidance) that starts flight operations under the scope of the trading scheme for the first time. Examples of a change in operation might be the introduction of a new flight route or an increase in the frequency of flights on an existing route. In order for the scheme to be workable, any changes in operation would need to be identifiable and capable of independent verification.

5.3.4 It would also be necessary to define how any allowances would be allocated to new entrants/changes in operation for which no historic data would be available.

5.3.5 The creation of a reserve of allowances for new entrants could help provide access to the market for new operators. However, the total of allowances available to existing entities in the system plus the allowances assigned to the new entrants reserve may in such a case not exceed the overall amount of allowances available for allocation to the aviation sector. A new entrants reserve would therefore reduce the amount of allowances available to entities already operating in the scheme.

5.3.6 If it is decided to make provision for the allocation of allowances to new entrants and/or changes in operation, states will need to consider how to treat aircraft operators that cease to operate, stop operating on certain routes or decrease the number of flights operated.

Guidance

5.3.7 Under allowance distribution methods based on grandfathering or benchmarking States may wish to whether to make special provision for new entrants. The two main options are:

1. New entrants are required to buy allowances on the market until the next distribution period. Operators can retain allowances if they stop operating or reduce their operations.

2. A proportion of the allowances allocated to the aviation sector are used to create a new entrant reserve to enable allocations of allowances to be made to new entrants on a similar basis to allocations to existing operators.

CHAPTER 6 ADMINISTRATIVE PROCEDURES

6.1 Monitoring and reporting

6.1.1 A basic feature of emissions trading schemes is the requirement for emissions to be monitored and periodically reported. The accountable entity, the entity responsible for monitoring and reporting emissions, as well as the methodology to be used for calculating emissions must be defined prior to inclusion of a sector in an emissions trading scheme.

Monitoring and Reporting obligations

6.1.2 To establish emission inventories for accountable entities such as individual aircraft operators, States can rely either on self-reporting by trading participants or reporting by third parties. It is important to note that there is a distinct difference between monitoring and reporting at a state level versus a trading entity level. Additional information regarding the former can be found in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Monitoring and Reporting data

6.1.3 For monitoring purposes, emissions can either be calculated based on actual trip fuel or based on flight movement data.

6.1.4 If monitoring of emissions is calculated on the basis of actual trip fuel, CO_2 emissions can be derived from the carbon content of that fuel. Aircraft emissions would be calculated according to the generic formula:

< Emissions > = < Fuel Consumption > * < Emissions Factor >

6.1.5 CO_2 emission factors depend on the fuel type, the carbon content and the fraction of the fuel oxidised. They should roughly be within a range of ±5 percent of actual emissions. IPCC default values for the CO_2 emission factors as published in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* can be used by States. For jet fuel (based on mass) the IPCC default value is 3.16. In other words, the burning of 1 tonne of jet fuel produces 3.16 tonnes of CO_2. The same value is used by ICAO.

6.1.6 Because the use of actual trip fuel would provide information relating to each individual flight, both the accuracy of the reported data as well as the environmental effectiveness of the emissions trading system would benefit.

6.1.7 If actual trip fuel data cannot practicably be obtained, emissions modelling techniques can be used to calculate estimates. The detail available can range from origin and destination (OD) data to actual flight movement data with full flight trajectory information.

6.1.8 The method based on origin and destination data involves the calculation of average fuel consumption and emissions for a range of representative aircraft categories for the origin-destination flight distance. Examples include the EMEP/CORINAIR (Core Inventory of Air Emissions in Europe) Emission inventory guidebook.

6.1.9 The method based on actual flight movement data involves the calculation of fuel consumption and emissions throughout the full trajectory of each flight segment using aircraft and engine-specific aerodynamic performance information. Compared to the method based on the origin-destination flight distance this method offers increased accuracy since the estimation is based on individual flights and therefore would improve the environmental and economic effectiveness of the system. Examples include the System for assessing Aviation's Global Emissions (SAGE), by the United States Federal Aviation Administration, and AERO2k, by the European Commission.

Guidance

6.1.10 Two basic options for monitoring and subsequent reporting of CO_2 emissions can be considered: (i) calculation based on the carbon content of the actual trip fuel, and (ii) estimation based on actual flight movement data or origin and destination (OD) data.

6.1.11 When possible the method with the highest accuracy based on actual trip fuel data should be applied, and perhaps incentivised. For those trading entities (aircraft operators) that cannot meet high reporting standards, a minimum reporting standard based on emissions modeling techniques could be set that is consistent across the sector.

6.2 Verification

6.2.1 To ensure environmental integrity of the trading system effective and independent verification procedures should be defined. Such procedures will also help to ensure equitable treatment of all participants and identify the need to correct data or calculation errors.

6.2.2 An entity that meets the auditing capabilities required by the State shall carry out a predefined verification procedure. ICAO could be considered along with State accredited verification entities to facilitate or assist such verification.

6.2.3 Several methods exist to verify the emissions reported. Firstly, aircraft operators could submit emissions data to the verification entity, based on actual fuel use.

6.2.4 Secondly, air navigation service providers could in cooperation with the verification body calculate estimates of actual emissions using best available data with regard to flight paths, aircraft and estimated aircraft weight.

6.2.5 Thirdly, aviation authorities could provide the verification body with calculated emissions based on actual individual flight data submitted by aircraft operators. Annex 6 to the Chicago Convention requires an operator to maintain fuel and oil records, to be retained for a period of three months. Such requirements for example exist under the US Federal Aviation Regulations (FAR) and the Joint Aviation Requirements (JAR) in Europe.

6.2.6 Flight specific information needed for reporting and verification purposes may be subject to concerns regarding commercial confidentiality. States should ensure that appropriate arrangements are in place to protect confidentiality. For example, it may be possible to secure confidentiality by reporting data in aggregated form over a predefined period.

6.2.7 In addition, fuel use data collected by States and regulatory authorities outside the emissions trading system could be used to compare against data submitted by the reporting entity or against modelled estimates.

6.2.8 Consideration must be given to the fact that flight recorder data may not be easily obtainable which could increase the administrative burden of this approach.

6.2.9 A fourth approach may be envisaged in which a calculated estimate of the emissions is used as the basis for verification but where the reporting entity is allowed to demonstrate with actual fuel use data that its emissions are below the calculated estimate. In order to reduce the administrative burden, the verification body can use this data to adjust the calculated estimate for the subsequent year if it accepts the actual fuel use data submitted by the reporting entity.

Guidance

6.2.10 Verification should be carried out by an accredited organisation independent of the organisation whose data are being verified, with the aim of verifying the reliability, credibility and correctness of the data. The State is responsible for the accreditation of such entities.

6.3 Enforcement

6.3.1 Effective enforcement of emission reduction obligations is required to assure the environmental integrity of the trading system and to protect the interests of compliant participants.

6.3.2 The effectiveness of enforcement depends upon several factors, including the frequency and quality of verification, government attitude, and legal constraints on the types of penalties that can be imposed.

6.3.3 Deterrence of non-compliance is key to designing an effective enforcement mechanism.. This may involve establishing penalties for non-compliance at meaningful levels and providing for public disclosure of information on the compliance status of trading participants.

6.3.4 Various types of penalties for non-compliance can be considered. Among these are:

- Monetary penalties, set at a level higher than the market price of an allowance times the number of allowances exceeded;
- Trading restrictions within the trading system; and
- Reduction of the number of allowances distributed for subsequent compliance periods.

6.3.5 States could also consider the penalty system in use for other sectors and apply similar penalties as far as possible to international aviation as well.

Guidance

6.3.6 Various options are available for the penalties that might be used. Among them are:

- Monetary penalties.
- Restricting a noncompliant participant’s rights under the trading system.

- Reducing the number of allowances assigned for subsequent periods.

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GLOSSARY

The terms contained herein are not intended to be universal definitions, but rather to clarify concepts as used in this document.

Accountable Entity
A physical or legal person which, in a given emissions trading scheme, is responsible for emissions from international aviation under the scheme.

Aerial work operation
An aircraft operation in which an aircraft is used for specialized services such as agriculture, construction, photography, surveying, observation and patrol, search and rescue, aerial advertisement, etc.

Air Operators Certificate (AOC)
A certificate authorizing an operator to carry out specified commercial air transport operations.

Air navigation service provider (ANSP)
A body that manages flight traffic on behalf of a company, region or country.

Allocation
Method for initial distribution of allowances among States for a commitment period.

Allowance (Emission allowance)
An allowance is a tradable emission permit that can be used for compliance purpose in an emissions trading system. An allowance grants the holder the right to emit a specific quantity of pollution once (e.g. one tonne of CO_2).

Annex B Countries
Annex B countries are the 39 emissions-capped industrialised countries and economies in transition listed in Annex B of the Kyoto Protocol.

Annex I Countries
Annex I countries are the 36 industrialised countries and economies in transition listed in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC).

Anthropogenic greenhouse-gas emissions
Greenhouse-gas emissions resulting from human activities.

Assigned Amount (AA) and Assigned Amount Units (AAUs)
A Kyoto Protocol unit equal to 1 metric tonne of CO_2 equivalent. Each Annex I Party issues AAUs up to the level of its assigned amount, established pursuant to Article 3, paragraphs 7 and 8, of the Kyoto Protocol. Assigned amount units may be exchanged through emissions trading.

Auctioning
Auctioning is an initial distribution method in which allowances are sold in an auction.

Available Tonne Kilometres (ATK)
Available (offered) capacity for passengers and cargo expressed in metric tonnes, multiplied by the distance flown.

Baseline
Total amount of allowances distributed to a sector or an individual trading entity.

Benchmarking
An initial distribution method in which allowances are allocated free of charge based on a specific benchmark, for example emissions per unit of output.

Bunker fuels
A term used to refer to fuels consumed for international marine and air transport.

Business Aviation
Business aviation, one of the components of general aviation, consists of companies and individuals using aircraft as tools in the conduct of their business.

Cap and Trade
The Cap and Trade system involves trading of emission allowances, where the total amount of allowances is strictly limited or 'capped' by a regulatory authority. Allowances are created to account for the total allowed emissions. At the end of each compliance period each entity must surrender sufficient allowances to cover its emissions during that period. Trading occurs when an entity can reduce units of emission at a lower cost than another entity and then sells the allowance. A Cap and Trade system is generally based on those entities included in the cap.

CO_2
Carbon dioxide, a naturally occurring gas that is also a by-product of burning fossil fuels and biomass, land use changes and other industrial processes. Carbon dioxide is the reference gas against which the global warming potential of other greenhouse gases is measured.

CO_2 Equivalent (CO_2e)
The universal unit of measurement used to indicate the global warming potential (GWP) of a greenhouse gas.

Cost(s)
Direct cost for buying emission permits. Indirect cost for operation of an Emissions Trading System.

Certified Emission Reductions (CERs)
A Kyoto Protocol unit equal to 1 metric tonne of CO_2 equivalent. CERs are issued for emission reductions from CDM project activities.

CH_4
Methane, a greenhouse gas.

Cirrus cloud
A type of cloud composed of ice crystals and shaped like hair filaments. May partly be aviation induced.

Clean Development Mechanism (CDM)
A mechanism under the Kyoto Protocol through which developed countries may finance greenhouse-gas emission reduction or removal projects in developing countries, and receive credits for doing so which they may apply towards meeting mandatory limits on their own emissions.

Closed emissions trading
An emissions trading scheme that is designed to limit or reduce emissions within one sector only without providing access to allowances or credits outside the scheme.

Code Sharing
Code sharing refers to a practice where a flight operated by an airline is jointly marketed as a flight for one or more other airlines. Most major airlines nowadays have code sharing partnerships with other airlines, and code sharing is a key feature of the major airline alliances.

Commercial air transport operation
An aircraft operation involving the transport of passengers, cargo or mail for remuneration or hire.

Contrails
The condensation trail left behind jet aircraft. Contrails only form when hot humid air from jet exhaust mixes with ambient air of low vapour pressure temperature.

Credit
A term most commonly used in relation to emission reductions that have been achieved below a predefined, agreed baseline. Once the reduction has been verified by an accredited entity, the authority issues a credit. The credit grants the holder the right to emit a specific quantity of pollution once (e.g. one tonne of CO_2).

Distribution
Method for apportioning allowances among accountable entities.

Domestic flights
Emissions from civil domestic passenger and freight traffic that departs and arrives in the same country (commercial, private, agriculture, etc.), including take-offs and landings for these flight stages.

Dry lease
A leasing arrangement in which only the aircraft is provided, without crew or maintenance guarantees. Under a dry-lease arrangement, the aircraft is operated under the AOC of the lessee.

Emission Inventory
An Emission Inventory is a report on actual emissions.

Emission Reduction Unit (ERU)
A Kyoto Protocol unit equal to 1 metric tonne of CO_2 equivalent. ERUs are generated for emission reductions or emission removals from joint implementation project.

Emissions Trading
Emissions trading is a market-based system that in principle allows entities the flexibility to select cost-effective solutions to achieve established environmental goals. With emissions trading, entities can meet established emission goals by: (a) reducing emissions from a discrete emissions unit within an entity's boundaries; (b) reducing emissions from another place within the entity; or (c) securing emission reductions from the marketplace. Emissions trading encourages the implementation of cost-effective emission reduction strategies and provides incentives to emitters to develop the means by which emissions can inexpensively be reduced. Under the Kyoto Protocol, "emissions trading" is one of the three Kyoto mechanisms, by which an Annex I Party may transfer Kyoto Protocol units to or acquire units from another Annex I Party. An Annex I Party must meet specific eligibility requirements to participate in emissions trading.

European Union (EU)
The European Union (EU) is a supranational and intergovernmental union of 25 (27 as of 1st January 2007) independent, democratic member states. The European Union is the world's largest confederation of independent states, established under that name in 1992 by the Treaty on European Union (the Maastricht Treaty). However, many aspects of the Union existed before that date through a series of predecessor relationships, dating back to 1951.

Flexible Mechanisms
The Kyoto Protocol has provisions that allow for flexibility in how, where, and when emissions reductions are made via three mechanisms: the Clean Development Mechanism, International Emission Trading and Joint Implementation.

Fungibility
The inter-changeability of emission units (allowances or credits) among the mechanisms.

Gateway
Instrument created to solve trading problems due to lack of AAUs for international aviation under the Kyoto protocol. The aviation sector obtains allocated allowances and can, as a maximum, sell as many allowances as it has already bought during the trading period from non-aviation sectors.

General aviation operation
All civil aviation operations other than commercial air transport operations or aerial work operations.

Geographical scope
Refers to the geographical coverage of aviation emissions under the trading scheme, i.e. specification of the countries, routes and type of flights/aircraft to be included.

Greenhouse gases (GHGs)
The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent --but very powerful -- greenhouse gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

GTI
Global Temperature Index.

GTP
Global Temperature Potential, indicates global mean temperature change as a result of emissions of a greenhouse gas.

GWP
Global Warming Potentials (GWP) are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme CO_2 over a period of time (100 years). Carbon dioxide has been designated a GWP of 1; Methane, for instance, has a GWP of 23.

Grandfathering
Method for the initial distribution of allowances free of charge to entities in an emission trading scheme according to historical emissions.

H_2O
Water (vapour)

HC
Hydrocarbons.

HFCs
Hydrofluorocarbons, a group of greenhouse gases subject to limitations under the terms of the Kyoto Protocol.

Integrated Trading
An open emissions trading approach whereby international aviation emissions are incorporated into emissions trading schemes consistent with the UNFCCC process and the Chicago Convention.

Intergovernmental Panel on Climate Change (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) has been established by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. It is open to all Members of the UN and of the WMO.

Joint Implementation (JI)
A mechanism under the Kyoto Protocol through which a developed country can receive "emissions reduction units" when it helps to finance projects that reduce net greenhouse-gas emissions in another developed country (in practice, the recipient state is likely to be a country with an "economy in transition"). An Annex I Party must meet specific eligibility requirements to participate in joint implementation.

Kyoto Commitment Period
The Kyoto commitment period is the period in which Annex B countries that have ratified the Kyoto Protocol have committed to reduce their collective emissions of greenhouse gases by an average of 5.2% (2008 to 2012).

Kyoto Mechanisms
Three procedures established under the Kyoto Protocol to increase the flexibility and reduce the costs of making greenhouse-gas emissions cuts; they are the Clean Development Mechanism, emissions trading, and joint implementation.

Kyoto Protocol

An international agreement standing on its own, and requiring separate ratification by governments, but linked to the UNFCCC. The Kyoto Protocol, among other things, sets binding targets for the reduction of greenhouse-gas emissions by industrialized countries.

Kyoto Unit
A unit, representing the equivalent of one tonne of carbon dioxide emissions, that a Party to the Kyoto Protocol can surrender to meet its Kyoto obligations. These units are tradable between Kyoto Parties and includes AAUs, CERs, ERUs, and RMUs.

Leasing
A commercial arrangement whereby one party (the lessor) agrees to provide an aircraft for use to another party (the lessee). (See also >> dry lease and >> wet lease).

Lessee
The party receiving an aircraft under a leasing arrangement.

Lessor
The party providing an aircraft under a leasing arrangement.

NO_X
Nitrogen oxides, a generic term for oxides of nitrogen (NO, NO_2, NO_3).

N_2O
Nitrous oxide, a greenhouse gas.

Non-Annex B Countries
Countries not included in Annex B of the Kyoto Protocol. Non-Annex B countries currently do not have binding emission reduction targets.

Non-Annex I Countries
Countries not included in Annex I of the United Nations Framework Convention on Climate Change UNFCCC.

O_3
Ozone.

Offsets
An emissions reduction achieved by undertaking a greenhouse gas emission reduction project.

Open emissions trading
An emissions trading system where allowances can be traded in and outside the given scheme or sector. E.g., within an emissions trading scheme for aviation, participants would be allowed to buy allowances from sectors outside the aviation emissions trading scheme.

Operator
A person, organization or enterprise engaged in or offering to engage in an aircraft operation.

PFCs
Perfluorocarbons, a group of greenhouse gases.

Radiative forcing (RF)
A change in average net radiation (in Wm-2) at the top of the troposphere resulting from a change in either solar or infrared radiation due to change in atmospheric greenhouse gas concentrations; perturbance of the balance between incoming solar radiation and outgoing infrared radiation.

RFI
Radiative Forcing Index

Removal Unit (RMU)
A Kyoto Protocol unit equal to 1 metric tonne of carbon dioxide equivalent. RMUs are generated in Annex I Parties by land use, land-use change and forestry (LULUCF) activities that absorb carbon dioxide.

Revenue Tonne Kilometres (RTK)
Utilized (sold) capacity for passengers and cargo expressed in metric tonnes, multiplied by the distance flown.

Soot
Substance emitted by aircraft; may have both warming and cooling climate impacts.

SBSTA
The UNFCCC Conference of Parties (COP) established the Subsidiary Body for Scientific and Technological Advice (SBSTA). SBSTA provides advice to the COP on scientific, technological and methodological matters.

Sulphate
Substance emitted by aircraft, which may have a cooling impact.

SF_6
Sulphur hexafluoride, a greenhouse gas.

Surrendering
Handing in of allowances for emissions by the accountable entity in order to fulfil the obligations under the emissions trading scheme.

Tankering
The practice of aircraft operators taking up fuel at airports with lower fuel prices.

Trading entity
Entities obliged to surrender allowances for emissions generated that are allowed to trade.

United Nations Framework Convention on Climate Change (UNFCCC)
The Convention on Climate Change sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases. The Convention enjoys near universal membership, with 189 countries having ratified. Under the Convention, governments gather and share information on greenhouse gas emissions, national policies and best practices, launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries and cooperate in preparing for adaptation to the impacts of climate change.

Verification
Verification provides independent assurance that emissions reporting has been realised in an accurate manner. The verifiers are accredited. The level of assurance provided will depend on the scope of the verification which is usually agreed by the transacting parties and may include: adequacy of measuring and monitoring systems for emission reduction credits, reviewing the operations of the underlying emission reductions project etc.

Wet lease

A leasing arrangement in which the aircraft is provided plus at least one pilot. Under a wet-lease arrangement, the aircraft is normally operated under the AOC of the lessor. A wet lease is typically utilized during peak traffic seasons or annual heavy maintenance checks, or to initiate new routes. When an air carrier provides less than an entire aircraft crew, occasionally the wet lease is referred to as a *damp lease*.

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English only

APPENDIX C

Guidance on Aircraft Emissions Charges Related to Local Air Quality

(Prepared by CAEP's Emissions Charges Task Force)

(October 31, 2006)

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Chapter 1 - Scope of Guidance and Application of Existing ICAO Policies on Charges to Aircraft Emissions Charges Related to Local Air Quality

1.1 Introduction and Background

1.1.1 In the context of emissions related levies, the 35th Assembly of ICAO recognized the continued validity of the Council's Resolution of 9 December 1996 on Environmental Charges and Taxes which applies to emissions in general. It also requested that the ICAO Council develop further guidance on emissions levies related to local air quality.

1.1.2 This guidance was developed to respond to this Assembly request. It is intended to assist those States that have decided to levy emission charges on aircraft with respect to aircraft emissions that have local air quality effects or intend to do so. Specifically, this guidance addresses how to implement such charges consistent with ICAO policy. It should be noted that the guidance is not of a regulatory nature. Rather, it provides States with advice and information that they may need or find helpful. This guidance cannot, and does not purport to, cover every conceivable issue that might arise; indeed ICAO recognizes that States have their own legal obligations, existing agreements, current laws and established polices. States should therefore exercise discretion in applying this guidance to their specific circumstances.

1.2 Scope of the Guidance and Key Terms

1.2.1 Consistent with the remit to develop guidance on implementing local emissions charges, this guidance only addresses such charges. ICAO has an environmental goal to limit or reduce the impact of aviation emissions on local air quality. Charges are but one potential means for addressing aircraft emission issues. The Assembly requested the Council "to continue to study policy options to limit and reduce the environmental impact of aircraft engine emissions placing special emphasis on the use of technical solutions while continuing its consideration of market-based measures." Assembly Resolution A35-5, Appendix H, Action Clause 2b). Further, when market-based measures such as emissions charges are adopted, States are encouraged "to evaluate the costs and benefits of the various measures, including existing measures, with the goal of addressing aircraft engine emissions in the most cost-effective manner." Assembly Resolution A35-5, Appendix I, Action Clause 2. Thus, for purposes of this guidance, it is assumed that a State (or its delegate) that has chosen to proceed with a local emissions charge on aircraft already has considered a range of options and has carried out a cost-effectiveness analysis and that the State is in the implementation stage for such a measure. By providing this guidance, ICAO does not mean to promote the use of emissions charges. However, it provides this guidance to promote consistency in approaches among those States that have decided to employ such charges.

1.2.2 While this guidance focuses on implementation of a local emissions charge, it may also be of assistance to those States (or their delegates) that are in the earlier stage of considering whether to proceed with a local emissions charge, as compared to other options. In such a case, the State (or its delegate) could use the guidance to assist in its consideration of a potential charges measure.

1.2.3 In the context of this guidance, the following terms are defined as meaning:

a) Aircraft Emissions with Local Air Quality Effects: For the purposes of this guidance, aircraft emissions with local air quality effects are defined as those aircraft emissions generated in the vicinity of an airport by aircraft either arriving or departing from that airport. The aircraft emissions include those generated from aircraft main engines either on the ground or in the air up to a level deemed to have local effect, as defined by the jurisdiction where the emissions are released. The aircraft pollutants of concern for these purposes are those gaseous emissions currently controlled for certification of aircraft engines under ICAO Annex 16, volume II, including oxides of nitrogen (NOx), carbon monoxide (CO), and hydrocarbons (HC). It is also recognized that secondary pollutants and particulate matter (PM) emissions from aircraft may have local effect and are a source of continuing research and evolving scientific understanding. To the extent that this research and understanding develops so as to allow ICAO to conclude that: 1) a new standard for direct emissions from aircraft engines is warranted or 2) a causal relationship can be demonstrated from direct emissions of precursors, then the directly emitted pollutant(s) may also be identified as an aircraft emissions of concern for purposes of this emissions charging guidance.

b) ICAO recognizes that different States may have different standards or thresholds for designating whether a pollutant as emitted has local effect. In many cases, this is expressed in terms of a maximum altitude up to which a particular pollutant is emitted. Some States may specify a specific altitude for such purposes. Others may direct that modelling be undertaken to identify the altitude at which pollutants may have local effect in a particular area, often referred to as the "mixing height" within the atmospheric "boundary layer." In basic terms, the mixing height is the height of the vertical mixing of the air and suspended particles above the ground within the atmospheric "boundary layer." Also in basic terms, the "boundary layer" is that part of the troposphere that is directly influenced by the presence of the earth's surface. States that specify a mixing height be determined for purposes of local air quality assessment typically have accepted models for such analyses and/or specify a default height for the mixing height, such as 3000 feet.

c) Local Emissions Charge for Aircraft: ICAO defines a Charge as "a levy that is designed and applied specifically to recover the costs of providing facilities and services for civil aviation." (Doc 9082/7) and (ICAO Assembly Resolution A35-5, Appendix I). In the context of aircraft emissions with local air quality effects, a Local Emissions Charge for

Aircraft is a levy (or fee) that is designed and applied specifically to prevent or mitigate environmental impact to local air quality caused by and directly attributable to civil aircraft operations.

d) Tax: ICAO defines a Tax as "a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entirety or on a cost-specific basis." (ICAO Assembly Resolution A35-5, Appendix I).

1.3 Existing ICAO Policies on Charges

1.3.1 To the extent that local emissions charges are to be levied on international flights, those charges should be consistent with ICAO policies on charges. The policies that are particularly relevant to emissions charges are enumerated in this section of the guidance. These policies have been culled from the ICAO Council Resolution on Environmental Charges and Taxes (adopted 9 December 1996) (referred to in this guidance as "Council Resolution"), ICAO Assembly Resolution A35-5, Consolidated Statement of Continuing ICAO Policies and Practices Related to Environmental Protection (referred to in this guidance as "A35-5"), and ICAO's Policies on Charges for Airports and Air Navigation Services (Doc. 9082/7) (referred to in this guidance as "ICAO's Policies"). Before implementing an aircraft emissions local emissions charging scheme, a State (or its delegate) should confirm that the scheme is consistent with these policies.

1.3.2 Take into Account the Interests of All Parties Concerned: When market-based emissions measures, such as charges, are adopted, Contracting States are encouraged "to take into account the interests of all parties concerned …" *Source:* A35-5, Appendix I, 2nd Action Clause.

1.3.3 Non-Discrimination**:** The ICAO Council urges "States that are considering the introduction of emissions-related charges to take into account the non-discrimination principle in Article 15 of the Convention on International Civil Aviation. . . ." *Source*: Council Resolution, 5th Action Clause. "Charges must be non-discriminatory both between foreign users and those having the nationality of the State in which the airport is located and engaged in similar international operations, and between two or more foreign users." *Source:* ICAO Policies, Paragraph 23(iv).

1.3.4 Take into Account the Potential Impacts on the Developing World: When market-based measures, such as emissions charges, are adopted, Contracting States are encouraged "to take into account the potential impacts on the developing world …" *Source:* A35-5, Appendix I, 2nd Action Clause. In light of the non-discrimination provision in Article 15 of the Chicago Convention, the way in which the potential impacts on the developing world are taken into account must not discriminate on the basis of State of Registry. This may or may not preclude the possibility of exemptions or waivers based on technical criteria, a transitional approach or a phased implementation. An example of a technical approach for taking into account the potential impacts on the developing world without running afoul of the non-discrimination requirement might be to exempt de minimis operations into an airport from the charging scheme. Operators from developing States may be able to benefit from de minimis exemptions, to the extent they may have fewer operations into a particular airport than operators from developed States. Nonetheless, because any operator from any State could take advantage of a de minimis exemption if its operations were below the threshold, such a scheme would not be discriminatory based on State of registry.

1.3.5 Transparency: Charging authorities are urged to "Ensure transparency as well as the availability and presentation of all financial data required to determine the basis for charges." *Source: ICAO Doc 9082/7*, Paragraph 15(iii).

1.3.6 Cost-Basis**:** "States that are considering the introduction of emissions-related charges" are urged to take into account the principle that "the charges should be related to costs." *Source*: Council Resolution, 5th Action Clause. Further, "charges should be based on the costs of mitigating the environmental impact of aircraft engine emissions to the extent that such costs can be properly identified and directly attributed to air transport." *Source:* A35-5, 10th "Whereas" Clause.

1.3.7 Cost-Effective Measures: When market-based measures, such as emissions charges, are adopted, States are encouraged "to evaluate the costs and benefits of the various measures, including existing measures, with the goal of addressing aircraft engine emissions in the most cost-effective manner ..." *Source:* A35-5, Appendix I, 2nd Action Clause.

1.3.8 Minimize Competitive Distortion: "States that are considering the introduction of emissions-related charges" are urged to take into account the principle that "the charges should not discriminate against air transport compared with other modes of transport." *Source*: Council Resolution, 5th Action Clause. In addition, authorities are urged to "Ensure there is no overcharging or other anti-competitive practice or abuse of dominant position." *Source: ICAO Doc 9082/7*, Paragraph 15(ii).

1.3.9 No Fiscal Aims: "States that are considering the introduction of emissions-related charges" are urged to take into account the principle that "there should be no fiscal aims behind the charges." *Source*: Council Resolution, 5th Action Clause.

1.3.10 Charges, rather than Taxes: The ICAO Council "Strongly recommends that any environmental levies on air transport which States may introduce should be in the form of charges rather than taxes...." *Source*: Council Resolution, 4th Action Clause.

1.3.11 Funds Collected Should Be Used to Mitigate Environmental Impact: The ICAO Council "Strongly recommends that any environmental levies on air transport which States may introduce should be in the form of charges rather than taxes and that the funds collected should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions, for example to: (a) addressing the specific damage caused by these emissions, if that can be identified; (b) funding scientific research into their environmental impact; or (c) funding research aimed at reducing their environmental impact, through developments in technology and new approaches to aircraft operations." *Source*: Council Resolution, 4th Action Clause.

1.4 Other Existing ICAO Guidance

1.4.1 In addition to the policies outlined in section 1.3, States may also wish to note that Appendix A of ICAO Assembly Resolution A35-5 states that "ICAO is conscious of and will continue to take into account the adverse environmental impacts that may be related to civil aviation activity and its responsibility and that of its Contracting States to achieve maximum compatibility between the safe and orderly development of civil aviation and the quality of the environment." Specifically in relation to local air quality, the Resolution states that ICAO will strive to "limit or reduce the impact of aviation emissions on local air quality."

1.4.2 States may also wish to note that Appendix I of A35-5 states that there has been increasing recognition by Governments of the need for each economic sector to pay the full cost of the environmental damage it causes. Appendix I also states that market-based measures are policy tools that are designed to achieve environmental goals at a lower costs and in a more flexible manner than traditional regulatory measures.

1.4.3 Appendix I also recalls Principle 16 of the Rio Declaration on Environment and Development (1992) which states that "national authorities should endeavor to promote the internalization of external costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment."

Chapter 2 - Process for Implementing Local Emissions Charges

This Chapter further identifies how States wishing to implement local emissions charges on aircraft might do so, specifically identifying the process steps that are involved.

2.1 **Responsibility of ICAO Contracting States**. It is ultimately the responsibility of individual ICAO Contracting States to develop appropriate solutions to environmental problems at their airports, with due regard to ICAO rules and policies. Appendix I of Assembly Resolution A35-5 recognizes in the context of market based measures that Contracting States have legal obligations, existing agreements, current laws and established policies. During the different phases of the introduction of any measure, ICAO Contracting States may chose to delegate their powers to any competent authority. Thus, while this guidance is specifically provided for States, it may also be applied by their delegates.

2.2 **An Airport-by-Airport Approach**. This guidance is intended to apply to any airport being served by international air traffic that has an identified local air quality (LAQ) problem and at which emissions charges have been identified as an appropriate instrument for mitigation. ICAO recognizes that a local emissions charging scheme needs to be tailored to the specific characteristics of the airport concerned by means of an airport-by-airport approach. Nonetheless, a general framework may be implemented at a State-level in order to set up a common methodology for the implementation of the scheme on an airport level for airports meeting the above criteria.

2.3 **An Inclusive and Transparent Process**. ICAO urges States to institute or oversee an inclusive and transparent process when adopting and implementing local emissions charges. The steps in this could include, but may not necessarily be limited to, the following:

a) Local Air Quality Assessment, including

   i. Identification of relevant local air quality standards and regulations;
   ii. Determination of airport air quality;
   iii. Compliance and impact assessment; and
   iv. Quantification of aircraft relative contribution.

b) Designing a Local Emissions Charges Scheme, including

   i. Aircraft engine emissions classification;
   ii. Establishing a cost-basis; and
   iii. Ways of levying the charge.

c) Administration, including

   i. Provision for consultation;
   ii. Dissemination of the evaluation results;
   iii. Notification of decisions;
   iv. Dispute resolution; and
   v. Reporting and recordkeeping.

The remainder of this document provides detailed guidance on these steps, in the same order as listed in this section.

Chapter 3 - Local Air Quality Assessment

3.1 **Overview**. States (or their delegates) that intend to introduce Local Emission Charges on aircraft should make an assessment of the existing and forecast future airport local air quality by comparing pollutant concentrations in the air in the vicinity of the airport against the relevant local air quality (LAQ) standard(s) and goals to determine if any exceedences exist or are predicted. This will identify whether a local air quality issue exists (or will exist in future) and to what extent. Accordingly, this chapter provides guidance on assessing LAQ at airports, determining compliance or otherwise with local air quality standards and goals, and quantifying the aircraft contribution to any non-compliance and its impact.

The recommended process involves four steps:

Step 1: Identification of Relevant Local Air Quality Standards and Regulations
Step 2: Determination of Airport Air Quality
Step 3: Compliance and Impact Assessment
Step 4: Quantification of Aircraft Relative Contribution.

More detail on the steps that are suggested is provided below.

3.2 Step 1 - Identification of Relevant Local Air Quality Standards and Regulations

3.2.1 Responsibility for defining and achieving acceptable air quality in and around airports rests with the State. States have historically developed their own air quality regulations and guidelines and, therefore, a number of national air quality standards exist. Some airports or regions may also establish criteria or goals that are more stringent than State standards (e.g., due to regional concerns).

3.2.2 In assessing local air quality in the vicinity of airports, it is important to identify any relevant local air quality standards and goals established by the State (or its delegate) to protect public health and welfare and the environment in general. These standards usually identify the levels or concentrations of pollutants that the State deems acceptable or unacceptable within a specified volume of air. Generally, local air quality standards or regulations will indicate the emissions species to be assessed, acceptable concentrations of each species over a specific period of time, the location or locations where the assessment is to be made and the period over which the assessment should be made. Other requirements such as measurement, modelling and reporting may also be specified. For more information on standards, regulatory drivers, and other background information related to State requirements, consult the ICAO CAEP Airport Air Quality Guidance Manual, xx.

3.3 Step 2 - Determination of Airport Air Quality

3.3.1 Airports and their associated activities are sources of different gaseous and particulate emissions. There are many air pollutants present in gaseous emissions from aviation-related activities that impact the environment. However, not all pollutants are relevant or regulated, and State requirements should be considered. Common emissions species considered in airport air quality assessments, which are relevant to this guidance, are oxides of nitrogen (NOx), hydrocarbons (HC), and carbon monoxide (CO), though other pollutants such as sulfur oxides (SOx) are often assessed as well.

3.3.2 Local air quality in and around an airport is quantified in terms of pollutant concentrations, as identified in Step 1 above. These concentrations can be calculated from airport activity data and numerical models of the emissions of each source and their interaction with the physical environment. Alternatively or additionally, existing pollutant levels can be measured using automated air sampling and analyzing equipment.

3.3.3 Numerical Modelling**.** Existing and/or predicted future concentration levels can be calculated utilizing software tools (numerical models). Local air quality modeling consists of the following two basic steps.

3.3.3.1 Emissions Inventory. An airport emissions inventory identifies the total amount of emissions of each species under consideration (e.g., pollutant kilograms over a specified period) generated by airport sources, either currently or at some future time. There are many emissions sources at airports and they typically are grouped into four categories:

i. aircraft,
ii. aircraft handling,
iii. stationary or infrastructure-related sources, and
iv. landside vehicle traffic sources.

The total airport emissions inventory is quantified by totaling all airport source emissions. For aircraft this should cover emissions generated during the landing and takeoff (LTO) cycle, calculated using inputs including aircraft and engine types, performance data, engine emissions data, number of aircraft movements, engine emissions factors (e.g., an emissions rate expressed as g/kg of fuel), and the respective operational parameters over a determined period. For the other sources including aircraft handling, stationary and infrastructure-related sources and landside traffic sources, individual emission source data for each source and species is required, as well as equipment and activity/operating data. The inventory should take into account the quantity of each species and the periods over which species of pollutants are emitted. In some cases, e.g., when subsequent dispersion modeling is to be performed based upon these data, inventories also take other parameters into account, such as location, time and temperature of the emissions.

The emissions inventory is a necessary input to dispersion modeling and determination of pollutant concentrations as outlined below. For more information on emissions inventorying and temporal and spatial distribution (e.g., steps, inventory parameters, emission species, airport emissions sources, and other considerations or factors), consult the ICAO CAEP Airport Air Quality Guidance Manual, xx.

3.3.3.2 <u>Dispersion Modeling.</u> Dispersion is the process by which atmospheric pollutants disseminate due to atmospheric conditions, terrain, buildings, chemical reactions and other factors. Dispersion modeling is a calculation procedure that takes parameters (including, among others, airport source emissions calculated in the emissions inventory, the timing and location of the emissions, meteorological conditions, and topography) and estimates the expected pollutant concentration levels at receptor locations, such as positions on an airport or at neighboring residential areas. These pollutant concentrations are calculated to determine whether emissions from the airport result in unacceptably high air pollution levels, and exceed State standards or goals (by comparison to relevant regulations). Various computer models with varying levels of sophistication are available to perform such modeling. ICAO CAEP is developing dispersion modelling guidance to include in the Airport Air Quality Guidance Manual for CAEP/8 in 2010. Until such time that ICAO CAEP guidance on dispersion modelling is available, States should follow State-specific guidelines and are encouraged to use best available data and methodologies.

3.3.4 Measurement. Air quality measurements of existing conditions can be conducted using air sampling and analyzing equipment that measure and record the current concentrations of a pollutant species at a specific location. Using a series of measurements, pollutant levels can be tracked over time and the average levels over a specific period (e.g., 1-hour, 8-hour, 24-hour, or 1 year) can be determined. Proprietary measurement equipment, including mobile units that can be installed temporarily, is widely available. Air quality measurements of existing pollutant levels can be used either directly or in combination with modelled results to determine the existing air quality situation at and in the vicinity of the airport (as measurements can only be taken of existing conditions, future local air quality can only be assessed using modelling). When measurements are used in combination with modelling, the measured data can be used to evaluate and refine modelled results or, conversely, modeling can be used to put the results of measurements into a proper context (e.g., when major off-site pollution sources dominate local air quality). ICAO CAEP is developing measurement guidance to include in the Airport Air Quality Guidance Manual for CAEP/8 in 2010. Until such time that ICAO CAEP guidance on measurement is available, States should follow State-specific guidelines and are encouraged to use best available data and methodologies.

3.3.5 Air Quality Forecasts. Air quality measurements and the corresponding modelling calculations indicate only the existing situation at an airport. To predict the air quality situation at some time in the future, the inventory needs to be repeated for some future operational scenario. Factors to be taken into account include, for example, projections of the volume of air traffic movements, the fleet mix including types of aircraft and engines, changes in airport infrastructure, changes in aircraft operational procedures, the expansion and/or replacement of non-aircraft sources including ground service equipment and other vehicles, and background concentrations of the pollutant species in the area. Once the expected growth (or reduction) of each of the relevant sources has been evaluated, the new inventory can be used to model the expected future air quality concentrations.

3.4 **Step 3 - Compliance and Impact Assessment**. The next step is to compare the measured and/or calculated existing and forecast pollutant concentrations to the concentrations specified in applicable State regulations in order to assess existing and future compliance with the standards and requirements. As State air quality standards are generally based on the protection of health of the population and the environment in general, exceedances of these limits are indicative of an adverse impact and typically action is required to alleviate the non-compliance and its impact.

3.5 **Step 4 - Quantification of Aircraft Relative Contribution**. To determine the relative contribution of aircraft to the LAQ situation, that contribution needs to be put in context with other airport sources and all airport sources may need to be put into the larger context of whatever local area is subject to the emissions standard or requirement. The contribution of an airport source's emissions to the airport's total emissions and its overall impact is dependent on the amount, time, and location of the emissions. Should such detailed analysis not be practicable, simplifying assumptions might be employed to estimate the aircraft contribution.

Chapter 4 - Designing a Local Emission Charges Scheme

4.1 **Overview**. Once the local air quality situation and the aircraft contribution to adverse impact has been determined, the charging scheme itself can be designed. The relevant steps States may wish to consider for designing such a charge are addressed in this Chapter.

4.2 Aircraft Engine Emissions Classification

4.2.1 In implementing a charging scheme, a common methodology for quantifying the amount of emissions from different aircraft engines should be identified, such that the charges applicable to specific aircraft can be determined and differentiated. Thus, a classification scheme is recommended to enhance consistency in the way aircraft engine emissions are calculated for purposes of applying a charge. The classification scheme should incorporate an accepted methodology for quantifying the amount of emissions emitted by each aircraft during a landing and takeoff (LTO) cycle. The methodology within this classification scheme should be transparent, reliable, consistently applied, and generally accepted by stakeholders.

4.2.2 ICAO recommends that an emissions classification scheme with the following elements be implemented:

a) <u>Calculation Based on Absolute Mass of Emissions</u>. The basis on which the aircraft is classified should be the absolute mass of the specified emissions within a landing and takeoff (LTO) cycle. As noted previously in, and for the purpose of, this guidance, the emissions of potential concern are NOx, HC and CO. To determine the mass of emissions per aircraft, every aircraft type has to be considered individually by identifying the specific engine type and using the relevant emissions data together with the number of those engines fitted to the aircraft.

b) <u>LTO Cycle</u>. Historically, ICAO has developed certification standards for aircraft engine emissions based on a standardized LTO cycle, with default assumptions for the time an aircraft will operate in each of the four LTO modes (take-off, climb out, approach and taxi). In the daily aircraft operation, however, thrust settings and time in each mode are very much dependent on the specific conditions like aircraft weight, outside temperature, wind, airport altitude, runway conditions and airline procedures. It should be noted that actual emissions will also vary according to factors such as ambient conditions and the mechanical condition of the engine. The ICAO standardized LTO-cycle will, therefore, not necessarily reflect actual emissions from aircraft engines at a specific airport. Therefore, within the context of emissions charges, actual times in mode or approximated actual times (e.g., average actual data or performance based times) and performance based thrust settings are preferred over ICAO default times whenever available. Likewise, for practicality, actual aircraft operational data for a specific aircraft may need to be averaged over a specified time period (e.g., the previous 3 months, previous 6 months, etc.) Absent the availability of average actual data or performance-based data, the default ICAO standard assumptions might be used.

For more information on calculating emissions during the LTO-cycle, consult the ICAO CAEP Airport Air Quality Guidance Manual, xx

c) Calculation of the Emission Value for an Aircraft. The following sets forth a recommended methodology for calculating an absolute amount of a specified emission (in this Guidance, either NOx, CO or HC) from an aircraft's engines during an LTO cycle, using NOx as an example. While the information is specific to NOx, the same approach can be taken for other emissions by replacing the "NOx index" (i.e., EI_{NOx}) in the formula with the index for another emission (for example, by replacing the "NOx index" with the "CO index").

Aircraft main engine emissions are a function of four parameters: aircraft fleet, time-in-mode and fuel flow, aircraft movements, and main engine emission indices. The basic equation is a function of these four parameters, as shown below. The purpose and need for quantifying aircraft emissions drive the level of accuracy required, which in turn, determines the sophistication level of the equation inputs used. For emissions charges purposes, a refined method for calculating aircraft emissions using best available and refined data (i.e., refined engine emission indices, aircraft time-in-mode including representation of mixing height, aircraft thrust level) should be utilized to most closely approximate actual aircraft LTO operations.

The absolute amount of NOx within the LTO cycle is calculated by using the ICAO pollutant emission index (EI) values for all LTO-modes of the individual engine and multiplying those EI's by the corresponding modal fuel flow. An EI is the mass of pollutant (CO, HC or NOx), in grams, divided by the mass of fuel used in kilograms. When ICAO engine emission indices (EIs) are used to calculate aircraft emissions, it is important to use the pollutant EI of the measured data, and not the pollutant Dp/Foo characteristic level of the regulatory data, which also is reported in the ICAO databank.

(Note: The characteristic Dp/Foo level is used to determine compliance of an engine type with emission standards. It is derived by correcting the measured EI values of an engine to the reference standard engine and reference atmospheric conditions and calculating an average Dp/Foo level. This is then converted to a characteristic level by the application of a coefficient corresponding to the number of tests and number of engines tested. The resulting statistically corrected values are always higher than the average Dp/Foo level.)

The formula is as follows:

$$Aircraft - NOx_{LTO} = E_N * \sum_{LTO-\mathrm{mod}\,es} \left(60 * time * fuelflow * EI_{NOx} \div 1000\right)$$

where:

E_N: number of engines fitted to the aircraft

Time: time in mode (in minutes)

Fuel flow: fuel flow per mode (in kg/sec)

EI_{NOx}: index per LTO mode, NOx emissions (in g/kg fuel)

Multi-Pollutant Considerations.

As noted above, the approach for calculating mass NOx could also be used for other emissions, such as HC or CO. However, there may be instances where a State or its delegate may want to take multiple emissions into account in a single aircraft engine emissions classification scheme. Although there is no ICAO-endorsed methodology for considering multiple emissions, one example methodology is the ECAC emissions classification scheme for NOx, as reflected in ECAC/27, Report, Strasbourg, 8-9 July 2003. NOx is the primary emission used for this classification methodology. However, ECAC recognized that some engines, particularly older engines, may have relatively low NOx emission values, but at the same time relatively high hydrocarbon emissions (HC). HC – applied as factor in relation to the ICAO limit – is mainly used in this calculation to avoid any undue treatment of engine technology with higher HC. The current ICAO standard[1] requires that any regulated engine shall not exceed the characteristic HC Dp/Foo of 19.6 g/kN rated output[2] during the LTO cycle test regime. For non-regulated engines (i.e. in this context engines without ICAO emissions certification), hydrocarbons are not being considered as the term Dp/Foo in g/kN is not applicable for unregulated engines.

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1 ICAO, Annex 16, Volume II: Aircraft Engine Emissions, 2nd edition, July 1993.

2 D_p is the mass of any gaseous pollutant emitted during the reference emissions LTO cycle. F_{oo} is the rated output, which for engine emissions purposes, is the maximum power/thrust available for take-off under normal operating conditions at ISA sea level static conditions without the use of water injection as approved by the certifying authority.

Accordingly, under the ECAC aircraft engine emissions classification scheme, all considered aircraft are set into a linear scale with the value:

$Emission\ Value_{Aircraft} \; = \; a * NOx_{Aircraft}$	(no dimension)

Where

a = 1 if the average HC D_p/F_{oo} is less than or equal than the current ICAO standard of 19.6 g/kN rated output or for unregulated engines.

a > 1 if the average HC D_p/F_{oo} is larger than the current ICAO standard. a = average measured HC $D_p/F_{oo)}$ / 19.6, with a maximum value for ‘a’ of 4.0

d) Application to Aircraft with Engines that Are Not Certified under Volume II, Part III, Chapter 2 or Chapter 3 of Annex 16 to the Chicago Convention. It is recommended that all civil aircraft with engines that are certified (i.e., regulated) under Volume II, Part III, Chapter 2 or Chapter 3 of Annex 16 to the Chicago Convention be classified with the above recommended methodology. This guidance does not address how or whether States should classify aircraft with non-certified aircraft engines. However, should a State decide to cover such aircraft with a charging scheme, the State should apply a consistent methodology to those aircraft. Appendix II gives one example of how some States have addressed the application of charges aircraft that are powered by non-certified aircraft engines.

e) Data Sources. Emission factors for ICAO-certified turbojet and turbofan engines of rated outputs > 26.7 kN are published in the ICAO Aircraft Exhaust Emissions Databank and can be found on:. http://www.caa.co.uk/default.aspx?categoryid=702&pagetype=90

4.3 **Establishing a Cost-Basis**. As noted previously in this guidance, if local emissions charges are to be applied to aircraft, those charges should be based on the costs of mitigating or preventing the environmental impact of aircraft engine emissions. In determining the cost-basis, States may find it beneficial to consider the following guidelines.

4.3.1 Types of Costs. The costs at issue are the costs that are properly identified and directly attributable to the aircraft contribution to LAQ adverse impact. These costs can be quantified in terms of damage, mitigation and/or prevention costs, as follows:

4.3.1.1 Damage costs. Damage costs are the costs incurred due to repercussions (effects) of direct environmental impacts (for example, from the emission of pollutants) such as the degradation of land or human-made structures or health effects. These costs are borne by a party (ies) other than the emitter or producer of a product or service. Damage cost can take many forms, such as the adverse effects on human health, water contamination, etc. caused by the degradation of local air quality from pollutants such as NOx, HC, and CO. If aircraft emissions charges are to be based on the value of the adverse environmental impact, an environmental damage cost assessment of the aircraft's contribution to adverse impact would need to be performed. Once the effects of environmental damage are known, the next step is to try to monetize the adverse effects, to the extent possible. It is beyond the scope of this guidance to address the means by which this process might be carried out. Nonetheless, some States may have guidance available on how to monetize such effects. After the damages are valued, a charge then can be set to recover those costs, apportioned to aircraft based on their contribution to the damage.

This process may be difficult to implement, however. While the environmental impacts may be readily identified in the form of smog alert days and adverse effects on health, it can be difficult to quantify these costs in terms of a monetary value. Health care or medical costs, for example, cannot be easily apportioned to a specific pollution species or source.

4.3.1.2 Mitigation costs. Mitigation costs are the cost aimed at adopting corrective measures to reduce an adverse environmental impact. This corrective action is typically in response (or reactive) to a problem once it has been discovered. If the charges are to be based on the costs of measures identified to alleviate the adverse impact, an assessment of the available measures would need to be undertaken. ICAO urges that any mitigation measures that are to be funded by aircraft charges be the most cost-effective measures available.

4.3.1.3 Prevention costs. Prevention costs are the costs to be incurred by taking actions aimed at avoiding anticipated adverse environmental impacts. This corrective action is typically proactive in anticipation of a problem. If a LAQ charge on aircraft operations is to be based on prevention costs, an assessment of the available measures would need to be undertaken. ICAO urges that any prevention measures that are to be funded by aircraft charges be the most cost-effective measures available.

4.3.1.4 Relationship Between Damage Costs and Mitigation and/or Prevention Measures. To the extent that mitigation and prevention measures are intended to address the damage from aircraft emissions, ideally the costs of any mitigation or prevention measures should be no greater than estimated damage costs. However, due to the fact that full or complete information for damage valuation may not be available, for a multitude of reasons, correlating damage costs with mitigation and prevention costs can be difficult. Nonetheless, the damage assessment process based on the best information available can provide a guidepost for determining the magnitude of the mitigation or prevention measures one might take to address the problem.

4.3.2 Avoiding Over-Charging. To the extent that aircraft emissions charges are to be based on the costs of addressing the portion of an LAQ problem that is directly attributable to the operation of aircraft, when a State (or its delegate) implements such a charge, care should be taken to avoid overcharging for the same problem. For example, if a general levy is put in place to deal with a specific NOx impact level from all sources of local emissions (including aircraft) on or in the proximity of an airport, then an aircraft emissions charge aimed at addressing that same NOx impact level would be inappropriate if it led to aircraft paying more than their share of the full damage, mitigation, or prevention cost.

4.3.3 Proper calibration, review and uses of charges. To the extent Local Emissions Charges are to be used, they should be calibrated on a periodic basis (e.g., annually, biennially, etc., but typically not less frequent than every four years) to address an identified existing or future local air quality problem. The charges will usually be levied by an airport on an aircraft operator. Local emissions charges can address the cost mentioned in paragraph 4.3.1 above in line with the policies and principles described in Chapter 1.

A requirement to evaluate and justify an emissions charge (and its level) over a specified period of time should be made part of any emissions charging scheme adopted by States. Once an environmental problem attributed directly to aircraft has been corrected and is not projected to return, LAQ aircraft emissions charges should cease to be imposed.

4.3.4 Use of Funds to Address LAQ Impacts: Existing ICAO policy (the December 1996 Council Resolution and Assembly Resolution A35-5) states the funds collected from an emissions charge should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions. The December 1996 Resolution provides three examples:

a) Addressing the specific damage caused by these emissions, if that can be identified;

b) Funding scientific research into their environmental impact;

c) Funding research aimed at reducing their environmental impact, through developments in technology and new approaches to aircraft operations.

4.3.4.1 As these categories are only examples, States may want to consider other categories of costs consistent with ICAO policy. For example, States may want to fund the mitigation or prevention of aircraft emissions from within the aviation sector. Such measures may also include air quality data gathering, monitoring and reporting systems for aircraft emissions, to the extent calibrated to address aircraft contribution to a local air quality concern. Examples of such measures might include the following:

a) Local air quality monitoring on the airport and in the vicinity to the extent it is believed aircraft may be contributing or are contributing to a local air quality problem;

b) Airport-related emission inventory calculation and dispersion modelling to the extent it is believed aircraft may be contributing or are contributing to a local air quality problem;

c) Installation of fixed ground power and ventilation for aircraft at piers aimed at mitigating emissions;

d) Installation of low emission fuel station (e.g., liquid natural gas, bio-fuels, etc.) for handling equipment and airside traffic aimed at mitigating emissions;

e) Improvements to aircraft ground movement systems such as taxiways designed to reduce emissions; and

f) Air quality management, research and development aimed at addressing aircraft local air quality emissions.

4.3.5 Cost-Effectiveness. Simply defined, cost-effectiveness represents achieving an environmental objective to reduce or avoid any adverse impacts on LAQ in the least costly way. States are encouraged to employ this concept in every facet of activities related to emissions charges, as a means of ensuring consistency with ICAO's policies on charges. Cost-Effectiveness Analysis is a technique that evaluates the variable costs or variable benefits against a prescribed objective (status quo or baseline) to determine cost-effectiveness. For a more detailed definition and discussion of cost-effectiveness analysis, please see ICAO's Balanced Approach Report (Doc 9829 AN/451).

4.4 Ways of Levying the Charge

There are different ways in which a State (or its delegate) might levy an aircraft emissions charge. This guidance describes some of the concepts and possibilities; in practice schemes may be a hybrid of these.

4.4.1 LTO Cycle. To the extent that the Emissions Classification scheme described above is employed, it would be most logical to levy the local emissions charge (LEC) based on the emissions generated on an LTO cycle basis for each aircraft. In this manner, an LEC scheme could be based on records of movements used to generate periodic (e.g., monthly) invoicing.

4.4.2 Direct Charge. A stand-alone, direct charge would be administered as a specific fee, separate from other fees an airline operator is subject to at a particular airport. This approach is likely to be the most transparent means for levying and collecting a charge, as the charging amount and its relation to the aircraft operator's emissions could be clearly reflected on the invoice that is used and not intertwined with other fees. For example, the charge levied could be expressed as a fee for each aircraft based on a fixed amount per kilogram of a certain species of pollutant (e.g., $x / kg NOx) emitted during the LTO cycle, which typically would be determined through application of the aircraft emissions classification methodology.

4.4.3 Modified Landing (or Takeoff) Charge. An alternative scheme could involve applying a modification to an already existing fee, such as a Landing (or Take-off) Fee. For example, for a specified level of NOx emitted in the LTO cycle (as determined through the aircraft emissions classification methodology), the Landing Fee is increased by x%.

4.4.4 Surcharges and Rebates.

4.4.4.1 Surcharge. A Surcharge is a charge applied to an aircraft movement which emits more than a certain threshold of a particular pollutant species. This can take the form of a Direct charge to the aircraft operator or an increased Landing (or Take-off) fee. The threshold could be defined on a scale set according to an aircraft's emissions as determined through the aircraft emissions classification methodology. The size of the surcharge can be linked to the extent to which the emissions are over the threshold. If the threshold is set at zero, then all aircraft would be paying a surcharge.

4.4.4.2 Rebate**.** A Rebate is a refund (or discount) applied to an aircraft movement which emits less than the threshold of a particular pollutant species. A Rebate on lower emissions aircraft would generally be applied in conjunction with a Surcharge on the higher emissions aircraft, using the same threshold. The Rebate can take the form of a direct refund to the aircraft operator or a decreased Landing (or Take-off) Fee. The size of the rebate can be linked to the extent to which the emissions are below the threshold.

4.4.4.3 Related to Costs. The level of the surcharges and rebates in a surcharge/rebate scheme should be based on analysis indicating that these surcharges/rebates will address the identified emissions problem. If it is intended that the total of the Surcharges collected (over a certain period) is to be greater than the total of the Rebates distributed, then the difference (i.e., net monies collected), should be related to costs as outlined in section 4.3 of this guidance.

It is also possible to set up a Surcharge and Rebate scheme, where there are no net monies collected (i.e., the total Surcharges are equal to the total Rebates) or where the total Surcharges are less than the total Rebates.

Chapter 5 - Administration

5.1 Provision for Consultation. Opportunities for meaningful consultation with stakeholders should be provided from the point a charge is being considered, through the point such a measure is adopted, and after adoption throughout the period of implementation.

5.1.1 Consultation aims to provide a forum in which all points of view may be explored in order to provide stakeholders the opportunity to be made aware of a perceived problem and to be notified that there is an intent to pursue corrective action through the implementation of local emissions charges.

5.1.2 Consistent with a transparent process, inviting stakeholders to participate in the discussions on the development of a new charge may help to highlight any practical issues or difficulties at an early stage. An open dialogue can be vital in developing mutual trust between all participants.

5.2 **Dissemination of the Evaluation Results**. Information on the local air quality situation, evaluation of impacts, determination of the aircraft contribution to those impacts, and on the cost-basis for the charge should be disseminated to stakeholders.

5.3 **Notification of Decisions**. Information regarding a proposed charge should be communicated as early as possible. When a revision of charges or the imposition of new local emissions charges is contemplated by a State or its delegate, appropriate notice should be given to the airlines or their representative bodies, normally at least four months in advance, in accordance with the regulations applicable in each State. Reasonable advance notice of the final decision should also be provided.

5.4 **Dispute Resolution**. In order to avoid and or minimize disputes it is important to have an open dialogue with the stakeholders and be transparent in the methodology and calculations of the charge. There may be a need for a "first resort" mechanism in case a dispute arises. Essentially, this entails having a neutral party at the local level available to focus on conciliation or mediation, or full arbitration if the State concerned so decides. Beyond that, there should be an appeals process consistent with the regulatory regime in the State concerned.

5.5 **Reporting and Recordkeeping**. Any State (or its delegate) imposing local emissions charges on aircraft that are in international operation should annually report the existence of such charging schemes to ICAO. Furthermore, the charging authority should maintain records regarding the charges collected and the use of funds and make them available to all users.

Appendix I – Glossary of Terms

This appendix contains a glossary of key terms used in the development of ICAO's guidance document on aircraft charges related to local air quality. This glossary does not, in any way, contain an exhaustive list of terms related to aviation environmental issues. Rather, it contains those key terms needed to better explain the nature of this guidance and its use in the proper context.

CAEP – Committee on Aviation Environmental Protection

Certificated Aircraft Engine - A certificated aircraft engine is defined as an engine that has demonstrated compliance with the requirements for emissions certification specified in ICAO Annex 16, Volume II, Part III, Chapter 2 or Chapter 3. Any aircraft engine that does not meet this compliance would be termed a non-certificated aircraft engine.

A **Charge** as a levy that is 'designed and applied specifically to recover the costs of providing facilities and services for civil aviation.' In the context of local emissions, a **Local Emissions Charge for Aircraft** is a levy (or fee) that is designed and applied specifically to alleviate environmental impact to local air quality caused by and directly attributable to civil aircraft operations.

Cost-Effectiveness Analysis (CEA) is a technique that evaluates the variable costs or variable benefits against a prescribed objective (status quo or baseline). CEA differs from **Cost-Benefit Analysis** (CBA) in that it asks a different question; namely, given a particular objective, which is the least costly (or most efficient) way achieving it? For a more detailed definition and discussion of cost-effectiveness, please see ICAO's Balanced Approach Report (Doc 9829 AN/451).

Damage Cost. The cost incurred due to repercussions (effects) of direct environmental impacts (for example, from the emission of pollutants) such as the degradation of land or human-made structures or health effects. These costs are borne by a party (ies) other than the emitter or producer of a product or service. Damage cost can take many forms, such as the adverse effects on human health, water contamination, etc. caused by the degradation of local air quality from pollutants such as NOx, HC, and CO.

Mitigation Cost represents the cost aimed at adopting corrective measures to reduce an adverse environmental impact. This corrective action is typically in response (or reactive) to a problem once it has been discovered.

Prevention Cost represents the cost to be incurred by taking actions aimed at avoiding anticipated adverse environmental impacts. This corrective action is typically proactive in anticipation of problem.

States' Delegates represent those entities acting on behalf of States to address a specified environmental purpose.

Tax. ICAO defines a **Tax** as "a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entirety or on a cost-specific basis." (ICAO Assembly Resolution A35-5, Appendix I).

Appendix II - ECAC Approach to Charges for Aircraft Powered by Non-Certified Aircraft Engines

In 2003 42 ECAC member states agreed upon a recommendation with respect to a scheme for the classification of aircraft Nox emissions (ref. ECAC 27-4). Two sets of data are used, one for those engines which are regulated by ICAO and other for those which are not. Data for regulated jet engines of equal to, or more than, 26.7 kN thrust are based upon the standardised ICAO landing and take-off (LTO) cycle as set out in ICAO Annex 16, Volume II and published in Document 9646-AN/943 (1995) and amendments. Data for unregulated engines have been reported by their manufacturers to the Swedish Aeronautical Institute (FOI). The Institute has been charged with producing an interim database that, with the manufacturer's consent, could be distributed to authorised parties. A proposal for an internationally recognized permanent emissions database for such engines has been put to ICAO.

To ensure non-discrimination, all civil aircraft with a maximum take-off weight (MTOW) over 8618 kg should be classified using the recommended methodology. Member states may classify emissions from other aircraft (e.g., aircraft not exceeding 8618 kg MTOW that are powered by small turboprops or piston engines, and helicopters) at their discretion. With respect to NOx, the contribution to emissions of these aircraft is very small compared to those of heavier aircraft.

The Swedish Defence Research Agency (FOI) is the keeper of a database of EIs for turboprop engines supplied by the manufacturers for the purposes of developing emissions inventories. Although the database is publicly available only through FOI, the International Coordinating Council of Aerospace Industries Associations (ICCAIA) closely monitors who requests the use of the database to ensure the data is not misused. The FOI database is not endorsed by ICAO because the data are not certified and may have inaccuracies resulting primarily from the unregulated test methodologies. There is also a significant issue of an appropriate idle setting for turboprops. Therefore, ICAO has included this information in this guidance document because it recognizes that the FOI turboprop database may assist airports in conducting emission inventories. Currently, documentation of how the EIs were derived and the types of turboprop engines is unavailable. Information about turboprop engines, suggested TIMs and how to obtain the data from FOI can be found at the following web links:

> www.foi.se -> English -> Activities -> What FOI can do for you? -> Confidential database for Turboprop Engine Emissions
>
> or http://www.foi.se/FOI/templates/Page____4618.aspx

Switzerland's Federal Office of Civil Aviation (FOCA) has developed a methodology and a measurement system to obtain emissions data from piston-powered aircraft. For these engine types, there is no requirement for emissions certification; hence the FOCA data is one of the few sources of data available for conducting emission inventories with respect to aircraft with these engines. However, the FOCA data has not been corroborated by ICAO, and is not endorsed by ICAO. Therefore, ICAO has included this information in this guidance document because it recognizes that FOCA's data may assist airports in conducting emission inventories for certain aircraft for which they otherwise might not have any data sources. The reader is referred to

FOCA's website below to obtain documentation of the emissions measurement system, the consistent measurement methodology, and recommendations for the use of their data to conduct simple emission inventories using suggested TIMs. All material is openly available for download at

http://www.aviation.admin.ch/fachleute/lufttechnik/entwicklung/00653/index.html?lang=en

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English only

APPENDIX D

for insertion in Doc 9082, Part II, after "Noise-related charges"[1]

Emissions-related aircraft charges to address local air quality problems at or around airports

1. The Council recognizes that although reductions in certain pollutants emitted by aircraft engines that affect local air quality (LAQ) are being addressed by a variety of measures of a technical or operational nature, some States may opt to apply emissions charges to address LAQ problems at or around airports. The Council considers that the costs incurred in mitigating or preventing the problem may, at the discretion of States, be attributed to airports and recovered from the users and that States have the flexibility to decide on the method of cost recovery and charging to be used in the light of local circumstances. In the event that LAQ emissions-related charges are to be levied the Council recommends that the following principles be applied:

i) LAQ emissions-related charges should be levied only at airports with a defined local air quality problem, either existing or projected, and should be designed to recover no more than the costs of measures applied to the mitigation or prevention of the damage caused by the aircraft.

ii) The cost basis for charges should be established in a transparent manner and the share directly attributable to aircraft should be properly assessed.

iii) Consultations with stakeholders should take place before any such charges are imposed on air carriers.

iv) LAQ emissions-related charges should be designed to address the local air quality problem in a cost-effective way.

v) LAQ emissions-related charges should be designed to recover the costs of addressing the local air quality problem at airports from the users in a fair and equitable manner, should be non-discriminatory between users and not be established at such levels as to be prohibitively high for the operation of certain aircraft.

vi) LAQ emissions-related charges could be associated with the landing fee, possibly by means of surcharges or rebates, or in the form of separate charges but should be subject to the proper identification of costs.

vii) It is recommended that the aircraft emissions charges scheme be based on data that most accurately reflect the actual operations of aircraft. In the absence of such data, ICAO standardized LTO-cycle times-in-mode should be used (ICAO Annex 16 – Environmental Protection to the Convention on International Civil Aviation, Volume II – Aircraft Engine Emissions).

[1] Text further amended by the Council during the consideration of the CAEP/7 report.

viii) Any State imposing LAQ emissions-related charges on aircraft that are in international operation should annually report the existence of such charging schemes to ICAO. The charging authority should maintain records regarding the fees collected and the use of funds to be made available to all users.

2. Additional guidance on LAQ emissions-related charges appears in “Guidance on Aircraft Emissions Charges Related to Local Air Quality” (Doc 9884).

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Agenda Item 3: Review of proposals relating to aircraft noise, including the amendment of Annex 16, Volume I

3.1 REPORT OF WORKING GROUP 1 (AIRCRAFT NOISE) GENERAL OVERVIEW

3.1.1 Introduction

3.1.1.1 The Co-rapporteurs of WG1 presented the working group's report. The main aim of Working Group 1 was to keep ICAO noise certification standards (Annex 16, Volume I) up to date and effective, while ensuring that the certification procedures (*Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft* (ETM) (ICAO Doc 9501)) were as simple and inexpensive as possible.

3.1.2 Work Accomplished

3.1.2.1 The detailed work of WG1 had been undertaken by a number of Task Groups and the activities and accomplishments of each were reported as summarized in the following paragraphs.

Certification Workshop Task Group

3.1.2.2 Three Workshops had been held since CAEP/6, in Montreal, in Rio de Janeiro and in Bangkok.

Future of Noise Certification Task Group (FTG)

3.1.2.3 A priority objective of WG1 had been the completion of a multiyear study into the future of the noise certification scheme and the extent to which the current scheme fulfilled the purpose of noise certification. The activity involved a study of the noise problem around airports and understanding the role of the current scheme in influencing aircraft design. A number of sub-topics were involved, as follows:

a) **The design process**. The aim of this work was to obtain a better understanding of the influence of noise certification requirements on aircraft design in general and whether the current scheme appropriately covered the different operational conditions. The conclusion of the work suggested that, whilst the noise design of an aircraft was driven by targets expressed in terms of noise levels at the certification conditions, the incorporation into the design of features enabling optimum application of noise abatement procedures was not encouraged by the current certification scheme. The work already underway concerning selectable and variable technology should rectify this situation.

b) **Correlation of noise levels around airports and noise certification levels**. An analysis had been completed correlating noise levels around airports arising from day-to-day operations with noise certification levels. Eleven airports in various parts of the world had been studied. A reasonably high degree of correlation between noise certification levels and operational noise levels had been found. WG1 consequently concluded that the study revealed no underlying problem with the current noise certification scheme.

c) **Impact analysis**. A MAGENTA based study had been completed of the noise problem at airports. The MAGENTA model had been used to assess the impact of both departures and arrivals on the population living around airports. WG1 had concluded that the study had shown there to be no compelling need to change the current scheme. It had also been agreed that noise problems far from an airport arising from arriving aircraft would probably best be solved by operational means.

d) **Report on the future of the Noise Certification Scheme**. Following the completion of these activities WG1 had concluded that there was no fundamental need to change the structure of the noise certification scheme. A more detailed report on this work was presented in a separate report to the meeting. It was recommended that the work items on correlation and impact analysis could be considered closed and that further work would concentrate on the incorporation into the design of features enabling optimum application of noise abatement procedures.

Rotorcraft Task Group (RTG)

3.1.2.4 RTG had examined: (1) ways to make rotorcraft noise reduction schemes more effective in addressing both noise certification and Land Use Planning (LUP) and ways to develop guidelines for providing helicopter data for LUP purposes; (2) all technical issues relating to helicopter noise certification; (3) the need for guidance on noise certification requirements for helicopters certificated for CAT A airworthiness; and (4) the noise requirements/exemptions for modifications to helicopter design for external attachments. The Steering Group had also agreed that the noise certification data for helicopters used by the RTG as a tool in different studies on proposals for new helicopter noise Standards should be put in the noise certification database (NoisedB).

Supersonic Task Group (SSTG)

3.1.2.5 The SSTG had continued to monitor information available about the ongoing research programmes in Europe, the United States and Japan. A summary of the status of the related research in Europe and the US was presented separately in the report of the Supersonic Research Focal Points (SRFPs).

Technical Issues Task Group (TITG)

3.1.2.6 The TITG had addressed technical issues that had arisen in the application of the certification schemes and related guidance. The principal effort in this area had been development of a new version of the ETM. This work is reported on separately.

Technology Task Group (TTG)

3.1.2.7 The work of this group had included:

a) Current status of research. In view of the progress achieved within the various national and international research programmes, it had been considered that enough material was available to present an information paper summarizing the current status of research aimed at technological solutions. Details were reported separately to the meeting.

b) Best Practices Database. It had been decided to examine the continued role of the Best Practices Database maintained by ICCAIA, in supporting the development of models used to populate future fleets and the replacement of retired aircraft in future studies.

c) Noise-Emissions Trade-offs. This topic had already been addressed in the discussions under Agenda Item 1 (see para 1.19 of this report); and

d) Noise database. The first version of NoisedB has been approved by WG1 and WG1 had agreed on a voluntary process for updating and maintaining the data in the database.

3.1.3 Discussions and conclusions

3.1.3.1 The meeting noted the work accomplished and endorsed WG1's actions and conclusions.

3.2 PROPOSED AMENDMENTS TO ANNEX 16 – ENVIRONMENTAL PROTECTION, VOLUME 1 - AIRCRAFT NOISE

3.2.1 Introduction

3.2.1.1 The Co-Rapporteurs of WG1 presented a number of proposals for the amendment of Annex 16, Volume I.

3.2.2 Helicopters

Certification and land-use planning

3.2.2.1 It was noted that Annex 16, Volume I, Attachment H. *Guidelines for Obtaining Helicopter Noise Data for Land-Use Planning Purposes* had been adopted at CAEP/6. In order to further develop Attachment H on particular technical points, some studies had been conducted by the RTG. It had previously been recognized that it might be desirable, for LUP purposes, to provide data for positions in addition to the microphone position(s) used for noise certification. It had been agreed by the RTG that Attachment H should be modified to provide the option for such additional microphone positions. Accordingly, new text had been developed for proposed inclusion in Attachment H.

Technical issues related to noise certification

3.2.2.2 It had been considered that in the definition of a "derived version of a helicopter" given in Annex 16, Volume I, Part I, the term "adversely" could be interpreted as not referring to Chapter 11 but only to Chapter 8. Since it was agreed that the definition should be the same for both chapters, the Steering Group had already agreed to RTG's proposed amendment to Note 2 of the definition.

Noise certification requirements for helicopters in "CAT A" operational mode

3.2.2.3 CAT A procedures form part of the flight manual normal procedures and are used under specific operational circumstances. There had been cases where, due to the specific design characteristics of a rotorcraft, the use of these operational rotor rpm modes could have had an impact on noise certification. Consequently, RTG had agreed on a revision of Chapter 8, paragraph 8.6.1.6 of Annex 16, Volume I. The paragraph now states that the maximum normal operating rotor speed corresponding to the reference flight condition must be used during each noise certification procedure. It was also proposed that the text of Chapter 11, paragraph 11.5.1.5 of Annex 16, Volume I be revised in the same way.

3.2.3 **Technical issues**

Definitions relating to wind speeds

3.2.3.1 The current definitions of the various wind speed limits and the definitions in the regulatory documents were ambiguous and inconsistent. Clarification was particularly important since exceeding wind speed limits is a common reason for having to suspend very expensive noise certification tests. Differences in technical implementation due to ambiguities and inconsistencies could potentially lead to big differences in costs of noise certification among different applicants and potentially in differences in repeatability and accuracy of the results. Using guidance issued by the World Meteorological Organization (WMO) and with the help of expert advice from the ICAO Meteorology (MET) Section, revised Annex 16, Volume I provisions that create a technically sound and well defined set of specifications were developed. Those specifications are unique to Annex 16 and do not therefore conflict with definitions and terminology already used in other ICAO Annexes.

Update of IEC references

3.2.3.2 Annex 16 contained references to several International Electrotechnical Commission (IEC) standards that establish specifications for equipment used in aircraft noise certification. Over the years, these specifications had been updated to reflect advances in electronics and manufacturing and measurement techniques. Inclusion of the most recent IEC Standards in the Annex was therefore being proposed, with an allowance to revert to earlier Standards which were still appropriate as an alternative, provided the level of quality deemed necessary continued to be met. The continuing acceptance of earlier Standards was regarded as an interim measure until such time as the use of obsolescent equipment ended.

Guidance on repairs limits for engine acoustic liners

3.2.3.3 The acoustic panels in the engines/nacelles of commercial aeroplanes can be damaged during normal service, and concerns had been raised as to whether this could lead to a deterioration of noise levels. Manufacturers specify how to repair and restore the functionality of a damaged part. The emphasis of the repair methods is on safety and structural integrity while minimizing any adverse impact on acoustic performance. For each engine and nacelle combination, there is an "acoustic area loss limitation" on the accumulation of lining losses due to repair. It had been agreed that the repair limitations in the maintenance manuals adequately safeguarded the integrity of the acoustic treatments, and it had been concluded that this work item did not need to be pursued further.

Review of Annex 16 concerning a possible change in V_2 increment as a function of take-off mass and/or aircraft configuration

3.2.3.4 It was noted that this task had been added to the work plan after an application for noise certification in a State had proposed to vary the speed increment applied to V_2 as a function of take-off mass. The intent of the applicant's proposal was to adjust the V_2 such that the lateral noise level would remain constant with changing take-off mass. The application had been denied. If the application had been approved it would have altered the historical relationship between lateral noise and take-off mass that is seen when looking at the mass range over which an aeroplane model is certificated, i.e., lateral noise increases with decreasing take-off mass due to the increase in duration as mass/speed decrease.

WG1 had not been able to identify any previous applications that used a variable speed increment. It was therefore proposed that Annex 16, Volume I, be amended to avoid any future use of a variable increment.

Applicability provisions

3.2.3.5 It was recalled that in Amendment 8 to Annex 16, Volume I, Chapter 1, *Administration*, the words "Type Certificate" had replaced the previously used expression "certificate of airworthiness for the prototype". This reflected current usage and aligned Annex 16 with other ICAO documents. The Steering Group had subsequently agreed that the same change should be made throughout the Annex. On further reflection, WG1 considered that if changes were to be made in this way, the notion of originality conveyed by the word "prototype" might be lost. WG1 did not believe that this had been the intention and now recommend a small change to paragraph 1.10 of Chapter 1 to restore the applicability rules to their original meaning. This change referred to the application to the State of Design and was thereby consistent with the applicability language used in Annex 8 — *Airworthiness of Aircraft*. WG1 also recommend that the applicability language of Annex 16, Volume I be further aligned with Annex 8 by referring to "date of submission of the application" rather than "date of acceptance of the application".

Editorial corrections

3.2.3.6 The WG also suggested some minor editorial corrections to the Annex.

3.2.4 **Discussion and conclusions**

3.2.4.1 The meeting noted some corrections which needed to be made to the French language text of the Annex and requested the Secretary to take the necessary action. The meeting agreed to all the proposed changes to Annex 16, Volume I.

3.2.4.2 The proposed amendments to Annex 16, Volume I are shown in Appendix A to the report on this agenda item.

3.2.5 **Recommendation**

3.2.5.1 In light of the foregoing, the meeting developed the following recommendation:

RSPP | **Recommendation 3/1 — Amendments to Annex 16 — *Environmental Protection,* Volume I — *Aircraft Noise***

That Annex 16, Volume I be amended as indicated in Appendix A to the report on this agenda item.

3.3 PROPOSED AMENDMENTS TO THE *ENVIRONMENTAL TECHNICAL MANUAL ON THE USE OF PROCEDURES IN THE NOISE CERTIFICATION OF AIRCRAFT* (ETM, DOC 9501)

3.3.1 **Introduction**

3.3.1.1 The Co-rapporteurs of WG1 presented a number of proposals for the amendment of the ETM.

3.3.2 **Rotorcraft**

3.3.2.1 The RTG proposed supporting guidance material in the three areas where corresponding amendments to Annex 16, Volume I were being proposed (see para. 3.2.2 above). These were:

a) certification and land-use planning;

b) technical issues related to noise certification; and

c) noise certification for helicopters in CAT A operational mode.

It was also proposed to add guidance to the ETM on noise certification of modifications to helicopters for external attachments.

3.3.3 **Technical Issues**

Differential Global Positioning Systems used in certification testing

3.3.3.1 Differential Global Positioning Systems are widely used in aircraft noise certification tests to track flight paths. Guidance material on this subject was developed for inclusion in the ETM.

Evaluation of noise measurement to establish no-acoustical change following engine modifications

3.3.3.2 The noise certification process for a new or derivative aircraft and/or engine was well established. However, there was often a need to assess minor modifications to an aircraft type design that resulted in insignificant noise changes. The ETM currently listed some examples of types of aircraft engine changes where component testing could provide adequate demonstration of the magnitude of small changes to EPNL. Various experimental and measurement arrangements had been used by manufacturers to carry out such testing, including in-duct acoustic measurements, that had been used to provide information that a modification to engine design had resulted in EPNL changes that were within the limits of "no-acoustical change" as defined in the ETM. However, no guidance material identifying acceptable experimental measurement techniques was currently available. Some guidance material had consequently been developed. It covered the use of acoustic measurements taken during indoor near-field and in-duct engine tests, for the purpose of assessing small changes in EPNL due to minor engine design modifications.

V_y investigation

3.3.3.3 This task addressed the regulatory differences between airworthiness performance rules and noise rules that may affect future Chapter 10 tests. Determination of best rate of climb speed V_y, which is specified as a reference speed in Chapter 10 tests, had been removed from the airworthiness requirements. The TITG had decided to address this issue by providing guidance in the ETM after considering the possible test cost increase and stringency implications of defining a new reference speed.

Other technical issues

3.3.3.4 Several other minor revisions to the text had been agreed to improve its readability and clarify its meaning.

3.3.4 **Discussion and conclusions**

3.3.4.1 The meeting agreed to the proposed amendments to the ETM. The amendments are shown in Appendix B to the report on this agenda item.

3.3.5 **Recommendation**

3.3.5.1 In light of the foregoing, the meeting developed the following recommendation:

> **Recommendation 3/2 — Amendments to the *Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft* (Doc 9501)**
>
> That the *Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft* (Doc 9501) be amended as indicated in Appendix B to the report on this agenda item.

3.4 **PROGRESS IN THE DEVELOPMENT OF A NEW ENVIRONMENTAL TECHNICAL MANUAL**

3.4.1 **Introduction**

3.4.1.1 The co-rapporteur of WG1 presented a report on progress made in developing a new version of the ETM. It was recalled that it had been agreed at CAEP/5 to explore the possibility of developing a new version of the document and the basic format for the new version had been agreed at CAEP/6. Progress on developing the document had continued since CAEP/6 and a progress report was presented to this meeting.

3.4.1.2 It had also been agreed that the new document should consist of a merging of the existing document with the United States Federal Aviation Administration (FAA) Advisory Circular AC36-4C.

3.4.2 **Current status of development**

3.4.2.1 The current status of each chapter of the new ETM was presented to the meeting. Current, but not necessarily final drafts of Chapters 1 to 4 had been reviewed by the focal points and were published on the CAEP website for review by CAEP members; these drafts were in various stages of maturity and could not be considered as final until approved by WG1 and the Steering Group. Chapters 5 through 7 were in less advanced stages of drafting and had not been presented for review as yet.

3.4.3 **Completion of the document**

3.4.3.1 It was expected that the complete text of the new ETM would be ready for presentation to the SG approval prior to CAEP/8 with final approval at the CAEP meeting itself. Formal publication by ICAO should follow as soon as possible thereafter.

3.4.4 **Discussion and conclusion**

3.4.4.1 The meeting noted the progress that had been made.

3.5 THE FUTURE OF THE NOISE CERTIFICATION SCHEME

3.5.1 Background

3.5.1.1 The Co-Rapporteurs of WG1 noted that this matter had been under study since CAEP/5 and also that it was confined to the noise certification scheme applied to jet and heavy propeller driven aeroplanes only.

3.5.1.2 The task could be summarized as being an assessment of how well the certification scheme met the CAEP-agreed purpose of noise certification. The definition of the "purpose" of noise certification was first developed at CAEP/3 and subsequently modified at the CAEP Steering Group meeting held in Madrid in June 1999, and was as follows:

> "The prime purpose of noise certification is to ensure that the latest available noise reduction technology is incorporated into aircraft design demonstrated by procedures which are relevant to day to day operations, to ensure that noise reduction offered by technology is reflected in reductions around airports."

3.5.1.3 The task had been split into three strands, i.e. the design process, problem identification and a comparison of certificated noise levels with noise levels arising from day to day operations monitored around airports. Each of these strands had been studied in detail and the results of these studies are summarized below.

3.5.2 The design process

3.5.2.1 The object of this study was to obtain a better understanding of the influence of noise certification requirements on aircraft design in general and how the impact of any potential changes to the certification scheme on aircraft design might be assessed. The study provided an insight into the factors balancing noise requirements with the other design considerations, the process of designing to an optimum configuration which targeted multiple noise objectives, and the role of technology development and the mechanisms for its incorporation into airframes and engines.

3.5.2.2 The conclusion of this work suggested that, whilst the noise design of an aircraft is driven by targets expressed in term of noise levels at the certification conditions, the incorporation into the design of features enabling optimum application of noise abatement procedures was not encouraged by the current certification scheme. The work already underway concerning selectable and variable technology should rectify this situation.

3.5.2.3 Concerning the influence on design of the cumulative margin concept introduced by Chapter 4, it was concluded that designing to a cumulative noise objective could result in improving preferentially one or two of the three points, but not to the detriment of the third point. The cumulative margin concept also provided greater flexibility for the optimisation of the aircraft design for requirements such as performance, mass, fuel burn and emissions, as well as noise.

3.5.3 Problem identification

3.5.3.1 The MAGENTA model has been used to assist in the identification of noise problem areas around airports and assess the relevance of the noise certification scheme to these problems. The chosen metric for "problem" assessment was the distribution of noise impacted population in terms of the contribution made by aircraft departures and arrivals at various altitudes and distances along flight tracks, and the association of the problem (number of people exposed) to an aircraft operational configuration (departure/arrival state, distance, and aircraft altitude) which could then be related to a noise certification demonstration procedure (flyover, lateral, or approach).

3.5.3.2 It was concluded that the majority of the level weighted population "highly annoyed" by departing aircraft would seem to be living some 7 to 12 km from start of roll. At this distance departing aircraft would probably be in a configuration bracketed by the lateral and cut-back certification reference procedures, suggesting that "noise reduction offered by technology is reflected in reductions around airports" at these locations.

3.5.3.3 It was further concluded that for arriving aircraft there were two locations at which significant numbers of people were highly annoyed, between 0 and 3 km and between 9 and 12 km. The certification point at 2 km was representative of the first location and a preliminary assessment suggested that it may also be representative, in terms of configuration at least, of the second. However WG1 considered that such "far out" problems, where they are shown to exist, would probably best be solved by operational means rather than a change to the certification scheme itself. It was therefore being recommended that the noise arising from arriving aircraft at locations far away from the airport be studied by WG2.

3.5.3.4 Overall, the group had concluded that the results of the MAGENTA study into problem identification did not reveal a compelling need to change the current certification scheme at this stage.

3.5.4 **Correlation of noise certification and operational levels**

3.5.4.1 This activity was primarily concerned with an assessment of the relevance of the noise certification reference procedures to day-to-day operations. A study had been conducted of the correlation of noise certification levels with operational noise levels recorded by airport noise monitoring stations at a number of airports in North America, Europe and Australia.

3.5.4.2 WG1 had chosen the non-parametric Spearman rank order correlation coefficient as the most appropriate measure of correlation.

3.5.4.3 Each of the different airport datasets had been manipulated in a manner appropriate to the available underlying available data descriptors. However, whatever the noise unit and whatever underlying characteristics the datasets may have had, the results were broadly similar.

3.5.4.4 As might have been expected, each of the datasets had data points which might be considered as outliers. Both parametric and non-parametric means had been used to identify these outliers. The few individual aircraft types that had been revealed to be outliers at a significant number of monitors and/or airports did not suggest there was a fundamental problem with the certification scheme itself.

3.5.4.5 However it was noted that two aircraft types in the study had been identified as outliers at four or more of the study airports. WG1 had considered whether the past certification history of these particular outlying aircraft should be reviewed as a specific work item in the future, with the aim of demonstrating the robustness of the current certification requirements or of identifying if improvements were necessary. However, the proprietary nature of the data required for such a study would make it impossible for WG1 to carry out the work itself. The ICCAIA members directly concerned with these outlier aircraft had agreed to conduct a study to better understand the observed behaviour, working closely with the appropriate certificating authorities and utilising all available data. It had been agreed that any underlying problem with the certification scheme itself that the study might reveal would be brought to the attention of WG1 (or the appropriate task group) during the CAEP/8 work programme.

3.5.4.6 It had been concluded overall that there was a reasonably high degree of correlation between noise certification levels and operational noise levels.

3.5.5 **Discussion and conclusions**

3.5.5.1 Concerning the design process, an observer expressed concern about the cumulative margin concept now included in Chapter 4 of the Annex. He believed that this did not achieve CAEP's goals in that it did not ensure a reduction in noise at each of the certification points.

3.5.5.2 A member was concerned that the report text relating to the cumulative margin concept to other design considerations mixed different concepts and was not clear.

3.5.5.3 The meeting agreed that, in the context of design, the work relating to selectable and variable technology should be continued. It also noted that the cumulative margin concept for noise also provided flexibility for the optimization of the aircraft design requirements for performance, mass, emissions, etc.

3.5.5.4 There was considerable discussion on the question of the noise problem distant from an airport (i.e. 9 to 12 km from the airport). It was suggested that the selectable and variable technology mentioned above might be expected to help alleviate this problem, although it was not clear what design certification steps could be taken to influence the matter. It was indicated that selectable and variable technology was starting to be introduced into service now and more information on this subject would be provided at the next WG1 meeting.

3.5.5.5 There was some difference of opinion among members concerning the benefits in the "far out" case that could be expected from operational measures. One member considered that the discussion highlighted a gap in the knowledge of members concerning the rapid developments that were taking place in managing air traffic more flexibly and the opportunities this could give to alleviate noise problems.

3.5.5.6 The meeting agreed that the problem of noise from arriving aircraft far away from airports should be studied further by WG2. However, it was considered that the meaning of "far away" needed to be more precisely defined. Several members considered that 9 — 12 km was the appropriate distance, but other members thought that longer distances should be considered. It was also suggested that WG2 should review the matter further before any decision was taken. It was eventually agreed that 9 — 12 km should be the initial focus of attention with extension to a greater distance if this proved to be appropriate.

3.5.5.7 The meeting endorsed the conclusion from the correlation study that there was no compelling need to change the current certification scheme. A member noted that WG1 had suggested that this item could be considered as closed, however, he believed that until the ICCAIA study aimed at better understanding the outlier aircraft had been concluded, the subject should remain open. The meeting agreed. The meeting agreed that this issue was closed for now but may need to be reopened depending on the findings of the ICCAIA study. The meeting also endorsed the conclusion that there was a reasonably high degree of correlation between noise certification levels and operational noise levels.

3.6 CURRENT STATUS OF RESEARCH INTO TECHNICAL SOLUTIONS TO NOISE REDUCTION

3.6.1 The meeting was provided by the Task Focal Point with a report on the current status of worldwide research into technical means of reducing noise at source. This followed up on the first Noise Technology Workshop organized by CAEP/ICAO in 2001. It was suggested that the information would form a good basis for holding a second such workshop later in 2007.

3.6.2 It was noted that there was a definite trend towards the integration of noise technology aspects into larger initiatives dealing with a number of environmental goals being addressed in an operational context. With such initiatives, integrated research solutions were beginning to appear which offered a combination of technological and operational solutions.

3.6.3 The meeting noted the detailed information provided with interest. It was agreed that the possibility of holding a second workshop in conjunction with a Steering Group meeting would be considered further by the Focal Point. A member commented that it would be useful if eventually noise reduction technology goals, similar to those developed for emissions, could arise from this work. He also suggested the utility of applying the TRL process to noise standards. In response it was cautioned that the scope of technologies involved was much wider for noise than for emissions and this might make goal setting much more difficult. A similar difficulty existed in regard to predicting how quickly technologies might progress through the Technology Readiness Scale. The member noted that, despite such difficulties, such goals had been set in the past.

3.7 STATUS OF KNOWLEDGE RELATING TO SONIC BOOM

3.7.1 The Research Focal Points presented a report summarizing the current understanding of sonic boom noise. It included a brief background on the overall nature of sonic booms and the problems arising there from. Past and present research on the phenomenon was reviewed with a focus on what was known and not known, particularly regarding human response to “low” sonic booms.

3.8 REVIEW OF SUPERSONIC STANDARDS

3.8.1 Introduction

3.8.1.1 The Rapporteurs of WG1 and WG3 introduced a paper reporting on a review of the status of the development of provisions relating to noise and emissions from supersonic aircraft. It was noted that major investigations into the development of a new high speed supersonic aircraft concept had been undertaken during the 1990s. Some current industry programmes were concentrating on smaller applications such as business jets. CAEP had consequently decided to expand its work programme and investigate some environmental aspects associated with these developments. WG1 had consequently been reviewing the need for a revision of the noise provisions and WG3 had been reviewing the need for a revision of the emissions standards for aircraft and engines intended for supersonic transport aircraft. The Working Groups had reviewed the historic background of the development of the present supersonic emissions standard.

3.8.2 **Noise**

3.8.2.1 It was noted that Annex 16, Volume I, in Chapter 12, establishes the procedures of Chapter 2 as being applicable for supersonic aircraft, but does not include noise level Standards. In a Note, the Chapter indicates that the noise levels of Chapter 3 should be used as guidelines in this respect.

3.8.2.2 WG1 believed that if Standards were to be developed, it would be necessary for them to be as stringent as for the latest subsonic aircraft, i.e. consistent with Chapter 4.

3.8.2.3 WG1 further considered that there was insufficient information available for it to begin establishing limits or demonstration procedures for sonic boom control for operations over populated areas.

3.8.3 **Emissions**

3.8.3.1 WG3 noted that manufacturers had developed emissions goals and timelines covering the period up to 2013. WG3 had acknowledged these goals and timetable as useful information for deciding on future work. However, it was considered that the expectations were optimistic since the work faced significant challenges that would need to be resolved.

3.8.3.2 WG3's review of the existing supersonic LTO emissions standard led it to the preliminary conclusion that the requirements were outdated and should not be applied to new engine projects. There would need to be significant revisions for any new supersonic transport aircraft, including consideration of in-flight emission impacts.

3.8.4 **Discussion and conclusions**

3.8.4.1 The meeting noted the current status of discussions and observations from WG1 and WG3. It agreed that in view of the uncertainties, no goals or timelines could be determined at present.

3.8.4.2 The meeting discussed the WG's request for guidance on the further information that CAEP would require in order to make decisions on future Standards. Some members considered that CAEP's role was reactive at present and it could not give the working groups further direction until it had, itself, received further information. Another member thought that some direction could be given but it would need further study. It was agreed that, for the present, States should be encouraged to provide any information they might have which might help to advance the debate.

3.8.4.3 A member asked whether any provisions had been considered concerning damage to buildings from sonic booms. In response it was stated that past experience had indicated that such damage was extremely rare and of a minor nature. Another member indicated that in his State such damage was avoided by confining supersonic flight to areas away from human habitation.

3.9 **REPORT OF WORKING GROUP 2**

3.9.1 The Rapporteur presented a summary report of work relating to noise undertaken by WG2. Several topics had been addressed and would be the subject of separate presentations to the meeting. The topics were:

a) updating of the guidance material on the balanced approach, including development of a generic presentation on the subject;

b) development of an amendment to the Airport Planning Manual concerning the balanced approach guidance material and inclusion of the information from States on their practices;

c) curfews at airports;

d) a revised version of Circular 205 on noise contour calculation;

e) development of an ICAO circular on noise and emissions effects of noise abatement departure procedures;

f) a review of research into noise abatement procedures; and

g) a review of the implementation of the continuous descent approach procedure.

3.10 STATUS OF THE WORK ON THE REVISION OF THE ICAO AIRPORT PLANNING MANUAL, PART 2: LAND-USE AND ENVIRONMENTAL CONTROL

3.10.1 Introduction

3.10.1.1 The Rapporteurs of WG2 noted that the *Airport Planning Manual* (APM), Part 2, is now in its third edition, dated 2002. In order to further update the APM a State Letter requesting information on States' policy regarding land use planning and management of land in areas surrounding airports had been sent to States in September 2005.

3.10.2 State Letter replies

3.10.2.1 Responses to the State Letter had been received from 30 States, of whom thirteen already had information in the APM. Several of the States did not fully respond to the requests of the State Letter and two States, although replying, did not provide any information. Based on the replies received, a revision to the APM had been developed.

3.10.3 Cross-reference to the balanced approach document

3.10.3.1 Since land use planning and management was one of the elements of the *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829), WG2 was suggesting the inclusion in Chapter 2 of the APM of a new paragraph 2.2.6 containing a cross-reference to Doc 9829.

3.10.4 Discussion and conclusions

3.10.4.1 The meeting agreed with the proposed amendments which are shown in Appendix C to the report on this agenda item.

3.10.5 **Recommendation**

3.10.5.1 In light of the foregoing, the meeting developed the following recommendation:

Recommendation 3/3 — Amendment of the *Airport Planning Manual*, Part 2 — *Land Use and Environmental Control* (Doc 9184)

That the *Airport Planning Manual* (Doc 9184) be amended as indicated in Appendix C to the report on this agenda item.

3.11 CURFEWS

3.11.1 Introduction

3.11.1.1 It was noted that the issue of curfews had been raised during the 35th Session of the ICAO Assembly, and, as a consequence, CAEP had been requested to study the problem. WG2 had been charged with preparing information on the scope and scale of the problem for this meeting's review. A study had consequently been conducted by a member of TG2. The study was not an exhaustive and comprehensive review of curfews, but limited itself to examining the types of curfew, the reasons for curfews and their global scope and scale. In this context of the scale, scale had been understood as the number of airports that apply curfews and scope as the type of restriction (partial or total).

3.11.1.2 A curfew is already defined in the Balanced Approach Guidance document as follows:

"***Curfew.*** An airport curfew is a global or aircraft-specific partial operating restriction that prohibits take-off and/or landing during an identified time period."

A global curfew is one which bans all flights during a specific time period. A partial curfew prohibits the operation of specific aircraft types, or prevents the use of specific runways or only affects landings or take-offs. Curfews normally apply only at night, e.g. from 2300 hr to 0700 hr.

3.11.1.3 A curfew established at an airfield does not only affect that airfield and its environs. It may also affect the departure and arrival times at other airports.

3.11.1.4 There is growing pressure to impose curfews in some parts of the world. Curfews are often seen as simple and ready-to-use instruments for affecting the noise climate around an airport. The increased pressure arises because many airports are located in densely populated noise sensitive areas, leading to many complaints about noise and even lawsuits against airport organizations.

3.11.1.5 In preparing information on the scale and scope of curfews, it had been noted that the Boeing Company had developed a database of worldwide regulations on noise that could be used to provide information. This database had consequently been utilized to prepare a "snapshot in time" of the curfew situation at the airports it covered. The Boeing database contained information on 610 of the world's major international and regional airports, approximately half of which are in North America. Out of the total list, about 227 airports have curfews. It was noted that a few airports in the database were labelled as having curfews, but the details indicated that they were historic curfews which no longer applied. Approximately half of the airports with curfews were in Europe and a third were in North America. The remainder were spread over the rest of the world. Of the 30 busiest airports (passenger numbers above 30 million p.a.), 18 were in North America and only 4 of these had curfews. The 6 in Europe all had curfews. Of the remaining 6 – all of which were in Asia – only 2 had curfews.

3.11.1.6 The curfews could affect many types of operation carried out at night, such as: scheduled short- and long-haul passenger flights, passenger charter flights, scheduled and charter freight flights, express and mail flights. Short haul passenger operations accounted for a significant proportion of night flights (34 per cent in Europe). Long-range flights, which often arrive early in the morning, also exhibit a directionality, with two thirds departing in the early morning but less than half landing late in the evening.

3.11.1.7 The study included an inventory of 227 airports with curfews, as extracted from the Boeing database.

3.11.1.8 The Steering Group had raised the possibility of placing the curfew inventory on the ICAO website. However, WG2 recommended that this not be done for practical reasons (duplication and maintenance of data, resource difficulties, etc.). The Meeting was invited to consider instead recommending that an internet link to the Boeing database be placed on the ICAO website.

3.11.2 **Discussion and conclusions**

3.11.2.1 Some concern was expressed about the accuracy of the Boeing document and whether it would be maintained for the foreseeable future. The meeting was informed by an observer that the document was updated regularly, based on information provided by airports, and also that Boeing had every intention of continuing to produce the document.

3.11.2.2 Concerning a link to the Boeing document on the ICAO website, the Secretary indicated that the Boeing Company had been approached on this matter and had no objection to ICAO's posting the link.

3.11.2.3 The meeting noted the information provided and agreed that it responded to the Council's request. It also endorsed the use of the Boeing document and agreed to a link to it being placed on the ICAO website.

3.12 **UPDATE OF THE BALANCED APPROACH GUIDANCE MATERIAL (DOC 9829)**

3.12.1 **Introduction**

3.12.1.1 The Co-Rapporteurs of WG2 recalled that the *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829) had been published by ICAO in 2004. The document provided States with an internationally agreed approach to addressing aircraft noise problems at individual airports, in an environmentally responsive and economically responsible way. The balanced approach encompassed four principal elements: reduction of noise at source, land-use planning and management, noise abatement operational procedures and operating restrictions on aircraft.

3.12.1.2 It had initially been intended to include appendices in the document related to airport case studies and encroachment analysis. However, since these were not completed at the time of the first edition, it had been agreed to include them in a subsequent version.

3.12.1.3 It had also been suggested, at the 35th Session of the ICAO Assembly, that strategies for addressing "people issues" be incorporated into the Guidance Material on the Balanced Approach, and this issue was subsequently added to WG2's work programme.

3.12.2 **People issues**

3.12.2.1 A number of changes to the Document had been developed to reflect this aspect. These included, in particular, information on communication strategies and enhanced information for public access. Some members of the WG had expressed the view that the document would be improved if more emphasis were placed on proactive strategies aimed at preventing problems from emerging in the first place. However, the Steering Group had decided that inclusion of text on proactive strategies was not necessary, since use of the Balanced Approach could take forecasts into account when dealing with an identifiable noise problem and consultation was already contemplated in the guidance.

3.12.3 **Encroachment analysis**

3.12.3.1 The CAEP/6 meeting had called for the development of an appendix on encroachment to be added to the document, based on the work performed before CAEP/6. The group had however concluded that the methodology previously developed was not yet sufficiently mature to be incorporated. Another study on encroachment was ongoing in one State and, due to time considerations, WG2 had recommended, and the Steering Group had agreed, that development of the encroachment analysis appendix be continued into the CAEP/8 cycle.

3.12.4 **Airport case studies**

3.12.4.1 An Information Paper presented to CAEP/6 had contained some airport case studies but had not been published with the initial Balanced Approach document. This had now been expanded to include additional studies, and it was being proposed that this information be published with the revised Document.

3.12.5 **Discussion and conclusions**

3.12.5.1 The meeting agreed with the proposed amendments to Doc 9829 which are shown in Appendix D to the report on this agenda item. It noted that this was a living document which would continue to need periodic updating.

3.12.6 **Recommendation**

3.12.6.1 In light of the foregoing, the meeting developed the following recommendation:

> **Recommendation 3/4 — Amendment to the *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829)**
>
> That *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829) be amended as indicated in Appendix D to the report on this agenda item.

3.13 GENERIC PRESENTATION ON THE BALANCED APPROACH

3.13.1 Introduction

3.13.1.1 The Task Group Rapporteur noted that the arranging of workshops to promote the Balanced Approach guidance document and the Airport Planning Manual (APM) had been agreed by CAEP/6 as part of the WG2 Work Programme. However, experience with the organizing of the Operational Benefits Seminars had shown that a considerable effort in terms of funding and staff resources was required. It was therefore considered that it would be very difficult to organize similar workshops for the Balanced Approach.

3.13.1.2 It had been agreed that, as an alternative, extensive exposure could be gained through presentations on the subject at events already scheduled, such as seminars, conferences and symposia and also to organizations such as ACAC, LACAC, AFCAC, ECAC, etc. Task Group 1 had consequently developed a generic presentation containing key elements of the Balanced Approach for use in promoting the guidance material.

3.13.2 Discussion and conclusions

3.13.2.1 The meeting was reminded that the Steering Group had already agreed to the generic presentation, recognizing that it shall be periodically updated to reflect the developments in this area. It was agreed that the use of the presentation was subject to prior approval by ICAO. Such approval would be applied to the credentials of the individuals that would provide the presentation on behalf of ICAO and on the appropriateness of the event where the presentation would be delivered. A number of amendments to the presentation were suggested to align it with the updated guidance document (see 3.12 above) and other developments. The task group rapporteurs agreed to review the presentation accordingly.

3.13.2.2 It was suggested that, for the sake of uniformity, some speakers' notes should be drafted to accompany the visual presentation, and it was also suggested that a taped seminar could be posted on the ICAO website.

3.13.2.3 Some members wondered how the question of the interaction with emissions aspects (in respect of noise abatement procedures) should be dealt with. In response, it was stated that this was an important and fast developing subject and that an inclusion in the presentation on it had yet to be developed.

3.13.2.4 The meeting endorsed the presentation, subject to it being updated.

3.14 GUIDANCE ON MANAGEMENT OF 'AREA-WIDE' AIRCRAFT NOISE

3.14.1 Introduction

3.14.1.1 A member drew attention to the fact that pressures to impose operational constraints or oppose airport growth in his State were increasingly coming from residents living in areas outside conventional noise contours (e.g. outside the contours that are used to delineate areas that are subject to land use planning controls or that are used to define eligibility for some form of remediation (e.g. acoustic insulation). The residents of these 'distant' areas generally lived under busy flight paths. Typically residents in these areas had expectations that there would be little or possibly no noise. Residents were particularly aggrieved when:

a) they unknowingly moved into a house under a busy flight path; this dissatisfaction was compounded if they made a housing decision after examining 'official' information (e.g. published noise contours) that had led them to believe they would get no noise; and

b) flight paths were moved over their residence without consultation; for example, they had been effectively ignored in the environmental assessment process because they were in an area which was considered to have 'insignificant' levels of aircraft exposure.

3.14.1.2 This issue was not amenable to being addressed with many of the traditional noise management tools which focussed on dealing with 'close in' aircraft noise.

3.14.2 **Management Options For 'Distant' Noise**

The Balanced Approach

3.14.2.1 While the Land Use Planning element of the balanced approach did not appear to be of potential use, application of the other three elements might be of benefit:

a) *Reduction of noise at source* may be helpful. However, for many distant residents the issue primarily related to the high numbers of movements and a lack of respite rather than the level of intrusive noise per se; and

b) *Noise abatement operational procedures* had potential beneficial application:

   1) they might be used to optimise the location of flight paths relative to the location of housing in the 'distant' areas. However, growing pressures to relocate flight paths to reduce emissions may work against the implementation of potential options; and

   2) the noise benefits of some operational procedures (e.g. CDAs) may have the greatest positive effect; and

c) Implementation of *Operating Restrictions* (e.g. curfews & movement caps) would generally give relief for distant residents. However, application of the 'distant' noise management strategies suggested would probably be preferred if assessed using the cost/benefit analysis principles in Chapter 9 of the *Balanced Approach Guidance.*

'Distant' Noise Management Strategies

3.14.2.2 A number of strategies, which are distinctly different to the conventional 'close in' noise management approaches, could be applied to address the issue. In particular these could be focussed on implementing measures to ensure that people were not subjected to surprise noise and were given the opportunity to be involved in decisions on the location of flight paths in the vicinity of their residence.

3.14.2.3 *Area wide noise disclosure* – the concept was that detailed, up to date, aircraft noise and flight path information covering, at least, the whole of the Terminal Area around an airport, should be well advertised and be readily accessible to any member of the public. It was intended that this information would be available for examination by potential house buyers before they made a purchase decision. Issues to be studied would include:

a) what information should be available (including examples of useful concepts such as live flight tracking sites, Flight Path Movements Charts, etc);

b) which body or bodies should be responsible for producing and updating the information;

c) how often should it be updated;

d) how far out should the information extend (e.g. should it extend to major feed flight paths into the terminal area);

e) how should the information be delivered (internet sites, newspapers, reports, etc); and

f) administrative/legislative issues

3.14.2.4 *Inclusive aircraft noise assessment* – in order to ensure that distant communities were not excluded from environmental impact assessment processes, assessments of proposed projects that would potentially change flight paths around airports needed to be based on area wide aircraft noise exposure information. These techniques were likely to be focussed on:

a) the examination of flight paths across the terminal area and on time-stamped activity levels on those flight paths; and

b) aircraft noise information based on comprehensive area wide noise grids.

3.14.2.5 *Community/*airport *partnerships* – well formed community engagement processes/structures needed to be put in place which catered for the residents of ‘distant’ areas in order to:

a) enhance awareness of distant flight paths; and

b) give recognition to residents that they had a legitimate stake in how the airport operated.

3.14.2.6 In light of the foregoing, the member suggested that CAEP should develop an ICAO guideline document on the management of “area wide” noise.

3.14.3 **Discussion and conclusions**

3.14.3.1 Some members indicated that they faced similar problems in their States. In response to a query, the member presenting the paper stated that although the paper concentrated on one airport where the problem was greatest, it was a generic problem in his State. An observer was of the view that land use planning could be valuable in these cases, that the new supplemental measures in the Balanced Approach guidance material could be applied to the issue, and that no action should be taken until there had been time to assess the effectiveness of these measures.

3.14.3.2 There was also some question concerning the presenter's definition of "close in" and "far out". Any such definitions might not be applicable in some areas, especially where several busy airports were close together.

3.14.3.3 The meeting noted the information provided, and considered whether guidance material on area-wide noise mitigation should be developed. One member considered that the development of guidance was not warranted but that the contents of the paper could be disseminated as information for interested parties. The meeting subsequently agreed that the experience described could usefully be included as a case study in the guidance on the balanced approach. Any other information or case studies on far out noise and the trade-offs between noise and emissions with respect to abatement procedures could also be included.

3.15 REPLACEMENT OF ICAO CIRCULAR 205: RECOMMENDED METHOD FOR COMPUTING NOISE CONTOURS AROUND AIRPORTS

3.15.1 Introduction

3.15.1.1 The Task Group Rapporteur presented a proposal for a replacement of Circular 205. The present Circular had been published in 1988 and described 'best practice' noise contouring methodology as it was at that time. Much of the basic methodology - also described in guidance published by the Society of Automotive Engineers (AIR-1845) and the European Civil Aviation Conference (ECAC Document 29) - is still embodied in numerous national and international noise models.

3.15.1.2 Apart from having been overtaken by technology improvements that have already been incorporated into some state-of-the-art models, Circular 205, like the other publications, had two major limitations. Firstly, it focused mainly on the algorithms that have to be programmed into computer models and contained little advice on the practical application of the methodology. Secondly, it provided none of the data which is an essential component of any real modelling system, e.g., noise-power-distance data. Thus its practical value had diminished with time: for noise modelling specialists it had become obsolete, while for potential users it was too narrow and too theoretical. The proposed replacement for Circular 205 aimed to overcome these limitations.

3.15.2 Description of the revised guidance

3.15.2.1 CAEP had postponed its review of Circular 205 until similar work in ECAC had reached a conclusion. When the ECAC work had been completed, WG2 had developed a replacement of Circular 205 which built upon the work undertaken by ECAC and by SAE. Much of the text had been taken from ECAC Document 29, 3rd Edition, Vol. 2. With this strategy, commonality with ECAC Document 29 3rd Edition and a successor to SAE AIR-1845 had been achieved, as was the case in the late 1980s, when these three documents were first published.

3.15.2.2 Designed principally for those who construct and maintain aircraft noise contour models, it was proposed that the new material should replace the existing ICAO Circular 205. The material recommended a specific methodology for calculating aircraft noise exposures around civil airports; this is described in sufficient detail for computer modelling by competent programmer/analysts. It did not include a computer code, but it did fully describe algorithms that could be programmed to create one.

3.15.2.3 Overall, this new guidance represented a major advance in three important respects. Firstly, it provided much-needed guidance on the practical implementation of aircraft noise contour modelling, especially regarding the crucial importance of correctly representing aircraft types and their operating configurations and procedures. Secondly, it fully described up-to-date algorithms that incorporated the latest internationally agreed advances in segmentation modelling. Finally, the methodology was supported by an on-line, industry-backed, international aircraft noise and performance (ANP) database and could be applied to any airport scenario - where necessary adjusting for significant variations of mean atmospheric conditions.

3.15.2.4 The recommended approach was not the only way to produce accurate noise contours; indeed for specific airports locally developed methods could sometimes be more effective. However, WG2 and the international aircraft noise modelling community as a whole, considered it to represent current best practice for general application. Used diligently it could be expected to deliver reasonably accurate noise contours for most airports. This did not mean that the guidance couldn't be improved upon. Indeed it was important to keep the methodology and the supporting data under constant review and development.

3.15.3 **Effect of new guidance**

3.15.3.1 It was difficult, if not virtually impossible, to provide comparisons between noise contours produced using the proposed guidance and that currently in ICAO Circular 205, since to WG2's knowledge Circular 205 was no longer actively applied in any national or international noise models. However, comparisons could be made against current state-of-art national and international models, although differences would naturally vary, depending on the model being used. In order to understand the likely changes, it was useful to first review one of the key changes.

3.15.3.2 A major advance was the improved modelling of noise to the side of a flight-path. Previously, lateral attenuation was calculated as a function of lateral distance and elevation angle only, using a methodology developed by SAE. This was derived empirically from a large set of data from 1980's vintage aircraft, predominantly aircraft with fuselage-mounted engines (B727 and DC-9). This lateral attenuation model remained reliable for aircraft with fuselage-mounted engines, but it was now recognised that part of this 'attenuation' was in fact a lateral directionality associated with engine installation effects. Although lateral directivity might be sensitive to various features of engine installation, at present only two lateral directivity functions were employed: for aircraft with fuselage-mounted and wing-mounted engines respectively. The algorithms had been derived by the SAE by analysing measured data from a number of sources.

3.15.3.3 The new lateral attenuation algorithms had little effect for aircraft with fuselage-mounted engines. However, there was a more significant effect for aircraft with wing-mounted engines, where the noise contours were wider (i.e. noisier to the side of the flight-path) but only very slightly longer (i.e. no significant difference directly under the flight-path). For a single event contour the increase in area seen for aircraft with wing-mounted engines was typically around 20-30 percent. This difference would be reduced when modelling whole airport scenarios, typically to around 5-15 percent, because the aircraft fleet would not normally be composed entirely of aircraft with wing-mounted engines, and secondly because of the general dispersion of departing flight tracks.

3.15.4 **The ANP Database**

3.15.4.1 This database was online and industry-backed and provided the required data to enable the practical implementation of the recommended methodology for a wide range of aircraft types in computerised noise modelling systems. It facilitated data commonality within the international community of aircraft noise modellers. The database was currently supported by EUROCONTROL, in collaboration with the FAA and U.S.DOT/Volpe Center.

3.15.4.2 In most cases, data was provided by the aircraft manufacturers via the ANP data request form and contains the principal aircraft noise and performance data specified in the proposed guidance. Because of the many different measurement and processing methodologies that could be employed by aircraft manufacturers to produce new ANP datasets, the quality of new submissions was systematically inspected for consistency and reasonableness.

3.15.4.3 The ANP database required endorsement by ICAO in order that it could become an approved ICAO database and be referred to in the proposed guidance. As part of this process, discussions were ongoing within EUROCONTROL to obtain that organization's official commitment to support the database for a minimum period of five years.

3.15.5 **Discussion and conclusions**

3.15.5.1 It was pointed out that this guidance was linked to some of CAEP's other modelling work and was a good example of the additional rigour now being incorporated into models. It was also noted that it had taken several years and work by both SAE, ECAC and WG2 to develop the material.

3.15.5.2 In view of the pace of developments in the modelling field, it was suggested that the new material should be published by ICAO as an amendable manual instead of a circular.

3.15.5.3 The Secretary informed the meeting that a formal approach had been made to EUROCONTROL concerning that organization's continuing support of the ANP database and that EUROCONTROL had stated its intention to continue maintaining the database for a further five years. EUROCONTROL also agreed that a link to this database be placed on the ICAO public website.

3.15.5.4 The meeting endorsed the new material and agreed to recommend that it be published as a new manual to replace Circular 205. It was pointed out that there was a reference to Circular 205 in Annex 16, Volume I, which would need to be changed. The Secretary indicated that this would be done after the Council had agreed to the publication of the new Manual. The meeting also welcomed the support from EUROCONTROL and agreed that the ANP database should become an ICAO-approved database for use with the new manual. The proposed material is shown in Appendix E to the report on this agenda item.

3.15.6 **Recommendation**

3.15.6.1 In light of the foregoing, the meeting developed the following recommendation:

Recommendation 3/5 — Publication of a new ICAO manual containing the Recommended Method for Computing Noise Contours around Airports

That ICAO should publish the material contained in Appendix E to the report on this agenda item as a manual to replace the present Circular 205.

3.16 ICAO CIRCULAR ON NADP NOISE AND EMISSIONS EFFECTS

3.16.1 Introduction

3.16.1.1 The Task Group Rapporteur presented a proposal for material to be included in an ICAO Circular on the noise and emissions effects to be expected from using the noise abatement departure procedures described in PANS-OPS.

3.16.1.2 It was recalled that at CAEP/6, WG2 had presented a comparative analysis of the noise effects of noise abatement operating procedures. It had subsequently been agreed to expand this in terms of both number of aircraft types and also in terms of environmental effects. Specifically the task had emerged as developing quantitative information on noise abatement departure procedures (NADP) designed according to the guidance in PANS-OPS, Part V, Chapter 3. The material was intended to provide information to airports and operators to assist in the selection and development of specific procedures.

3.16.1.3 This work had now been carried out by WG2/TG3 and results were presented to the meeting. They included material that was proposed for publication by ICAO in a Circular.

3.16.2 Noise Abatement Departure Procedures

3.16.2.1 The ICAO *Procedures for Air Navigation Services — Aircraft Operations* (PANS-OPS, Doc 8168) PANS-OPS, Part V, Chapter 3 provided guidance on noise abatement departure procedures. It provided recommendations regarding the conditions in which noise abatement procedures could be safely used and the envelope within which the main flight parameters defining the procedure could be safely adapted for airport noise mitigation. Examples of such flight parameters were the height at which engine thrust is reduced and the height at which acceleration and flap/slat retraction were initiated.

3.16.2.2 PANS-OPS included two examples of procedures. One procedure (NADP1) was intended to mitigate noise at relatively shorter distances and the other (NADP2) was intended to reduce noise at relatively greater distances from the brake release point. PANS-OPS furthermore stated that the number of departure procedures developed and used by the operator for a given aircraft should be limited to two; one identified as the normal procedure and the other to be used for noise abatement. Within these constraints, the operator had the latitude to determine which procedure and parameters to select.

3.16.2.3 The PANS-OPS guidance did not provide quantitative information regarding the zones where these procedures provided noise reduction or the magnitude of the noise reduction under the takeoff flight path. The selection of an appropriate procedure with regard to airport-specific environmental constraints required the quantification and analysis of the available operational solutions for each runway and departure corridor.

3.16.2.4 The goal of the task accomplished by WG2/TG3 was to provide quantitative information for each of a number of jet aircraft on the noise differences between several variants of the procedures mentioned above.

3.16.3 Assessment of NADP Noise and Emissions Effects

3.16.3.1 Prior to the assessment of NADP noise and emissions effects the Task Group had to define the type of noise and emissions effects to be included, the type of comparison and the graphical representation. The types of departure procedures to be included in the analysis as well as operational assumptions also had to be defined. For a number of NADP variants, noise and emissions effects were assessed as follows:

a) noise profiles, providing maximum A-weighted noise levels below the flight path as a function of distance from brake release and the difference between the two noise profiles; and

b) gaseous emissions, in terms of relative NOx emitted up to 1000 ft AGL and 3000 ft AGL and relative CO_2 emitted up to adjusted top of climb. Results were presented in terms of percentages relative to one of two procedures.

3.16.3.2 Four NADP variants were defined for inclusion in the assessment. Two NADP1 variants were defined, one featuring a cutback at 800 ft and the other with a cutback at 1500 ft. Two NADP2 variants were defined of which one featuring a cutback at the end of the acceleration and flap retraction phase and the other with a cutback at the beginning. The comparison of the four procedures allowed a quantification of the effect of cutback height and/or timing, as well as the difference between NADP1 and NADP2.

3.16.3.3 It was also agreed to include two cases with different takeoff thrust settings and takeoff masses, in order for the material to better reflect daily operational practice. The first case assumed full takeoff thrust and maximum takeoff mass. The second assumed a reduced takeoff thrust and performance limited takeoff mass.

3.16.3.4 Noise and emissions data was developed for eight aircraft types, including large narrow-body and large wide-body aircraft, regional jets and business jets. The aircraft were from four different manufacturers.

3.16.3.5 Based on the results, basic conclusions could be drawn concerning trends observed for the eight aircraft included in the study. The noise reduction characteristics of NADP1 and NADP2 in zones respectively close-in and distant from the brake release point were demonstrated, as well as the existence of a crossover point between these zones, located between 5.5 nautical miles and 11 nautical miles from brake release depending on aircraft type. The report also demonstrated the influence of cutback height on both the location of noise reduction areas and amount of noise reduction in those areas. In terms of NOx and CO_2 emissions, some trends were observed in favour of NADP1 or NADP2 depending on type of emissions. No single departure procedure appeared to minimize overall noise and emissions simultaneously. The report concluded therefore that depending on local airport requirements, tradeoffs must be made between close-in versus distant noise, NOx versus CO_2 emissions and finally noise versus gaseous emissions.

3.16.3.6 It was proposed that the complete report should be published as an ICAO Circular on NAPD noise and emissions effects. The introduction of the report provided basic guidelines with regard to how the information should be used. The material is contained in Appendix F to the report on this agenda item.

3.16.4 **Discussion and conclusions**

3.16.4.1 A member noted that emissions quantities were quoted as total emissions from beginning to end of the take-off and initial climb manoeuvre, unlike noise which was indicated as instantaneous values along the flight path. This would not allow the variation in emissions output along the flight path to be considered. Also, results were quoted as percentages rather than absolute values. In reply it was stated that time did not allow for the concentration of emissions along the flight path. Concerning the percentages, these gave a relative impact, although it was acknowledged that in a real case absolute values would be used.

3.16.4.2 Another member noted that further work to asses the effects of variable thrust take-offs (at constant take-off mass) would be useful. While acknowledging that this would be useful information, it was generally agreed that, since work on this topic had been ongoing since before CAEP/6, it now should be published as soon as possible and not delayed until CAEP/8 by awaiting further information.

3.16.4.3 The meeting endorsed the material produced and agreed to recommend that it should be published as an ICAO circular.

Recommendation 3/6 — Publication of a new ICAO circular on noise and emission effects from PANS-OPS noise abatement departure procedures

That the material contained in Appendix F to the report on this agenda item be published as an ICAO circular.

3.17 REVIEW OF CONTINUOUS DESCENT APPROACH (CDA) IMPLEMENTATION AND ASSOCIATED BENEFITS

3.17.1 Introduction

3.17.1.1 The Task Group Rapporteur introduced a report on a study of the implementation of CDA techniques and an assessment of the benefits being obtained.

3.17.1.2 Early in its work WG2 determined that there was no commonly agreed definition of CDA (nor for the base-case e.g. non-CDA) making a global CDA assessment impossible. WG2 therefore expanded its task to include a review of recent CDA trials and related operational developments.

3.17.2 Main conclusions

3.17.2.1 An extensive review of present practice had led to the following main conclusions:

a) a global assessment had not been possible because:

   1) there was no commonly agreed definition for the full CDA scope;

   2) there was no common specification for the "non-CDA" base-case;

   3) the nature of non-CDA operations (base-case) varied greatly between airports: and

   4) there was no internationally accepted methodology for emission or noise assessment that could differentiate between the operational nuances resulting from CDA, although manufacturers and CDA trial sponsors had developed proprietary assessment tools. CAEP work on models and interdependencies should help in the future in this regard.

b) various CDA trials indicated consistently significant potential environmental, social, financial and economic benefits. These results were considered sufficiently robust to form the basis for recommendations for future CDA related activities;

c) the number and variety of CDA initiatives indicated a proliferation of local rules with the attendant risk of inefficiency and non-optimal practice, etc;

d) although CDA was widely perceived as being inconsistent with maintaining airfield capacity, in fact some simple versions of CDA operated effectively in a vectoring environment and did not adversely affect runway capacity;

e) initial consideration of global CDA harmonisation was already underway in ICAO's Operations Panel and Obstacle Clearance Panel. These bodies had a working definition for Continuous Descent Final Approach aimed at unguided final approaches;

f) some work on developing regionally harmonised CDA was underway (e.g. FAA and EUROCONTROL). This could form the basis for the development of a global (ICAO) CDA concept; and

g) development of the capability to undertake a global assessment (and harmonised exploitation) of CDA would require collaboration between the operational and environmental sections of ICAO.

3.17.2.2 Various key CDA trials indicated consistent benefits for the CDA segment of flight (which could vary in extent), as follows:

a) a reduction in noise impact on the ground (by modelling) of around 3-6dB, at between 7.5 and 30 nm from touchdown. Typically however, this was outside the airport noise contours that are used in decision making;

b) fuel saving of around 50 to 150 kg per flight depending mainly on aircraft type and CDA segment length;

c) reduced NO_x and CO_2 of the order of 20-40%; and

d) for air quality purposes (below 3,000 AGL), trial results differ mainly due to differences in existing (base-case) vectoring techniques used for comparison with CDA.

3.17.2.3 These benefits may be restricted to approach segments some distance from an airport (e.g. before acquisition of the ILS). The noise benefit may therefore fall outside the noise contours which are critical to an airport's operation and development (e.g. used for defining land-use planning restrictions). There was, however, a generally increasing trend of community concern about aircraft noise at some distance from an airport and CDA had a significant role in these circumstances.

3.17.3 **CDA Concept Development – Risk Management**

3.17.3.1 The report identified a number of potential problems which should be taken into account in developing and harmonizing CDA material and had proposed solutions to these problems as follows:

a) CDA exploitation might be delayed because of over-focus on emerging technology. This could be avoided by adopting a two-stage approach, based on a unified core CDA concept covering present and future practice, with early dissemination of harmonised present good practice;

b) The misconception that CDA always reduces runway capacity may prevent CDA adoption: ICAO consultative bodies should collaborate to produce harmonised material that should clarify CDA options including radar (vectoring) variant CDA techniques;

c) CDA harmonisation should not become rapidly outdated: ICAO work on a harmonised CDA concept/definition should take account (to the extent possible), of future ATM developments (e.g. more advanced FMS capability, sequencing/metering tools and P-RNAV deployment etc). A focus on desired outcomes and behaviour rather than the methods of achieving these would help;

d) Lack of support for harmonisation, where present practice would not comply with proposed CDA concept: A reasonable balance between the need for harmonisation and the need for local flexibility would be required;

e) Criticism of airports that are unable to act upon guidance. Any CDA guidance should accept the fact that for some airports (e.g. complex multi-runway TMAs), CDA may not be viable or only partially achievable; and

f) Potential withdrawal of established CDA due to changing operational requirements, which could lead to a politically driven airport constraint: (e.g. if simultaneous parallel runway operations are proposed and converging traffic prevents CDA; or where increased throughput requires vectoring from CDA compliant arrival routes). Relevant ICAO provisions should be reviewed and revised if necessary. The CDA concept should allow a fall-back to radar variant CDA in periods when traffic load demands increased vectoring.

3.17.4 **Discussion and conclusions**

3.17.4.1 One member reiterated that CDA had been rejected at a major airport in his State because of the concentration of flight tracks which it implied. Another member commented that the question of developing definitions was especially important in light of the revolution in aircraft navigation that was taking place, although modelling capabilities to assess these procedures are still under development.

3.17.4.2 The meeting noted the difficulties that had been experienced in assessing CDA globally. It endorsed the need for coordination and cooperation among the relevant ICAO consultative bodies on this subject and requested the Secretariat to draw the matter to the Air Navigation Commission's attention. The meeting also noted that an appropriate work programme item for WG2's future work would need to be developed to ensure continuation of this work in CAEP. It was further agreed that WG2 should reassess CDA once further progress had been made on the definition and operational issues aspects.

3.18 REVIEW OF NOISE ABATEMENT PROCEDURES AND IMPLEMENTATION OF RESEARCH

3.18.1 Introduction

3.18.1.1 The Co-Rapporteurs of WG2 introduced a report on a review of research and development (R&D) activities into, and implementation of, noise abatement procedures (NAP). It was noted that NAP was one of the four elements of the balanced approach to noise mitigation. WG2 had attempted to define a baseline for this survey by collecting information on noise abatement procedures in use today.

3.18.1.2 To collect information on NAP R&D a questionnaire had been distributed by WG2 TG3 members to known coordinators or contact persons of NAP R&D and implementation projects. The response obtained in terms of completed questionnaires was used as the basis for this report to CAEP.

3.18.2 Survey results

3.18.2.1 The number of organizations surveyed had been limited, as was the scope of the responses. Therefore, the survey could not be considered as representative of all NAP R&D in progress. The study did, however, represent a snapshot in time but because of the nature of R&D, the material would be transient in nature. There were indications that additional R&D was either being defined for the near term and/or that the existing R&D would continue.

3.18.2.2 Because of the limited survey results, it had not been possible to determine a baseline from which reported improvements could be determined. Consequently, meaningful comparisons between R&D programmes could not be made nor conclusions drawn. The emissions effects from some current practice NAPs had not been assessed or modelled. The responses to the survey had tended to focus on the implementation of continuous descent approach techniques (CDA) and other proven noise abatement techniques had not been extensively reported.

3.18.3 Conclusions

3.18.3.1 It was evident that some noise management measures had tradeoffs against fuel burn, emissions, flight time and airport and airspace capacity. For example, an optimum flap or thrust setting that reduced noise may result in an increase in fuel burn or emissions. It was therefore essential that these tradeoffs be fully assessed before selection or adoption of a technique.

3.18.3.2 On-going R&D needed to optimize procedures, determine the technologies needed and identify ways to facilitate acceptance by the communities around airports, airport operators, pilots and ATC. While the work showed promise at this stage, many limitations needed to be overcome if the full potential were to be realized.

3.18.3.3 It was suggested that the detailed results of the review could be useful to the wider aviation community to help it avoid duplication of effort and as an initial signpost to potential improvements in practice. However, because of the limitations mentioned earlier the results would not be suitable as the basis of an ICAO Circular, but could more appropriately be posted on the ICAO website.

3.18.4 Discussion and conclusions

3.18.4.1 The meeting noted the survey results and agreed that WG2 should periodically review and update the information. Such a review was not expected to be carried out more frequently than every three years. The meeting also agreed to request WG2 to include guidance on trade-offs in an update of the review for CAEP/8. The meeting finally agreed that the information should be made available on the ICAO public website.

3.19 OPTIMIZING RUNWAY USE TO ACHIEVE EMISSIONS REDUCTION AT AIRPORTS

3.19.1 A member described a runway rotation system being used at a major airport in his State and the development of a computer modelling tool to assist in the process and to reduce fuel burn by optimizing runway use. An initial application of the tool was in examining whether the runway use patterns enforced under a noise sharing regime were leading to significant additional fuel burn.

3.19.2 In essence, the approach to optimising runway use was to ascertain all the runway modes that were operationally available at an airport at any given time (primarily through dynamic examination of wind and traffic data) and then to compute which runway mode would give the least fuel burn (or the minimum NO_x, PM10, etc) over say the next hour. The origins and destinations of the traffic into and out of the airport in that hour were likely to be significant determinants of the most 'fuel efficient' runway mode for that time period. Fuel burn and emissions were calculated for all the aircraft movements expected during the chosen time period. Trade offs could be calculated by comparing noise and emissions when the airport was operated in a noise-optimized manner or in an emissions-optimized manner. The model was currently in the prototype stage, and development was continuing.

3.19.3 Members found the concept of considerable interest. It was suggested that the model might be of use to CAEP in the future and the member concerned thought that it could be provided to CAEP once it had been fully developed.

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APPENDIX A

PROPOSED AMENDMENT TO

INTERNATIONAL STANDARDS AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION

ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME I
AIRCRAFT NOISE

1. The text of the amendment is arranged to show deleted text with a line through it and new text highlighted with grey shading, as shown below:

1. ~~Text to be deleted is shown with a line through it.~~	text to be deleted
2. New text to be inserted is highlighted with grey shading.	new text to be inserted
3. ~~Text to be deleted is shown with a line through it~~ followed by the replacement text which is highlighted with grey shading.	new text to replace existing text

TEXT OF PROPOSED AMENDMENT TO THE

INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION

ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME I
AIRCRAFT NOISE

. . .

PART I. DEFINITIONS

. . .

Derived version of a helicopter. A helicopter which, from the point of view of airworthiness, is similar to the noise certificated prototype but incorporates changes in type design which may affect its noise characteristics adversely.

Note 1.— In applying the Standards of this Annex, a helicopter that is based on an existing prototype but which is considered by the certificating authority to be a new type design for airworthiness purposes shall nevertheless be considered as a derived version if the noise source characteristics are judged by the certificating authority to be the same as the prototype.

Note 2.— "Adversely" refers to an increase of more than 0.3 EPNdB in any one of the noise certification levels for helicopters certificated according to Chapter 8 and 0.3 dB(A) in the certification level for helicopters certificated according to Chapter 11.

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PART II. AIRCRAFT NOISE CERTIFICATION

CHAPTER 1. ADMINISTRATION

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1.10 Unless otherwise specified in this volume of the Annex, the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date of application submitted to the State of Design for a type certificate, or the date of application under an equivalent prescribed procedure by the certificating authority of the State of Design. The application shall be effective for a duration equal to the period applied in the designation of the airworthiness regulations appropriate to the aircraft type, except in special cases where the certificating authority accepts an extension of this period.

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CHAPTER 2. SUBSONIC JET AEROPLANES — APPLICATION FOR TYPE CERTIFICATE ~~OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED~~SUBMITTED BEFORE 6 OCTOBER 1977

2.1 Applicability

Note.— See also Chapter 1, ~~1.9~~1.10 and 1.11.

2.1.1 The Standards of this chapter shall be applicable to all subsonic jet aeroplanes for which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, before 6 October 1977, except those aeroplanes:

. . .

c) powered by engines with a bypass ratio of less than 2 and for which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, before 1 January 1969, and for which a certificate of airworthiness for the individual aeroplane was first issued before 1 January 1976.

. . .

CHAPTER 3. 1.— SUBSONIC JET AEROPLANES — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 6 October 1977 and before 1 January 2006
2.— PROPELLER-DRIVEN AEROPLANES OVER 5 700 kg — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 1 January 1985 and before 17 November 1988
3.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 17 November 1988 and before 1 January 2006

3.1 Applicability

Note 1.— See also Chapter 1, ~~1.9~~ 1.10 and 1.11.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

3.1.1 The Standards of this chapter shall be applicable to:

a) all subsonic jet aeroplanes, including their derived versions, other than aeroplanes which require a runway[1] length of 610 m or less at maximum certificated mass for airworthiness, in respect of which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977 and before 1 January 2006;

b) all propeller-driven aeroplanes, including their derived versions, of over 5 700 kg maximum certificated take-off mass (except those described in Chapter 6, 6.1), for which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985 and before 17 November 1988, except where the Standards of Chapter 10 apply; and

c) all propeller-driven aeroplanes, including their derived versions, of over 8 618 kg maximum certificated take- off mass, for which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988 and before 1 January 2006.

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3.6 Noise certification reference procedures

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3.6.2 Take-off reference procedure

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d) the speed shall be the all-engines operating take-off climb speed selected by the applicant for use in normal operation, which shall be at least V_2 + 19 km/h (V_2 + 10 kt) but not greater than V_2 + 37 km/h (V_2 + 20 kt) and which shall be attained as soon as practicable after lift-off and be maintained throughout the take-off noise certification test. The increment applied to V_2 shall be the same for all reference masses of an aeroplane model unless a difference in increment is substantiated based on performance characteristics of the aeroplane;

. . .

CHAPTER 4. 1.— SUBSONIC JET AEROPLANES — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 1 January 2006

2.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 1 January 2006

4.1 Applicability

Note. — See also Chapter 1, ~~1.9~~ 1.10 and 1.11.

4.1.1 The Standards of this chapter shall be applicable to:

a) all subsonic jet aeroplanes, including their derived versions, other than aeroplanes which require a runway[1] length of 610 m or less at maximum certificated mass for airworthiness, in respect of which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 2006;

b) all propeller-driven aeroplanes, including their derived versions, of over 8 618 kg maximum certificated take-off mass, for which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 2006; and

. . .

CHAPTER 5. PROPELLER-DRIVEN AEROPLANES OVER 5 700 kg — APPLICATION FOR TYPE CERTIFICATE ~~OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED~~ SUBMITTED BEFORE 1 JANUARY 1985

5.1 Applicability

Note 1.— See also Chapter 1, ~~1.9~~ 1.10 and 1.11.

. . .

5.1.2 The Standards of this chapter shall be applicable to all propeller-driven aeroplanes, including their derived versions, of over 5 700 kg maximum certificated take-off mass for which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977 and before 1 January 1985.

5.1.3 The Standards of Chapter 2, with the exception of Sections 2.1 and 2.4.2, shall be applicable to derived versions and individual aeroplanes of over 5 700 kg maximum certificated take-off mass and to which Standards of Chapter 6 do not apply and are of the type for which the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, before 6 October 1977, and for which a certificate of airworthiness for the individual aeroplane was issued on or after 26 November 1981.

5.1.4 The Standards of Chapter 3, with the exception of Section 3.1, shall be applicable to all propeller-driven aeroplanes, including their derived versions, of over 5 700 kg maximum take-off mass, for which either the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985.

. . .

CHAPTER 6. PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR TYPE CERTIFICATE ~~OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED~~ SUBMITTED BEFORE 17 NOVEMBER 1988

6.1 Applicability

Note 1.— See also Chapter 1, ~~1.9~~ 1.10 and 1.11.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

The Standards of this chapter shall be applicable to all propeller-driven aeroplanes, except those aeroplanes specifically designed for aerobatic purposes or agricultural or fire fighting uses, of a maximum certificated take-off mass not exceeding 8 618 kg for which:

a) the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1975 and before 17 November 1988, except for derived versions for which an application for a ~~certificate of airworthiness~~ Type Certificate was ~~accepted~~ submitted, or another equivalent procedure was carried out by the certificating authority, on or after 17 November 1988, in which case the Standards of Chapter 10 apply; or

. . .

CHAPTER 8. HELICOPTERS

8.1 Applicability

Note.— See also Chapter 1, ~~1.9~~ 1.10 and 1.11.

. . .

8.1.2 For a helicopter for which the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985, except for those helicopters specified in 8.1.4, the noise levels of 8.4.1 shall apply.

8.1.3 For a derived version of a helicopter for which the application for a change of type design was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988, except for those helicopters specified in 8.1.4, the noise levels of 8.4.1 shall apply.

8.1.4 For all helicopters, including their derived versions, for which the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 21 March 2002, the noise levels of 8.4.2 shall apply.

. . .

8.6 Noise certification reference procedures

8.6.1 General conditions

. . .

8.6.1.6 In 8.6.2 c), 8.6.3.1 c) and 8.6.4 c), the maximum normal operating rpm shall be taken as the highest rotor speed for each reference procedure corresponding to the airworthiness limit imposed by the manufacturer and approved by the certificating authority. Where a tolerance on the highest rotor speed is specified, the maximum normal operating rotor speed shall be taken as the highest rotor speed about which that tolerance is given. If the rotor speed is automatically linked with flight condition, the maximum normal operating rotor speed corresponding with ~~that~~ the reference flight condition shall be used during the noise certification procedure. If rotor speed can be changed by pilot action, the ~~highest~~ maximum normal operating rotor speed specified in the flight manual limitation section for ~~power on~~ the reference conditions shall be used during the noise certification procedure.

. . .

CHAPTER 9. INSTALLED AUXILIARY POWER UNITS (APU) AND ASSOCIATED AIRCRAFT SYSTEMS DURING GROUND OPERATIONS

Note.— Standards and Recommended Practices for this chapter are not yet developed. In the meantime, guidelines provided in Attachment C may be used for noise certification of installed auxiliary power units (APU) and associated aircraft systems in:

a) all aircraft for which the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977; and

. . .

CHAPTER 10. PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR TYPE CERTIFICATE ~~OF AIRWORTHINESS FOR THE PROTOTYPE~~ OR DERIVED VERSION ~~ACCEPTED~~ SUBMITTED ON OR AFTER 17 NOVEMBER 1988

10.1 Applicability

Note 1.— See also Chapter 1, ~~1.9~~ 1.10 and 1.11.

. . .

10.1.2 For an aeroplane for which the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate or for all derived versions was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988, except for those aeroplanes specified in 10.1.4, the noise limits of 10.4 a) shall apply.

10.1.3 For aeroplanes specified in 10.1.2 which fail to comply with the Standards of this chapter and where the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate or all derived versions was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, before 17 November 1993, the Standards of Chapter 6 shall apply.

10.1.4 For single-engined aeroplanes, except those aeroplanes specifically designed for aerobatic purposes and agricultural or fire fighting uses, self-sustaining powered sailplanes, float planes and amphibians, for which:

a) the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate or their derived versions was ~~accepted~~ submitted, or another equivalent procedure was carried out by the certificating authority, on or after 4 November 1999, the noise limits of 10.4 b) shall apply;

b) an application for the ~~certificate of airworthiness~~ Type Certificate for the derived version was ~~accepted~~ submitted, or other procedure was carried out, on or after 4 November 1999, but for which the application for the ~~certificate of airworthiness for the prototype~~Type Certificate, or another equivalent procedure was carried out by the certificating authority, before 4 November 1999, the noise limits of 10.4 b) shall apply;

. . .

CHAPTER 11. HELICOPTERS NOT EXCEEDING 3 175 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

11.1 Applicability

Note.— See also Chapter 1, ~~1.9~~ 1.10 and 1.11.

. . .

11.1.2 For a helicopter for which the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~issued~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 11 November 1993, except for those helicopters specified in 11.1.4, the noise levels of 11.4.1 shall apply.

11.1.3 For a derived version of a helicopter for which the application for the ~~certificate of airworthiness~~ Type Certificate for a change of type design was ~~issued~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 11 November 1993, except for those helicopters specified in 11.1.4, the noise levels of 11.4.1 shall apply.

11.1.4 For all helicopters, including their derived versions, for which the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 21 March 2002, the noise levels of 11.4.2 shall apply.

. . .

11.5 Noise certification reference procedure

11.5.1 General conditions

. . .

11.5.1.5 The maximum normal operating rpm shall be taken as the highest rotor speed corresponding to the airworthiness limit imposed by the manufacturer and approved by the certificating authority for overflight. Where a tolerance on the highest rotor speed is specified, the maximum normal operating rotor speed shall be taken as the highest rotor speed about which that tolerance is given. If rotor speed is automatically linked with flight condition, the maximum normal operating rotor speed corresponding with ~~that~~ the reference flight condition shall be used during the noise certification procedure. If rotor speed can be changed by pilot action, the ~~highest~~ maximum normal operating rotor speed specified in the flight manual limitation section for ~~power-on~~ the reference conditions shall be used during the noise certification procedure.

. . .

CHAPTER 12. SUPERSONIC AEROPLANES

12.1 Supersonic aeroplanes — application for ~~certificate of airworthiness for the prototype accepted~~ Type Certificate submitted before 1 January 1975

12.1.1 The Standards of Chapter 2 of this Part, with the exception of maximum noise levels specified in 2.4, shall be applicable to all supersonic aeroplanes, including their derived versions, in respect of which either the application for the ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, before 1 January 1975, and for which a certificate of airworthiness for the individual aeroplane was first issued after 26 November 1981.

. . .

12.2 Supersonic aeroplanes — application for ~~certificate of airworthiness for the prototype accepted~~ Type Certificate submitted on or after 1 January 1975

Note.— Standards and Recommended Practices for these aeroplanes are not yet developed but the noise levels of Chapter 3 of this Part applicable to subsonic jet aeroplanes may be used as guidelines for aeroplanes for which the application for a ~~certificate of airworthiness for the prototype~~ Type Certificate was ~~accepted~~ submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1975.

. . .

CHAPTER 13. TILT-ROTOR AIRCRAFT

Note 1.— Standards and Recommended Practices for this chapter are not yet developed. In the meantime, guidelines provided in Attachment F may be used for noise certification of tilt-rotor aircraft for which ~~a type certificate of airworthiness was issued~~ the application for a Type Certificate was submitted or another equivalent prescribed procedure was carried out by the certificating authority on or after 13 May 1998 and to provide data for land-use planning purposes.

. . .

APPENDIX 1. EVALUATION METHOD FOR NOISE CERTIFICATION OF SUBSONIC JET AEROPLANES — APPLICATION FOR TYPE CERTIFICATE ~~OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED~~ SUBMITTED BEFORE 6 OCTOBER 1977

. . .

APPENDIX 2. EVALUATION METHOD FOR NOISE CERTIFICATION OF:

1.— SUBSONIC JET AEROPLANES — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 6 October 1977

2.— PROPELLER-DRIVEN AEROPLANES OVER 5 700 kg — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 1 January 1985 and before 17 November 1988

3.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg — Application for Type Certificate ~~of Airworthiness for the Prototype accepted~~ submitted on or after 17 November 1988

4.— HELICOPTERS

Note.— See Part II, Chapters 3, 4 and 8.

. . .

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

Replace Section 2.2 as follows:

. . .

2.2 Test environment

2.2.1 Microphone locations

Locations for measuring noise from an aircraft in flight shall be surrounded by relatively flat terrain having no excessive sound absorption characteristics such as might be caused by thick, matted, or tall grass, shrubs, or wooded areas. No obstructions which significantly influence the sound field from the aircraft shall exist within a conical space above the point on the ground vertically below the microphone, the cone being defined by an axis normal to the ground and by a half-angle 80° from this axis.

Note.— Those people carrying out the measurements could themselves constitute such obstructions.

2.2.2 Atmospheric conditions

2.2.2.1 *Specifications*

For the purposes of noise certification in this section the following specifications apply:

Time constant (of a first order system) is the time required for a device to detect and indicate 100*(1-1/e) percent (about 63%) of a step function change. (The mathematical constant, *e*, is the base number of the natural logarithm, approximately 2.7183 - also known as *Euler's number,* or *Napier's constant*.)

Distance constant (or response length) is the passage of wind (in meters) required for the output of a wind speed sensor to indicate 100*(1-1/e) percent (about 63%) of a step-function increase of the input speed.

Wind speed sample (at a certain moment) is the value measured at that moment for wind speed using a sensor/system with characteristics as follows:

Range:	1 m/s (3.6 km/h) to more than 10 m/s (36 km/h);
Linearity:	+/- 0.5 m/s (1.8 km/h) over the specified range; and
Distance constant (response length):	less than 5 meters for systems having dynamic behaviour best characterised by a distance constant; or
Time constant:	less than 3 seconds for wind speeds at or above 5 m/s (18 km/h) for systems having dynamic behaviour best characterised by a time constant.

Wind direction sample (at a certain moment) is the value obtained at that moment from a wind direction sensor/system with characteristics as follows:

Wind speed operating range:	1 m/s (3.6 km/h) to more than 10 m/s (36 km/h);
Linearity:	+/- 5 degrees over the specified range; and
Resolution:	5 degrees.

Note.— For the entire wind sensing system used to obtain wind speed and direction samples, the combined dynamic characteristics, including physical inertia of the sensor(s), and any temporal processing, such as filtering of the sensor signal(s), or smoothing or averaging of the wind sensor data, shall be equivalent to a first order system (such as an R/C circuit) with a time constant of no greater than 3 seconds at a wind speed of 5 m/s (18 km/h).

Wind vector (at a certain moment). At least once every second the wind vector shall be determined. Its magnitude will be represented at a certain moment by the wind speed sample at that moment and the direction of the vector shall be represented by the wind direction sample at that moment.

Average wind speed shall be determined from the series of individual wind speed samples obtained during the aircraft test run, using a linear averaging process over 30 seconds, or an averaging process that has a time constant of no more than 30 seconds, the result of which is read out at a moment approximately 15 seconds after the time at which the aircraft passes either over or abeam the microphone. Alternatively, each wind vector shall be broken down into its “along track” (u) and “cross-track” (v) components. The u and v components of the series of individual wind samples obtained during the aircraft test run shall be separately averaged using a linear averaging process over 30 seconds, or an averaging process that has a time constant of no more than 30 seconds, the result of which is read out at a moment approximately 15 seconds after the time at which the aircraft passes either over or abeam the microphone. The average wind speed and direction (with respect to the track) shall then be calculated from the averaged u and v components according to Pythagorean Theorem and “arctan(u/v)”.

Average cross-wind component shall be determined from the series of individual values of the “cross track” (v) component of the wind samples obtained during the aircraft test run, using a linear averaging process over 30 seconds or an averaging process that has a time constant of no more than 30 seconds, the result of which is read out at a moment approximately 15 seconds after the time at which the aircraft passes either over or abeam the microphone.

Maximum wind speed. The maximum value within the series of individual wind speed samples recorded every second over a period that spans the 10 dB-down time interval.

Maximum cross-wind component. The maximum value within the series of individual values of the “cross track” (v) component of the wind samples recorded every second over a period that spans the 10 dB-down time interval.

2.2.2.2 Except as provided in 2.2.2.5, the tests shall be carried out under the following atmospheric conditions:

a) no precipitation;

b) ambient air temperature not above 35°C and not below -10°C, and relative humidity not above 95 per cent and not below 20 per cent over the whole noise path between a point 10 m (33 ft) above the ground and the aircraft;

Note.— Care should be taken to ensure that the noise measuring, aircraft flight path tracking and meteorological instrumentation are operated within the environmental limitations specified by the manufacturer.

c) relative humidity and ambient temperature over the whole noise path between a point 10 m (33 ft) above the ground and the aircraft altitude at the time of PNLTM, such that the sound attenuation due to atmospheric absorption in the one-third octave band centred on 8 kHz will not be more than 12 dB/100 m;

Note.— Section 7 of this appendix specifies the method for calculation of atmospheric absorption coefficients based on temperature, humidity, and frequency.

d) if the atmospheric absorption coefficients vary over the PNLTM sound propagation path by more than ±0.5 dB/100 m in the 3 150 Hz one-third octave band from the value of the absorption coefficient derived from the meteorological measurement obtained at 10 m above the surface, 'layered' sections of the atmosphere must be used to compute equivalent weighted sound attenuations in each one-third octave band, sufficient sections being used to the satisfaction of the certificating authority; where multiple layering is not required, equivalent sound attenuations in each one-third octave band shall be determined by averaging the atmospheric absorption coefficients for each such band at 10 m (33 ft) above ground level and at the flight level of the test aircraft at the time of PNLTM, for each measurements;

e) at 10 m (33 ft) above ground, for aeroplanes, the average wind speed shall not exceed 22 km/h (12 kt) and the average cross-wind component shall not exceed 13 km/h (7 kt). For helicopters, the average wind speed shall not exceed 19 km/h (10 kt) and the average cross-wind component shall not exceed 9 km/h (5 kt). For aeroplanes, the maximum wind speed shall not exceed 28 km/h (15 kt) and the maximum cross-wind component shall not exceed 18 km/h (10 kt). All wind speed samples shall be taken with the sensor installed such that the horizontal distance between the anemometer and any obstruction is at least 10 times the height of the obstruction. Installation error for the wind direction sensor shall be no greater than 5 degrees; and

f) no anomalous meteorological or wind conditions that would significantly affect the measured noise levels when the noise is recorded at the measuring points specified by the certificating authority.

2.2.2.3 Meteorological measurements of ambient temperature and relative humidity shall be obtained within 30 minutes of each noise test measurement. Meteorological data shall be interpolated to actual times of each noise measurement. Wind measurements shall be obtained continuously during each aircraft test run.

2.2.2.4 When a multiple layering calculation is required by 2.2.2.2 d), the atmosphere between the aircraft and 10 m (33 ft) above the ground shall be divided into layers of equal depth. The depth of the layers shall be set to not more than the depth of the narrowest layer across which the variation in the atmospheric absorption coefficient of the 3 150 Hz one-third octave band is not greater than ±0.5 dB/100 m, with a minimum layer depth of 30 m (100 ft). This shall apply over the propagation path at PNLTM. The mean of the values of the atmospheric absorption coefficients at the top and bottom of each layer may be used to characterize the absorption properties of each layer.

2.2.2.5 For helicopters the requirements of 2.2.2.2 b), c) and d) shall only be applied at a point 10 m (33 ft) above ground.

2.2.2.6 The atmospheric conditions shall be measured within 2 000 m (6 562 ft) from the microphone locations and shall be representative of the conditions existing over the geographical area in which noise measurements are made.

. . .

3. MEASUREMENT OF AIRCRAFT NOISE RECEIVED ON THE GROUND

3.1 Definitions

For the purposes of this section the following definitions apply:

. . .

Sound incidence angle. In degrees, an angle between the principal axis of the microphone~~, as defined in IEC 61094-3[1] and IEC 61094-4[2], as amended~~ and a line from the sound source to the centre of the diaphragm of the microphone.

Note.— When the sound incidence angle is 0°, the sound is said to be received at the microphone at "normal (perpendicular)~~ incident~~ incidence"; when the sound incidence angle is 90°, the sound is said to be received at "grazing incidence". The principal axis of a measurement microphone is through the centre of the diaphragm and perpendicular to it.

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3.7 Analysis systems

. . .

3.7.3 The one-third octave band analysis system shall ~~at least~~ conform to the class ~~2~~ 1 electrical performance requirements of IEC ~~61260[4]~~ 61260[2] as amended, over the range of one-third octave nominal midband frequencies from 50 Hz to 10 kHz inclusive.

Note 1.— The certificating authority may allow the substitution of an analysis system that complies with class 2 as an alternative to class 1 electrical performance requirements of IEC 61260[2].

Note 2.—Tests of the one-third octave band analysis system should be made according to the methods described in IEC ~~612604[4]~~ 61260[2] or by an equivalent procedure approved by the certificating authority, for relative attenuation, anti-aliasing filters, real-time operation, level linearity, and filter integrated response (effective bandwidth).

. . .

3.8 Calibration systems

The acoustical sensitivity of the measurement system shall be determined using a sound calibrator generating a known sound pressure level at a known frequency. The sound calibrator shall at least conform to the class 1L requirements of IEC ~~60942[5]~~ 60942[3] as amended.

. . .

~~1 IEC 61094-3: 1995 entitled "Measurement microphones — Part 3: Primary method for free-field calibration of laboratory standard microphones by the reciprocity technique". This IEC publication may be obtained from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland.~~

~~2 IEC 61094-4: 1995 entitled "Measurement microphones — Part 4: Specifications for working standard microphones". This IEC publication may be obtained from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland.~~

~~3~~ 1 IEC 61265: 1995 entitled "Electroacoustics — Instruments for measurement of aircrft noise — Performance requirements for systems to measure one-third-octave band sound pressure levels in noise certification of transport-category aeroplanes". This IEC publication may be obtained from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland.

~~4~~ 2 IEC 61260: 1995 entitled "Electroacoustics — Octave-band and fractional-octave band filters". This IEC publication may be obtained from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland.

~~5~~ 3 IEC 60942: ~~1997~~ 2003 entitled "Electroacoustics – Sound calibrators". This IEC publication may be obtained from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland.

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5. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY

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5.2 Data reporting

. . .

5.2.3 The following atmospheric environmental data, measured immediately before, after, or during each test at the observation points prescribed in Section 2 of this appendix shall be reported:

a) air temperature and relative humidity;

b) ~~maximum, minimum and average~~ wind ~~velocities~~ speeds and wind directions; and

. . .

APPENDIX 3. NOISE EVALUATION METHOD FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR TYPE CERTIFICATE ~~OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED~~ SUBMITTED BEFORE 17 NOVEMBER 1988

. . .

APPENDIX 4. EVALUATION METHOD FOR NOISE CERTIFICATION OF HELICOPTERS NOT EXCEEDING 3 175 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

. . .

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

. . .

2.2 Test environment

. . .

2.2.2 The tests shall be carried out under the following atmospheric conditions:

a) no precipitation;

b) relative humidity not higher than 95 per cent or lower than 20 per cent and ambient temperature not above 35°C and not below 2°C at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground ~~(if the measurement site is within 2 000 m of aerodrome weather measuring equipment, the aerodrome reported temperature, relative humidity and wind speed may be used). Combinations~~ combinations of temperature and humidity which lead to an absorption coefficient in the 8 KHz one-third octave band of greater than 10 dB/100 m shall be avoided~~. Absorption coefficients as a function of temperature and relative humidity are given in Section 7 of Appendix 2 or SAE ARP 866 A~~;

Note.— Absorption coefficients as a function of temperature and relative humidity are given in Section 7 of Appendix 2 or SAE ARP 866A

.

c) at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground, average wind speed shall not exceed 19 km/h (10 kt) and the average crosswind ~~average wind speed~~ component ~~at right angles to the direction of flight~~ shall not exceed 9 km/h (5 kt) ~~at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground~~; and

~~*Note.— Average wind speed is defined over a 30-second time period.*~~

d) no other anomalous meteorological conditions that would significantly affect the noise level when recorded at the measuring points specified by the certificating authority.

Note.— Meteorological specifications are given in Section 2.2.2.1 of Appendix 2.

2.2.3 The atmospheric conditions shall be measured within 2 000 m (6 562 ft) from the microphone locations and shall be representative of the conditions existing over the geographical area in which noise measurements are made.

2.3 Flight path measurement

. . .

2.3.1 The helicopter position relative to the flight path reference point shall be determined by a method independent of normal flight instrumentation, such as radar tracking, theodolite triangulation or photographic scaling techniques, approved by the certificating authority.

~~2.3.2 The helicopter noise shall be measured over a distance sufficient to ensure adequate data during the period that the noise is within 10 dB(A) of the maximum value of dB(A).~~

~~2.3.3~~2.3.2 Position and performance data required to make the adjustments referred to in Section 5 of this appendix shall be recorded at an approved sampling rate. Measuring equipment shall be approved by the certificating authority.

2.4 Flight test conditions

2.4.1 The helicopter shall be flown in a stabilized flight condition over a distance sufficient to ensure that the time-varying sound level is measured during the entire time period that the sound level is within 10 dB(A) of L_{Amax}.

Note.— L_{Amax} is defined as the maximum of the A-frequency-weighted S-time-weighted sound level measured during the test run.

~~2.4.1~~ 2.4.2 The helicopter flyover noise test shall be conducted at the airspeed referred to in Part II, Chapter 11, 11.5.2 with such airspeed adjusted as necessary to produce the same advancing blade tip Mach number as associated with the reference conditions.

~~2.4.2~~ 2.4.3 ~~Advancing~~ The reference advancing blade tip Mach number ~~(Mat)~~ (M_R) is defined as the ratio of the arithmetic sum of blade tip rotational speed ~~(Vt)~~ (V_T) and the reference helicopter true airspeed ~~(Vr)~~ (V_r) divided by the speed of sound ~~(c)~~ (c_R) at 25°C such that:

$$\cancel{Mat = \frac{(Vt + Vr)}{c}}$$

$$M_R = \frac{(V_T + V_r)}{c_R}$$

3. NOISE UNIT DEFINITION

3.1 The ~~value of~~ sound exposure level L_{AE} is defined as the level, in decibels, of the time integral of squared A-weighted sound pressure (P_A) over a given time period or event, with reference to the square of the standard reference sound pressure (P_0) ~~or~~ of 20 ~~micropascals~~ μPa and a reference duration of one second.

3.2 This unit is defined by the expression:

$$L_{AE} = 10 \log \frac{1}{T_0} \int_{t1}^{t2} \left(\frac{P_A(t)}{P_0} \right)^2 dt$$

where T_0 is the reference integration time of one second and ($t2 - t1$) is the integration time interval.

3.3 The above integral can ~~also be expressed~~ be approximated from periodically sampled measurement as:

$$\cancel{L_{AE} = 10\log\frac{1}{T_0}\int_{t1}^{t2} 10^{\frac{L_A(t)}{10}}dt}$$

$$L_{AE} = 10\log\frac{1}{T_0}\sum_{t=1}^{n(t2-t1)} 10^{(0.1L_A(t))}$$

where $L_A(t)$ is the time varying ~~A-weighted~~ A-frequency-weighted S-time-weighted sound level and n is the number of samples per second.

3.4 The integration time ($t2 - t1$) in practice shall not be less than the 10 dB-down time interval during which $L_A(t)$ first rises to ~~within~~ 10 dB(A) ~~of~~ below its maximum value ~~(L_{Amax})~~ and last falls below 10 dB(A) of its maximum value.

~~3.5 The SEL may be approximated by the following expression:~~

~~$L_{AE} = L_{Amax} + \Delta A$~~

~~where ΔA is the duration allowance given by~~

~~$\Delta A = 10 \log_{10}\tau$~~

~~where $\tau = (t2 - t1)/2$.~~

~~L_{Amax} is defined as the maximum level, in decibels, of the A weighted sound pressure (slow response) with reference to the square of the standard reference sound pressure P_0.~~

4. MEASUREMENT OF HELICOPTER NOISE RECEIVED ON THE GROUND

4.1 General

4.1.1 All measuring equipment shall be approved by the certificating authority.

4.1.2 Sound pressure level data for noise evaluation purposes shall be obtained with acoustical equipment and measurement practices that conform to the specifications given in 4.2.

4.2 Measurement system

The acoustical measurement system shall consist of approved equipment equivalent to the following:

a) a microphone system with ~~frequency response compatible with measurement and analysis system accuracy as stated in~~ performance characteristics meeting the requirements of 4.3;

b) tripods or similar microphone mountings that minimize interference with the sound being measured;

c) recording and reproducing equipment ~~characteristics, frequency response, and dynamic range compatible with the response and accuracy requirements~~ with performance characteristics meeting the requirements of 4.3; and

d) ~~acoustic~~ sound calibrators using sine wave ~~or broadband noise~~ signals of known sound pressure level meeting the requirements of 4.3. ~~If broadband noise is used, the signal shall be described in terms of its average and maximum root mean square (rms) value for non-overload signal level.~~

4.3 Sensing, recording and reproducing equipment

4.3.1 The microphone shall be of the type that has a pressure or a diffuse-field sensitivity whose frequency response is nearly flat at grazing incidence.

~~4.3.1~~ 4.3.2 ~~With the approval of the certificating authority the sound level produced by the helicopter may be stored on a magnetic tape recorder for later evaluation. Alternatively, the A-weighted sound level time history may be written onto a graphic level recorder set at "slow" response from which the SEL value may be determined or the SEL may be directly determined from an integrating sound level meter complying with the Standards of International Electrotechnical Commission (IEC) Publication No. 804[1] for a Type 1 instrument set at "slow" response.~~ The SEL may be directly determined from an integrating sound level meter. Alternatively, with the approval of the certificating authority the sound pressure signal produced by the helicopter may be stored on an analog magnetic tape recorder or a digital audio recorder for later evaluation using an integrating sound level meter. The SEL ~~value~~ may also be calculated from one-third octave band data obtained from measurements made in conformity with Section 3 of Appendix 2 and using the equation given in 3.3. In this case each one-third octave band sound pressure level shall be weighted in accordance with the A-weighting values given in ~~IEC Publication No. 651.[1]~~ IEC Publication 61672-1.[1]

~~4.3.2~~ 4.3.3 ~~The characteristics of the complete system shall comply with the recommendations given in IEC Publication No. 651[1] with regard to the sections concerning microphone, amplifier and indicating instrument characteristics. The text and specifications of IEC Publication No. 651 entitled "Sound Level Meters" are incorporated by reference into this section and are made a part hereof.~~ The characteristics of the complete system with regard to directional response, frequency weighting A, time weighting S (slow), level linearity, and response to short-duration signals, shall comply with the class 1 specifications given in IEC 61672-1.[1] The complete system may include tape recorders or digital audio recorders according to IEC 61672-1.[1]

Note.— The certificating authority may approve the use of equipment compliant with class 2 of the current IEC standard, or the use of equipment compliant with class 1 or Type 1 specifications of an earlier standard, if the applicant can show that the equipment had previously been approved for noise certification use by a certificating authority. This includes the use of a sound level meter and graphic level recorder to approximate SEL using the equation given in 3.3. The certificating authority may also approve the use of magnetic tape recorders that comply with the specifications of the older IEC 561 standard if the applicant can show that such use had previously been approved for noise certification use by a certificating authority.

~~4.3.3 If a tape recording is used, the tape recorder shall comply with IEC Recommendation 561.[1]~~

~~4.3.4 The response of the complete system to a sensibly plane progressive sinusoidal wave of~~

~~constant amplitude shall lie within the tolerance limits specified in Table IV and Table V for Type I instruments in IEC Publication No. 651, for weighting curve A over the frequency range 45 to 11 500 Hz.~~

~~4.3.5~~ 4.3.4 The overall sensitivity of the measuring system shall be checked before tests start, after testing has ended, and at intervals during testing using ~~an acoustic~~ a sound calibrator generating a known sound pressure level at a known frequency. The sound calibrator should conform to the class 1 requirements of IEC 60942. The output of the ~~acoustic~~ sound calibrator shall have been checked by a standardizing laboratory within 6 months of the test series; tolerable changes in output shall be not more than 0.2 dB. The equipment shall be considered satisfactory if the variation over the period immediately prior to and immediately following each test series within a given test day is not greater than 0.5 dB.

Note.~~— A pistonphone operating at a nominal 124 dB and 250 Hz is generally used for this purpose.~~ *The certificating authority may approve the use of calibrators compliant with class 2 of the current IEC standard, or the use of calibrators compliant with class 1 of an earlier standard, if the applicant can show that the calibrator had previously been approved for noise certification use by a certificating authority.*

4.3.5 When the sound pressure signals from the helicopter are recorded, the SEL may be determined by playback of the recorded signals into the electrical input facility of an approved sound level meter that conforms to the class 1 performance requirements of IEC 61672-1. The acoustical sensitivity of the sound level meter shall be established from playback of the associated recording of the signal from the sound calibrator and knowledge of the sound pressure level produced in the coupler of the sound calibrator under the environmental conditions prevailing at the time of the recording of the sound from the helicopter.

4.3.6 A wind screen should be employed with the microphone during all measurements of helicopter ~~noise~~ sound levels. Its characteristics should be such that when it is used, the complete system including the wind screen will meet the specifications ~~above. Its insertion loss at the frequencies of the pistonphone should also be known and included in the acoustic reference level for analysis of the measurements.~~ in 4.3.3.

4.4 Noise measurement procedures

~~4.4.1 The microphone shall be of the pressure-sensitive type designed for nearly uniform grazing incidence response.~~

~~4.4.2~~ 4.4.1 The microphone shall be mounted with the centre of the sensing element 1.2 m (4 ft) above the local ground surface and shall be oriented for grazing incidence, i.e. with the sensing element substantially in the plane defined by the nominal flight path of the helicopter and the measuring station. The microphone mounting arrangement shall minimize the interference of the supports with the sound to be measured.

~~4.4.3~~ 4.4.2 If the ~~noise~~ helicopter sound pressure signal is ~~tape~~ recorded, the frequency response of the electrical system shall be determined, during each test series, at a level within 10 dB of the full-scale reading used during the tests, utilizing random or pseudo-random pink noise. The output of the noise generator shall have been checked by an approved standards laboratory within six months of the test series, and tolerable changes in the relative output at each one-third octave band shall be not more than 0.2 dB. Sufficient determinations shall be made to ensure that the overall calibration of the system is known for each test.

~~4.4.4~~ 4.4.3 Where ~~a~~ an analog magnetic tape recorder forms part of the measuring chain, each reel of magnetic tape shall carry 30 s of this electrical calibration signal at its beginning and end for this purpose. In addition, data obtained from tape-recorded signals shall be accepted as reliable only if the level difference in the 10 kHz one-third octave band filtered levels of the two signals is not more than 0.75 dB.

Note.— Digital audio recorders typically do not exhibit substantial variation in frequency response or level sensitivity, therefore the pink noise testing described in 4.4.3 is not necessary for digital audio recorders.

~~4.4.5~~ 4.4.4 ~~Background~~ The A-frequency-weighted sound level of the background noise, including ambient noise and electrical noise of the measurement systems, shall be determined in the test area with the system gain set at levels which will be used for helicopter noise measurements. ~~If helicopter sound pressure levels do not exceed background sound pressure levels~~ If the L_{Amax} of each test run does not exceed the A-frequency-weighted sound level of the background noise by at least 15 dB(A), flyovers at an approved lower height may be used and the results adjusted to the reference measurement ~~point~~ height by an approved method.

1 ~~Available from the Central Office of the International Electrotechnical Commission, 3 rue de Varembé, Geneva, Switzerland.~~IEC 61672-1: 2002 entitled “Electroacoustics – Sound level meters – Part I: Specifications”. This IEC publication may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.

2 IEC 60942: 2003 entitled “Electroacoustics – Sound calibrators”. This IEC publication may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.

. . .

APPENDIX 6. NOISE EVALUATION METHOD FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR TYPE CERTIFICATE ~~OF AIRWORTHINESS FOR THE PROTOTYPE ACCEPTED~~ SUBMITTED ON OR AFTER 17 NOVEMBER 1988

. . .

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

. . .

2.2 General test conditions

. . .

2.2.2 The tests shall be carried out under the following atmospheric conditions:

. . .

c) average wind speed shall not exceed 19 km/h (10 kt) and crosswind average wind speed shall not exceed 9 km/h (5 kt);

Note.— ~~Average wind speed is defined over a 30-second time period.~~ Meteorological specifications are defined in Section 2.2.2.1 of Appendix 2.

. . .

2.2.3 The atmospheric conditions shall be measured within 2 000 m (6 562 ft) from the microphone locations and shall be representative of the conditions existing over the geographical area in which noise measurements are made.

. . .

Replace Section 4 as follows:

4. MEASUREMENT OF AEROPLANE NOISE RECEIVED ON THE GROUND

4.1 General

4.1.1 All measuring equipment shall be approved by the certificating authority.

4.1.2 Sound pressure level data for noise evaluation purposes shall be obtained with acoustical equipment and measurement practices that conform to the specifications given hereunder in 4.2.

4.2 Measurement system

The acoustical measurement system shall consist of approved equipment equivalent to the following:

a) a microphone system designed to have mostly-uniform frequency response for sound incident on the diaphragm from random directions, or in the pressure field of a closed cavity, with performance characteristics meeting the requirements of 4.3;

b) microphone installation and mounting hardware that minimizes interference with the sound being measured, in the configuration specified in 4.4;

c) recording and reproducing equipment performance characteristics meeting the requirements of 4.3; and

d) sound calibrators using sine wave signals of known sound pressure level meeting the requirements of 4.3.

4.3 Sensing, recording and reproducing equipment

4.3.1 The sound level produced by the aeroplane shall be recorded. A magnetic tape recorder, graphic level recorder or sound level meter is acceptable at the option of the certificating authority.

4.3.2 The characteristics of the complete system with regard to directional response, frequency weighting A, time weighting S (slow), level linearity, and response to short-duration signals, shall comply with the class 1 specifications given in the IEC Publication 61672-1.[1] The complete system may include tape recorders according to IEC 61672-1.[1]

Note.— The certificating authority may approve the use of equipment compliant with class 2 of the current IEC standard, or the use of equipment compliant with class 1 or Type 1 specifications of earlier standards, as an alternative to equipment compliant with class 1 of the current IEC standard, if the applicant can show that the equipment had previously been approved for noise certification use by a *certificating authority. The certificating authority may also approve the use of magnetic tape recorders that comply with the specifications of the older IEC 561 standard if the applicant can show that such use had previously been approved for noise certification use by a certificating authority.*

4.3.3 The over-all sensitivity of the measuring system shall be checked before tests start, after testing has ended, and at intervals during testing using a sound calibrator generating a known sound pressure level at a known frequency. The sound calibrator should conform to the class 1 requirements of IEC 60942.[2]

Note.— The certificating authority may approve the use of calibrators compliant with the class 2 specifications of the current IEC standard, or the use of calibrators compliant with class 1 of an earlier standard, if the applicant can show that the calibrator had previously been approved for noise certification use by a certificating authority.

4.3.4 When the sound from the aeroplane is tape recorded, the maximum A-frequency-weighted and S-time-weighted sound level may be determined by playback of the recorded signals into the electrical input facility of an approved sound level meter that conforms to the class 1 performance requirements of IEC 61672-1.[1] The acoustical sensitivity of the sound level meter shall be established from playback of the associated recording of the signal from the sound calibrator and knowledge of the sound pressure level produced in the coupler of the sound calibrator under the environmental conditions prevailing at the time of the recording of the sound from the aeroplane.

4.4 Noise measurement procedures

4.4.1 The microphone shall be a 12.7 mm diameter pressure type, with its protective grid, mounted in an inverted position such that the microphone diaphragm is 7 mm above and parallel to a circular metal plate. This white-painted metal plate shall be 40 cm in diameter and at least 2.5 mm thick, and shall be placed horizontally and flush with the surrounding ground surface with no cavities below the plate. The microphone shall be located three-quarters of the distance from the centre to the edge along a radius normal to the line of flight of the test aeroplane.

4.4.2 If the noise signal is tape-recorded, the frequency response of the electrical system shall be determined, during each test series, at a level within 10 dB of the full-scale reading used during the tests, utilizing random or pseudorandom pink noise. The output of the noise generator shall have been checked by an approved Standards laboratory within six months of the test series, and tolerable changes in the relative output at each one-third octave band shall be not more than 0.2 dB. Sufficient determinations shall be made to ensure that the over-all calibration of the system is known for each test.

4.4.3 Where a magnetic tape recorder forms part of the measuring chain, each reel of magnetic tape shall carry 30 s of this electrical calibration signal at its beginning and end for this purpose. In addition, data obtained from tape recorded signals shall be accepted as reliable only if the level difference in the 10 kHz one-third octave band filtered levels of the two signals is not more than 0.75 dB.

Note.— Digital audio recorders typically do not exhibit substantial variation in frequency response or level sensitivity, therefore the pink noise testing described in 4.4.3 is not necessary for digital audio recorders. Design characteristics for digital audio recorders should be compliant with class 1 performance specifications of IEC 61672-1.[1]

4.4.4 The A-frequency-weighted sound level of the background noise, including ambient noise and electrical noise of the measurement systems, shall be determined in the test area with the system gain set at levels which will be used for aeroplane noise measurements. If the maximum A-frequency-weighted and S-time-weighted sound level of the aeroplane does not exceed the A frequency-weighted sound level of the background noise by at least 10 dB, a take-off measurement point nearer to the start of roll shall be used and the results adjusted to the reference measurement point by an approved method.

1 IEC 61672-1: 2002 entitled “Electroacoustics – Sound level meters – Part I: Specifications”. This IEC publication may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.

2 IEC 60942: 2003 entitled “Electroacoustics – Sound calibrators”. This IEC publication may be obtained from the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.

End of new text.

5. ADJUSTMENT TO TEST RESULTS

. . .

5.2 Corrections and adjustments

Replace the equation under the Note to 5.2.2 c) 3) as follows:

$$M_R = \frac{\left[\left(\frac{D\pi N}{60}\right)^2 + V_T^2\right]^{1/2}}{c}$$

. . .

ATTACHMENT C. GUIDELINES FOR NOISE CERTIFICATION OF INSTALLED AUXILIARY POWER UNITS (APU) AND ASSOCIATED AIRCRAFT SYSTEMS DURING GROUND OPERATION

Note.— See Part II, Chapter 9.

1. INTRODUCTION

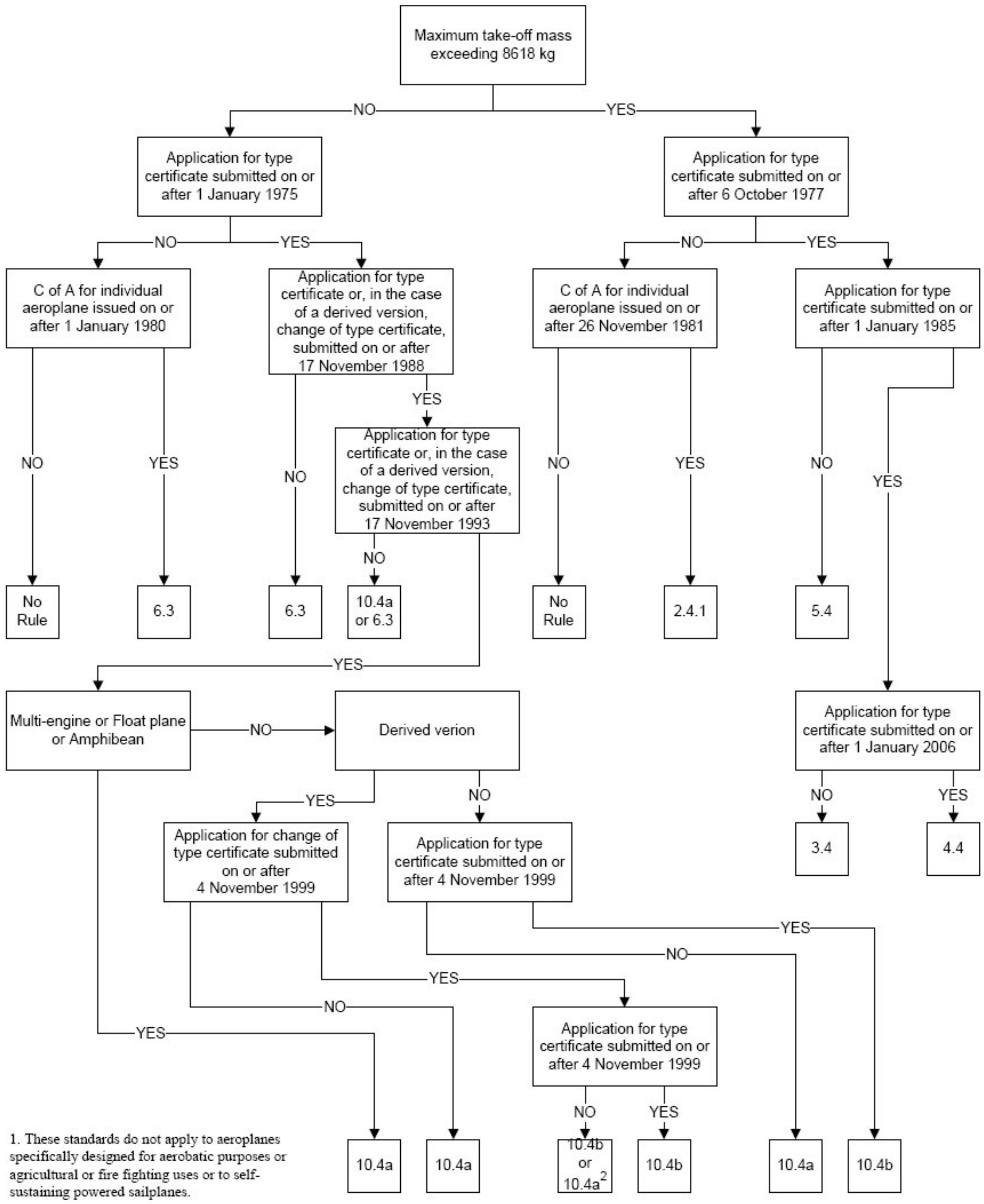
. . .

1.2 It should apply to installed APU and associated aircraft systems in all aircraft for which the application for a ~~certificate of airworthiness for the prototype~~Type Certificate, or another equivalent prescribed procedure, is ~~made~~ submitted on or after 26 November 1981.

. . .

Replace Attachment E as follows:

ATTACHMENT E. APPLICABILITY OF ANNEX 16 NOISE CERTIFICATION STANDARDS FOR PROPELLER-DRIVEN AEROPLANES[1]



1. These standards do not apply to aeroplanes specifically designed for aerobatic purposes or agricultural or fire fighting uses or to self-sustaining powered sailplanes.

2. The option to apply the standards of 10.4a does not apply for applications for change of type certificate submitted on or after 4 November 2004.

ATTACHMENT F. GUIDELINES FOR NOISE CERTIFICATION OF TILT-ROTOR AIRCRAFT

. . .

1. APPLICABILITY

The following guidelines should be applied to all tilt-rotor aircraft, including their derived versions, for which a ~~type certificate of airworthiness~~ an application for Type Certificate was ~~issued~~ submitted on or after 13 May 1998.

. . .

ATTACHMENT H. GUIDELINES FOR OBTAINING HELICOPTER NOISE DATA FOR LAND-USE PLANNING PURPOSES

. . .

2. DATA COLLECTION PROCEDURES

2.1 Data suitable for land-use planning purposes may be derived directly from Chapter 8 noise certification data. Chapter 8 applicants may optionally elect to acquire data suitable for land-use planning purposes via alternative take-off, approach and/or flyover procedures defined by the applicant and approved by the certificating authority. Alternative flyover procedures should be performed overhead the flight path reference point at a height of 150 m. In addition, an applicant may optionally elect to provide data at additional microphone locations.

2.2 Chapter 11 noise certification data may be provided for land-use planning purposes. Chapter 11 applicants may optionally elect to provide data acquired via alternative flyover procedures at 150 m above ground level. In acquiring data for land-use planning purposes, Chapter 11 applicants should give consideration to acquiring data from two additional microphones symmetrically disposed at 150 m on each side of the flight path and/or additional take-off and approach procedures defined by the applicant and approved by the certificating authority. In addition, an applicant may optionally elect to provide data at additional microphone locations.

— — — — — — — —

English only

APPENDIX B

PROPOSED AMENDMENT TO

ENVIRONMENTAL TECHNICAL MANUAL ON THE USE OF PROCEDURES IN THE NOISE CERTIFICATION OF AIRCRAFT
(ETM, DOC 9501)

1. The text of the amendment is arranged to show deleted text with a line through it and new text highlighted with grey shading, as shown below:

1. ~~Text to be deleted is shown with a line through it.~~	text to be deleted
2. New text to be inserted is highlighted with grey shading.	new text to be inserted
3. ~~Text to be deleted is shown with a line through it~~ followed by the replacement text which is highlighted with grey shading.	new text to replace existing text

See paragraph 2.1.5

Chapter 1
GENERAL

. . .

1.4 CHANGES TO THE NOISE CERTIFICATION LEVELS FOR DERIVED VERSIONS

. . .

1.4.3 Aircraft/engine model design changes and airframe/engine performance changes may result in very small changes in aircraft noise certification levels that are not acoustically significant. These changes are referred to as no-acoustical changes (NACs). For this manual, NACs, which do not result in modification of an aircraft's noise certification levels, are defined as:

. . .

c) for helicopters certificated according to the Standards of Annex 16, Volume I, Chapter 8, changes in ~~helicopter noise~~ any one of the noise certification levels approved by the certificating authority which do not exceed 0.3 EPNdB; and ~~at any one of the noise certification levels.~~

d) for helicopters certificated according to the Standards of Annex 16, Volume I, Chapter 11, changes in the noise certification level approved by the certificating authority which do not exceed 0.3 dB(A).

. . .

~~1.4.4 j)~~ 1.4.5 ~~d~~Due to the applicability dates for Chapters 6 and 10 of Annex 16, Volume I, ~~concerning helicopters and~~ some light-propeller driven aeroplanes~~, some aircraft~~ are not required to have certified noise levels. However some modifications to these aircraft can be applied which may impact the noise characteristics. In this case, the no-acoustical change criterion application will be treated with a procedure approved by the certificating authority.

1.4.~~5~~6 Noise certification approval of modified helicopters should be granted according to the following criteria:

a) an NAC approval for a derived version shall be made only if the "flight datum" helicopter was flight tested to obtain the certificated noise level(s) ~~were acquired by testing the "flight datum" helicopter design;~~

b) noise levels for a helicopter designated as an NAC design cannot be used as the "flight datum" for any subsequent design changes; and

c) for changes exceeding 0.3 dB, compliance with Annex 16, Volume I requirements ~~can~~ may be achieved either by testing or, subject to the approval of the certificating authority, by analytical means. If analytical means are employed, the noise certification level(s) cannot be used as the "flight datum" for any subsequent design changes.

A flow chart illustrating the criteria for dealing with modified helicopters is presented in Figure 1-1.

1.4.7 Due to applicability dates for Chapters 8 and 11 of Annex 16, Volume I, some helicopters are not required to have certified noise levels. However some modifications to these helicopters can be applied which may impact the noise characteristics. In this case, the no-acoustical change criterion application will be treated with a procedure approved by the certificating authority.

. . .

See paragraph 2.2.6

Chapter 2

EQUIVALENT PROCEDURES FOR SUBSONIC JET AEROPLANES

. . .

2.3 STATIC ENGINE NOISE TESTS AND PROJECTIONS TO FLIGHT NOISE LEVELS

2.3.1 General

. . .

2.3.1.4 Types of static test accepted for the purposes of certification compliance demonstration in aeroplane development include engine and ~~component noise tests and performance testing~~ rig noise tests. Such tests are useful for assessing the effects of mechanical and thermodynamic cycle changes to the engine on the individual noise sources. Such configuration and/or design changes often occur as engines are developed subsequent to the initial noise certification of an aircraft to ease production difficulties, reduce cost, improve durability and for operational reasons.

2.3.1.5 Static engine noise testing is discussed in detail in subsequent sections. For component tests, the criteria for acceptability are less definable. There are many instances, particularly when only small changes in EPNLr are expected, where component testing will provide an adequate demonstration of noise impact. For example:

a) changes in the specification of sound-absorbing linings within an engine nacelle;

b) changes in the mechanical or aerodynamic design of the fan, compressor or turbine;

c) changes to combustor designs (including material changes);~~ and~~

d) changes to bleed valves; and

e~~d~~) changes to the exhaust system ~~minor exhaust system changes~~.

. . .

See paragraph 2.2.5

Chapter 4

EQUIVALENT PROCEDURES FOR PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 KG

. . .

4.2 TAKE-OFF TEST AND REFERENCE PROCEDURES

. . .

4.2.5 The take-off reference procedure defined in Chapter 10 of Annex 16, Volume I requires that the second phase of the procedure shall be flown at the best rate of climb speed (V_y). The aeroplane testing procedures described in Appendix 6 of Annex 16, Volume I require that the flight test shall be conducted at V_y. The reference height to which the measured noise levels are to be corrected is calculated from the climb rate corresponding to V_y. Recent changes to the airworthiness requirements have eliminated the need to determine V_y for small propeller-driven aeroplanes. In this case applicants will nevertheless have to determine V_y for the purpose of showing compliance with Chapter 10 of Annex 16, Volume I. If the minimum airworthiness approved climb speed is greater than V_y then this speed shall be used and noted in the aircraft flight manual.

4.2.6 Applicants may alternatively show compliance with Chapter 10 at the climb speed for which the aircraft flight manual performance information is calculated provided they demonstrate, to the satisfaction of the certificating authority, that the resulting noise level is not less than would have been obtained using V_y.

. . .

See paragraph 2.2.6

Chapter 5

EQUIVALENT PROCEDURES FOR HELICOPTERS — FLIGHT TEST PROCEDURES

. . .

5.1 FLIGHT TEST PROCEDURES

5.1.1 Noise certification guidance

. . .

5.1.1.3.4 The second speed requirement states that the level overflights shall be made in equal numbers with a headwind component and tailwind component (see 11.6.4 of Chapter 11 of Annex 16, Volume I). For practical reasons, if the absolute wind speed component in the direction of flight, as measured at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground (see 2.2.2 d) of Appendix 4 of Annex 16, Volume I), is less than 9 km/h (5 kt), then the effect of wind can be considered to be negligible. In this case, the measured overflight may be used to satisfy a ~~pass~~ test run in either the headwind or tailwind direction if the overflights are conducted in pairs. Each pair should consist of two overflights performed one after the other in opposite directions over the reference flight track.

See paragraph 2.1.8

5.1.1.4 *Helicopter test rotor rpm*

Operational rotor rpm modes (e.g. CAT A) can form part of the AFM normal procedures and are used under specific operational circumstances. They typically involve airspeed ranges below those of the certification reference procedures. However, in some cases, such as a high pilot workload in the final approach phase combined with IFR conditions, their use has been permitted at higher airspeeds which includes the reference speed for noise certification. Hence, the maximum normal operating rotor speed corresponding to the reference flight condition should take into account any relevant operational rotor rpm mode. The decision on how and which operational rotor rpm modes are to be applied for noise certification is normally coordinated with the flight test experts of the certification authority and is dealt with on a case-by-case basis.

Editorial Note.— Subsequent paragraphs to be re-numbered as necessary.

. . .

See paragraphs 2.1.5 and 2.1.10

5.1.3 Procedures for the determination of changes in noise levels

. . .

5.1.3.2 *Modifications for which changes in noise level(s) need not be determined*

Chapters 8 (8.1.5) and 11 (11.1.5) of Annex 16, Volume I require that "certification of helicopters which are capable of carrying external loads or external equipment shall be made without such loads or equipment fitted".

It follows that changes in noise level(s) arising from modifications associated with the installation or removal of external equipment need not be determined. For the purposes of this paragraph "external equipment" means any instrument, mechanism, part, appurtenance, or necessary accessory that is attached to, or extends from, the helicopter exterior but is not used, nor is intended to be used, in operating or controlling the helicopter in flight and is not part of an airframe or engine.

In this respect the following are considered to be no-acoustical changes:

a) the addition or removal of external equipment;

b) changes to the airframe made to accommodate the addition or removal of external equipment, to provide for an external load attaching means, to facilitate the use of external equipment or external loads, or to facilitate the safe operation of the helicopter with external equipment mounted to, or external loads carried by, the helicopter;

c) reconfiguration of the helicopter by the addition or removal of floats and skis;

d) flight with one or more doors and/or windows removed or in an open position; or
e) any changes in the operational limitations placed on the helicopter as a consequence of the addition or removal of external equipment, floats, skis, or flight operations with doors and/or windows removed or in an open position.

. . .

See paragraph 2.2.4

Chapter 6

EVALUATION METHODS

. . .

6.9 ACQUISITION OF IN-DUCT AND/OR NEAR-FIELD DATA FOR DEMONSTRATION OF "NO-ACOUSTICAL CHANGE" (NAC)

6.9.1 Certificating authorities have found it acceptable for applicants to conduct noise tests to evaluate minor engine changes of the types described in Section 2.3.1.5 of this manual. Frequently the objective for these tests is to provide evidence that the changes involved produce negligible impact on EPNL noise values and may therefore be categorized as no-acoustical changes (NACs) relative to the certificated aircraft configuration. Such testing has included component tests, static engine tests in a test cell, near-field microphone measurements, and in-duct dynamic pressure measurements.

6.9.2 The overall guiding principles to be followed in providing acceptable evidence for substantiation of engine non-acoustical changes are:

– the measurements and analyses should adequately model the noise such that small changes in aircraft noise levels can be quantified; and

– the noise measurement technique and the test environment should not introduce changes to the noise sources that invalidate the predicted small changes in aircraft noise levels.

These guiding principles should be applied in all cases, with details of the approach being justified on a case-by-case basis as appropriate.

Note 1.— It is important that the near-field or in-duct measurements enable a sufficiently accurate prediction of the changes to engine noise in the far-field.

Note 2.— It is important that the noise generating mechanisms of interest are not significantly affected by the test cell environment. The test cell should have an exhaust collector to minimize re-circulation. There should be insignificant inlet distortion or inflow turbulence, or a turbulence control *screen or inflow control device should be employed to minimize such distortions or turbulence. Test cell measurements might not be appropriate for assessing jet noise changes because of the influence of the test cell on the jet development.*

Note 3.— Care must be taken to ensure the noise source under investigation is not masked by other unrepresentative noise components. Whilst a reduced acoustic standard of components not under investigation might be acceptable in many cases, there are examples where such differences might invalidate the premise of a non-acoustical change (e.g. noise from the intake being masked by a hard-walled bypass duct or significant noise from an overboard air dump contaminating the measured noise).

6.9.3 Typical measurement systems used to acquire data for substantiation of an engine non-acoustical change include:

a) near-field microphones either in test cells or out-door facilities;

b) in-duct transducer measurements in the fan inlet or exhaust duct; and

c) core probes to assess combustor or low pressure turbine design changes.

6.9.4 The measurement and data analysis process should be accomplished on the basis of the following criteria:

a) An adequate array of transducers should be used to ensure that the measurements adequately model the noise. To determine overall changes in sound pressure level the measured noise levels will typically need to be averaged azimuthally, radially and/or axially in order to avoid false conclusions being drawn from anomalous readings from single transducers.

b) It should be ensured that changes in the local environment (e.g. test cell temperature) do not result in significant anomalies in the measured noise differences.

c) Microphones should be mounted on the test cell wall or on the ground or floor, but not in the shadow of any support structures or other test hardware.

d) In-duct transducers should be flush mounted with minimal loss of area of acoustic treatment. Rake-mounted transducers in the flow path should be avoided if they shed wakes that impinge on downstream structures and thereby create significant noise.

e) Core probes should be fixed securely to the pylon, boat-tail fairing or other support and not be excessively buffeted by the flow.

f) The specifications of the measurement system and calibration procedures for microphones, recording and reproducing systems should be in accordance with Section 3 of Appendix 2 of Annex 16, Volume I. Laboratory calibrations of in-duct transducers and core probes should be conducted before and, if possible, after each test. The dynamic range of the transducers should be sufficient to avoid overload.

g) Data should be acquired over the relevant engine operating speeds and for all relevant combinations of engine variables, as specified in the latest version of SAE ARP 1846 (see Section 2.3.3.1.1 of this manual).

h) The interpretation of in-duct measurements should take into account the possibility that decaying or cut-off acoustic waves may be present that may mask changes sensed in the far field of the propagating wave.

i) Two alternative methods could be used in the subsequent analysis of the measured noise levels to demonstrate a non-acoustical change.

   – The measured component noise changes could be incorporated into a noise model that predicts the aircraft EPNL. This method has the added value of taking into account in-flight effects and the relative significance of the different noise sources.

   – In some circumstances, it might be possible to reach the conclusion of a non-acoustical change without the need to incorporate the measured component noise changes into a noise model that predicts aircraft EPNL. The measured noise changes could be examined to see if there is no increase in noise levels at any relevant frequency or engine condition.

Generally, noise models that predict the aircraft noise level expressed in EPNL are based on far field static test data. Consequently, in either analysis it will be necessary to agree with the certificating authority the method for calculating the impact on far field static noise resulting from near field microphone measurements or in-duct transducer measurements. This will normally require sound engineering judgement, seeking out patterns in the data and technical explanations for any observed differences.

Furthermore, the statistical (un)certainty in the data should be considered. For example if statistical analysis shows that the uncertainty in the data is large and the differences are small, then no conclusions can be drawn from the data. On the other hand, if the tests show large decreases in noise levels that outweigh the uncertainty in the data it may be possible to conclude, with reasonable certainty, that the changed engine is indeed quieter than the original engine.

. . .

See paragraph 2.1.4

Insert new Appendix 9 as follows**:**

Appendix 9

GUIDANCE ON FLIGHT TEST WINDOWS AND FOR CORRECTION OF LAND-USE PLANNING NOISE DATA MEASURED IN ACCORDANCE WITH ANNEX 16, VOLUME 1, ATTACHMENT H

1. BACKGROUND

1.1 At CAEP/6, guidelines for the provision of rotorcraft noise data for land-use planning (LUP) purposes were approved as Attachment H to Annex 16. The objective of Attachment H is the provision of noise data, in metrics suitable for LUP purposes, at the noise certification flight conditions and/or at alternative flight conditions representing normal operating procedures or other recommended flight procedures.

1.2 Detailed guidance on flight test windows and adjustments of LUP data to reference conditions for alternative flight procedures specifically designated for LUP data provision is provided in this appendix. To be consistent with noise certification data and to provide comparable accuracy, the detailed guidance is based on the flight test windows and data adjustment procedures utilized for noise certification flight procedures to the fullest extent practical.

1.3 In developing these flight test windows and data adjustment procedures, the needs associated with LUP data provision have been balanced against the test costs in acquiring LUP data with the intent of encouraging additional optional flight testing and measurements by applicants.

1.4 The guidance on test windows for alternative flight procedures is provided in Section 2, while guidance on adjustment of LUP data to reference conditions is provided in Sections 3 and 4, with Section 3 addressing reference conditions and Section 4 providing specific guidance on adjustment procedures.

Note.— The test windows and adjustments to data provided in this appendix address constant airspeed and flight path conditions only. Varying airspeed and flight path conditions may require additional guidance not yet provided in this appendix.

2. TEST WINDOWS

2.1 Alternative constant airspeed and flight path conditions

2.1.1 The flight test windows and procedures for alternative constant flight conditions for LUP are provided in Table X-1 together with the existing requirements for noise certification. For these LUP procedures, "No Change" denotes the recommended use of the Chapter 8 or 11 test windows and procedures.

2.1.2 Many of the flight test windows and procedures currently used for noise certification testing can be applied when acquiring noise data for LUP purposes under Attachment H. Thus the flight test windows and procedures detailed in Table X-1 make as much use of current Chapter 8 and Chapter 11 adjustment procedures as practical. In addition, it should be noted that the "No Correction Window" as defined in ETM paragraph 5.1.1.1 may be used.

2.1.3 Table X-1 includes, relative to the noise certification requirements, an expanded airspeed tolerance of +/-7 kt for Chapter 8 helicopters and +/-5 kt for Chapter 11 helicopters (or +/-7 kt if the Chapter 8 Δ_2 adjustment is used) and a minimum number of test runs of 4. The 90% confidence interval limit of 1.5 dB currently applied to the three-microphone average of EPNL in Chapter 8 is also applied to the corresponding three-microphone average of SEL. In the case of Chapter 11, the current 90% confidence interval requirement for the SEL at the flight track microphone is retained. In addition, the 90% confidence interval calculated for each time-integrated and maximum noise level metric at each microphone should be reported.

2.1.4 These guidelines primarily address the balance between LUP data needs and test costs for applicants providing data under Attachment H. In particular, increasing the airspeed test window by 2 kt will reduce test costs while incurring little impact on the final results. Reducing the required minimum number of test runs from 6 to 4 also reduces test costs while the needed accuracy of the data is maintained by the 90% confidence interval limit.

2.2 Alternative non-constant/varying airspeed and flight path conditions [Reserved]

3. REFERENCE CONDITIONS

3.1 Flight procedures designed to represent normal or noise abatement operations can vary from simple fixed flight path-fixed airspeed procedures similar to noise certification test conditions to complex varying flight path-varying airspeed procedures. The resulting reference flight procedures and data correction procedures must be approved by the certificating authority.

3.2 The primary test conditions that affect adjustments to the noise data are the reference atmospheric conditions, the reference helicopter flight path, and the reference helicopter airspeed. For acquiring noise data for LUP purposes, the reference atmospheric conditions should be the same as those specified in 8.6.1.5 of Chapter 8 and 11.5.1.4 of Chapter 11 of the Annex.

3.3 If predefined reference constant flight path and constant speed conditions similar to, but different than those defined for noise certification testing under Chapter 8 are used, the same correction procedures defined in Appendix 2 can be used with (i) the new reference conditions substituted in the correction procedures as appropriate and (ii) the correction procedure modified as necessary to give results in terms of corrected sound exposure level, L_{AE}, and any other metrics selected by the applicant.

3.4 In the process of developing flight profiles for land-use planning and noise abatement procedures, a reference flight path and/or reference airspeed procedure may not have been determined prior to obtaining a set of noise data suitable for land-use planning purposes. In such cases, the flight path and airspeed test data may be used to derive appropriate reference values. The method used shall be approved by the certificating authority.

3.4.1 *Constant Flight Path.* If a reference flight path is not predefined, a reference path needs to be derived or otherwise determined from the flight test data. One method to define the reference path is to determine the mean of the test runs by calculating the path of each test run using a least-squares linear fit of the aircraft position data (in X, Y and Z coordinates) between the 10 dB-down points and averaging the calculated results.

3.4.1.1 An example is the case where, as a result of flight testing multiple glide slopes, a fixed glide slope approach is deemed appropriate for pilot acceptability. If the selected flight path was repeated as necessary to obtain a statistically valid set of noise levels, the flight path data can be averaged to define the reference flight path.

3.4.2 *Constant Airspeed.* If a reference ground speed V_r is not predefined, a value of V_r needs to be derived or otherwise determined from the measured data. One method to define V_r is to determine the mean of the test runs by averaging the true airspeeds (TAS) of each test run that meets the test window criteria.

3.4.2.1 An example of this is the case where the sensitivity of noise level with airspeed and rate-of-descent (ROD) is of interest. The test programme might incrementally test a range of fixed indicated airspeeds for one or more rates of descent, with the reference ground speed for a LUP flight profile subsequently defined after the flight test programme.

3.4.2.2 For the special case of determining V_r for the flyover condition when using the equivalent Mach number method (5.1.1.3 and 5.1.1.8.2 of the ETM) to correct for source noise, a separate method is described in 4.1.1.8.

Note.— The reference ground speed V_r can be derived from true airspeed data as, by definition, the true airspeed and ground speed are identical for the zero wind reference condition.

3.4.3 *Varying Airspeeds and/or Flight Paths*
[Reserved]

4. ADJUSTMENTS TO REFERENCE CONDITIONS

4.1 Constant airspeed and flight path conditions

4.1.1 *Measurements processed using the procedures of Annex 16, Volume 1, Appendix 2*

4.1.1.1 Corrected as-measured noise data are typically adjusted to reference conditions using standardized procedures. The following adjustments to noise data assume measured one-third octave and aircraft position time history data are available as per Appendix 2.

Note.— Corrected as-measured noise data are data corrected per the requirements of 3.9 and 3.10 of Appendix 2 to Annex 16.

4.1.1.2 If a reference flight condition with a fixed flight path and (or) fixed airspeed different from those defined for noise certification testing under Chapter 8 is measured, the same data adjustment procedures defined in Appendix 2 can be used with (i) the new reference conditions substituted in the correction procedures as appropriate and (ii) the correction procedures modified as necessary to give results in terms of sound exposure level, L_{AE}, and any other metrics selected by the applicant.

4.1.1.3 The adjustments to be applied to time-integrated noise metrics, e.g., L_{AE} or EPNdB, should include:

- Bandsharing correction (for tone-corrected metrics such as EPNL)
- Δ_1 adjustment for sound attenuation
- Δ_2 duration adjustment (for time-integrated metrics)
- Δ_3 source noise adjustment (for overflights)

Note.— The bandsharing correction, the Δ_1 adjustment and theΔ_3 adjustment should also be applied as appropriate to the maximum noise level (e.g., PNLT, L_{Amax}) if the value is to be published.

4.1.1.4 Δ_1 can be calculated for L_{AE} and L_{Amax} as follows:

a) determine the aircraft position at the time that the noise at L_{Amax} was emitted and the slant range to the microphone diaphragm;

b) determine the reference aircraft position based on the reference flight path and the reference slant range to the microphone diaphragm;

c) calculate a new reference L_{Amax} from the one-third octave spectrum as corrected using the equation in 8.3.1 of Appendix 2; and

d) calculate Δ_1 by subtracting the test L_{Amax} from the reference L_{Amax} as in 8.3.2 of Appendix 2.

Note 1.— Use of the Δ_1 *adjustment derived for EPNL and PNLTM is acceptable for application to* L_{AE} *and* L_{Amax} *noise data.*

Note 2.— If the temperature and humidity meteorological conditions are within the zero attenuation adjustment window, the reference and test slant ranges may be replaced by the reference and test distances to the helicopter when the helicopter is over the centre noise measuring point (see 5.1.1.1.2 of the ETM). This assumes that the measurement points are the same or close to the locations used for noise certification testing and the aircraft slant ranges are similar to those seen during noise certification testing. If additional measurement points are used that are significantly further from the flight path, consideration should be given to the increased error that is inherently added by the increased distances.

4.1.1.5 The Δ_2 adjustment is only applied to time-integrated noise metrics. The measured and reference distance values used in determining Δ_1 adjustments to the test data may be used to determine the distance term of the Δ_2 adjustment.

4.1.1.6 An example of calculating Δ_2 for L_{AE} is:

a) determine a mean ground speed V_G for each test run;

b) if a reference ground speed V_r has not been predefined, determine a reference ground speed from the test results to be used as V_r in the Δ_2 adjustment; and

c) calculate Δ_2 as in 8.4 of Appendix 2 from the slant ranges determined from the Δ_1 adjustment procedure, mean ground speed V_G of the test run, and the reference ground speed V_r.

4.1.1.7 During noise certification testing, an accepted source noise correction procedure for overflights is the method described in 8.5 of Appendix 2. This correction is normally made using a sensitivity curve of the maximum PNLTM versus main rotor advancing blade tip Mach number. For other time-integrated metrics, the corresponding maximum noise metric should be used in place of PNLTM.

4.1.1.7.1 An alternative method, the equivalent Mach number test procedure, is to calculate an adjusted reference true airspeed based on the pre-selected reference airspeed and/or test airspeed and the test day outside air temperature (see 5.1.1.8.2 of the ETM and 4.1.1.8). Either method is acceptable for correcting overflight data for LUP purposes at other speeds when the reference airspeed is known beforehand.

Note.— Use of the source noise correction derived for EPNL and PNLTM is acceptable for application to L_{AE} *and* L_{Amax} *noise data.*

4.1.1.8 For some overflight tests without a predefined reference airspeed V_r for which the equivalent Mach number correction method is intended to be used, test runs may be flown at selected airspeeds without first adjusting the airspeed for test day outside air temperature. In this case, the reference airspeed V_r may be derived from the test data so that it includes the correction for source noise. This can be achieved by the following process:

a) calculate a main rotor advancing tip Mach number M_T for each test run from the test true airspeed V_T, the main rotor blade tip rotational speed V_{TIP}, and the speed of sound c_T calculated from the on-board measurement of outside air temperature:

$$M_T = \frac{V_T + V_{TIP}}{c_T}$$

b) calculate the mean of the test Mach numbers;

c) set the reference Mach number M_R equal to the mean of the test Mach numbers;

d) calculate V_r from the reference Mach number M_R, the main rotor blade tip rotational speed V_{TIP}, and the speed of sound c at 25°C:

$$V_r = c\ (M_R) - V_{TIP}$$

e) calculate the adjusted reference airspeed V_{ar} and Δ_2 for each test run as in the normal manner (see 5.1.1.8.2 of the ETM, 8.4.2 of Appendix 2 and 5.2.3 of Appendix 4)

Note.— A value of V_r can be selected that is different from that calculated above with V_{ar} adjusted accordingly as long as each test run used to determine the mean noise level for the chosen V_r is within the test windows.

4.1.2 *Measurements Processed Using the Procedures of Annex 16, Volume 1, Appendix 4*

Note 1.— Chapter 11 applicants are encouraged to record the sound pressure signals and/or one-third octave data and, if possible, aircraft position time history data in addition to the requirements of Appendix 4. This will enable additional analysis and provision of data, including additional sound metrics.

Note 2.— In addition to the center microphone required by Chapter 11, applicants should give consideration to acquiring data using two additional measurement points symmetrically disposed at 150 m. The corrections in this section can be applied to the noise levels measured at those locations. This requires the calculation of the slant range distance from the aircraft position at the overhead point to the sideline location.

4.1.2.1 The following corrections assume corrected as-measured data obtained from an integrating sound level meter and aircraft position at the overhead point are available as per Annex 16, Volume 1, Appendix 4. When as-measured one-third octave data is used to calculate L_{AE}, the method described in Section 4.1.1 can be used if aircraft time history position data is also available.

Note.— Corrected as-measured noise data are data corrected per the requirements of 4.3.5 of Appendix 4 to Annex 16.

4.1.2.2 The adjustments to be applied to time-integrated noise metrics, e.g., L_{AE}, should include:

- Δ_1 adjustment (separated into spherical spreading and duration terms – see 4.1.2.3 below)
- Δ_2 adjustment

Note 1.— The separation of the Δ_1 adjustment into spherical spreading and duration terms is based on the terms specified in Appendix 2.

Note 2.— The spherical spreading term of the Δ_1 adjustment should be applied to the maximum noise value (e.g., L_{Amax}) if the value is also to be provided.

4.1.2.3 An example of calculating Δ_1 is:

a) determine the slant range distance SR from the aircraft to the microphone using the measured aircraft height H when the helicopter is over the center noise measuring point (*Note.— SR will equal H for the flight track microphone*);

b) determine the reference slant range SR_{REF} to the microphone using the reference aircraft height H_{REF}; and

c) calculate spherical spreading term of Δ_{1SS} as follows:

$$\Delta_{1SS} = 20 \log (SR/SR_{REF})$$

The duration term of the Δ_1 adjustment need only be applied to the time-integrated metric and is calculated as follows:

$$\Delta_{1D} = -7.5 \log (SR/SR_{REF})$$

4.1.2.4 The Δ_2 adjustment need only be applied to the time-integrated noise metric. For overflights, the equation described in 5.2.3 of Appendix 4 and reproduced here should be used to calculate Δ_2.

$$\Delta_2 = 10 \log (V_{ar}/V_r)$$

where V_{ar} is the adjusted reference true airspeed.

To calculate the Δ_2 adjustment for take-off and approach flight conditions, the ground speed of each test run is required. However, Chapter 11/Appendix 4 does not require measurement of the ground speed V_G. If each test run is performed with a headwind component, then it is considered acceptable that a Δ_2 adjustment need not be calculated. Note, however, that the resulting noise level will be higher than if corrected. If ground speed is measured, then Δ_2 should be calculated using the following equation:

$$\Delta_2 = 10 \log (V_G/V_r)$$

where V_r is predefined or calculated as in 3.4.2.

4.2 Varying airspeed and flight path conditions [Reserved]

Table 9-1.

Annex 16/ETM *Paragraph*	*Test Window/Procedure*	*Noise Certification*	**Constant LUP** *Flight Conditions*
Chapter 8			
8.7.4	Total Adjustments	Takeoff: 4 EPNdB/2 EPNdB Approach & Flyover: 2 EPNdB	No change for integrated noise metrics
8.7.5	Rotor Speed (Nr)	+/-1%	No change
8.7.6	Airspeed	+/- 5 kts	+/- 7 kt
8.7.7	Overflights w/ Headwind/Tailwind	equal numbers	No change
8.7.8	Zenith Angle	+/-10 deg or +/-20 m	No change
8.7.9	Overflight Height @ Overhead	+/- 9 m	No change
8.7.10	Approach Angle	+/- 0.5 deg 'Wedge'	No change
8.7.11	Mass	90% to 105%	No change
App 2, 2.2.2(b)	Temp @ 10 m	-10 to 35 deg C	No change
App 2, 2.2.2(b)	RH @ 10 m	20 to 95%	No change
App 2, 2.2.2(c)	8 kHz Attenuation	12 dB/100 m	No change
App 2, 2.2.2(e)	Wind @ 10 m	10 kts	No change
App 2, 2.2.2(e)	Crosswind @ 10 m	5 kts	No change
App 2, 3.5.2	Microphone Height	1.2 m	1.2 m (Note 1)
App 2, 5.4.2	Number of Test Runs	6	4
App 2, 5.4.2	90% C.I. - 3 Micr Average (Note 2)	1.5 EPNdB	1.5 dB SEL
	90% C.I. - Each Metric at Each Mic	N/A	To be reported
ETM 5.1.1.1	No Correction Window	Equivalent to <0.3 dB Delta	No change (Note 3)
ETM 5.1.1.8.2	Airspeed for Equivalent Mach No.	+/- 3 kts	No change
Chapter 11			
11.6.5	Total Adjustments	2 dB(A)	No change
11.6.6	Rotor Speed (Nr)	+/-1%	No change
11.6.7	Airspeed - Constant	+/- 3 kts	+/- 5 kt (Note 4)
11.6.4	Headwind/Tailwind	equal numbers	No change
11.6.8	Zenith Angle	+/-10 deg	No change
11.5.2.1(a)	Height @ Overhead	+/- 15 m	No change
	Approach Angle	n/a	+/- 0.5 deg 'Wedge'
11.6.9	Mass	90% to 105%	No change
App 4, 2.2.2(b)	Temp @ 10 m	-10 to 35 deg C	No change

Annex 16/ETM *Paragraph*	*Test Window/Procedure*	*Noise Certification*	**Constant LUP** *Flight Conditions*
App 4, 2.2.2(b)	RH @ 10 m	20 to 95%	No change
App 4, 2.2.2(b)	8 kHz Attenuation	10 dB/100 m	No change
App 4, 2.2.2(c)	Wind @ 10 m	10 kts	No change
App 4, 2.2.2(c)	Crosswind @ 10 m	5 kts	No change
App 4, 4.4.2	Microphone Height	1.2 m	1.2 m (Note 1)
App 4, 6.3.1	Number of Test Runs	6	4
App 4, 6.3.2	90% Confidence Interval	1.5 dB SEL	No change
	90% C.I. - Each Metric at Each Mic	N/A	To be reported
ETM 5.1.1.3.2	Equivalent Mach No.	+/- 3 kts	No change

Notes:
1. LUP measurements at other heights must be corrected to 1.2 m using an approved method.
2. The three-microphone average is based on the three noise certification microphone locations.
3. No change for Chapter 8 certification microphone locations. Other measurement locations to be evaluated.
4. Can use +/-7 kt if velocity term of Chapter 8 Δ_2 is used.

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See paragraph 2.2.1

Insert new Appendix 10 as follows:

Appendix 10

GUIDANCE FOR THE USE OF DGPS-BASED TIME SPACE POSITION INFORMATION TRACKING SYSTEMS

1. INTRODUCTION

1.1 Purpose

1.1.1 The use of conventional GPS receivers onboard aircraft to obtain Time Space Position Information (TSPI) is not considered to be accurate enough for noise certification testing. However, by using data from a second, localized, fixed-position GPS receiver, a substantial improvement in accuracy can be achieved. Such an arrangement is referred to as a Differential GPS (DGPS) System.

1.1.2 Certificating Authorities may approve the use of such DGPS systems, based on the particular characteristics of the hardware, related software, installation, and operational specifics proposed by the applicant. This appendix summarizes recommended requirements for DGPS systems proposed for use during noise certification testing.

1.2 Background

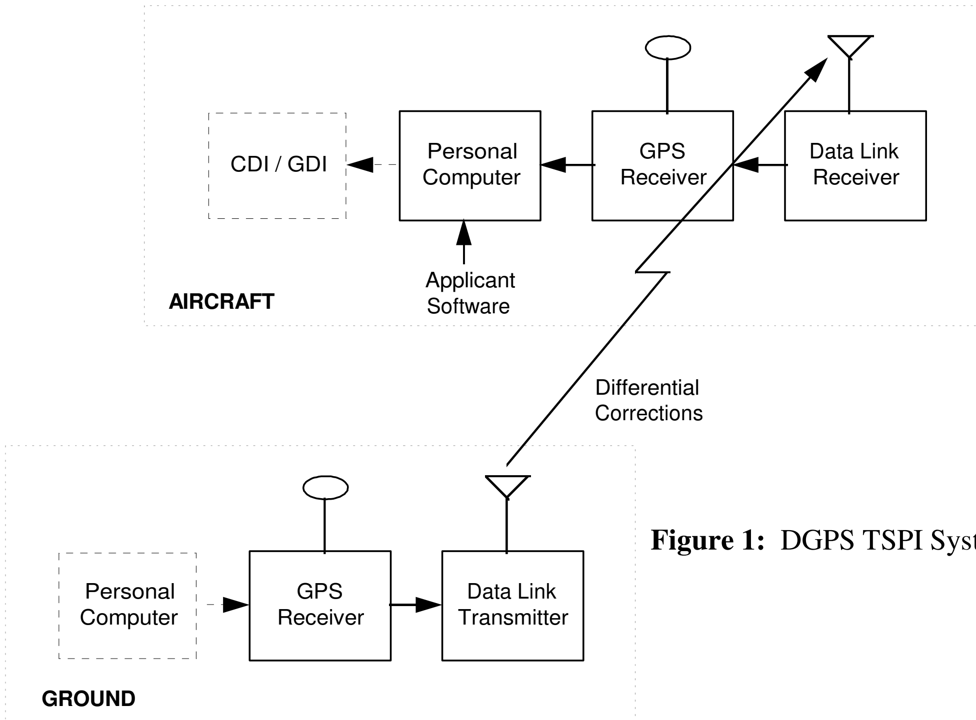

Figure 1: DGPS TSPI System Basic Architecture

1.2.1 Typically, the hardware components of these systems are (see Figure 1): GPS receivers and antennae on the ground and in the aircraft; data link transmitter and antenna on the ground and corresponding receiver and antenna in the aircraft; a laptop computer in the aircraft; and batteries and electronic power supplies. Software, running on the laptop computer in the aircraft, provides the user control/display function and performs data logging. A personal computer is generally needed to initialize the GPS receiver on the ground, but is not necessary for continuous operation.

1.2.2 In addition to generating flight reference data for post processing, some applicants' systems provide the pilot with information to navigate the aircraft. Measured aircraft position is compared to a desired reference flight path, and steering commands are sent to a course/glide slope deviation indicator (CDI/GDI) installed specifically for use with the DGPS system.

1.2.3 Variations on the basic architecture shown in Figure 1 are possible. For example, it is possible to eliminate the data link elements by: (1) collecting and storing data from both GPS receivers during a flight; and (2) post-processing these data in a single computer after the flight is complete. However, without a data link, DGPS data cannot be used for aircraft guidance, nor can an aircraft-based operator obtain "quick-look" information regarding the DGPS solution quality. Another possible variation on the basic architecture in Figure 1 involves uses of a two-way data link; typically, identical transceivers would be used on the ground and in the aircraft. This enables ground tracking of the aircraft during testing.

2. SYSTEM DESIGN ISSUES

This section discusses DGPS system design issues, including configuration, airport survey, DGPS receiver output data, and sources of error in DGPS systems.

2.1 Coordinate frames and waypoint navigation

2.1.1 The native coordinate system for GPS, i.e., the one in which its computations are performed, is the World Geodetic Survey of 1984 (WGS-84). Most GPS receivers provide output position information (latitude, longitude and altitude) in a variety of geodetic coordinate systems by transforming the WGS-84 position data.

2.1.2 Aircraft noise certification tests typically involve use of a rectangular coordinate frame whose definition is based upon an array of microphones or the centerline of an airport runway. Typically, the frame x-axis is established from two points on the ground that are nominally aligned with the runway centerline; the y-axis is orthogonal to the x-axis and also level; and the z-axis is vertical.

2.1.3 Some GPS receivers can furnish data in a rectangular coordinate system based on waypoints. These are user-defined reference points intended to facilitate navigation along a route or in a local area. If a receiver supports waypoint navigation, then two such points (defined in terms of latitude, longitude, and altitude) can be entered into the receiver[1]. The receiver will subsequently provide aircraft position relative to the coordinate frame implicitly defined by the points, i.e., distance from the line connecting the two points and distance to one point.

2.1.4 If waypoint navigation is to be used for noise testing, then the initial survey performed to determine the position of the two waypoints is critical to the accuracy of the TSPI results (See Section 2.2). If waypoint navigation is not available or is not to be used, then the geodetic position solution, i.e., latitude, longitude and altitude, must be transformed to a local coordinate system through post processing by the applicant prior to noise data processing.

2.2 Test site survey

2.2.1 A careful survey of the airport and nearby areas where noise testing is to be conducted is critical to the success of a measurement programme. The following steps are involved in a survey.

a) An initial reference location, including numerical values for its latitude, longitude and altitude, is selected and its coordinates are stored in a permanent file for record-keeping. Normally the initial reference location will be a surveyed monument on the airport, upon which latitude/longitude are stamped. (Often the monument will have been derived from a third-order[2] survey, in which case geodetic position errors on the order of hundreds of feet are not uncommon. However, such errors have virtually no effect on the measurement of positions relative to that point or another point derived from it.) The published airport reference altitude can be assigned to the monument. (Although this altitude typically is applicable to the base of the tower, the altitude difference between the monument and tower will not degrade the accuracy of differential measurements relative to the reference location.)

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[1] For noise certification testing it is recommended that the GPS receiver read the waypoints from a printable data file. Alternatively, the waypoints could be keyed into the receiver and then written to a data file.

[2] Prior to the advent of satellite-based techniques in the 1990s, land surveys were performed using an optical theodolite (to measure angles) and chain (to measure linear distance). Networks of interlocking triangles were surveyed, with measurements collected at each vertex. The accuracy of such a survey was classified by the amount that the sum of the interior angles of a triangle deviated from 180 degrees (after accounting for the earth's curvature). A first-order survey was the most accurate; the vertices were typically 10 to 40 miles apart, and the angular error 1 arc second or less. Also, for a first-order survey, the latitude/longitude of one point was measured by astronomical means (accuracy approximately 50 feet). A second-order survey had vertices 5 to 10 miles apart and maximum angular error of 5 arc minutes. A third-order survey had vertices 1 to 2 miles apart and angular error not exceeding 15 arc minutes.

Many GPS receivers have a “survey” mode whereby they average position measurements over a user-selected period of time, e.g., 24 hours, to generate a surveyed position estimate. Typical resulting absolute accuracies are 3 to 10 feet, which are more than adequate if the DGPS-based TSPI system measurements will not be related to measurements from another system.

b) The DGPS-based TSPI system, with the ground-station antenna at the initial reference location, is used to measure the coordinates of the location where the ground-station antenna will be installed for the remainder of the test series. The latitude/longitude/altitude of this second location is stored in a permanent file for record-keeping. If convenient, the ground-station antenna may be installed at the initial reference location and left there during the test series.

c) If waypoint navigation is to be used for the measurement programme, the DGPS-based TSPI system, with the ground station at the second, i.e., the normal, location, is used to measure the latitude/longitude/altitude of the FROM and TO waypoints which will be used to establish the test programme coordinate frame. At least three measurements should be made to guard against errors. The resulting locations should be stored in a permanent file for record-keeping.

d) The DGPS-based TSPI system, with the ground station at its normal location, is used to measure the microphone positions. The measured positions are stored in a permanent file for record-keeping. If waypoint navigation is to be used for the measurement programme, microphone positions should be recorded in test coordinates; otherwise, latitude/longitude /altitude should be used.

e) (Alternative to 4) If it is not feasible to use the DGPS-based TSPI system to survey the microphone locations, and another technique must be used, then direct measurements of at least three common points should be performed in order that the relationship between the two surveys can be determined. For example, if the microphones are surveyed using classical techniques, then a DGPS-based TSPI survey of the two microphones at the ends of a microphone line and one other microphone, as far removed from the first two as possible, will be sufficient. The surveys should agree to within 1 foot at each common point. If they differ by more than 1 foot and the difference can be described by an offset and a rotation, then it may be possible to adjust the results of one survey to agree with the other. Such adjustments should be approved by the certificating authority prior to testing.

The above tests should be performed as a minimum before and after each measurement programme. Post-test data analysis should include a comparison of the two surveys.

2.3 Receiver output data

2.3.1 Three kinds of GPS receiver output data are of interest:

a) data stored during flight testing, for use during post-test processing of noise data, collected from either the aircraft receiver (when a real-time data link is used) or from both receivers (when a real-time data link is not used);

b) differential correction data output by the ground-station receiver, transmitted to the aircraft via a real-time data link, and input to the aircraft receiver (these data are not stored, but directly influence the accuracy of the stored data addressed in item (1)); and

c) data collected from the ground-station GPS receiver during multipath verification tests prior to flight testing.

This section addresses the GPS receiver messages[3] which support these three purposes. All data are typically furnished via RS-232 serial port; suitable GPS receivers generally have multiple RS-232 ports.

2.3.1 *Data stored during aircraft noise testing (real-time data link used)*

2.3.1.1 GPS receivers provide TSPI data in a variety of formats, both industry-standard and proprietary. In the United States, the National Marine Electronics Association (NMEA) has issued standards (References 1 and 2) which are intended to facilitate user communications with GPS receivers and other navigation devices. Some GPS manufacturers have adopted NMEA standards, some use proprietary formats, and some use both. Those manufacturers that provide NMEA outputs generally only implement a subset of the full set of messages set forth in the standards, and some follow the older Version 1.5 rather than Version 2.0, upon which this guidance was based. Also, GPS receiver manufacturers have chosen different parameters to indicate the quality or status of the TSPI data.

2.3.1.2 DGPS-based TSPI systems considered for noise certification tests, using a real-time data link, should save data from the aircraft GPS receiver in raw, i.e., the receiver's native, format in permanent files for record-keeping. Stored data should include time, e.g., Universal Time Coordinated (UTC) or GPS time with or without a local offset, aircraft latitude/longitude/altitude (or equivalently, aircraft position relative to a pre-defined waypoint), and a status or quality flag indicating the reliability of the DGPS solution. Typically the applicant will employ post-processing software which will read the raw data, parse and format these data, perform any necessary transformations, and generate a file which will be used for noise data processing. Storage of raw data allows the certificating authority to verify the validity of the post-processed results.

2.3.2 *Data stored during aircraft noise testing (real-time data link not used)*

DGPS-based TSPI systems considered for noise certification tests which do not use a real-time data link should save data from both the ground and aircraft GPS receivers in raw, i.e., the receiver's native, format in permanent files for record-keeping. Manufacturers' proprietary formats should be used; NMEA standard messages do not support this application. For post-processing, stored data should include time, e.g., UTC or GPS time with or without a local offset, satellite ephemeris (See Section 2.6.4 for a discussion of satellite ephemeris/clock data), pseudoranges[4], signal-to-noise ratios[5], and carrier phase[6]. Applicants using dual-frequency (L1/L2) receivers will typically also save L2 carrier phase data[7]. Typically, post-processing of the ground-based and airborne GPS data will be performed using

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[3] Standards organizations and manufacturers employ different terminology for pre-defined groups of data parameters available from receiver output ports. For example, in the United States, the National Marine Electronics Association (NMEA) uses the term "sentences," the Radio Technical Commission for Maritime Services (RTCM) uses "messages," Novatel Communications uses "logs," and Trimble Navigation Ltd. uses "Cycle Printouts."

[4] Pseudorange is the receiver's measured distance to a satellite, and is derived from the coarse/acquisition (C/A) code. It includes a receiver clock bias error, and may be quantified in units of time or distance.

[5] Signal-to-noise ratio (also called carrier-to-noise ratio) is derived from the receiver's tracking loop circuits, and is a measure of the received signal strength. It is usually quantified in dB-Hz, and varies from approximately 33 to 50.

[6] Carrier phase is the amount of carrier cycles (at 1,575.42 MHZ) which have accumulated since logging of this parameter was begun. It may be quantified in radians, degrees, cycles, or feet (to convert to cycles, divide by the wavelength, 0.6247 feet).

[7] The highest accuracy DGPS systems employ the signal carrier (L2=1,575.42 MHZ), rather than the code (L1=1.023 MHZ) which modulates the carrier, as the basic measurement observable. These techniques require that the number of full carrier cycles, i.e., 8 inch wavelengths, between the ground station and aircraft be determined once during a test. After the cycle count is established, the ground-station/aircraft-separation is tracked to fractions of a wavelength, provided that the receiver carrier tracking loops (circuits) maintain phase lock.

manufacturer-supplied software. If this is not the case, then any applicant-developed software should be approved by the certificating authority.

2.3.3 *Real-time DGPS messages*

GPS receiver manufacturers have implemented both industry-standard and proprietary messages for use on real-time DGPS data links. The Radio Technical Commission for Maritime Services (RTCM), Special Committee 104 (SC-104) has issued a standard (Reference 3) that is followed by most manufacturers. Manufacturers usually implement only a subset of the RTCM/SC-104 messages, and some follow the older Version 2.0 rather than Version 2.1, upon which this guidance was developed. Some manufactures have also implemented proprietary DGPS messages; these frequently bear a close resemblance to the RTCM/SC-104 messages.

For applicants implementing a real-time DGPS data link, it is preferred that RTCM/SC-104 messages be employed for this purpose. Type-1 or Type-9 messages (each of which contains the actual DGPS corrections) should be selected and transmitted at a rate of 0.5 Hz or higher. Other message types, e.g., Type-3 (ground-station location) and Type-5 (satellite health), may be used, but should be sent at a rate of once per minute or slower. There is no recommended requirement for storing real-time DGPS correction data; however, the data status or quality flag (discussed in Section 2.3.1) should provide an indication that the correction data has been properly received and processed by the aircraft.

2.3.4 *Messages for multipath testing*

Applicant-designed systems using code-based DGPS processing should collect and save data from dedicated multipath tests to be conducted prior to aircraft noise testing (see Section 2.5). Data collected during multipath tests should include individual satellite pseudoranges and signal-to-noise ratios. These parameters are only provided by receiver manufacturers' proprietary messages. It is not necessary for applicants to conduct a dedicated test for systems using carrier-based DGPS processing.

2.4 System accuracy and sources of DGPS error

If only divergence (spherical spreading) of the noise is considered, and atmospheric absorption mechanisms are ignored, then 0.1 dB of change in the noise level corresponds to approximately 1.1% of the distance between the aircraft noise source and the measurement microphone. Thus, for an aircraft altitude of 400 feet (approximate minimum altitude during noise certification tests), a position error of 4.4 feet along the line-of-sight vector connecting the microphone and aircraft can be expected to introduce 0.1 dB error in the processed noise data. Equivalently, a position error of 10 feet along the line-of-sight vector can be expected to introduce 0.23 dB error in the processed noise data.

For most DGPS systems, the most important error sources are, in decreasing order of importance: multipath, correction latency, and tropospheric delay. When these error sources are properly controlled, DGPS systems can provide accuracies between a few inches and approximately 15 feet for an aircraft in low-dynamics flight regimes. Even the poorest of these accuracies is superior to that achieved by other conventional TSPI systems used for aircraft noise tests, including microwave and photoscaling. The best accuracies are superior to those for a laser tracker.

DGPS systems suitable for consideration by noise certification applicants can be expected to achieve accuracy of a few inches to five feet. The highest accuracy is achieved using carrier-based techniques and post-flight processing of data collected from both the aircraft and ground-station computers. Code-based solutions which use carrier smoothing, e.g., Novatel RT-20, achieve accuracies of 3 to 5 feet, provided that the error sources discussed in this section are addressed properly. Consequently, it is expected that the DGPS systems used for noise certification tests will introduce less than 0.2 dB error into the noise data, in a worst case scenario, i.e., a noise certification approach operation. Typical errors will be less than 0.1 dB for noise certification take-off and sideline measurements.

In addition to the three error sources cited above, increases in DGPS position errors can also occur when the ground station and aircraft do not have the same manufacturer and model GPS receiver, or when the ground station and aircraft receivers use different satellite ephemeris/clock data (specifying the satellite orbital parameters).

Sections 2.5 and 2.6 address all of the above errors, and include methods for minimizing these errors or eliminating them entirely.

2.5 Multipath errors

2.5.1 *Characteristics*

Multipath refers to signals from GPS satellites which are reflected from objects, e.g., the ground, buildings, and aircraft structural elements, before reaching the GPS antenna. Multipath signals add (algebraically) to the desired line-of-sight signal, and thereby decrease the accuracy of measurements made with the latter. Multipath conditions can occur independently at the aircraft and ground-station antennae. Thus the differential correction data from the ground are not directly useful for correction for multipath errors at the aircraft antenna. Rather, the broadcast corrections can contain ground-station multipath errors which, in a statistical sense, add to those in the aircraft.

Measurements have consistently shown that the presence of multipath conditions at the ground station is significantly more deleterious than at the aircraft, because ground-station multipath conditions vary slowly, acting like a bias over a test run of a few minutes, while the more dynamic motion of the aircraft causes the effects of airborne multipath conditions to behave like noise (which can be reduced somewhat by processing techniques such as filtering and averaging). For code-based processing, ground-station multipath error is typically between 1 and 10 feet. Under very adverse conditions, e.g., GPS antenna near the side of, and well below the top of, a large building, multipath errors can be several hundred feet. Multipath errors associated with carrier-based processing techniques are significantly less than those for code-based methods, and are usually on the order of centimeters. The extent of the multipath error primarily depends on two factors: (1) the capability of the ground- station antenna; and (2) the location of the ground-station antenna relative to reflecting objects such as paved runways, buildings, and parked aircraft. Receiver processing, e.g., use of narrow correlators (available in most Novatel receivers) and/or carrier smoothing (available from several manufacturers), can reduce multipath errors.

2.5.2 *Code-based system ground station*

To mitigate the effects of multipath conditions on DGPS-based TSPI performance, the applicant's ground-station installation should meet the following requirements:

– the ground station should employ a multipath-limiting antenna, such as one with a choke ring or an absorbing-ground plane; and

– the ground-station antenna should be mounted on a pole or tower, with unobstructed visibility of the sky. A minimum height of 10 feet above ground level is recommended for the ground-station antenna.

Additionally, to ensure that significant, undetected multipath-errors do not corrupt the TSPI data collected during aircraft-noise testing, the applicant's ground-station installation should be tested for adequate multipath condition performance prior to commencing with the test by: (1) collecting GPS receiver data during the same hours of the day as when the system will be used for noise tests, plus additional 1 hour buffers on either side of this period; and (2) examining the data on a per-satellite (rather than navigation solution) basis, including at least pseudoranges and signal-to-noise ratios, for multipath signatures. Reference 4 (beginning on page 560) gives a procedure for examining GPS data for multipath.

If multiple periods of significant (several feet) multipath error are found when examining the data, then a new location for the ground-station antenna should be selected and tested. If only one or two isolated, brief multipath incidents are found, then antenna location can be retained but aircraft testing should not be conducted during these periods. (The satellite-user geometry repeats with a period of approximately 23 hr 56 min. Thus if a ground-station multipath incident is observed one day, a similar incident is expected to occur 4 min earlier the following day.) These procedures are similar to those utilized by the United States Coast Guard in checking out a marine DGPS station installation (References 5 and 3)[8]. After establishing a ground-station antenna site/configuration that satisfies the multipath conditions criterion, the ground-station antenna should not be moved without performing another multipath test. The ground-station GPS receiver and any computer used in conjunction with the receiver may be removed and re-installed without repeating the multipath test. The multipath, verification test data should be saved as part of the permanent test series data archive, and should be made available for inspection by the certificating authority.

2.5.3 *Carrier-based system ground station*

To mitigate the effects of multipath conditions on DGPS-based TSPI performance, the applicant's ground-station installation should meet the following recommended specifications:

– the ground station should employ a multipath-limiting antenna, such as one with a choke ring or an absorbing ground plane; and

– the ground-station antenna should be mounted on a pole or tower, with unobstructed visibility of the sky. A minimum height of 10 feet above ground level is recommended for the ground-station antenna.

There is no recommended requirement for collecting data to assess multipath errors when carrier-based processing is employed.

2.5.4 *Aircraft installation*

It is expected that aircraft manufacturers will select a location on each aircraft model that minimizes multipath effects; no recommended specifications have been developed. For most smaller aircraft, e.g., ten seats or fewer, it has been found that the roof area directly behind the windshield is most advantageous. Manufacturers of larger aircraft have found forward positions on the roof to be desirable, but others have mounted the GPS antenna on the tail structure. Selecting a location for the GPS antenna

[8] Coast Guard DGPS ground stations employ two GPS receiver/antenna pairs. The "additional" receiver/antenna pair (termed the integrity monitor) provide a real-time continuous check on the validity of the differential corrections generated by the "basic" receiver/antenna pair (termed the reference station). DGPS ground-station architectures being investigated for the FAA Local Area Augmentation System (LAAS) program employ between 2 and 4 receiver/antenna pairs to verify the corrections sent to the aircraft. No requirement for redundant ground-station equipment is recommended for DGPS-based TSPI systems used in noise certification tests.

on a helicopter is more challenging, since the rotor will momentarily obscure most areas on the airframe. Mounting the GPS antenna on the top of the rotor shaft is the recommended location on a helicopter.

2.6 Other sources of DGPS error

2.6.1 *Correction latency*

Correction latency, also called staleness, refers to the delay between the time of validity of a differential correction at the ground station and the time that the correction is applied in the aircraft. Delays in processing at both ends of the ground-to-air data link can cause stale corrections to introduce unacceptably large errors.

A second form of latency, solution latency, refers to the delay between the time at which a GPS receiver's measurement is valid and the time when it is available at the output of the receiver. Solution delays are inherently smaller than correction delays and, in this context, are only of concern for aircraft guidance.

For a system with a real-time data link which employs code-based DGPS solutions, it is strongly recommended that ground-to-aircraft messages conform to the RTCM/SC-104 standards used by the Coast Guard DGPS system[9]. These messages contain pseudorange rates-of-change (as well as the correction at an identified time), to allow the user to correct for most of the latency-induced error. It is also preferred that the corrections be computed and transmitted at least at a 0.5 Hz rate.

2.6.2 *Tropospheric delay*

The troposphere is that portion of the atmosphere between the earth's surface and an altitude of approximately 20 miles. Differences in meteorological conditions between ground station and aircraft can cause dissimilar changes in the propagation times of signals from a satellite to these two locations; the effect is most pronounced for low-elevation-angle satellites. Since these changes are not common to the two locations, they are not removed by differential corrections. Such tropospheric effects can contribute up to 20 meters of ranging error on GPS signals, which can translate into as much as 10 to 12 meters (typically less than 2 meters in differential mode) of positioning error if not modeled and corrected. Approximately 90% of these tropospheric propagation-related errors are due to the hydrostatic (or dry) component of tropospheric delay.

Experiments performed for the FAA LAAS programme have found tropospheric differences to introduce DGPS errors between 1.5 and 3 feet when the aircraft was at 3 000 feet altitude, but only an inch or two when the receiver antennae were at the same altitude. To reduce the effects of tropospheric errors on DGPS-based TSPI systems used in noise certification tests, it is recommended that use of these systems be limited to aircraft within 20 nmi (lateral) and 5 000 feet (altitude) of the ground station.

If desired, the hydrostatic component of the tropospheric delay can be effectively removed with the application of the tropospheric delay model (Reference 9) developed by the Radio Technical Commission for Aeronautics (RTCA) per ICAO Annex 10 navigation Standards and Recommended Practices (SARPs), along with local meteorological measurements at the ground station. The relevant portion of this model is driven by local barometric pressure and satellite geometry (elevation angle). Reference 10

[9] The United States Coast Guard DGPS system's (as well as marine systems of other nations) broadcast messages include the rate-of-change of each pseudorange error, in addition to the pseudorange error at a reference time. The user's receiver is required to apply an adjusted correction consisting of the broadcast pseudorange error, plus its rate-of-change multiplied by the time elapsed between the time the adjusted correction is applied, and the validity time for the pseudorange correction.

provides a functional overview of the RTCA model, as well as comparisons with other tropospheric propagation delay models.

2.6.3 *Mismatched GPS receivers*

Experiments have shown that DGPS errors are increased when the GPS receivers at the ground station and in the aircraft are not “matched” in terms of manufacturer and model. With mismatched receivers, errors are increased moderately, e.g., 1.5 to 3 times those when the receivers are matched, when the satellites are operating normally. When a rare soft satellite-failure (signal degradation) occurs, errors of several thousand feet have been observed[10]. It is required that the applicant’s systems have the same manufacturer/model GPS receiver on the ground and in the aircraft.

2.6.4 *Mismatched satellite ephemeris/clock data*

GPS satellite broadcasts include a navigation message, in the form of 50 bit/sec modulation superimposed on the pseudorandom codes used for ranging. Within the navigation message are data sets that describe the satellite orbit (ephemeris information) and clock. These data sets are transmitted every 30 seconds. The GPS Control Segment[11] uploads multiple ephemeris and clock data sets to the satellites, typically once per day. Satellites typically change their broadcast ephemeris and clock message every four hours. The ephemeris/clock data sets are used by a receiver to compute its own position and, in the case of a reference station differential corrections for use by other receivers.

For a DGPS system to achieve full accuracy, both the ground station and aircraft receiver must use the same ephemeris and clock data sets. Internal receiver logic ensures that the ephemeris and clock data sets used by a given receiver are consistent for each satellite. However, occasionally the ground and aircraft receivers may use different ephemeris/clock data sets, unless measures are taken by the user to ensure that the sets match. Mismatched ephemeris/clock data sets can occur for several reasons, e.g., a receiver is too busy performing other tasks when the data sets change, or a receiver encounters an error while decoding new data and continues to use an old data set.

The RTCM/SC-104 messages used by the Coast Guard DGPS system guard against mismatched ephemeris/clock data sets by including the Issue of Data (IOD) — an eight-bit data set label broadcast by each satellite — in the broadcast messages (References 3 and 5). User receivers which conform to the RTCM/SC-104 standards will not apply differential corrections unless the IOD from the satellite and the DGPS correction message agree.

The applicant should ensure that the ground station and aircraft use the same ephemeris and clock data sets during testing. One way is to purchase GPS receivers and select DGPS messages which cause this check to be performed automatically. Another way to ensure agreement between the ground and aircraft ephemeris/clock data sets is to: (1) store in a permanent file for record-keeping, at a rate of once each 30 seconds, the IOD used by each receiver; and (2) compare the IODs during post-test processing.

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[10] Beginning on or before October 21, 1993, some differential users with mismatched ground and aircraft receivers experienced position errors of thousands of feet. The DoD’s GPS Joint Program Office (JPO) attributed the cause to a “deficiency” in the C/A code broadcast by satellite SVN19. It announced that the problem was corrected on January 10, 1994. Official statements are found in Notice Advisory to NAVSTAR User (NANU) 343-93294, 396-93337, and 006-94010.

[11] The Control Segment is the ground-based portion of the total GPS system. It includes: the Operational Control facility in Colorado Springs, Colorado, USA where the satellite ephemeris and clock data are calculated; five worldwide sites which collect satellite broadcast signals and provide data to the Operational Control facility; and three locations from which new ephemeris/clock data are uploaded to the satellites.

3. SYSTEM APPROVAL RECOMMENDATIONS

This section summarizes approval recommendations for DGPS-based TSPI systems proposed for use during noise certification tests.

3.1 Design issues

Each applicant's TSPI system design should address the issues identified in Table 1. The applicant's documentation (Section 3.3) should address each item in the table.

Table 1. TSPI System Design/Development Issues

Number	Issue	Major Considerations
1	Selection of processing method (real-time vs. post-test)	Need for aircraft guidance; ability to check test run quality.
2	Selection of solution method (carrier vs. code)	Accuracy (favours carrier); robustness (favours code); cost (favours code).
3	Use of geodetic or waypoint coordinates	Waypoints can simplify post-processing but not available for all receivers
4	Selection of GPS receiver and antenna	Items 1, 2, 3, and others (antenna multipath control; data messages; solution latency; matched air/ground receivers; and IOD capability).
5	Selection of data link equipment (if real-time system)	Assigned frequency; data rate; error detection/correction; flexible interface.

3.2 Data storage (logging) during noise testing

3.2.1 *System with real-time data link*

For applicants employing a real-time data link, the ground-station GPS receiver should output RTCM/SC-104 Type-1 messages at a rate of 0.5 Hz or greater, which should be transmitted to, and used by the aircraft GPS receiver.

The applicant's aircraft computer should collect data from the aircraft GPS receiver and generate permanent data files containing:

a) three-dimensional aircraft position copied directly from the receiver's data port, i.e., in raw/native form, and not processed;

b) the waypoints (latitude, longitude, and altitude) used to define the local coordinate frame (if waypoint navigation is used);

c) time, e.g., UTC or GPS time with or without a local offset, associated with each sample of position data copied directly from the receiver's data port; and

d) data quality/validity indication associated with each sample of position data.

If waypoints are used (b above), they should be included in the header of each data file. New waypoints should not be able to overwrite existing waypoints. If new waypoints are defined, then a new data file should be created.

For consistency with the noise-data collected during a certification test, it is recommended that a), c), and d) above, be saved in the GPS receiver's raw/native format at a rate greater or equal to 2 Hz, the rate associated with the noise data. However, if hardware limitations preclude following this recommendation, a sampling rate of 0.5 Hz or greater is acceptable.

3.2.2 *System not using real-time data link*

TSPI systems which do not use a real-time data link should save data from both the ground and aircraft GPS receivers in raw/native format in a permanent file for record-keeping. Manufacturers' proprietary formats should be used; NMEA standard messages do not support this application. Stored data should include: time, e.g., UTC or GPS time with or without a local offset, satellite ephemeris, pseudorange, signal-to-noise ratio, and carrier phase. If tropospheric delay is being modeled (per Section 2.6.2), local meteorological conditions should be measured and stored as well. It is recommended that applicants using dual-frequency (L1/L2) receivers also save L2 carrier phase data. Typically, post-processing of the ground-based and airborne GPS data will be performed using manufacturer-supplied software. If this is not the case, then any applicant-developed software should be approved by the certificating authority.

3.3 Documentation

The applicant should prepare and submit documentation which includes:

a) system description: identifies, at a minimum, the issues in Table 1.

b) hardware description: model and version number of all system components, including DGPS receivers, antennae, transceivers, and computer;

c) software description: software functionality and capabilities, data file formats, hardware required, and operating system;

d) system setup and operation: ground and aircraft installation of the system (including antennae), operating procedures, site survey procedures, power requirements, and system limitations; and

e) technique for validating installation: for example, an aircraft is parked in a known surveyed location and its position is read from the DGPS system and verified. This can be performed at the test site or at another location, e.g., aircraft home base. As a minimum, this process should be performed at the start and end of each measurement programme, and preferably at the beginning and end of each measurement day.

3.4 Accuracy verification test

The applicant should perform a one-time verification of the system accuracy, based on a minimum of six aircraft flight test runs which encompass the conditions, i.e., speed, altitude, range and maneuvers, for which the system will be later used as a reference. The accuracy-verification test should involve comparison of the DGPS-based TSPI system's position data with those from an accepted reference, such as a laser tracker or another approved DGPS system. This test should be performed on the complete DGPS-based TSPI system developed by the applicant. It is not adequate for an applicant seeking system approval to simply cite prior approval of another applicant's system designed around the same GPS receiver.

3.5 Software verification

Prior to using the system during a noise-measurement programme, any applicant-developed software (data logging and post processing) used to obtain data listed herein should be approved by the certificating authority. The approved software should be placed under version management.

3.6 Ground-station multipath mitigation and verification

3.6.1 *All systems*

The ground-station GPS receiver antenna should have a choke ring, absorbing ground plane, or other multipath-reducing technique. The antenna should be positioned on a pole or tower at a minimum height of 10 feet above ground level.

3.6.2 *Code-based systems*

Prior to each measurement programme, applicants using code-based DGPS systems should perform a multipath investigation using the ground-station receiver and antenna, as described in Section 2.5.2. The results of the investigation should be saved as part of the permanent test-series data archive, and be made available for inspection by the certificating authority.

3.7 Airport survey

Additional information on survey requirements may be found in Section 2.2. Prior to, and after completion of, each measurement programme, the applicant should use the DGPS-based TSPI system to survey the locations of either: (1) if no other method of survey is used, all microphones and waypoints (if used); or (2) if another method of survey is used, a recommended minimum of at least three points in common with the other method. Survey data should be stored as part of the measurement-programme permanent archive. If two survey methods are used, the common points should be reconciled to an accuracy of 1 foot and the adjustment procedure submitted to the certificating authority for approval.

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APPENDIX C

AMENDMENTS TO AIRPORT PLANNING MANUAL

Chapter 6

Land-use Administration

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6.2.3.11 … Transaction assistance is also applied ~~in Australia and~~ in some European countries, e.g. Germany (around Düsseldorf Airport) and the Netherlands.

…

Appendix 1

Cases of Effective Land-use Management Around Airports

Editorial Note: Change the existing text shown as follows:
crossed out text - text to be deleted; and text in *italics* – text to be added

2. THE AUSTRALIAN EXPERIENCE: LAND-USE PLANNING AROUND AIRPORTS

…

2.1.3 ~~The ANEF may be developed for a validity period of 15 years in order to represent the ultimate capacity of the airport~~. *At the major airports the ANEF is developed for a 20 year horizon and is updated every 5 years; contours may also be developed for a longer term horizon* in order to represent the ultimate capacity of the airport. For land-use planning purposes, the contours are meaningful at the delineation of 20-25-30-35-40 ANEFs.

2.1.4 … As a result, a 25 ANEF contour ~~was adopted~~ *is recommended* as the limit for *new* residential developments in areas around airports. …

2.1.5 ~~In the areas around airports where established residential development has existed for some time, it is generally not feasible to apply appropriate land use unless re-zoning opportunities for individual properties arise. (DELETED)~~

2.2 CASE OF MELBOURNE/TULLAMARINE AIRPORT

2.2.1 Melbourne Airport is a major domestic and international airport, with some ~~156 000~~ *175 000* aircraft movements in ~~1996~~ *2004*.

…

2.2.3 The overlay controls largely reflect the ANEF contours and the Australian Standard ~~AS2021-1994~~ *AS2021-2000*. Through the Administrative Appeals Tribunal. … As a result of this system, there is only a limited amount of residential or other development around this airport which is inconsistent with the Australian Standard ~~AS2021-1994~~ *AS2021-2000*.

~~2.3 OTHER LAND-USE PLANNING EXPERIENCES IN AUSTRALIA~~

~~2.3.1 Australia has extensive land-use planning experiences. In some instances, the planning guidance outlined in AS2021-1994 was adopted, but not in other instances. As a result, residential buildings have been constructed within the 25 and above ANEF contour.~~

~~2.3.2 As communities become better informed and more aware of issues such as aircraft noise, they have put greater pressure on local authorities to carry out appropriate land use planning and on aviation authorities and airlines to implement noise-abatement practices.~~

~~2.3.3 In Australia, residential buildings have been located around airports for many years and more recent developments have occurred. To remedy this situation, the interests of the people who have already invested in the locality have to he balanced with the arrangements for potential interested parties. This conflict of interest issue is one that confronts some airports and there are no easy solutions for the local authorities and State governments who are responsible for land use planning around airports. Where inappropriate development has occurred, experience has shown that pressure has been brought to bear on airports in relation to certain flight tracks of arriving and departing aircraft, and calls for curfews are not uncommon.~~

~~2.3.4 Australia is considering developing and providing additional information to the community, such as provide data on the flight paths of aircraft using the airport. This may be a useful supplement to the ANEF contours to better inform the communities around airports before commitment to residential buildings is made.~~

3. LAND USE MANAGEMENT AROUND WASHINGTON DULLES INTERNATIONAL AIRPORT/UNITED STATES

3.1 … Today, Dulles is the primary international gateway serving the US capital and handles approximately ~~300 000~~ *450 000* operations annually with its three-runway layout. …

…

4. LAND USE PLANNING IN BRAZIL

Editorial Note: Replace existing 4.1 with the new text as follows

4.1 *NOISE ZONING PLAN*

4.1.1 *The Noise Zoning Plan became a Federal Law in 1982 as a means to guarantee the compatibility of the urban and airport planning processes. The NZP defines areas subject to airport noise and specifies land use restrictions that will be implemented by local authorities. It is therefore the basis for controlling land use in the surrounding areas of the airport, so as to ensure a harmonious relationship with the community. The Department of Civil Aviation devises the NZP after the development of the airport is established by airport administration. NZPs have been established for about 550 Brazilian airports.*

4.1.2 *The Brazilian legislation defines two different types of NZP, the Basic Plan and the Specific Plan. The Basic Noise Zoning Plan establishes very stringent restrictions on land use and is more adequate for controlling land use in undeveloped areas. On the other hand, the Specific Noise Zoning Plan is applied to the already developed surrounding areas of the airport.*

4.1.3 *Land use restrictions adopted by each NZP are associated to the level of noise, as described in Table A1-1.*

4.1.4 *In the NZP, runways are classified in six categories in terms of annual volume of operations and aircraft profile. The classification is outlined in Table A1-2.*

4.1.5 *According to the Brazilian legislation the Specific Noise Zoning Plan is mandatory for airports with Category 1 runways. The Basic Noise Zoning Plan applies to all other airports and heliports.*

4.2 ***NOISE CONTOURS FOR BASIC NOISE ZONING PLAN***

4.2.1 *In order to define noise contours for Basic Noise Zoning Plans, the parameters and dimensions outlined in Tables A1-3 (Refer to Figure A1-1.) and A1-4 must be applied.*

4.3 ***THE BRAZILIAN NOISE METRICS FOR THE SPECIFIC NOISE ZONING PLAN***

4.3.1 *Since 1982, the unit adopted in Brazil for calculating cumulative noise nuisance is called the Weighted Noise Index (WNI). After 1994, the formula for calculating WNI was changed to allow for direct field measurements. The data used to forecast WNI at a given point in the vicinity of an airport are:*

- *Airport elevation and reference temperature;*
- *Aircraft fleet;*
- *Flight tracks;*
- *Average number of day and night operations;*
- *Distribution of aircraft movements over the various flight tracks to and from the airport runways;*
- *Noise and performance data off all aircrafts.*

The WNI of an airport is given by the formula:

$$WNI = 10\log_{10}\left\{\frac{1}{24}\left[15\,x10^{\frac{LD}{10}} + 9\,x10^{\frac{LN+10}{10}}\right]\right\}$$

in which:

LD is the LA_{eq} in the daytime (from 7 am to 10 pm)

LN is the LA_{eq} in the nighttime (from 10 pm to 7 am)

4.3.2 *Noise contours are designed in order to accommodate air traffic forecast for at least 20 years or airport capacity.*

4.3.3 *The values of WNI 65 and 75 are used as reference for designing noise contours of the Specific Noise Zoning Plan.*

4.4 ***NOISE ZONING PLAN ON INTERNET***

4.4.1 *Areas located around airports shall have their development authorized by the Brazilian Department of Civil Aviation before being approved by local authorities.*

4.4.2 *In order to facilitate the access to information on the NZP, the Brazilian DAC developed the NZPnet, a computer system tool that provides agility, reliability and transparency to all parts involved in the authorization process.*

4.4.3 *The system NZPnet supports the analysis and authorization of developments on the internet and has the following characteristics:*

- *It allows remote consultation – any person can access the system from anywhere by the internet to obtain information on the NZP. The user only needs to have a browser, e.g. Internet Explorer, and Mozzila Firefox;*

- *It is possible to visualize noise contours over cartographic bases – the user is able to identify the position of streets, blocks and plots of land in relation to the noise contours. As a result, the user can easily recognize the position of the estate in question;*

- *It allows consultation by means of geographic coordinates – after plotting the geographic coordinates (latitude and longitude) on the map displayed by the system, the user can obtain graphically the position of the estate with reference to the airport and the NZP; and*

- *It also allows the user to obtain additional information in relation to the estate – meaning that the user not only is able to visualize the location of the estate, but can also identify the restrictions imposed on the area and the information needed to submit insulation projects, when necessary. Furthermore, the user has information on how to proceed when submitting the development to the Brazilian DAC.*

4.5 ***LAND USE GUIDELINES FOR THE AVOIDANCE OF BIRD-HAZARDS***

4.5.1 *In 1995, the Ministry of the Environment established legislation aimed at the reduction and the control of bird hazard, creating the Airport Safety Area, a circle with radius of 13 km for VFR airports and 20 km for IFR airports. The ASA imposes restrictions for the development of any dangerous activities potentially attractive to birds, such as, slaughter houses, tanneries, waste disposal grounds, agricultural activities, urban solid residue treatment technology and others.*

4.5.2 *Nevertheless, when the local authority attests to the inexistence of an alternative location for the development of these activities, the Brazilian DAC conducts viability studies to establish preventive and corrective measures that will condition the issuance of environmental licenses.*

Table A1-1. Land Use Restrictions for Noise Zoning Plans

Areas defined by Noise Contours	*Basic Noise Zoning Plan*	*Specific Noise Zoning Plan*
Area I	*Only agricultural and industrial uses and outdoor recreational activities are permitted* *Industrial buildings must be insulated*	*Housing and public facilities, such as schools and hospitals, are not permitted* *Industrial and certain commercial buildings may be permitted if buildings are insulated* *Outdoor recreational activities are permitted*
Area II	*Housing and public facilities, such as schools and hospitals, are not permitted* *Agricultural, commercial and industrial uses are considered adequate and acceptable*	*Public facilities, such as schools and hospitals are not permitted* *Housing may be permitted in certain cases and only if noise reduction can be ensured by adequate sound insulation* *Industrial and commercial uses are permitted if offices have adequate soundproofing*

Table A1-2. Runway Categories for Noise Zoning Plans

Category 1	*Runway for High-Density Scheduled Traffic of Large Aircraft*	*Density of scheduled traffic of large aircraft is equal to or higher than 6.000 annual movements or night operations exceed 2 movements*
Category 2	*Runway for Medium-Density Scheduled Traffic of Large Aircraft*	*Density of scheduled traffic of large aircraft is lower than 6.000 annual movements and night operations do not exceed 2 movements* *Density of scheduled traffic of large aircraft is equal to or higher than 3.600 and lower than 6.000 annual movements; no night operations*
Category 3	*Runway for Low-Density Scheduled Traffic of Large Aircraft*	*Density of scheduled traffic of large aircraft is lower than 3.600 annual movements and no night operations*

Category 4	*Runway for High-Density Scheduled Traffic of Medium Aircraft*	*Density of scheduled traffic of medium aircraft is equal or higher than 2.000 annual movements or night operations exceed 4 movements*
Category 5	*Runway for Low-Density Scheduled Traffic of Medium Aircraft*	*Density of scheduled traffic of medium aircraft is lower than 2.000 annual movements or night operations do not exceed 4 movements*
Category 6	*Runway for Non Scheduled Traffic of Small Aircraft*	*Any density of non scheduled traffic of small aircraft*

Table A1-3. Airport Noise Contours for Basic Noise Zoning Plan

Noise Contour	*Runway Category*	*L1 (m)*	*L2 (m)*	*R1 (m)*	*R2 (m)*
1	*2*	*1,500*	---	*240*	---
	3 and 4	*500*	---	*180*	---
	5 and 6	*300*	---	*100*	---
2	*2*	---	*2,500*	---	*600*
	3 and 4	---	*1,200*	---	*400*
	5 and 6	---	*500*	---	*200*

Table A1-4. Heliports Noise Contours for Basic Noise Zoning Plan

Noise Contour	*Radius (m)*
1	*100*
2	*300*

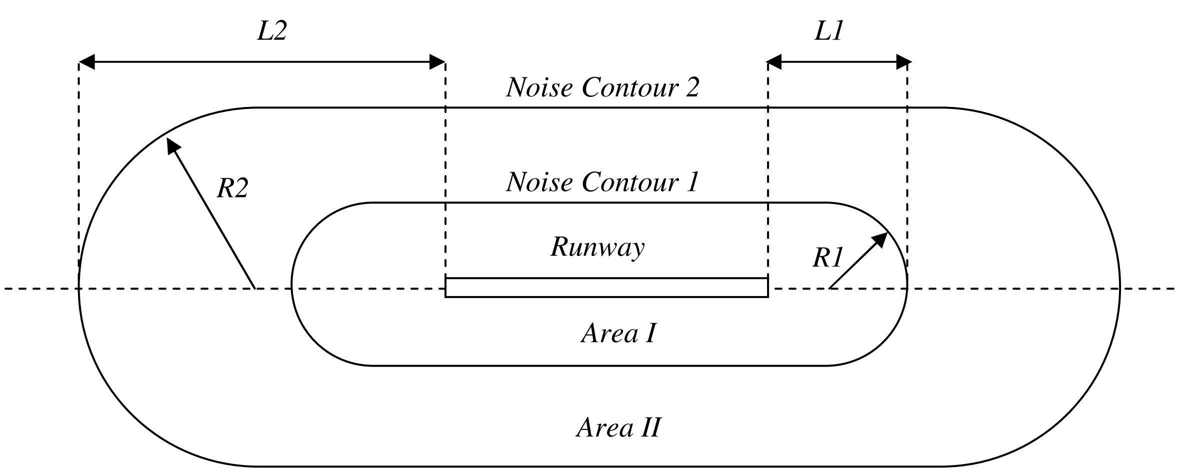


Figure A1-1. Noise Contours for Basic Noise Zoning Plan

. . .

Editorial Note.— New Sections 5 through 8 to be included in this amendment were approved at CAEP/6 and are not included here.

Editorial Note.— **Insert the new text as follows**

9. *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN ITALY*

9.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

9.1.1 *Italy has had national airport planning instruments at least for the last thirty years. Currently ENAC is working on a new National Airports Plan which will implement the provisions of the National Transport Plan of 2001 (Piano Generale dei Trasporti, PGT), and is preparing the list of national interest airports which will be used as a basis for future policy.*

9.1.2 *The National Transport Plan was introduced by Law n. 245, of June 15, 1984 in order to provide transport policy with a unitary orientation and coordinate the competences of State and Regions. The current Plan was adopted in 2001 (D.P.R. 14 rnarzo 2001). The PGT defines the "Integrated National Infrastructure System" (Sistema Nazionale Integrato dei Trasporti, SNIT) in order to determine what are the infrastructures with national relevance. In the case of airports this included 23 locations for which the PGT adopts some proposals (i.e. develop the Malpensa "hub"), but for the most part the PGT gives only general policy guidance and leaves more specific proposals for the "Airport Plan" which ENAC expects to complete before the end of 2005.*

9.1.3 *Airport planning is regulated by an 'instruction of the Ministry of Transport and Public Works (Circolare Ministero dei Trasporti e dei Lavori Pubblici 23 Febbraio 1996, n. 1408) which defines the purpose and contents of the "Airport Development Plan, (Piano di Sviluppo Aeroportuale).*

9.1.4 *Airport Development Plans include the spatial distribution of works and services, both public and private, within the entire airport and may define building characteristics. The plan is essentially a technical and programmatic document which must be in consonance with the National Transport Plan and has to analyze the relationship with spatial planning. In principle the airport development plan should conform to existing spatial plans, but in practice regional and local plans may be compulsorily modified in order to accommodate the new or expanded infrastructure.*

9.1.5 *Airport plans are usually implemented with three year programs defining with precision the projects to be undertaken during that period.*

9.2 *STATE BEST PRACTICES*

9.2.1 *Airport plans are drafted by the airport operator and follow a procedure that involves a preliminary approval by ENAC, an environmental impact assessment by the Ministry of the Environment and Spatial Planning, and consultation with regional and local authorities to ascertain the proposal's conformity with spatial planning. The plan is submitted to a "departmental conference" (conferenza dei servizi) in order to reach an agreement among* *administrations and integrate airport development with the plans and policies of regions, provinces and municipalities. The final approval is granted by ENAC.*

9.2.2 *The procedure of the airport master plan does not include citizen participation, as this is al-ready required for the environmental impact assessment.*

9.2.3 *Current airport development plans do not include land for long term development but only for those expansions that may be needed to carry out the projects already defined in the plan. There is no legal limit on the areas that the plan could reserve for future expansion but it has not been customary to include large external areas.*

9.2.4 *Permits and authorizations required for airport construction or development:*

a) *Buildinq permit: Airport construction does not require a building permit, but must undergo a special procedure to ascertain whether it is in accordance with spatial planning. The procedure is based an achieving a consensus among administrations in order to cooperate in projects of national importance. Once the consensus is reached it takes the place of all necessary authorizations or permits. When no consensus may be reached within a given term, the decision may be referred to the Cabinet of Ministers.*

b) *Environmental permits (water, waste, air, etc.): The environmental impact assessment procedure will usually cover all the permits required within the airport. If a facility was not included in the development plan it may be necessary to obtain permits for waste disposal or sewage discharge. It is usually required to obtain municipal permits regarding health and safety requirements.*

Facilities falling under the major-accident hazard legislation will be evaluated in the EIA if included in the airport plan or project, if not, they will be subject to the requirements of Decree n. 334, of August 17 implementing Directive 96/82/CE on the control major-accident hazards involving dangerous substances (Decreto Legislativo 17 agosto 1999, n. 334. Attuuazione della direttiva 96/82/CE relativa a1 controllo dei pericoli di incidenti rilevanti connessi con deteminate sostanze pericolose), and the implementation regulations of May 16 2001 (Decreto Ministeriale 16 maggio 2001, n. 293: "Regolamento di atuazione della direttiva 96/82CE, relativa a1 controllo dei pericoli di incidenti rilevanti connessi con de-terminate sostanze pericolose.

c) *Other permits: All airports must be authorized by ENAC. Individual projects not included within an airport master plan or not conforming to such plan require also the authorization of the Italian Civil-Aviation Authority. Projects included within the airport plan will be sent to ENAC for the purpose of verifying whether they are in accordance with the master plan.*

9.3 ***UNSUCCESSFUL PRACTICES***

9.3.1 *None identified at this time.*

10. ***LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN KOREA***

10.1 ***CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS***

10.1.1 *The Republic of Korea regulates in the Aviation Act that such area where aircraft noise influence exceeds certain level will be designated and published as a Noise Afflicted (Expected) Area.*

10.1.2 *As a part of Land-use planning & Management Plan, in the designated and published area there is restriction imposed to the new buildings to be constructed, and for the existing facilities and* *residents, etc, countermeasures for noise reduction such as installation of soundproof facilities and equipment to reduce TV signal blind area are carried out, as follows.*

	Sector	***Noise Level (WECPNL)***	***Land utilization restricted area***
Noise Afflicted Area	*First Class*	*More than 95*	*1. Green belt buffer* *2. Only facilities related to airport operation allowed*
	Second Class	*Less than 95 and more than 90*	*1. Industrial Area* *2. Green belt* *3. Only facilities irrelevant to aircraft noise are allowed to be installed*
Noise Affliction expected area	*Third Class*	*Less than 90 and more than 75*	*1. Semi Industrial Area* *2. Commercial Area* *3. Building must be insulated*

10.2 *STATE BEST PRACTICES/UNSUCCESSFULL PRACTICES*

10.2.1 *Since noise alleviation project is still in progress, it is hard to point out the best/unsuccessful practice.*

11. *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN SWEDEN*

11.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

11.1.1 *In Sweden land-use planning is the prerogative of municipalities. The Swedish CAA is involved in the land-use planning process as a party in the consultation procedure. The CAA also provides relevant information about, and sees to, the interests of the aviation sector in the planning processes. These include i.e. noise restriction areas and obstacle limitation surfaces around airports including areas of interest for the future expansion of the airports.*

11.1.2 *However, the major airports in Sweden are designated by the CAA to be of national interest for transport and communication in accordance with Swedish law. This means that the County Administrative Boards have the obligation to check that the above mentioned interests of the airports are protected in the planning processes.*

11.2 *STATE BEST PRACTICES*

11.2.1 *In 1996/97 the Swedish government adopted national guidelines for traffic noise, which should not be exceeded when building new residential buildings or erecting infrastructure including major reconstructions.*

- *30 dB(A) as an equivalent indoor level,*
- *45 dB(A) as a maximum indoor level at night,*
- *55 dB(A) as an equivalent outdoor level (by the facade),*

- *70 dB(A) as a maximum level at a patio connected to the building,*

11.2.2 *For aircraft noise the outdoor level is set to FBN 55 dB(A), which is a noise index almost identical to Lden.*

11.2.3 *As a first step to reduce aircraft noise exposures, noise insulation of buildings, should at least include properties exposed to the following noise levels outside:*

- *FBN 60 dB(A),*
- *80 dB(A) as a maximum level, when the noise event occurs in average three times per night,*
- *90 dB(A) as a maximum level, when the noise event occurs regularly during daytime and in evenings,*
- *100 dB(A) as a maximum level, when the noise event occurs regularly during daytime at weekdays only and during occasional evenings.*

11.2.4 *The first step, and the measures related to it, should be achieved by 2007. The Swedish Environmental Courts have in several cases established terms for reductions of aircraft noise that goes beyond the goal of the first step.*

11.2.5 *The Swedish government recently decided a new policy regarding measures to reduce traffic noise. The goal is to reduce the number of people exposed to traffic noise exceeding the national noise guidelines by 5 percent by 2010 compared with the level in 1998. This goal supersedes the first step and should be achieved in the most effective way.*

11.3 *UNSUCCESSFUL PRACTICES*

11.3.1 *The Swedish CAA does not have the right to regulate the land-use around airports. However, in practice the CAA is the major aviation stakeholder in the land-use planning process for the local governments.*

12 LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN AZERBAIJAN

12.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

12.1.1 *The legislation of the Republic of Azerbaijan.*

12.2 *STATE BEST PRACTICES*

12.2.1 *Development of agricultural land so as not to attract birds.*

12.3 *UNSUCCESSFUL PRACTICES*

12.3.1 *Construction of residential areas.*

13. *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN CHINA*

13.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

13.1.1 *The policy of Hong Kong SAR Government is to have due regard to aircraft noise in planning land-uses around the Hong-Kong International Airport.*

14. *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN CUBA*

14.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

14.1.1 *The State policy on land-use planning and management related to lands adjacent to airports is controlled by the Aerodromes Directorate of the country's IACC through a structure that exists in the State Administration Bodies, through a Ministry which controls the planning policy and in whose structure there is a Physical Planning Directorate, to which are sent all the proposals for construction in accordance with the country's Planning Programme, which are presented in a format that requires macro- or micro-location in accordance with their characteristics and specificities which is analysed and approved, if its soundness is accepted by the IACC.*

14.1.2 *In Cuba, the use of the lands in question is controlled, taking into account the environmental impact (contamination of the waters, atmosphere and soils) that the new investment may cause, through the granting and control of the environmental licence by the aeronautical authority.*

14.2 *STATE BEST PRACTICES*

14.2.1 *The Cuban State takes into account all suggestions at the global level that are in accordance with the stopping, attenuation or elimination of all processes or production that are harmful to the environment. Our State also agrees with any policy that leads to the well-being of human beings*

14.3 *UNSUCCESSFUL PRACTICES*

14.3.1 *We have no reports of unsuccessful practices.*

15 *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN ETHIOPIA*

15.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

15.1.1 *The current state policy on land use planning and management related to lands adjacent to airports in Ethiopia is well beneficial and weight its balance to the forward safe aviation operation.*

15.1.2 *Through state letter distributed by the Aviation Authority every Regional government administration and the federal government as a whole were made to have deep awareness to land use management around Airports.*

15.1.3 *In short the message was every state developer should at first take receive permissions from the Aviation Authority before any scratch is to be deployed around airport for safe air operations.*

15.2 *STATE BEST PRACTICES*

15.2.1 *Best practice based on the above requirement so far were attained where governmental and non-governmental organizations had tried to use adjacent areas around airports. After the* *request, first the authority checks the area for safe operation and gives permission if it is ok. Then proceeds for its implementations.*

15.3 ***UNSUCCESSFUL PRACTICES***

15.3.1 *No unsuccessful practices were faced so far.*

16 *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN JORDAN*

16.1 ***CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS***

16.1.1 *JCAR Part 150 Airport Noise Compatibility Planning*

16.2 ***STATE BEST PRACTICES***

16.2.1 *Developed land-use planning around Queen Alia International Airport (QAIA).*

16.3 ***UNSUCCESSFUL PRACTICES***

16.3.1 *Land-use planning has not been developed for Amman-Markar Airport and King Hussein Airport.*

17 *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN LITHUANIA*

17.1 ***CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS***

17.1.1 *The Decision of the Government of the Republic of Lithuania on the Special Provisions for Use of Land and Forest (published in the newspaper State News, 2002, No. 70-2887) defines that construction and refurbishing of the objects in the aerodrome sanitary protection area and the industrial activities in this area shall be agreed upon with the State Service of Health Care at the Ministry of Health Protection and the Civil Aviation Administration.*

17.1.2 *For the purpose the sanitary protection areas of all international airports (Vilnius, Kaunas, Palanga and Siauliai) which cover the territory of the airport and the area of a defined size in their vicinity have been defined. Use of these territories for the agricultural needs (field cultivation, horticulture) shall be additionally agreed upon with the Ministry of Agriculture.*

17.1.3 *The Law on Construction of the Republic of Lithuania provides that before the commencement of construction a detailed plan shall be produced with consideration of the special design provisions of the appropriate State Authorities. Where the object extends into the aerodrome protection or sanitary areas the Civil Aviation Administration shall set special provisions which limit use of these territories with due consideration of a potential effect to flight safety and operations of the aircraft.*

18 *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN MAURITIUS*

18.1 ***CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS***

18.1.1 *With a view to protect and control development around the airport, an appropriate land use plan was developed in collaboration with the Ministry of Lands and Housing, the authority responsible for the National Development Strategy. The National Development Strategy provides a strategic framework for national land use planning and local plans known as Outline Planning Schemes, which are regional plans for District Council areas.*

18.1.2 *Outline Planning Schemes in the vicinity of the airport provides the framework for local authorities to plan, shape and control the use of land within the airport surroundings.*

18.1.3 *Airports of Mauritius had commissioned ADPi to produce a noise exposure map for the airport, based on a two-runway configuration, the existing Runway and a planned future second Runway. The Noise exposure map identifies lands that are affected by the noise generated by aircraft.*

18.1.4 *Four zones subject to high noise impact have been identified and integrated in the outline scheme.*

(1) Zones where existing houses need to be relocated, as these houses are located, in zones where noise level exceed the permissible level.

(2) Zones where no new residential development will be permitted.

(3) Zones where only infill development in existing built up areas will be permitted.

(4) Zones where new houses may be permitted if slight acoustic protection is provided.

18.1.5 *The Outline Scheme also integrates an obstacle limitation surface, which limits the height of permissible construction in the vicinity of the airport and in the approach and take-off climb areas of the runways. Outline Scheme facilitate the control development around the airport that is compatible with airport activities or aircraft operations.*

19 *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN NORWAY*

19.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

19.1.1 *No chapter two aircraft are allowed to operate within Norwegian airspace since April 2002.*

19.1.2 *Norwegian national noise guideline is related to the Building act.*

19.1.3 *The guideline has to be implemented in all planning for areas exposed to aircraft noise.*

19.1.4 *All airports shall have a noise zone map according to the guideline, showing actual aircraft noise zones.*

19.1.5 *Regulated land use must be in accordance with the current guideline, released in January 2005.*

19.2 *STATE BEST PRACTICES*

19.2.1 *Today's practice is to apply two zones around all airports and heliports serving more than 25 movements during the busiest three months consecutive summer period. In the inner red zone, where Lden is above 62dBA, recommended land use is restricted to non noise sensitive use only. Outside the red zone, we have a yellow zone from Lden 52dBA. Noise sensitive buildings are allowed if indoor noise limits can be satisfied. We also have to meet requirements for a quiet outdoor area.*

19.3 *UNSUCCESSFUL PRACTICES*

19.3.1 *Norway has national guidelines for land use in aircraft noise zones that has been applied for a long time. Therefore, we can not give current examples of unsuccessful practice.*

20 *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN PAKISTAN*

20.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

20.1.1 *Civil Aviation Authority (CAA) Pakistan views are appended below:*

a) New Islamabad International Airport is being planned at Pind Ranjha 30 km south west of Islamabad. The planning caters for the Environmental Impact Studies which also includes the noise pollution besides undertaking other studies which shall have an impact on environment.

b) The recommended methods of ICAO shall be adopted by the consultants for noise control, noise zoning, and mitigation measures. The study is expected to be carried out in the 1st Quarter of 2006.

21. *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN ROMANIA*

21.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

21.1.1 *Airports are regarded as an essential element in the economic, social and cultural development or the areas they serve. Therefore, all effort must be made in order to keep this infrastructure opened for public use, respecting all the applicable safety and security regulations.*

21.1.2 *Even if, at present, the traffic is relatively low compared with other countries (see Figure 1) and the existing airport capacity is generally sufficient, it has a constant growing rate and it is possible to grow even further as a result of Romania's future accession to the European Union. Therefore, expansion programmes must be applied at those airports where congestion might appear in the near future, in parallel with a more efficient use of the existing capacity.*

21.1.3 *Also, all airports are encouraged to elaborate and include the development plans in the Urban Development Plans, in order to make the local authorities as well as the public concerned, aware of their intentions.*

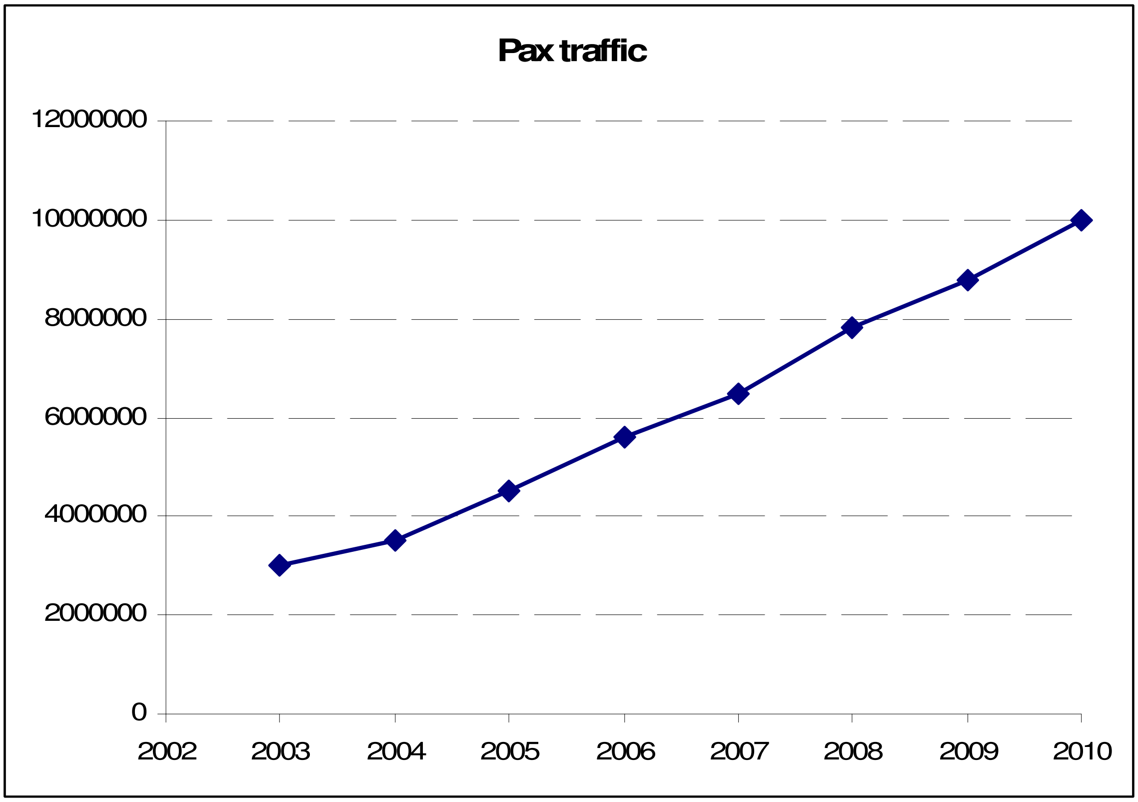
21.1.4 *As regards the construction of new airports, the National Plan of Land Use, approved by law, foresees the necessity of new airports in the future, in areas that are not well covered in a satisfactory way by the existing infrastructure, but such initiatives are going to be supported financially only from local and private resources.*

21.2 *STATE BEST PRACTICES*

21.2.1 *The areas around the airports are declared as aeronautical restricted areas, in accordance with the specification of Annex 14 to the Chicago Convention, meaning that any construction in these areas needs the approval of the Romanian Civil Aeronautical Authority. The criteria for the granting of such an approval are established through Romanian Civil Aeronautical Regulations, which are published in the Official Journal.*

21.2.2 *Also, the airports, as my other commercial entity, need the approval of Local Authorities for Environmental Protection. In the Certificate issued by these authorities, which is updated periodically, specifications are made regarding the necessary measures and actions to be taken in order to improve the environmental impact of the airport.*

Figure 1



21.2.3 *By Governmental Decision no. 321/2005, it was imposed for big airports (meaning airports with over 50.000 aircraft movements per year) to elaborate noise maps as well as action plans for the reduction of environmental impact. Even if, at the moment, no airport in Romanian overlaps the above mentioned movement limit, by Order of the Minister of Transports, the 4 main airports, that are under the authority of the Ministry of Transport, are obliged to present noise maps(deadline 30th April, 2007) and action plans (deadline 18th May, 2008). For the other airports, this obligation applies depending on the traffic evolution.*

21.2.4 *For the same 4 main airports mentioned above, Development Programmes have been approved by Governmental Decisions or by Law, establishing the main actions to be taken in the future as well as the development perimeter, information that has been published in the Official Journal in accordance with the transparency principles.*

21.2.5 *With some exceptions, most of he airport are not situated in the vicinity of urban areas. In one case (namely for the second airport in the Capital) a flight ban was imposed during the night, with the exception of emergency flights.*

21.3 *UNSUCCESSFUL PRACTICES*

21.3.1 *No unsuccessful practices have been highlighted so far, due to the relatively low traffic on Romanian airports, the generally great distance from residential areas and, as a consequence the low environmental impact of the airports.*

22. *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN SAMOA*

22.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

22.1.1 *The Planning and Urban Management Agency's (PUMA) main role is to provide efficient and effective land use plans, regulations, service coordination and disaster management plans to improve quality of life for Samoa. The Agency was established in 2001 and is mandated under the Planning and Urban Management Act 2004 (the Act).*

22.1.2 *PUMA is still at its early stages, therefore developing land use plans, policies and regulations are done on a case by case basis. The Agency faces major challenges due to the existing situation of ad hoc / mix land use practices and the land tenure system. There are three primary types of land tenure in Samoa where 80% is comprise of Customary land, 16% is Government land and 4% is Freehold land. Majority of airport locations are surrounded by customary land, therefore in developing land use plans in relation to airports village values and aspiration together with Government must be considered.*

23. *LAND USE PLANNING AND MANAGEMENT AROUND AIRPORTS IN TURKEY*

23.1 *CURRENT STATE POLICY ON LAND-USE PLANNING AND MANAGEMENT RELATED TO LANDS ADJACENT TO AIRPORTS*

23.1.1 *The Republic of Turkey Ministry of Environment and Forestry's Regulation on Assessment and Management of Environmental Noise is a very new one and the implementation thereof will be in the years to come, For instance the preparation of the noise maps regarding major airports (Airports where number of take-off/landing is 50000 and more) will have been completed by the end or 2013.*

23.1.2 *Land-use planning related to lands adjacent to airports are planned by related municipalities with the coordination of Directorate General of Civil Aviation Turkey for the aviation and aerodrome safety criteria. ICAO Annex-14 Standards are taken into consideration and all measures are taken for the provision of flight safety while land-use planning is done.*

Editorial Note.— The amendment to the *Airport Planning Manual* will also include a revised Appendix. The amendments consist solely of revised information provided directly by States and are not reproduced in this report.

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English only

APPENDIX D

AMENDMENTS TO THE *GUIDANCE ON THE BALANCED APPROACH TO AIRCRAFT NOISE MANAGEMENT* (DOC 9829) MANUAL

. . .

GLOSSARY

. . .

Stakeholder. in this context, a party with an interest in or concern about the operations at an airport for which a Balanced Approach study is being or will be conducted. This includes governmental bodies, local authorities, airport authorities, operators, community members and bodies representing community members impacted by aircraft noise.

. . .

Chapter 2

THE BALANCED APPROACH

. . .

2.2 AN AIRPORT-BY-AIRPORT APPROACH

2.2.1 The Balanced Approach is …. be applied if similar noise problems are identified.

. . .

2. 4 CONSULTATION WITH STAKEHOLDERS

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~~2.4.2 Consultation aims to provide a forum in which all points of view may be explored in order to provide all stakeholders the opportunity to be made aware of a perceived problem and to be notified that there is an intent to pursue corrective action through the Balanced Approach; to inform stakeholders about the relevant aspects and considerations related to a noise problem and then likely costs and benefits associated with available measures to mitigate the noise problem ; to keep stakeholders apprised of the status of the process; and to permit them to comment and review prior to final resolution~~.

2.4.2 When establishing consultative arrangements careful consideration should be given to defining who is `stakeholder'. For example, experience has shown that people living in areas outside published noise contours, but under or near busy flight paths, may want to fully participate in consultation processes.

~~2.4.3 Consultation should begin when a noise problem is identified and should continue through to final resolution. Early consultation could possibly lead to resolution through voluntary measures or~~

~~agreements between, for example, an airport authority and operators serving that airport.~~

2.4.3 In order to enhance the communication within the consultation process, authorities could adopt a collaborative approach, involving all stakeholders. Such involvement would enable participants working together to become fully informed about the noise issues encountered at the airport and the proposed solutions. The collaborative approach would also enable stakeholders to gain a better understanding of the costs and benefits of an airport's operations, which may lead to a better acceptance of the solutions.

2.4.4 Ideally an airport should have well established ongoing consultation arrangements in place and should not simply initiate them when a problem arises. This will facilitate open, informed and transparent discussions about the evolving noise exposure patterns around an airport and lay the basis for meaningful interaction between the airport and its community when there is a need to change either flight paths or airport infrastructure to cope with increasing demand.

2.4.5 To enhance the quality of the consultation and build trust between an airport and its communities, it is valuable to make comprehensible aircraft noise information routinely available. This enables members of the public to easily track how the noise exposure patterns in the vicinity of their homes are changing over time.

2.5 NOTIFICATION OF DECISIONS

2.5.1 The Balanced Approach should include timely and adequate notice of decisions to all stakeholders. For interim decisions, if any, this notice should be given in a reasonable time to allow stakeholders to be involved in any remaining ~~the~~ consultation.
~~This would also allow time for parties affected~~ For final decisions, notice should be given with reasonable time for the interested parties to determine whether any adjustments to their operations are necessary. Further, Resolution A33-7 "invites States to keep the Council informed of their policies and programmes to alleviate the problem of aircraft noise in international civil aviation."

2.6 IMPLEMENTATION OF MEASURES

• • •

2.6.4. As noise control measures are implemented it is important that compliance with the controls be monitored and reported in a way that all parties clearly understand.

. . .

2.8 OTHER CONSIDERATIONS

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2.8.1

- ***Public education and awareness programmes.*** Airports or local planning agencies ~~that expect a reasonable chance of success in their planning efforts~~ should provide for public education and awareness in the planning process.

• • •

2.8.2 The use of complex technical aircraft noise descriptors alone can create frustration and negative reactions by the public if sufficient context is not provided. Accordingly, non-technical descriptors should be used wherever possible when providing aircraft noise information to the public. Nevertheless, technical information should also be made available.

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2.8.3 There may be unique situations …… of a project may have on the ability to use projected capacity for future growth.

Chapter 3

ASSESSMENT OF THE NOISE SITUATION AT AN AIRPORT

. . .

3.1.2 The noise objective to be achieved should be identified and defined in order to assist in determining the extent of the noise problem. For the purposes of assessment under the Balanced Approach an actual noise problem is deemed to exist if any difference between the defined objective and the assessed evolution of the noise climate can be identified. This may ~~will likely~~ be reflected in the evolution of the number of people affected by an unacceptable level of aircraft noise. However, it is recognized that ***ICAO*** Contracting States and their airports may have different standards and policies regarding what constitutes a noise problem, how these may be assessed and what objectives are sought in airport-related noise programmes.

. . .

3.1.4 The authority undertaking the assessment should have the means to measure, project and compare current and future noise exposures. Sections 3.2 through 3.7 ~~3.6~~ identify some of the tools, ~~and~~ procedures and supplemental information useful for assessing noise: noise contours, noise index, supplemental flight path based information, baseline, assessment methodology and management plans.

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3.2 NOISE CONTOURS / NOISE INDEX

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3.2.3 In light of the many factors contributing to the noise situation at a particular airport and in addition to measuring the noise from individual aircraft events in particular locations, it is customary in airport noise studies to model “noise contours” that are averaged over long periods of time. ~~typically one year~~. The contours are typically based on the ‘average day’ during a particular year, but can also be established for particular sub-divisions of the day (eg the night period) or averaging periods shorter than a year. These parameters can be chosen in accordance with the identified noise measure in order to obtain meaningful results.

. . .

3.2.9 A lower noise index value will define a larger noise contour, and a higher noise index value will define a smaller noise contour. For example, a 75-Ldn noise contour will encompass ~~affect~~ a smaller physical area than a 65-Ldn noise contour.

. . .

3.2.12 The ICAO Assembly urges that noise surrounding an airport should be assessed based on objective and measurable criteria for the purposes of the Balanced Approach. A common basis for such measurement is the number of people encompassed within a noise contour established under a specified noise index (such as 65-Ldn). In some circumstances a reduction in the number of persons within a specific contour can indicate noise benefits for all – for example, this would occur if a common aircraft type operating into an airport were replaced by a quieter aircraft type. On the other hand, reductions in the number of persons within a specified noise contour might be achieved simply by concentrating more noise on a small number of people. In such a case some people might benefit at the expense of others, and such potential effects should be taken into account.

. . .

3.3 SUPPLEMENTAL FLIGHT PATH BASED INFORMATION

3.3.1 Decision makers and non-experts often ask for aircraft noise to be described in terms of the location of aircraft flight paths, the number of flights and the time distribution of aircraft movements on the flight paths. These flight path based concepts can be used to demonstrate the changes in noise exposure patterns that would be brought about by the implementation of proposed noise control measures.

3.3.2 These concepts can be helpful in providing information which goes beyond the average day. Information can be gained on noise exposure at sensitive times and on both short and long term temporal variations in aircraft noise. Flight path based analyses are useful in revealing changes in noise exposure which may not be evident when using average day noise contours. For example, they can be helpful in examining the impacts of introducing a small number of aircraft movements.

~~3.3~~ 3.4 BASELINE

~~3.3.1~~ 3.4.1 It is typical for the authority conducting the assessment to identify the “baseline” noise situation. The main component of the baseline is the noise situation around the airport as it currently exists, taking into account existing noise controls and current operating and land-use regulations. ~~But,~~ The “baseline” noise situation is not only the current situation; it is also referred to as the “no further action scenario,” because it is the noise scenario that is expected to occur based on existing plans with no additional action.

~~3.3.2~~ 3.4.2 The baseline noise situation should he assessed …….. mitigation measure that has not been agreed would be outside the baseline.

~~3.3.3~~ 3.4.3 The length of time over which the noise situation ……authority might also want to assess the noise situation at intervals in the recent past as well.

~~3.4~~ 3.5 ASSESSMENT METHODOLOGY

~~3.4.1~~ 3.5.1 Once the baseline noise situation has been determined, it should be compared with whatever noise objective has been established for the airport in question. If the baseline noise situation does not meet the noise objective, measures may need to be taken. A comparison of the baseline noise situation with the noise situation that is projected to occur if a particular noise control measure is put in place (often referred to as the "action scenario") can show what change in noise exposure and what change ~~reduction~~ in the number of inhabitants within the specified noise contours ~~affected by aircraft noise~~ will result from the particular measure. ~~may have~~.

~~3.4.2~~ 3.5.2 The comparison for assessing available noise control .....inappropriate land use near airports.

~~3.4.3~~ 3.5.3. Under the Balanced Approach, the noise index (referred to as the "BA-noise index") used to establish the noise contour to identify the number of people affected by aircraft noise should be consistent with the noise index used to establish the contour to control land use. ~~This contour should also define an area that realistically and practically reflects the physical area and number of people actually affected by the aircraft noise at an airport.~~

3.5.4 Authorities may establish noise contours by statute or regulation which impose specific land use management requirements. Such statutory or regulatory noise contours may not reflect the full extent of aircraft noise effect around an airport. Many people consider themselves to be adversely affected by aircraft noise in areas some distance from the regulated zone. In cases where an Authority has determined that aircraft noise outside already specified contours is of concern, aircraft noise assessments could include examination of noise exposure over areas extending beyond the regulated zone.

~~3.5~~ 3.6 CONSIDERATION OF THE BA-NOISE INDEX VALUES

~~3.5.1~~ 3.6.1 The results of the assessment of the various scenarios depicting the possible evolution of the noise situation at an airport depend directly upon the BA-noise index. Measures available for management of the noise situation will vary depending on the unique circumstances of the airport. ~~and also on the variation of the corresponding contour that is used to define the area within which a noise problem is addressed~~.

~~3.5.2~~ 3.6.2 In most instances, the noise index values used to define, at a certain date, the contour boundaries of the noise zone (referred to as the regulated zone) surrounding an airport have been already determined and imposed ~~regulated~~ by the authority. There are usually multiple contours of decreasing exposure, with different building control and mitigation measures permitted in each.

~~3.5.3~~ 3.6.3 The Authority may discover……to achieve its noise objective.

~~3.6~~ 3.7 MANAGEMENT PLANS

~~3.6.1~~ 3.7.1 When identifying the baseline noise situation, ….. planned period into the future.

~~3.6.2~~ 3.7.2 Management plans also tend to …… already in place within those zones.

~~3.6.3~~ 3.7.3 They may also include housing …. housing restrictions.

~~3.6.4~~ 3.7.4 In addition to any information that may be …. technology developments and fleet renewal.

~~3.6.5~~ 3.7.5 Noise management plans could also consider trade-offs (see Chapter 8).

Chapter 4

. . .

Chapter 5

. . .

5.3.12 ***Real estate disclosure.*** When environmental regulations and issues affect development, real estate disclosure notices can be prepared. In order to be effective these notices ideally need to describe aircraft noise in a non-technical way that is comprehensible to the prospective resident. Identification of the aviation noise impact on real estate may foster an awareness of airport/community relationships and serve notice to prospective buyers of potential disturbances due to aircraft noise. Existing property owners and realtors often oppose real estate disclosure because it may make~~s~~ it more difficult to sell noise-impacted property. ~~It does not reduce the noise impact or the non-compatible land use.~~ However, ~~it~~ disclosure may deter buyers who are the most sensitive to noise or satisfactorily inform those who still wish to purchase a noise- impacted property to the extent they do not become noise complainants or noise litigants in the future.

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Chapter 6

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Chapter 7

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Chapter 8

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Chapter 9

. . .

Appendix 1

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Appendix 2

Insert here new proposed Part II — Airport Case Studies

Editorial Note.— The text of the new proposed Part II of Doc 9829, which consists of airport case studies related to elements of the "balanced approach" provided by States and/or airport authorities, is not reproduced in this report. It can be found in CAEP/7-WP/17.

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English only

Doc XXXX
AN/XXX

Recommended Method for Computing Noise Contours Around Airports

Approved by the Secretary General and published under his authority

First Edition - 2007

International Civil Aviation Organization

AMENDMENTS

The issue of amendments is announced regularly in the *ICAO Journal* and in the monthly *Supplement to the Catalogue of ICAO Publications and Audio-visual Training Aids*, which holders of this publication should consult. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS			
No.	Date Applicable	Date entered	Entered By

CORRIGENDA			
No.	Date Applicable	Date entered	Entered by

TABLE OF CONTENTS

EXPLANATION OF TERMS AND SYMBOLS

DEFINITION OF TERMS

Some important *terms* are described here by the general meanings attributed to them in this document. The list is not exhaustive; only expressions and acronyms used frequently are included. Others are described where they first occur.

In keeping with established practice in the field of aeroplane noise modelling, the units of measurement used in this document do not necessarily accord with the recommendations of ICAO Annex 5.

AIP. Aeronautical Information Publication.

Aeroplane configuration. The positions of slats, flaps and landing gear.

Aeroplane movement An arrival, departure or other aeroplane action that affects noise exposure around an aerodrome.

Aeroplane noise and performance data. Data describing the acoustic and performance characteristics of different aeroplanes types that are required by the modelling process. They include *NPD relationships* and information that allows engine thrust/power to be calculated as a function of *flight configuration.* The data are usually supplied by the aeroplane manufacturer although when that is not possible it is sometimes obtained from other sources. When no data are available, it is usual to represent the aeroplane concerned by adapting data for a suitably similar aeroplane - this is referred to as substitution.

Altitude. Height above mean sea level.

ANP database. The international Aircraft Noise and Performance database www.aircraftnoisemodel.org.

A-weighted sound level, L_A. Basic sound/noise level scale used for measuring environmental noise including that from aeroplanes and on which most noise contour metrics are based.

Backbone ground track. A representative or nominal ground track which defines the centre of a swathe of tracks.

Baseline noise event level. The noise event level read from an NPD database.

Brake release. Start of roll.

Corrected net thrust. At a given power setting (e.g. EPR or N1) net thrust falls with air density and thus with increasing aeroplane altitude; corrected net thrust is the value at sea level.

Cumulative sound/noise level. A decibel measure of the noise received over a specified period of time, at a point near an airport, from aeroplane traffic using normal operating conditions and flight paths. It is calculated by accumulating in some way the event sound/noise levels occurring at that point.

Decibel sum or average. Sometimes referred to elsewhere as 'energy' or 'logarithmic' (as opposed to arithmetic) values. Used when it is appropriate to sum or average the underlying energy-like quantities; e.g. decibel sum.

Energy fraction, F. Ratio of sound energy received from segment to energy received from infinite flight path.

Engine power setting. Value of the *noise related power parameter* used to determine noise emission from the NPD database.

Equivalent (continuous) sound level, L_{eq}. A measure of long-term sound. The level of a hypothetical steady sound, which over a specified period of time, contains the same total energy as the actual variable sound.

Event sound/noise level. A decibel measure of the finite quantity of sound (or noise) received from a passing aeroplane *sound exposure level*.

Flight configuration. Equals *Aeroplane configuration* plus *Flight parameters*.

Flight parameters. Aeroplane power setting, speed, bank angle and mass.

Flight path (or trajectory). A full description of the motion of the aeroplane in space (three dimensions) and time, which is accounted for via aeroplane speed. The flight path of an aeroplane is typically referenced to an origin at the start of take-off roll or at the landing threshold.

Flight path segment. Part of an aeroplane flight path represented for noise modelling purposes by a straight line of finite length.

Flight procedure. The sequence of operational steps followed by the aeroplane crew or flight management system: expressed as changes of flight configuration as a function of distance along the ground track.

Flight profile. A description of the aeroplane motion in the vertical plane above the ground track, in terms of its position, speed, bank angle and engine power setting (sometimes includes changes of *flight configuration* too), described by a set of *profile points*.

Ground plane (or Nominal Ground Plane). Horizontal ground surface through the aerodrome reference point on which the contours are normally calculated.

Ground speed. Aeroplane speed relative to a fixed point on the ground.

Ground track. Vertical projection of the flight path onto the ground plane.

Height. Vertical distance between aeroplane and *ground plane*

Integrated sound level. Otherwise termed *single event sound exposure level.*

International Standard Atmosphere, ISA. – defined by ICAO [ref. 11]. Defines variation of air temperature, pressure, and density with height above mean sea level. Used to normalise the results of aeroplane design calculations and analysis of test data.

Lateral attenuation. Excess attenuation of sound with distance attributable, directly or indirectly, to the presence of the ground surface. Significant at low angles of elevation (of the aeroplane above the ground plane)

Mass. The quantity of matter (in an aircraft)

Maximum noise/sound level. The maximum sound level reached during an event

Mean Sea Level, MSL. The standard earth surface elevation to which the *ISA* is referred.

Net thrust. The propulsive force exerted by an engine on the airframe.

Noise. Noise is defined as unwanted sound. But metrics such as A-weighted sound level (L_A) and effective perceived noise level (EPNL) effectively convert sound levels into noise levels. Despite a consequent lack of rigour, the terms sound and noise are sometimes used interchangeably in this document, as elsewhere - especially in conjunction with the word level.

Noise contour. A line of constant value of a cumulative aeroplane noise level or index around an airport

Noise impact. The adverse effect(s) of noise on its recipients; importantly it is implied that noise metrics are indicators of noise impact

Noise index. A measure of long term, or cumulative sound which correlates with (i.e. is considered to be a predictor of) its effects on people. May take some account of factors in addition to the magnitude of sound (especially time of day). An example is day-evening-night level, L_{DEN}.

Noise level. A decibel measure of sound on a scale which indicates its loudness or noisiness. For environmental noise from aeroplane, two scales are generally used: A-weighted sound level and Perceived Noise Level. These scales apply different weights to sound of different frequencies - to mimic human perception.

Noise metric. An expression used to describe any measure of quantity of noise at a receiver position whether it be a single event or an accumulation of noise over extended time. There are two commonly used measures of single event noise: the maximum level reached during the event, or its sound exposure level, a measure of its total sound energy determined by time integration.

Noise-power-distance data, NPD data. Noise event levels tabulated as a function of distance below an aeroplane in steady level flight at a reference speed in a reference atmosphere, for each of a number of *engine power settings*. The data account for the effects of sound attenuation due to spherical wave spreading (inverse-square law) and atmospheric absorption. The distance is defined perpendicular to the aeroplane flight path and the aeroplane wing-axis (i.e. vertically below the aeroplane in non banked level flight).

Noise-related power parameter, power or power setting. Parameter that describes or indicates the propulsive effort generated by an aeroplane engine to which acoustic power emission can logically be related; usually taken to be corrected net thrust.

Noise significance. The contribution from a flight path segment is 'noise significant' if it affects the event noise level to an appreciable extent.

Observer. Receiver.

Procedural steps. Prescription for flying a profile - steps include changes of speed and/or altitude.

Profile point. Height of flight path segment end point - in vertical plane above the ground track.

Receiver. A recipient of noise that arrives from a source; principally at a point on or near the ground surface.

Reference day. A set of atmospheric conditions on which ANP data are standardised.

Reference duration. A nominal time interval used to standardise single event sound exposure level measurements; equal to 1 second in the case of *SEL*.

Reference speed. Aeroplane groundspeed to which *NPD SEL* data are normalised.

SEL. *Sound Exposure Level.*

Single event sound exposure level. The sound level an event would have if all its sound energy were compressed uniformly into a standard time interval known as the *reference duration*.

Soft ground. A ground surface that is acoustically 'soft', typically grassy, that surrounds most aerodromes. Acoustically hard, i.e. highly reflective, ground surfaces includes concrete and water. The noise contour methodology described herein applies to soft ground conditions.

Sound. Energy, or acoustic energy. The squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 µPa, the threshold of human hearing. It is algebraically equivalent to $10^{L/10}$, where L is the sound level, expressed in decibels.

Sound attenuation. The decrease in sound intensity with distance along a propagation path. For aeroplane noise its causes include spherical wave spreading, atmospheric absorption and ® lateral attenuation.

Sound exposure. A measure of total sound energy emission over a period of time.

Sound Exposure Level, L_{AE} or SEL. A metric standardised in ISO 1996-1 [ref. 14] or ISO 3891 [ref. 15] = A-weighted single event sound exposure level referenced to 1 second.

Sound intensity. The strength of sound emission at a point - related to sound energy (and indicated by measured sound levels).

Sound level. A measure of sound energy expressed in decibel. Received sound is measured with or without 'frequency weighting'; levels measured with a weighting are often termed *noise levels*.

Stage/trip length. Distance to first destination of departing aeroplane; taken to be an indicator of aeroplane mass.

Start of Roll, SOR. The point on the runway from which a departing aeroplane commences its take-off. Also termed 'brake release'.

True airspeed. Actual speed of aeroplane relative to air (= groundspeed in still air).

Weight. The downward force of gravity exerted on an aeroplane. It is essentially proportional to the aeroplane's mass. Note, although strictly different entities, the terms *weight* and *mass* are used interchangeably throughout this document.

Weighted equivalent sound level, $L_{eq,W}$. A modified version of L_{eq} in which different weights are assigned to noise occurring during different period of the day (usually day, evening and night).

SYMBOLS

The mathematical *symbols* are the main ones used in equations in the main text. Other symbols used locally in both the text and the appendices are defined where they are used.

The reader is reminded periodically of the interchangeability of the words *sound* and *noise* in this document. Although the word *noise* has subjective connotations - it is usually defined by acousticians as 'unwanted sound' - in the field of aeroplane noise control it is commonly taken to mean just sound - airborne energy transmitted by acoustic wave motion.

d	Shortest distance from an observation point to a flight path segment
d_p	Perpendicular distance from an observation point to the flight path (slant distance or slant range)
d_λ	Scaled distance
F_n	Actual net thrust per engine

F_n/δ	Corrected net thrust per engine
h	Aeroplane altitude (above MSL)
L	Event noise level (scale undefined)
L(t)	Sound level at time t (scale undefined)
L_A, $L_A(t)$	A-weighted sound pressure level (at time t) - measured on the slow sound level meter scale
L_{AE}	(SEL) Sound Exposure Level [refs. 2,3]
L_{Amax}	Maximum value of $L_A(t)$ during an event
L_E	Single event sound exposure level
$L_{E\infty}$	Single event sound exposure level determined from NPD database
L_{EPN}	Effective Perceived Noise Level
L_{eq}	Equivalent (continuous) sound level
L_{max}	Maximum value of L(t) during an event
$L_{max,seg}$	Maximum level generated by a segment
ℓ	Perpendicular distance from an observation point to the ground track
lg	Logarithm to base 10
N	Number of segments or sub-segments
NAT	Number of events with L_{max} exceeding a specified threshold
P	Power parameter in NPD variable L(P,d)
P_{seg}	Power parameter relevant to a particular segment
q	Distance from start of segment to closest point of approach
R	Radius of turn
S	Standard deviation
s	Distance along ground track
s_{RWY}	Runway length
t	Time
t_e	Effective duration of single sound event
t_0	Reference time for integrated sound level
V	Groundspeed
V_{seg}	Equivalent segment groundspeed
V_{ref}	Reference groundspeed for which NPD data are defined
x,y,z	Local coordinates
x',y',z'	Aeroplane coordinates
$X_{ARP}, Y_{ARP}, Z_{ARP}$	Position of aerodrome reference point in geographical coordinates
z	Height of aeroplane above ground plane / aerodrome reference point
α	Parameter used for calculation of the finite segment correction Δ_F
β	Elevation angle of aeroplane relative to ground plane
ε	Aeroplane bank angle
γ	Climb/descent angle
φ	Depression angle (lateral directivity parameter)
λ	Total segment length
ψ	Angle between direction of aeroplane movement and direction to observer
ξ	Aeroplane heading, measured clockwise from magnetic north
$\Lambda(\beta,\ell)$	Air-to-ground lateral attenuation
$\Lambda(\beta)$	Long range air-to-ground lateral attenuation
$\Gamma(\ell)$	Lateral attenuation distance factor
Δ	Change in value of a quantity, or a correction (as indicated in the text)

Δ_F	Finite segment correction
Δ_I	Engine installation correction
Δ_{rev}	Reverse thrust
Δ_{SOR}	Start of roll correction
Δ_V	Duration (speed) correction

Subscripts

1, 2	Subscripts denoting start and end values of an interval or segment
E	Exposure
i	Aeroplane type/category summation index
j	Ground track/subtrack summation index
k	Segment summation index
max	Maximum
ref	Reference value
seg	Segment specific value
SOR	Related to start of roll
TO	Take-off

Chapter 1

GENERAL

1.1 INTRODUCTION

1.1.1 Contour maps are used to indicate the extent and magnitude of aeroplane noise impact around airports, indicated by values of a specified noise metric or index. A contour is a line along which the index value is constant. The index value aggregates, in some way, all the individual aeroplane noise events that occur during some specified period of time, normally measured in days or months, according to a specific noise metric. More information on noise indices, including those in use in various countries is provided in **Appendix A**.

1.1.2 The noise at points on the ground from aeroplanes flying into and out of a nearby aerodrome depends on many factors. Principal among these are the types of aeroplane and their powerplant; the power, flap and airspeed management procedures used on the aeroplanes themselves; the distances from the points concerned to the various flight paths; and local topography and weather. Airport operations generally include different types of aeroplanes, various flight procedures and a range of operational masses.

1.1.3 This document is principally written for aeroplane noise modellers, who develop and maintain the computer models and their databases. It fully describes a specific noise contour modelling system, which is considered by ICAO to represent current best practice. It does not prescribe a computer programme but rather the equations and logic that need to be programmed to construct a physical 'working model'. Any physical model that complies fully with the methodology described can be expected to generate contours of aeroplane noise exposure around civil airports with reasonable accuracy. **The methodology applies only to long-term average noise exposure; it cannot be relied upon to predict with any accuracy the absolute level of noise from a single aeroplane movement and should not be used for that purpose.**

1.1.4 This document explains in detail how to calculate, at one observer point, the individual aeroplane noise event levels, each for a specific aeroplane flight or type of flight, that are subsequently averaged in some way, or *accumulated*, to yield index values at that point. The required surface of index values is generated by repeating the calculations as necessary for different aeroplane movements – taking care to maximise efficiency by excluding events that are not 'noise-significant' (i.e. disregarding segments which do not contribute significantly to the total event level yields massive savings in computer processing).

1.1.5 This document builds on, as well as replaces, ICAO Circular published in 1988, which should now be discarded. Many essential features of the previously recommended process have been retained in this Circular; only parts that have subsequently proved to be inadequate or inappropriate have been improved or replaced. The document is not a programming manual; it does not provided detailed step-by-step instructions for constructing a computer code. Such details are left to the modeller/programmer, who then has the flexibility to adapt the model to specific needs. Two important associated reference documents are the Society of Automotive Engineers' Aerospace Information Report No 1845 [ref. 1] , and the European Civil Aviation Conference's Document 29 [ref.2, 3]. The aviation industry specialists in the organizations publishing these documents have long been engaged in the development of aeroplane noise standards and recommended practices.

1.1.6 An important advance on previous guidance is that a linked international Aircraft Noise and Performance (ANP) database is now available on-line and the recommended methodology is designed to make full use of this comprehensive ICAO-endorsed data source. It includes aeroplane and engine performance data and noise-power-distance (NPD) tables for the civil aeroplane types most commonly used at the world's busy airports.

1.1.7 There are a number of noise-generating activities on operational airports which are excluded from the 'air noise' calculation procedures given here. These include taxiing, engine testing and use of auxiliary power-units, and their noise generally comes under the heading of ground noise. In practice, the effects of these activities are unlikely to affect the noise contours in regions beyond the airport boundary. This does not necessarily mean that their impact is insignificant; however assessments of ground noise are usually undertaken independently of air noise analyses.

2 OUTLINE OF THE DOCUMENT

1.2.1 It is assumed that users are familiar with basic noise modelling principles. It is important to note that having a *best practice modelling methodology* is only one of three requirements for valid noise contour modelling. The others are *an accurate aeroplane noise and performance database* and a detailed understanding and description of *the aeroplane operations* that are the source of the noise. All three elements are covered in this document.

1.2.2 The noise contour generation process is illustrated in **Figure 1-1**. Contours are produced for various purposes and these tend to control the requirements for sources and pre-processing of input data. Contours that depict historical noise impact might be generated from actual records of aeroplane operations – of movements, masses, radar-measured flight paths, etc. Contours used for future planning purposes of necessity rely more on forecasts – of traffic and flight tracks and the performance and noise characteristics of future aeroplanes.

1.2.3 Each different aeroplane movement, arrival or departure, is defined in terms of its flight path geometry and the noise emission from the aeroplane as it follows that path (movements that are essentially the same in noise and flight path terms are included by simple multiplication). The noise emission depends on the characteristics of the aeroplane - mainly on the power generated by its engines. The recommended methodology involves dividing the flight path into segments. **Chapter 2** outlines the elements of the methodology. It explains the principle of segmentation on which it is based and that the observed event noise level is an aggregation of contributions from all 'noise-significant' segments of the flight path, each of which can be calculated independently of the others. **Chapter 2** also outlines the input data requirements for producing a set of noise contours.

1.2.4 **Chapter 3** describes the flight path segment calculations from pre-processed input data. This involves applications of aeroplane flight performance analysis, equations for which are detailed in **Appendix C**, using data from the ANP database. Flight paths are subject to significant variability - aeroplanes following any route are dispersed across a swathe due to the effects of differences in atmospheric conditions, aeroplane mass and operating procedures, air traffic control constraints, etc. This is taken into account by describing each flight path statistically – as a central or 'backbone' path which is accompanied by a set of dispersed paths. This too is explained in **Chapter 3** with reference to additional information in **Appendix D**.

1.2.5 **Chapter 4** sets out the steps to be followed in calculating the noise level of a single event – the noise generated at a point on the ground by one aeroplane movement. Data in the international ANP database apply to specific reference conditions. **Appendix E** deals with the re-calculation of NPD-data for non-reference conditions. **Appendix F** explains the acoustic dipole source used in the model to define sound radiation from flight path segments of finite length. **Appendix G** gives additional guidance for the case when the event level metric is L_{max} rather than L_E.

1.2.6 In addition to relevant flight paths, modelling applications described in Chapters 3 and 4 require appropriate noise and performance data for the aeroplane in question. The source of that information, the ICAO-endorsed international ANP database website, and how data can be obtained from it, is described in **Appendix H**.

1.2.7 Determining the event level for a single aeroplane movement at a single observer point is the core noise calculation in this methodology. This process has to be repeated for all aeroplane movements at each of a prescribed array of points covering the expected extent of the required noise contours. At each point the event levels are aggregated or averaged in a specific way to arrive at a 'cumulative level' or noise index value. This part of the process is described in **Chapter 5**.

1.2.8 **Chapter 6** summarises the options and requirements for fitting noise contours to arrays of noise index values. It provides guidance on contour generation and post-processing.

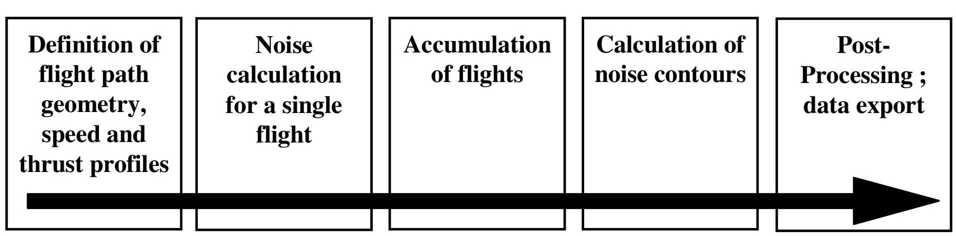

Figure 1-1: The noise contour generation process

Chapter 2

SUMMARY AND APPLICABILITY OF METHOD

2.1 INTRODUCTION

2.1.1 This document describes the major aspect of the calculation of noise contours for air traffic at an airport. It is primarily intended to be applied to civil commercial airports where the operations consist of mostly either jet-engine powered or propeller-driven heavy aeroplanes. If appropriate noise and performance data are available for propeller-driven light aeroplanes these may also be included in the evaluation. Where the noise impact derives mostly from helicopters, however, this document is not applicable - the operational patterns for such aircraft often differ markedly from those covered here and the aircraft themselves have different noise directivity patterns from the other types.

2.1.2 This document describes three different ways in which most practical noise models calculate aeroplane noise single event levels. In order of increasing complexity, these are the *closest point of approach* (CPA), *segmentation* and *simulation* methods. Each has its strengths and weaknesses but it is considered that, on balance, segmentation (otherwise known as 'integrated') models represent current best practice. This situation may change at some point in the future: 'simulation' models have greater potential and it is only the lack of the comprehensive data they require, and their higher demands on computing capacity, that restrict them to special applications (such as research) at present.

2.1.3 Segmentation modelling is supported by a comprehensive aircraft noise and performance database, which has been assembled over many years by the aircraft manufacturing industry in collaboration with the noise certificating authorities. This international aircraft noise and performance (ANP) database is now accessible on the Internet at http://www.aircraftnoisemodel.org; the ANP website is a primary source of data for the methodology recommended in this document.

2.1.4 The contour modelling system consists of a computer model that implements the recommended methodology and the ANP database together. This system is applied to a particular airport scenario with user-specified airport data and air traffic data specifying the aeroplane types, numbers, routeings and operating procedures.

2.1.5 These basic elements of the noise contour generation process are summarised in this chapter, and are expanded upon in subsequent chapters and appendices.

2.2 THE CONCEPT OF SEGMENTATION

2.2.1 For any specific aeroplane, the database contains baseline Noise-Power-Distance (NPD) relationships. These define, for steady straight flight at a *reference speed* in specified *reference atmospheric conditions* and in a specified flight configuration, the received sound event levels, both maximum and time integrated, directly beneath the aeroplane[1] as a function of distance. For noise modelling purposes, propulsive power is represented by a *noise-related power parameter*; generally *corrected net thrust*. Baseline event levels determined from the database are adjusted to account for differences between actual (i.e. modelled) and reference atmospheric conditions, aeroplane speed (in the case of sound exposure levels) and, for receiver points that are not directly beneath the aeroplane, differences between downwards and laterally radiated noise. This latter difference is due to *lateral directivity* (engine installation effects) and *lateral attenuation*. It is important to note that the event levels so adjusted still apply to the total noise from the aeroplane in steady level flight.

2.2.2 *Segmentation* is the process by which the recommended noise contour model adapts the infinite path NPD and lateral data to calculate the noise reaching a receiver from a non-uniform flight path, i.e. one along which the aeroplane flight configuration varies. For the purposes of calculating the event sound level of an aeroplane movement, the flight path is represented by a set of contiguous straight-line segments, each of which can be regarded as a finite part of an infinite path for which an NPD and the lateral adjustments are known. The maximum level of the event is simply the greatest of the individual segment values. The time integrated level of the whole noise event is calculated by summing the noise received from a sufficient number of segments, i.e. those which make a significant contribution to the total event noise.

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[1] Actually beneath the aeroplane perpendicular to the wing axis and direction of flight; taken to be vertically below the aeroplane when in non-turning (i.e. non-banked) flight.

2.2.3 The method for estimating how much noise one finite segment contributes to the integrated event level is a purely empirical one. The *energy fraction F* – the segment noise expressed as a proportion of the total infinite path noise – is described by a relatively simple expression which allows for the longitudinal directivity of aeroplane noise and the receiver's 'view' of the segment. One reason why a simple empirical method is generally adequate is that, as a rule, most of the noise comes from the nearest, usually, adjacent segment – for which the *closest point of approach* (CPA) to the receiver lies within the segment (not at one of its ends). This means that estimates of the noise from non-adjacent segments can be increasingly approximated, as they get further away from the receiver without compromising the accuracy significantly.

2.3 FLIGHT PATHS: TRACKS AND PROFILES

2.3.1 In the modelling context, a *flight path* (or trajectory) is a full description of the motion of the aeroplane in space and time[2]. Together with the propulsive thrust (or other noise related power parameter) this is the information need to calculate the noise generated. The gro*und track* is the vertical projection of the flight path on level ground. This is combined with the vertical *flight profile* to construct the 3-D flight path. Segmentation modelling requires that the flight path of every different aeroplane movement is described by a series of contiguous straight segments. The manner in which the segmentation is performed is dictated by a need to balance accuracy and efficiency – it is necessary to approximate the real curved flight path sufficiently closely while minimising the computational burden and data requirements. Each segment has to be defined by the geometrical coordinates of its end points and the associated speed and engine power parameters of the aeroplane (on which sound emission depends). Flight paths and engine power may be determined in various ways, the main ones involving synthesis from a series of procedural steps and analysis of measured flight profile data.

2.3.2 *Synthesis* of the flight path requires knowledge of (or assumptions for) ground tracks and their lateral dispersions, aeroplane mass, speed, flap and thrust-management procedures, airport elevation, atmospheric pressure, wind and air temperature. Equations for calculating the flight profile from the required propulsion and aerodynamic parameters are given in **Appendix C**. Each equation contains coefficients (and/or constants) which are based on empirical data for each specific aeroplane type. The aerodynamic-performance equations in **Appendix C** permit the consideration of any reasonable combination of aeroplane operational mass and flight procedure, including operations at different take-off masses.

2.3.3 *Analysis* of measured data , e.g. from flight data recorders, radar or other aeroplane tracking equipment, involves 'reverse engineering', effectively a reversal of the synthesis process, described in **Section 2.3.2**. Instead of estimating the aeroplane and powerplant states at the ends of the flight segments by integrating the effects of the thrust and aerodynamic forces acting on the airframe, the forces are estimated by differentiating the changes of height and speed of the airframe. Procedures for processing the flight path information are described in **Section 3.5**.

2.3.4 In an ultimate noise modelling application, each individual flight could, theoretically, be represented independently; this would guarantee accurate accounting for the spatial dispersion of flight paths - which can be very significant. But to keep data preparation and computer time within reasonable bounds it is normal practice to represent flight path swathes by a small number of laterally displaced 'subtracks'. (Vertical dispersion is usually represented satisfactorily by accounting for the effects of varying aeroplane masses on the vertical profiles.)

2.4 AIRCRAFT NOISE AND PERFORMANCE DATABASE

2.4.1 To support this methodology, use of data from the on-line international Aircraft Noise and Performance (ANP) database (www.aircraftnoisemodel.org), which is fully described in **Appendix H**, is recommended.

2.4.2 The ANP database contains aeroplane and engine performance coefficients and NPD relationships for a substantial proportion of the civil aeroplane types operating from airports in ICAO states. Data on additional aeroplane types, old and new, will be added as soon as they have been supplied to, and verified by, the database managers.

2.4.3 All new inputs are supplied or endorsed by the aeroplane manufacturers and generated according to SAE specifications [ref. 1] that are approved by ICAO. For aeroplanes that are common to both specifications, the data are identical to those in the US INM database [ref. 4]. For aeroplane types or variants for which data are not currently listed, the ANP database provides

[2] Time is accounted for via the aeroplane speed.

guidance on how they can best be represented by data for other, normally similar, aeroplanes that are listed.

2.4.4 The ANP database includes default ‘procedural steps’ to enable the construction of flight profiles for at least one common noise abatement departure procedure. More recent database entries cover two different noise abatement departure procedures. However it should be noted that these carry the caveat:

> *“Users should examine the applicability of ANP database default ‘procedural steps’ to the airport under consideration. These data are generic and in some cases may not realistically represent flight operations at your airport.”*

2.4.5 Although the manufacturers and database managers strive to ensure that the data are generated in strict accordance with the standard specifications, ultimate validation of the ANP data lies effectively with the user. Inconsistencies or deficiencies are most likely to be discovered by users who compare model predictions with measured data. Evidence of inconsistencies is fed back to the data suppliers through the database managers. The data suppliers then decide on the action required; only they can amend or approve database entries. To this end it must be recognised that acquiring reliable measured data is a very demanding task and it is necessary for data suppliers to demonstrate that the data meets acceptable quality criteria.

2.4.6 Access to the database is subject to terms and conditions designed to prevent misuse. User registration and password protection are overseen by the database managers.

2.5 AIRPORT AND AEROPLANE OPERATIONS

2.5.1 Case-specific data required for a particular airport scenario are described in the following paragraphs.

2.5.2 General airport data, including:

a) The aerodrome reference point (simply to locate the aerodrome in appropriate geographic co-ordinates). The reference point is set as the origin of the local Cartesian co-ordinate system used by the calculation procedure.

b) The aerodrome reference altitude (the altitude of aerodrome reference point). This is the altitude of the nominal ground plane on which, in the absence of topography corrections, the noise contours are defined.

c) Average meteorological parameters at or close to the aerodrome reference point (temperature, relative humidity, average windspeed and wind direction).

2.5.3 Runway data for each runway, including:

a) Runway designation;
b) Runway reference point (centre of runway expressed in local co-ordinates);
c) Runway length, direction and mean gradient; and
d) Location of start-of-roll and landing threshold[3].

2.5.4 Ground track data consist of a series of track coordinates and a description of track dispersion.

2.5.5 Aeroplane ground tracks are described by a series of coordinates in the (horizontal) ground-plane. The source of ground track data depends on whether relevant radar data are available or not. If they are, a reliable backbone track and suitable associated (dispersed) sub-tracks can be established by statistical analysis of the data. If not, backbone tracks are usually constructed from appropriate procedural information, e.g. using standard instrument departure procedures from AIPs. This conventional description includes the following information:

a) Designation of the runway the track originates from;
b) Description of the track origin (start of roll, landing threshold); and
c) Length of segments (for turns, radius and change of direction).

2.5.6 This information is the minimum necessary to define the core (backbone) track. It is important to note that average noise levels calculated on the assumption that aeroplanes follow the nominal routes exactly may be liable to localized errors of several decibels. Thus lateral dispersion should be represented by the following information:

[3] Displaced thresholds can be taken into account by defining additional runways.

a) Width of the swathe (or other dispersion statistic) at each segment end;
b) Number of subtracks; and
c) Distribution of movements perpendicular to the backbone track.

2.5.7 Air traffic data, including:

a) the time period covered by the data; and
b) the number of movements (arrivals or departures) of each aeroplane type on each flight track, subdivided by time of day as appropriate for specified noise descriptors[4], for departures, operating masses or stage lengths, and, if necessary, operating procedures.

2.5.8 Topographical data meeting the following criteria:

a) The terrain around most airports is relatively flat. However this is not always the case, in which case variations in terrain elevation relative to the airport reference elevation may need to be taken into account. The effect of terrain elevation can be especially important in the vicinity of approach tracks, where the aeroplane is operating at relatively low altitudes;

b) Terrain elevation data are usually provided as a set of (x,y,z) co-ordinates for a rectangular grid of certain mesh-size. But the parameters of the elevation grid are likely to be different from those of the grid used for the noise computation. If so linear interpolation may be used to estimate the appropriate z-co-ordinates in the latter; and

c) Comprehensive analysis of the effects of non-level ground on sound propagation is beyond the scope of this guidance. Moderate unevenness can be accounted for by assuming ‘pseudo-level’ ground; i.e. simply raising or lowering the level ground plane to the local ground elevation (relative to the reference ground plane) at each receiver point (see **Section 3.3.4**).

2.6 THE INTERNATIONAL AIRCRAFT NOISE AND PERFORMANCE (ANP) DATABASE

2.6.1 The ANP data are normalised to standard reference conditions that are widely used for airport noise studies (see **Appendices E and H**). Specific reference conditions apply to aeroplane noise-power-distance (NPD) data and aeroplane aerodynamic and engine data.

2.6.2 Reference conditions for NPD data include the following:
a) Atmospheric pressure: 101.325 kPa (1013.25 mb);
b) Atmospheric absorption: attenuation rates listed in **Table E-1** of **Appendix E;**
c) Precipitation: none;
d) Wind Speed: less than 8 m/s (15 kt);
e) Groundspeed: 160 kt; and
f) Local terrain: Flat, soft ground free of large structures or other reflecting objects within several kilometres of aeroplane ground tracks.

2.6.3 In addition, standardised aeroplane sound measurements are made 1.2 m above the ground surface. However for modelling purposes, it may be assumed that event levels are relatively insensitive to receiver height[5].

2.6.4 Comparisons of estimated and measured airport noise levels indicate that the NPD data can be assumed applicable when the near surface average conditions lie within the following envelope:

a) Air temperature is less than 30°C;
b) The product of air temperature (°C), and relative humidity, (percent) is greater than 500; and
c) Wind speed is less than 8 metres per second (15 kt)

2.6.5 This envelope is believed to encompass conditions encountered at most of the world’s major airports. **Appendix E** provides a method for converting NPD data to average local conditions which fall outside this envelope. In extreme cases,

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[4] Most noise descriptors require that events (i.e. aeroplane movements) are defined as average daily values during specified periods of the day (e.g. day, evening and night) - see **Chapter 5**.

[5] Calculated levels at 4 m or higher are sometimes requested. Comparison of measurements at 1.2 m and 10 m and theoretical calculation of ground effects show that variations of the A-weighted sound exposure level are relatively insensitive to receiver height. The variations are in general smaller than one decibel, except if the maximum angle of sound incidence is below 10° and if the A-weighted spectrum at the receiver has its maximum in the range of 200 to 500 Hz. Such low frequency dominated spectra may occur e.g. at long distances for low-bypass ratio engines and for propeller engines with discrete low frequency tones.

it is suggested that the relevant aeroplane manufacturers be consulted.

2.6.6 Reference conditions for aeroplane aerodynamic and engine data include the following:

a) Runway Elevation: mean sea level;
b) Air temperature: 15 °C;
c) Take-off gross weight: as defined as a function of stage length in the ANP database (see **Appendix H3.5**);
d) Landing gross weight: 90 percent of maximum landing gross weight; and
e) Engines supplying thrust: all.

2.6.7 Although ANP aerodynamic and engine data are based on these conditions, they can be tabulated for non-reference runway elevations and average air temperatures (see **Appendix C**).

2.6.8 The ANP database tabulates aerodynamic data for the take-off and landing gross weights noted above. Although the aerodynamic data themselves need not be adjusted for other gross weights when calculating cumulative noise levels, calculation of the take-off and climb-out flight profiles should be based on the appropriate operational take-off gross weights (see **Appendix C**).

Chapter 3

Description of the flight path

3.1 INTRODUCTION

3.1.1 Each different aeroplane movement in a noise model is described by its three-dimensional flight path and the varying engine power and speed along the path. As a rule, one modelled movement represents a subset of the total airport traffic, e.g. a number of (assumed) identical movements, with the same aeroplane type, mass and operating procedure, on a single ground track. That track may itself be one of several dispersed 'sub-tracks' used to model a swathe of tracks following one designated route. The ground track swathes, the vertical profiles and the aeroplane operational parameters are all determined from the input scenario data - in conjunction with aeroplane data from the ANP database.

3.1.2 The noise-power-distance (NPD) data (in the ANP database) define noise from aeroplanes traversing idealised horizontal flight paths of infinite length at constant speed and power. To adapt this data to terminal area flight paths that are characterised by frequent changes of power and speed, every path is broken into finite straight-line segments. The noise contributions from each of these segments are subsequently summed at the observer position.

3.2 RELATIONSHIPS BETWEEN FLIGHT PATH AND FLIGHT CONFIGURATION

3.2.1 The three-dimensional flight path of an aeroplane movement determines the geometrical aspects of sound radiation and propagation between aeroplane and observer. At a particular aeroplane mass and in particular atmospheric conditions, the flight path is governed entirely by the sequence of power, flap and attitude changes, in order to follow routes and maintain heights and speeds specified by ATC[6]. These actions divide the flight path into distinct phases which form natural segments. In the horizontal plane they involve straight legs, specified as a distance to the next turn, and turns, defined by radius and change of heading. In the vertical plane, segments are defined by the time and/or distance taken to achieve required changes of forward speed and/or height at specified power and flap settings. The corresponding vertical coordinates are often referred to as *profile points*.

3.2.2 For noise modelling, flight path information is generated either by *synthesis* from a set of procedural steps (i.e. those followed by the pilot) or by *analysis* of radar data - physical measurements of actual flight paths flown. Whatever method is used, both horizontal and vertical shapes of the flight path, are reduced to segmented forms. The horizontal shape is the *ground track* defined by the inbound or outbound routeing. Its vertical shape, given by the profile points, and the associated flight parameters speed, bank angle and power setting, together define the *flight profile* which depends on the *flight procedure* that is normally prescribed by the aeroplane manufacturer and/or operator. The flight path is constructed by merging the 2-D flight profile with the 2-D ground track to form a sequence of 3-D flight path segments.

3.2.3 It is important to note that, for a given set of procedural steps, the profile depends on the ground track; e.g. at the same thrust and speed the aeroplane climb rate is less in turns than in straight flight. Although this guidance explains how to take this dependency into account, it has to be acknowledged that doing so would normally involve a very large computing effort and users may prefer to assume that, for noise modelling purposes, the flight profile and ground track can be treated as independent entities; i.e. that the climb profile is unaffected by any turns. However, it is important to determine changes of bank angle, which affects the directionality of sound emission.

3.2.4 The noise received from a flight path segment depends on the geometry of the segment in relation to the observer and the aeroplane flight configuration. It is important to note that these parameters are interrelated - a change in one causes a change in the other. It is necessary to ensure that, at all points on the path, the configuration of the aeroplane is consistent with its motion along the path.

3.2.5 In a flight path synthesis, i.e. the construction of a flight path from a set of 'procedural steps' that describe the pilot's selections of engine power, flap angle, and acceleration/vertical speed, it is the motion that has to be calculated. In a flight path analysis, the reverse is the case: the engine power settings have to be estimated from the observed motion of the aeroplane - as determined from radar data, or sometimes, in special studies, from aeroplane flight recorder data (although in the latter case engine

[6] These specifications are in accordance with the aircraft operator's standard operating procedures.

power is usually part of the data). In either case, the coordinates and flight parameters at all segment end points have to be fed into the noise calculation.

3.2.6 The operational steps followed by arriving and departing aeroplanes are explained in **Chapter 4 of Volume 1**. **Appendix C** presents the equations that relate the forces acting on an aeroplane and its motion and explains how they are solved to define the properties of the segments that make up the flight paths. The different kinds of segments (and the sections of **Appendix C** that cover them) are *take-off ground roll* (**Appendix C5**), *climb at constant speed* (C6), *power cutback* (C7), *accelerating climb and flap retraction* (C8), *accelerating climb after flap retraction* (C9), *descent and deceleration* (C10) and *final landing approach* (C11).

3.2.7 Practical modelling involves varying degrees of simplification, depending on the nature of the application, the significance of the results and the resources available. A general simplifying assumption, even in the most elaborate applications, is that when accounting for flight track dispersion, the flight profiles and configurations on all the sub-tracks are the same as those on the backbone track. A minimum of six subtracks is recommended (see **Section 3.5.2**), which will greatly reduce computations for an small penalty in fidelity.

3.3 SOURCES OF FLIGHT PATH DATA

3.3.1 Radar data

3.3.1.1 Radar data are the most readily accessible source of information on actual flight paths flown at airports[7]. Radar data are usually available from airport noise and flight path monitoring systems, and are increasingly used for noise modelling purposes. However the analysis of radar data is a complex task for which methods are still under development [ref. 5]. Therefore, only general guidance can be offeredand it is left to the modeller to determine the appropriate approach.

3.3.1.2 Secondary surveillance radar presents the flight path of an aeroplane as a sequence of positional coordinates at intervals equal to the period of rotation of the radar scanner, typically about 4 seconds. The position of the aeroplane over the ground is determined in polar coordinates - range and azimuth - from the reflected radar return; its height[8] is measured by the aeroplane's own altimeter and transmitted to the ATC computer by a radar-triggered transponder. However, inherent positional errors due to radio interference and limited data resolution may be significant[9] . Thus, if the flight path of a specific aeroplane movement is required, it is necessary to smooth the data using an appropriate curve-fitting technique [e.g. refs. 6, 7]. However, for noise modelling purposes the usual requirement is for a statistical description of a swathe of flight paths; e.g. for all movements on a route or for just those of a specific aeroplane type. Here the measurement errors associated with the relevant statistics becp,e negligible due to the averaging processes.

3.3.2 Procedural steps

3.3.2.1 In many cases is not possible to model flight paths on the basis of radar data - because the necessary resources are not available or because the scenario is a future one for which there are no relevant radar data.

3.3.2.2 In the absence of radar data, or when its use is inappropriate, it is necessary to estimate the flight paths on the basis of operational guidance material, e.g., instructions given to flight crews via AIPs and aeroplane operating manuals - referred to here as *procedural steps*. Advice on interpreting this material should be sought from air traffic control authorities and the aeroplane operators where necessary.

3.4 CO-ORDINATE SYSTEMS

3.4.1 The local co-ordinate system

The local co-ordinate system (x,y,z) is a Cartesian one and has its origin (0,0,0) at the aerodrome reference point $(X_{ARP},Y_{ARP},Z_{ARP})$, where Z_{ARP} is the airport reference altitude and $z = 0$ defines the nominal ground plane on which contours are usually calculated. The aeroplane heading ξ in the xy-plane is measured clockwise from magnetic north (see **Figure 3-1**). All observer locations, the

[7] Aircraft flight data recorders provide comprehensive operational data. However this is not readily accessible and is costly to provide; thus its use for noise modelling purposes is normally restricted to special projects and model development studies.

[8] Usually measured as altitude above MSL (i.e. relative to 1013.25mb) and corrected to airport elevation by the airport monitoring system.

[9] However, these issues are of no consequence for the intended air traffic control purposes

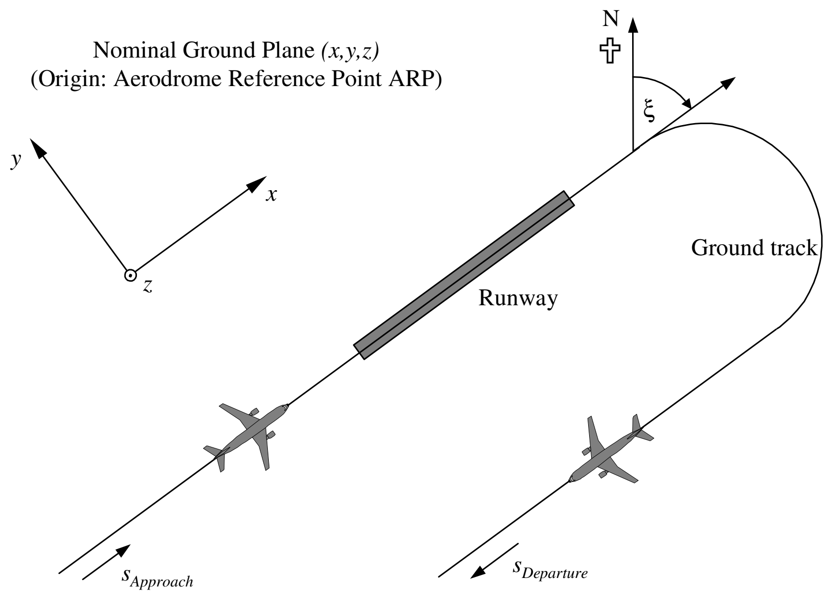

Figure 3-1: Local co-ordinate system (*x,y,z*) and ground-track fixed co-ordinates

basic calculation grid and the noise contour points are expressed in local co-ordinates[10].

3.4.2 The ground-track fixed co-ordinate system

3.4.2.1 This co-ordinate is specific for each ground track and represents distance *s* measured along the track in the flight direction. For departure tracks *s* is measured from the start of roll, for approach tracks from the touchdown point. Thus *s* becomes negative in areas

- behind the start of roll for departures and
- before crossing the runway landing threshold for approaches.

3.4.2.2 Flight operational parameters such as height, speed and power setting are expressed as functions of *s*.

3.4.3 The aeroplane co-ordinate system

The aeroplane-fixed Cartesian co-ordinate system (x',y',z') has its origin at the actual aeroplane location. The axis-system is defined by the climb-angle γ, the flight direction ξ and the bank-angle ε (see **Figure 3-2**).

3.4.4 Accounting for topography

In cases where topography has to be taken into account (see Section 2.5), the aeroplane height coordinate z has to be replaced by $z' = z - z_o$ (where z_o is the z-co-ordinate of the observer location O) when estimating the propagation distance d. The geometry between aeroplane and observer is shown in **Figure 3-3**[11].

[10] Usually the axes of the local co-ordinate are parallel to the axis of the map that contours are drawn on. However it is sometimes useful to choose the *x*-axis parallel to a runway in order to get symmetrical contours without using a fine computational grid (see **Chapter 6**).

[11] For non-level ground it is possible for the observer to be above the aircraft in which case, for calculating sound propagation *z´* (and the corresponding elevation angle β) is put equal to zero. (see Chapter 4)

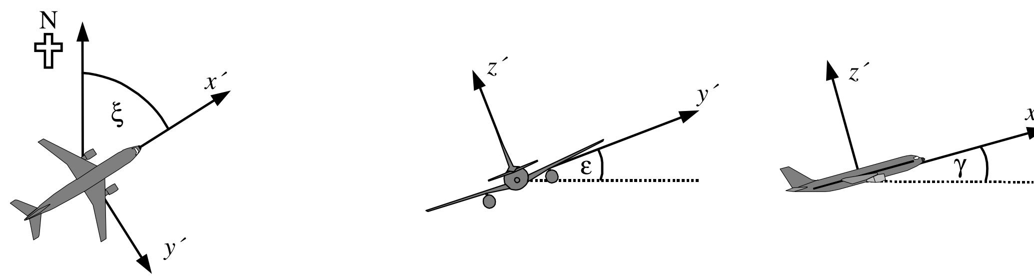

Figure 3-2: Aeroplane fixed co-ordinate system (*x'*,*y'*,*z'*)

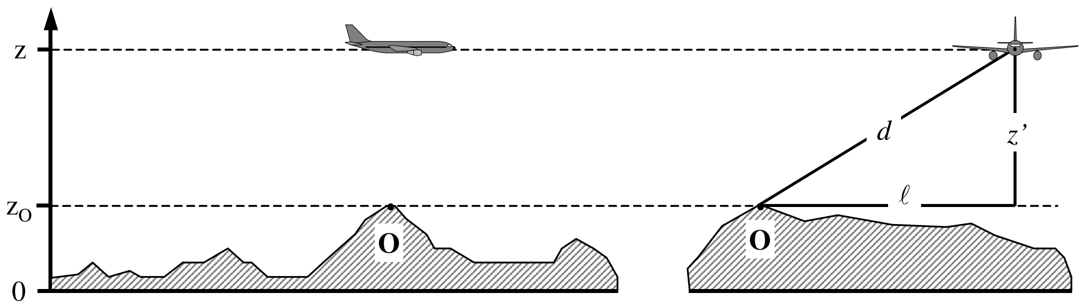

Figure 3-3: Ground elevation along (left) and lateral (right) to ground track. The nominal ground plane z = 0 passes through the aerodrome reference point. O is the observer location.

3.5 GROUND TRACKS

3.5.1 Backbone tracks

3.5.1.1 The backbone track defines the centre of the swathe of tracks followed by aeroplanes using a particular routeing. For the purposes of aeroplane noise modelling it is defined either by prescriptive operational data such as the instructions given to pilots in AIPs, or by statistical analysis of radar data as explained in **Section 3.3** - when this is available and appropriate to the needs of the modelling study. Constructing the track from operational instructions is normally quite straightforward as these prescribe a sequence of legs which are either straight - defined by length and heading, or circular arcs defined by turn rate and change of heading. (see **Figure 3-4**)

3.5.1.2 Fitting a backbone track to radar data is more complex, because actual turns are made at a varying rate and its line is obscured by the scatter of the data. Since formalised procedures have yet to be developed, it is common practice to match segments to the average positions calculated from cross-sections of radar tracks at intervals along the route. It is for the modeller to decide how to use available data to best advantage. A major factor is that the aeroplane speed and turn radius dictate the angle of bank, which may affect the sound radiation around the flight path as observed on the ground. (see Section 4.5)

3.5.1.3 Theoretically, seamless transition from straight flight to fixed radius turn would require an instantaneous application of bank angle ε, which is physically impossible. In reality it takes a finite time for the bank angle to reach the value required to maintain a specified speed and turn radius *r*, during which the turn radius reduces from infinity to *r*. For modelling purposes the radius transition can be disregarded and the bank angle assumed to increase steadily from zero (or other initial value) to ε at the start of the turn and to the next value of ε at the end of the turn[12].

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[12] How best to implement this is left to the user as it will depend on the way in which turn radii are defined. When the starting point is a sequence of straight or circular legs, a relatively simple option is to insert bank angle transition segments at the start of the turn and at its end in which the aircraft rolls at a constant rate (e.g. expressed in °/m or °/s).

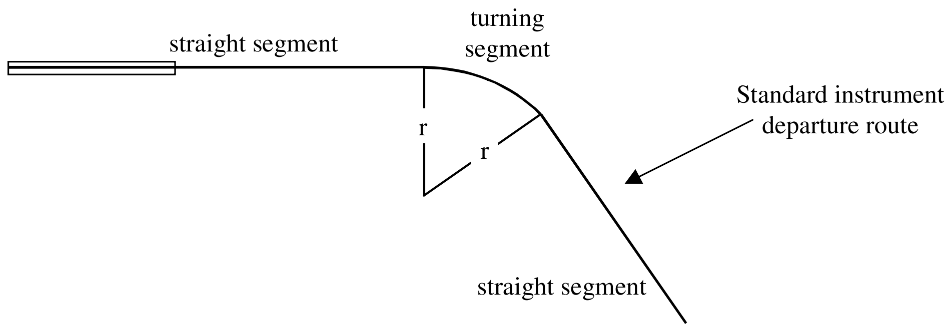

Figure 3-4: Ground track geometry in terms of turns and straight segments

3.5.2 Track dispersion

3.5.2.1 Where possible, definitions of lateral dispersion and representative sub-tracks should be based on relevant past experience from the study airport; normally via an analysis of radar data samples. The first step is to group the data by route. Departure tracks are characterised by substantial lateral dispersion which, for accurate modelling, has to be taken into account. Arrival routes normally coalesce into a very narrow swathe about the final approach path and it is usually sufficient to represent all arrivals by a single track. However, if the approach swathes are wide within the region of the noise contours they may need to be represented by sub-tracks in the same way as departure routes.

3.5.2.2 It is common practice to treat the data for a single route as a sample from a single population; i.e. to be represented by one backbone track and one set of dispersed subtracks. However, if inspection indicates that the data for different categories of aeroplane or operations differ significantly (e.g. if large and small aeroplanes have substantially different turn radii), further subdivision of the data into different swathes may be desirable. For each swathe, the lateral track dispersions are determined as a function of distance from the origin; movements then being apportioned between a backbone track and a suitable number of dispersed sub-tracks on the basis of the distribution statistics.

3.5.2.3 In the absence of measured swathe data, a nominal lateral spread across and perpendicular to the backbone track should be defined by a conventional distribution function. A Normal (Gaussian) distribution should provide an adequate description of most radar-measured swathes.

3.5.2.4 Typically a 7-point discrete approximation is used to model a swathe of aeroplane tracks, which represent the lateral dispersion by six subtracks equally spaced around the backbone track. The spacing of the subtracks depends on the standard deviation of the lateral dispersion function.

3.5.2.5 For normally distributed tracks with a standard deviation S, 98.8% of the tracks are located within a corridor with boundaries located at $\pm 2.5 \cdot S$. **Table 3-1** gives the spacing of the six subtracks and the percentage of the total movements assigned to each. **Appendix D** gives values for other numbers of subtracks.

Table 3-1: **Percentages of movements for a normal distribution function with standard deviation *S* for 7 subtracks (backbone track is subtrack 1).**

Subtrack number	Location of subtrack	Percentage of movements on subtrack
7	$-2.14 \cdot S$	3 %
5	$-1.43 \cdot S$	11 %
3	$-0.71 \cdot S$	22 %
1	0	28 %
2	$0.71 \cdot S$	22 %
4	$1.43 \cdot S$	11 %
6	$2.14 \cdot S$	3 %

3.5.2.6 The standard deviation S is a function of the co-ordinate s along the backbone-track. In the absence of any indicators of the standard deviation

– e.g. from radar data describing comparable flight tracks – the following values are recommended:

For tracks involving turns of less than 45 degrees:

$$S(s) = 0.055 \cdot s - 150 \quad \text{for} \quad 2700\,\text{m} \le s \le 30000\,\text{m}$$
$$S(s) = 1500\,\text{m} \quad \text{for} \quad s > 30000\,\text{m}$$
(3-1a)

For tracks involving turns of more than 45 degrees:

$$S(s) = 0.128 \cdot s - 420 \quad \text{for} \quad 3300\,\text{m} \le s \le 15000\,\text{m}$$
$$S(s) = 1500\,\text{m} \quad \text{for} \quad s > 15000\,\text{m}$$
(3-1b)

3.5.2.7 For practical reasons, *S(s)* is assumed to be zero between the start of roll and s = 2700 m or s = 3300 m depending on the amount of turn.

3.5.2.8 Routes involving more than one turn should be treated as per equation (3-1b). For arrivals, lateral dispersion can be neglected within 6000 m of touchdown.

3.6 FLIGHT PROFILES

3.6.1 The flight profile is a description of the aeroplane motion in the vertical plane above the ground track, in terms of its position, speed, bank angle and engine power setting. Aeroplane flight profiles should be defined to meet the requirements of the modelling application. In order to achieve high accuracy, the profiles should closely reflect the aeroplane operations they are intended to represent. This calls for reliable information on the atmospheric conditions, aeroplane types and variants, operating masses and the operating procedures – the variations of thrust and flap settings and the trade-offs between changes of height and speed –averaged over the time period(s) of interest. The modeller should exercise good engineering judgement to balance the accuracy and detail of the input information with the needs for, and uses of, the contour outputs.

3.6.2 The synthesis of flight profiles from ‘procedural steps’ obtained from the ANP database or from aeroplane operators is described in **Section 3.7** and **Appendix C**. This process yields both the flight path geometry and the associated speed and thrust variations based on the database, instead of radar data. In this case, it would normally be assumed that all (alike) aeroplanes in a swathe follow the backbone track profile.

3.6.3 Beyond the default information on procedural steps found in the ANP database, the aeroplane operators are the best source of reliable aeroplane operational information. For individual flights, the optimum source is the aeroplane flight data recorder (FDR) from which all relevant information can be obtained. However, even if such data are available, the pre-processing task is formidable. Thus, the normal practical solution is to make educated assumptions about mean masses and operating procedures.

3.6.4 Caution should be exercised before adopting the *default* procedural steps provided in the ANP database. These are standardised procedures that are widely followed but which may or may not be used by operators in particular cases. A major factor is the definition of take-off (and sometimes climb) engine thrust that can depend on prevailing circumstances. In particular, it is common practice to reduce thrust levels during departure (from maximum available) in order to extend engine life. **Appendix C** gives guidance on representing typical practice; this will generally produce more realistic contours than a full thrust assumption. However, if, for example, runways are short and/or average air temperatures are high, full thrust is likely to be a more realistic assumption.

3.6.5 When modelling actual scenarios, radar data are often used to supplement or replace this nominal information. Flight profiles can be determined from radar data in a similar way to the lateral backbone tracks - but only after segregating the traffic by aeroplane type and variant and sometimes by mass or stage length (but not by dispersion) - to yield for each sub-group a mean profile of height and speed against ground distance travelled. Again, when merging with the ground tracks subsequently, this single profile is normally assigned to the backbone and subtracks alike.

3.6.6 Knowing the aeroplane mass, the variation of speed and propulsive thrust can be calculated via step-by-step solution of the equations of motion. Before doing so it is helpful to pre-process the data to minimise the effects of radar errors by redefining the profile with straight line segments to represent the relevant stages of flight; with each segment being appropriately classified; i.e. as a ground roll, constant speed climb or descent, thrust cutback, or acceleration/deceleration with or without flap change. The aeroplane mass and atmospheric state are also required inputs.

3.6.7 **Section 3.5** makes it clear that special provision has to be made to account for the lateral dispersion of flight tracks about the nominal or backbone routeings. Radar data samples are characterised by similar dispersions of flight paths in the vertical plane. However it is not usual practice to model vertical dispersion as an independent variable; it arises mainly due to differences in aeroplane masses and operating procedures that are taken into account when pre-processing traffic input data.

3.7 CONSTRUCTION OF FLIGHT PATH SEGMENTS

3.7.1 Each flight path has to be defined by a set of segment coordinates (nodes) and flight parameters. The starting point is to determine the co-ordinates of the ground track segments. The flight profile is then calculated, remembering that for a given set of procedural steps, the profile depends on the ground track; e.g. at the same thrust and speed the aeroplane climb rate is less in turns than in straight flight. Finally the 3-D flight path segments are constructed by merging the 2-D flight profile with the 2-D ground track[13].

3.7.2 Ground track

3.7.2.1 Each ground track is defined by a series of (x,y) co-ordinates in the ground plane (e.g. from radar information) or by a sequence of vectoring commands describing straight segments and circular arcs (turns of defined radius r and change of heading $\Delta\xi$).

3.7.2.2 For segmentation modelling, an arc is represented by a sequence of straight segments fitted to sub-arcs. Although they do not appear explicitly in the ground-track segments, the banking of aeroplanes during turns influences their definition. **Appendix C.5** explains how to calculate bank angles during a steady turn but of course these are not actually applied or removed instantaneously. How to handle the transitions between straight and turning flight, or between one turn and an immediately sequential one, is not prescribed. The details of the transitions between straight and turning flight are likely to have a negligible effect on the final contours and are left up to the user (see **Section 3.5**); the requirement is mainly to avoid sharp discontinuities at the ends of the turn and this can be achieved simply, for example, by inserting short transition segments over which the bank angle changes linearly with distance. Only in the special case where a particular turn is likely to have a dominating effect on the final contours would it be necessary to model the dynamics of the transition more realistically, to relate bank angle to particular aeroplane types and to adopt appropriate roll rates. Here it is sufficient to state that the end sub-arcs $\Delta\xi_{trans}$ in any turn are dictated by bank angle change requirements. The remainder of the arc with change of heading $\Delta\xi - 2\cdot\Delta\xi_{trans}$ degrees is divided into n_{sub} sub-arcs according to the equation:

$$n_{sub} = \mathrm{int}(1 + (\Delta\xi - 2\cdot\Delta\xi_{trans})/30) \qquad (3\text{-}2a)$$

where int(x) is a function that returns the integer part of x. Then the change of heading $\Delta\xi_{sub}$ of each sub-arc is computed as

$$\Delta\xi_{sub} = (\Delta\xi - 2\cdot\Delta\xi_{trans})/n_{sub} \qquad (3\text{-}2b)$$

where n_{sub} needs to be large enough to ensure that $\Delta\xi_{sub} \leq 30$ degrees. The segmentation of an arc (excluding the terminating transition sub-segments) is illustrated in **Figure 3-4**[14].

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[13] For this purpose the total length of the ground track should always exceed that of the flight profile. This can be achieved, if necessary, by adding straight segments of suitable length to the last segment of the ground track.

[14] Defined in this simple way, the total length of the segmented path is slightly less than that of the circular path. However the consequent contour error is negligible if the angular increments are below 30°.

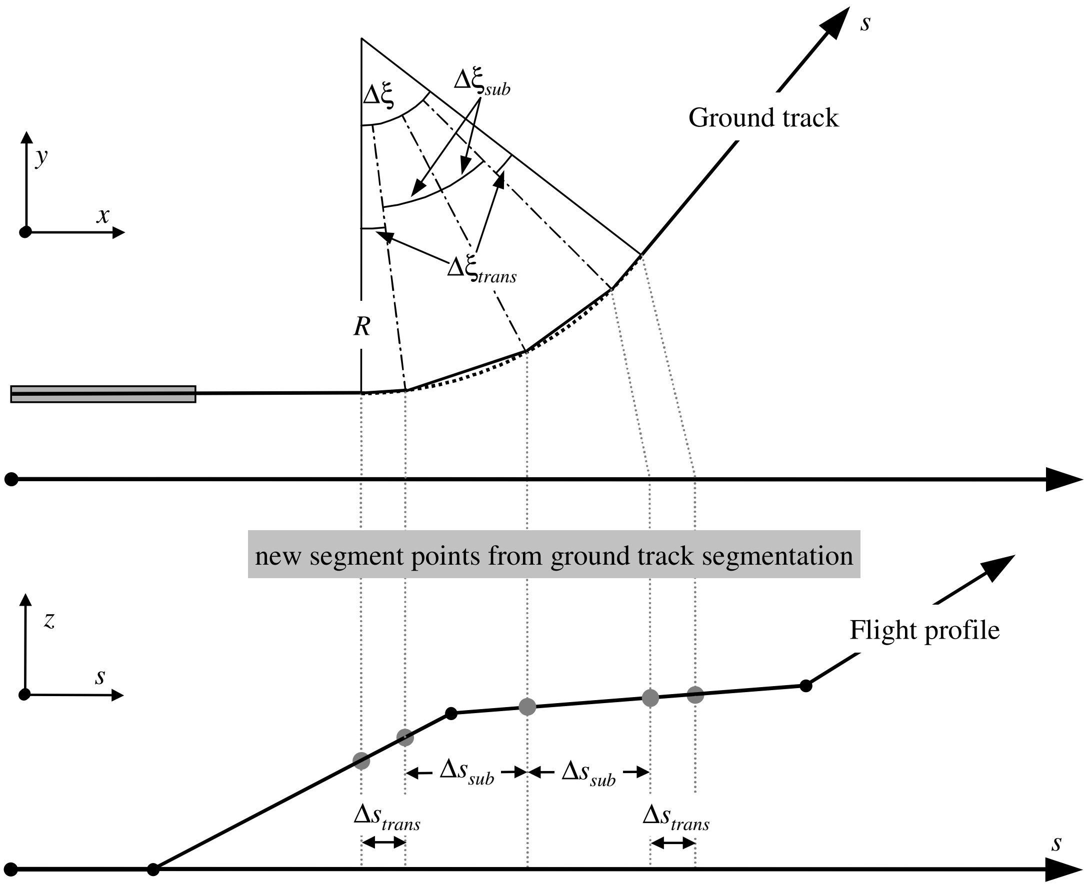

Figure 3-4: Construction of flight path segments dividing turn into segments of length Δ*s* (upper view in horizontal plane, lower view in vertical plane)

3.7.3 Flight profile

3.7.3.1 The parameters describing each flight profile segment at the start (suffix 1) and end (suffix 2) of the segment are:

s_1, s_2	distance along the ground track,
z_1, z_2	aeroplane height,
V_1, V_2	groundspeed,
P_1, P_2	noise-related power parameter (matching that for which the NPD-curves are defined), and
ε_1, ε_2	bank angle.

3.7.3.2 To build a flight profile from a set of procedural steps (*flight path synthesis*), segments are constructed in sequence to achieve required conditions at the end points. The end-point parameters for each segment become the start-point parameters for the next segment. In any segment calculation the parameters are known at the start; required conditions at the end are specified by the procedural step. The steps themselves are defined either by the ANP defaults or by the user (e.g. from aeroplane flight manuals). The end conditions are usually height and speed; the profile building task is to determine the track distance covered in reaching those conditions. The undefined parameters are determined via flight performance calculations described in **Appendix C**.

3.7.3.3 If the ground track is straight, the profile points and associated flight parameters can be determined independently of the ground track (bank angle is always zero). However ground tracks are rarely straight; they usually incorporate turns and, to achieve best results, these have to be accounted for when determining the 2-dimensional flight profile, where necessary splitting profile segments at ground track nodes to inject changes of bank angle. As a rule the length of the next segment is unknown at the outset and it is calculated provisionally assuming no change of bank angle. If the provisional segment is then found to span one or more ground track nodes, the first being at s, i.e. $s_1 < s < s_2$, the segment is truncated at s, calculating the parameters there by interpolation as described in paragraph 3.7.3.5. These become the end-point parameters of the current segment and the start-point parameters of a new segment - which still has the same target end conditions. If there is no intervening ground track node the provisional segment is confirmed.

3.7.3.4 If the effects of turns on the flight profile are to be disregarded, the straight flight, single segment solution is adopted although the bank angle information is retained for subsequent use.

3.7.3.5 Whether or not turn effects are fully modelled, each 3-dimensional flight path is generated by merging its 2-dimensional flight profile with its 2-dimensional ground track. The result is a sequence of co-ordinate sets (x,y,z), each being either a node of the segmented ground track, a node of the flight profile or both, the profile points being accompanied by the corresponding values of height z, ground speed V, bank angle ε and engine power P. For a track point (x,y) which lies between the end points of a flight profile segment, the flight parameters are interpolated as follows:

$$z = z_1 + f \cdot (z_2 - z_1) \tag{3-3a}$$

$$V = \sqrt{V_1^2 + f \cdot \left(V_2^2 - V_1^2\right)} \tag{3-3b}$$

$$\varepsilon = \varepsilon_1 + f \cdot (\varepsilon_2 - \varepsilon_1) \tag{3-3c}$$

$$P = \sqrt{P_1^2 + f \cdot \left(P_2^2 - P_1^2\right)} \tag{3-3d}$$

where

$$f = (s - s_1)/(s_2 - s_1) \tag{3-3e}$$

3.7.3.6 Note that whilst z and ε are assumed to vary linearly with distance, V and P are assumed to vary linearly with time (i.e. constant acceleration[15]).

3.7.3.7 When matching flight profile segments to radar data (*flight path analysis*) all end-point distances, heights, speeds and bank angles are determined directly from the data; only the power settings have to be calculated using the performance equations. As the ground track and flight profile coordinates can also be matched appropriately, this is usually quite straightforward.

3.7.4 Segmentation of the take-off ground roll

3.7.4.1 During takeoff, an aeroplane accelerates between the point of brake release (alternatively termed Start-of-Roll *SOR*) and the point of lift-off, where speed changes dramatically over a distance of 1500 to 2500 m, from zero to between around 80 and 100 m/s.

3.7.4.2 The take-off roll is thus divided into segments with variable lengths over each of which the aeroplane speed changes by specific increment ΔV of about 10 m/s. Although it actually varies during the take-off roll, an assumption of constant acceleration is adequate for this purpose. For equivalent take-off distance s_{TO} (see **Appendix C**) and take-off speed V_{TO} the number n_{TO} of segments for the ground roll is

$$n_{TO} = \mathrm{int}(1 + V_{TO}/10) \tag{3-4a}$$

and hence the change of velocity along a segment is

$$\Delta V = V_{TO} / n_{TO} \tag{3-4b}$$

and the time Δt on each segment is (constant acceleration assumed)

$$\Delta t = \frac{2 \cdot s_{TO}}{V_{TO} \cdot n_{TO}} \tag{3-4c}$$

3.7.4.3 The length $s_{TO,k}$ of segment k ($1 \le k \le n_{TO}$) of the take-off roll is then:

$$s_{TO,k} = (k - 0.5) \cdot \Delta V \cdot \Delta t = \frac{(2k-1) \cdot s_{TO}}{n_{TO}^2} \tag{3-4d}$$

Example: For a take-off distance s_{TO} = 1600 m and V_{TO} = 75 m/s, this yields n_{TO} = 8 segments with lengths ranging from 25 to 375 meters (see **Figure 3-5**):

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15 Even if engine power settings remain constant along a segment, propulsive force and acceleration can change due to variation of air density with height. However, for the purposes of noise modelling these changes are normally negligible.

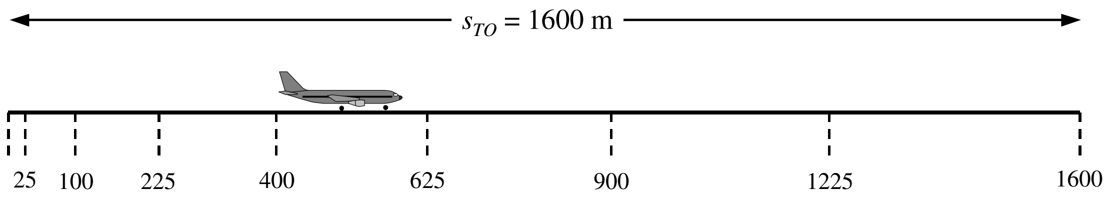

Figure 3-5: Segmentation of a take-off roll (example for 8 segments)

3.7.5 Segmentation of the initial climb segment

3.7.5.1 During the initial climb segment the geometry is changing rapidly particularly with respect to observer locations to the side of the flight track, where *elevation angle* will change rapidly as the aeroplane climbs through this initial segment. Comparisons with very small segment calculations show that a single climb segment results in a poor approximation of noise to the side of the flight track for integrated metrics. Calculation accuracy is improved by sub-segmenting the first lift-off segment. The length of each segment and number is strongly influenced by lateral attenuation. Noting the expression of total lateral attenuation for aeroplanes with fuselage-mounted engines (section 4.6.4), it can be shown that for a limiting change in lateral attenuation of 1.5 dB per sub-segment, that the initial climb segment should be sub-segmented based on the following set of height values:

$$z = \{18.9, 41.5, 68.3, 102.1, 147.5, 214.9, 334.9, 609.6, 1289.6\} \text{ metres}$$

3.7.5.2 The above heights are implemented by identifying which height in the set above is closest to the original segment endpoint. The actual sub-segment heights would then be calculated using:

$$z_i = z\,[z_i / z_N] \quad (i = 1..N) \tag{3-5}$$

where z is the original segment end height, z_i is the i^{th} member of the set of height values and z_N is the closest upper bound to height z. This process results in the lateral attenuation change across each sub-segment remaining constant, producing more accurate contours, but without the expense of using very short segments.

For example:

If the original segment endpoint height is at z = 304.8 m, then from the set of height values, 214.9 < 304.8 < 334.9 and the closest upper bound is to z = 304.8 m is z_7 = 334.9 m. The sub-segment endpoint heights are then computed by:

$$z_i = 304.8\,[z_i / 334.9] \quad (i = 1..N)$$

Thus for i = 1, z_i would be 17.2m and z_2 would be 37.8 m, etc.

3.7.6 Segmentation of airborne segments

3.7.6.1 After the segmented flight path has been derived according to the procedure described in section 3.7.1 and the sub-segmenting described in sections 3.7.4 and 3.7.5 has been applied, further segmentation adjustments may be necessary. These include

- the removal of flight path points which are too close together and
- the insertion of additional points when segments are too long.

3.7.6.2 When adjacent points are within 10 m of each other, and when the associated speeds and thrusts are the same, one of the points should be eliminated.

3.7.6.3 For airborne segments where there is a significant speed change along the segment, this should be subdivided as for the ground roll, i.e.

$$n_{seg} = \mathrm{int}\left(1 + \left|V_2 - V_1\right| / 10\right) \tag{3-6}$$

where V_1 and V_2 are the segment start and end speeds respectively. The corresponding sub-segment parameters are calculated in a similar manner as for the take-off ground roll, using equations 3-4b to 3-4d.

3.7.7 The landing ground roll

3.7.7.1 Although the landing ground roll is essentially a reversal of the take-off ground roll, special account has to be taken of

- *reverse thrust* which is sometimes applied to decelerate the aeroplane and
- aeroplanes leaving the runway after deceleration (aeroplanes that leave the runway

no longer contribute to air noise as noise from taxiing is disregarded).

3.7.7.2 In contrast to the take-off roll distance, which is derived from aeroplane performance parameters, the stop distance s_{stop} (i.e. the distance from touchdown to the point where the aeroplane leaves the runway) is not purely aeroplane specific. Although a minimum stop distance can be estimated from aeroplane mass and performance (and available reverse thrust), the actual stop distance depends also on the location of the taxiways, on the traffic situation, and on airport-specific regulations on the use of reverse thrust.

3.7.7.3 The use of reverse thrust is not a standard procedure - it is only applied if the needed deceleration cannot be achieved by the use of the wheel brakes. (Reverse thrust, due to a rapid change of engine power from idle to reverse settings, often produces a sudden burst of noise.

3.7.7.4 However, most runways are used for departures as well as for landings so that reverse thrust has a very small effect on the noise contours since the total sound energy in the vicinity of the runway is dominated by the noise produced from take-off operations. Reverse thrust contributions to contours may only be significant when runway use is limited to landing operations.

3.7.7.5 Physically, reverse thrust noise is very complex but because of its relatively minor significance to air noise contours it can be modelled simplistically - the rapid change in engine power being taken into account by suitable segmentation.

3.7.7.6 It is clear that modelling the landing ground roll is less straightforward than modelling for take-off roll. The following simplified modelling assumptions are recommended for general use, when no detailed information is available (see **Figure 3-6**):

a) The aeroplane touches down 300 m beyond the landing threshold (which has the co-ordinate $s = 0$ along the approach ground track). The aeroplane is then decelerated over a stop-distance s_{stop} - aeroplane specific values of which are given in the ANP database - from final approach speed V_{final} to 15 m/s. Because of the rapid changes in speed during this segment it should be sub-segmented in the same manner as for the take-off ground roll using equations 3-4a to 3-4d.

b) The engine power changes from final approach power at touchdown to a reverse thrust power setting P_{rev} over a distance $0.1{\cdot}s_{stop}$, then decreases to 10 % of the maximum available power over the remaining 90 percent of the stop distance. Up to the end of the runway (at $s = -s_{RWY}$) aeroplane speed remains constant.

c) NPD curves for reverse thrust are not at present included in the ANP database, and it is therefore necessary to rely on the conventional curves for modelling this effect. Typically the reverse thrust power P_{rev} is around 40% of the full power setting for narrow-body aeroplanes and 10% of the full power setting for wide-body aeroplanes. This is recommended when no operational information is available. However, at a given power setting, reverse thrust tends to generate significantly more noise than forward thrust and an increment ΔL should be applied to the NPD-derived event level, increasing from zero to a value ΔL_{rev} (5dB is recommended provisionally[16]) along $0.1{\cdot}s_{stop}$ and then falling linearly to zero along the remainder of the stop distance.

[16] This is based on a recommendation made in ECAC Document 29 3rd Edition but is still considered provisional pending the acquisition of further corroborative experimental data.

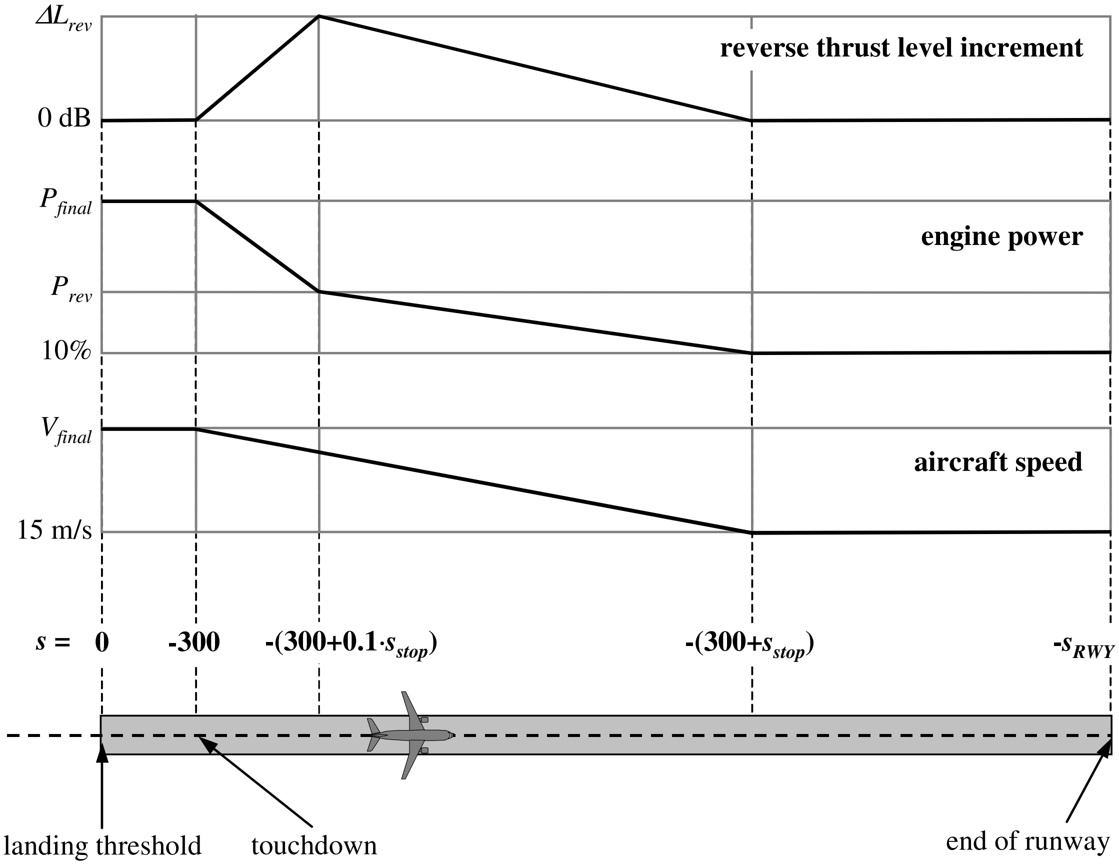

Figure 3-6: Modelling of landing ground roll

Chapter 4

NOISE CALCULATION FOR A SINGLE EVENT

4.1 INTRODUCTION

4.1.1 The core of the modelling process, described here in full, is the calculation of the event noise level from the flight path information described in **Chapter 3**.

4.2 SINGLE EVENT METRICS

4.2.1 The sound generated by an aeroplane movement at the observer location is expressed as a ‘single event sound (or noise) level’, which is an indicator of its impact on people. The received sound is measured on a decibel scale [refs. 14, 15].

4.2.2 The metrics most commonly used to encapsulate entire aeroplane events are ‘single event sound (or noise) exposure levels’, L_{AE}, which account for all (or most of) the sound energy in the events. Making provisions for the time integration that this involves gives rise to the main complexities of segmentation (or simulation) modelling. An alternative metric is L_{Amax}, which is the maximum instantaneous level occurring during the event, and is simpler to model. In the future, practical models can be expected to embody both L_{Amax} and L_{AE}. Either metric can be measured on different scales of noise and in this document only A-weighted sound level is considered. This applies a frequency weighting (or filter) to mimic a characteristic of human hearing. Symbolically, the scale is usually indicated by extending the metric suffix, i.e. L_{AE}, L_{Amax}. **Appendix A** provides a fuller description of the various noise metrics in use in ICAO member states.

4.2.3 The single event sound (or noise) exposure level is expressed as

$$L_E = 10 \cdot \log\left(\frac{1}{t_0}\int_{t_1}^{t_2} 10^{L(t)/10}\,dt\right) \qquad (4\text{-}1)$$

where t_0 denotes a reference time. The integration interval $[t_1,t_2]$ is chosen to ensure that (nearly) all significant sound in the event is encompassed. Very often, the limits t_1 and t_2 are chosen to span the period for which the level $L(t)$ is within 10 dB of L_{max}. This period is known as the “10-dB down” time. Sound (noise) exposure levels tabulated in the ANP database are 10-dB down values[17].

4.2.4 For aeroplane noise contour modelling, the main application of equation 4-1 is the standard metric Sound Exposure Level L_{AE} (acronym SEL) [refs. 14, 15]:

$$L_{AE} = 10 \cdot \log\left(\frac{1}{t_0}\int_{t_1}^{t_2} 10^{L_A(t)/10}\,dt\right) \text{ with } t_0 = 1\,\text{second} \qquad (4\text{-}2)$$

4.2.5 The exposure level equations above can be used to determine event levels when the entire time history of $L(t)$ is known. Within the recommended noise modelling methodology such time histories are not defined; event exposure levels are calculated by summing segment values, partial event levels each of which defines the contribution from a single, finite segment of the flight path.

4.3 DETERMINATION OF EVENT LEVELS FROM NPD-DATA

4.3.1 The principal source of aeroplane noise data is the international Aircraft Noise and Performance (ANP) database which is described in **Appendix H**. This tabulates L_{max} and L_E as functions of propagation distance d - for specific aeroplane types, variants, flight configurations (approach, departure, flap settings), and power settings P. They relate to steady flight at specific reference speeds V_{ref} along a notionally infinite, straight flight path[18].

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[17] 10dB-down L_E may be up to 0.5 dB lower than L_E evaluated over a longer duration. However, except at short slant distances where event levels are high, extraneous ambient noise often makes longer measurement intervals impractical and 10-dB down values are the norm. As studies of the effects of noise (used to ‘calibrate’ the noise contours) also tend to rely on 10-dB down values, the ANP tabulations are considered to be entirely appropriate.

[18] Although the notion of an infinitely long flight path is important to the definition of event

4.3.2 In a single look-up with input values P and d, the output values required are the *baseline levels* $L_{max}(P,d)$ and/or $L_{E\infty}(P,d)$. Unless values happen to be tabulated for P and/or d exactly, it will generally be necessary to estimate the required event noise level(s) by interpolation on the ANP database. A linear interpolation is used between tabulated power-settings, but a logarithmic interpolation is used between tabulated distances (see **Figure 4-1**). If P_i and P_{i+1} are engine power values for which noise level versus distance data are tabulated, the noise level $L(P)$ at a given distance for intermediate power P, between P_i and P_{i+1}, is given by:

$$L(P) = L(P_i) + \frac{L(P_{i+1}) - L(P_i)}{P_{i+1} - P_i} \cdot (P - P_i) \qquad (4\text{-}3)$$

4.3.4 By using equations (4-3) and (4-4), a noise level $L(P,d)$ can be obtained for any power setting P and any distance d that is within the envelope of the NPD data base.

4.3.5 For distances d that lie outside the NPD envelope, equation 4-4 is also used to extrapolate from the last two values, i.e. inwards from $L(d_1)$ and $L(d_2)$ or outwards from $L(d_{I-1})$ and $L(d_I)$ where I is the total number of NPD points on the curve. Thus

Inwards:

$$L(d) = L(d_2) + \frac{L(d_1) - L(d_2)}{\log d_2 - \log d_1} \cdot (\log d_2 - \log d) \qquad (4\text{-}5a)$$

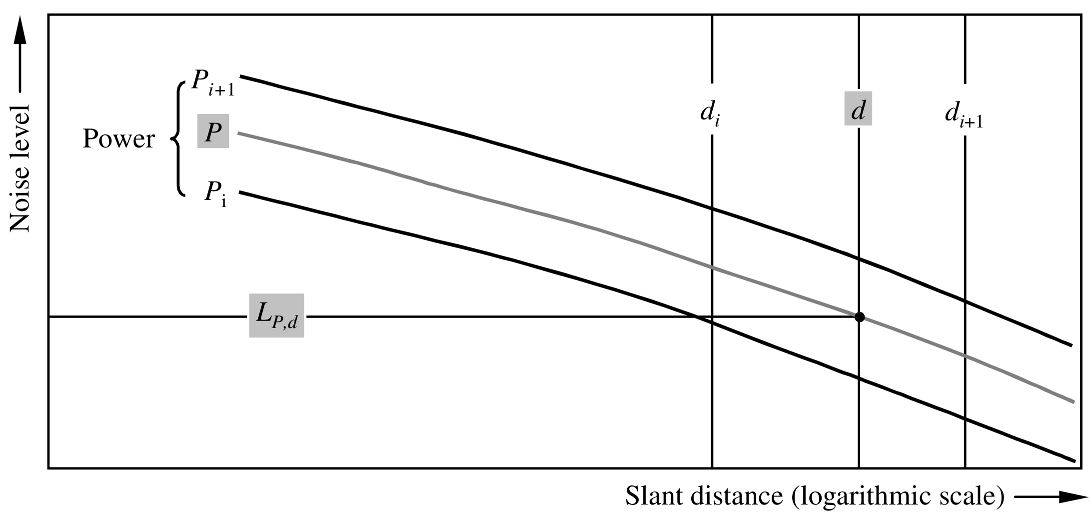

Figure 4-1: Interpolation in noise-power-distance curves

4.3.3 If, at any power setting, d_i and d_{i+1} are distances for which noise data are tabulated, the noise level $L(d)$ for an intermediate distance d, between d_i and d_{i+1} is given by

$$L(d) = L(d_i) + \frac{L(d_{i+1}) - L(d_i)}{\log d_{i+1} - \lg d_i} \cdot (\log d - \log d_i) \qquad (4\text{-}4)$$

Outwards:

$$L(d) = L(d_{I-1}) - \frac{L(d_{I-1}) - L(d_I)}{\log d_I - \log d_{I-1}} \cdot (\log d - \log d_{I-1}) \qquad (4\text{-}5b)$$

4.3.6 Since, at short distances (i.e. low values of d), noise levels increase very rapidly with decreasing propagation distance, it is recommended that a lower limit of 30 m be imposed on d, i.e. $d = \max(d, 30\text{ m})$.

4.4 GENERAL EXPRESSIONS

4.4.1 Segment event level L_{seg}

4.4.1.1 The segment values are determined by applying adjustments to the baseline (infinite path) values read from the NPD data. The maximum

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sound exposure level L_E, it has less relevance in the case of event maximum level L_{max} which is governed by the noise emitted by the aircraft when at a particular position at or near its closest point of approach to the observer. For modelling purposes the NPD distance parameter is taken to be the minimum distance between the observer and segment.

noise level from one flight path segment $L_{max,seg}$ can be expressed in general as

$$L_{max,seg} = L_{max}(P,d) + \Delta_I(\varphi) - \Lambda(\beta,\ell) \qquad (4\text{-}6a)$$

and the contribution from one flight path segment to L_E as

$$L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\varphi) - \Lambda(\beta,\ell) + \Delta_F \qquad (4\text{-}6b)$$

4.4.1.2 The 'correction terms' in equations 4-6 - which are described in detail in **Section 4.5** - account for the following effects:

Δ_V — *Duration correction:* the NPD data relate to a reference flight speed. This adjusts exposure levels to non-reference speeds. (It is not applied to $L_{max,seg}$.)

$\Delta_I(\varphi)$ — *Installation effect:* describes a variation in *lateral directivity* due to shielding, refraction and reflection caused by the airframe, engines and surrounding flow fields.

$\Lambda(\beta,\ell)$ — *Lateral attenuation:* significant for sound propagating at low angles to the ground, this accounts for the interaction between direct and reflected sound waves (ground effect) and for the effects of atmospheric non-uniformities (primarily caused by the ground) that refract sound waves as they travel towards the observer to the side of the flight path.

Δ_F — *Segment correction:* accounts for the finite length of the segment which obviously contributes less noise exposure than an infinite one. It is only applied to exposure metrics.

4.4.1.3 If the segment is part of the take-off ground roll and the observer is located behind the start of roll, special steps are taken to represent the pronounced directionality of jet engine noise that is observed behind an aeroplane about to take-off and a modified form of the noise fraction is also applied. These are described in **Section 4.5.6**. **Sections 4.4 to 4.6** describe the calculation of segment noise levels.

4.4.2 Event noise level L of an aeroplane movement

4.4.2.1 <u>Maximum level</u> L_{max} is simply the greatest of the segment values $L_{max,seg}$ (see **Equation 4-6a**)

$$L_{max} = \max(L_{max,seg}) \qquad (4\text{-}7)$$

where each segment value is determined from the aeroplane NPD data for power *P* and distance *d*. These parameters and the modifier terms $\Delta_I(\varphi)$ and $\Lambda(\beta,\ell)$ are explained in **Section 4.6**.

4.4.2.2 <u>Exposure level</u> L_E is calculated as the decibel sum of the contributions $L_{E,seg}$ from each noise-significant segment of its flight path; i.e.

$$L_E = 10 \cdot \lg\left(\sum 10^{L_{E,seg}/10}\right) \qquad (4\text{-}8)$$

4.4.2.3 The summation proceeds step by step through the flight path segments.

4.4.2.4 The determination of the segment noise levels $L_{max,seg}$ and $L_{E,seg}$ are described in **Sections 4.5 and 4.6**.

4.5 FLIGHT PATH SEGMENT PARAMETERS

4.5.1 The power *P*, and distance *d*, for which the baseline levels $L_{max,seg}(P,d)$ and $L_{E\infty}(P,d)$ are interpolated from the NPD tables, are determined from geometric and operational parameters that define the segment. This process is explained below.

4.5.2 Geometric parameters

4.5.2 **Figures 4-2a to 4-2c** show the source-receiver geometries when the observer **O** is (a) behind, (b) alongside and (c) ahead of the segment $\mathbf{S_1S_2}$ where the flight direction is from $\mathbf{S_1}$ to $\mathbf{S_2}$. In these diagrams

O	is the observer location
$\mathbf{S_1}$, $\mathbf{S_2}$	are the start and end of the segment
$\mathbf{S_p}$	is the point of perpendicular closest approach to the observer on the segment or its extension
d_1, d_2	are the distances between start, end of segment and observer
d_s	is the shortest distance between observer and segment
d_p	is the perpendicular distance between observer and extended segment *(minimum slant range)*
λ	is the length of flight path segment
q	is the distance from $\mathbf{S_1}$ to $\mathbf{S_p}$ (negative if the observer position is behind the segment)

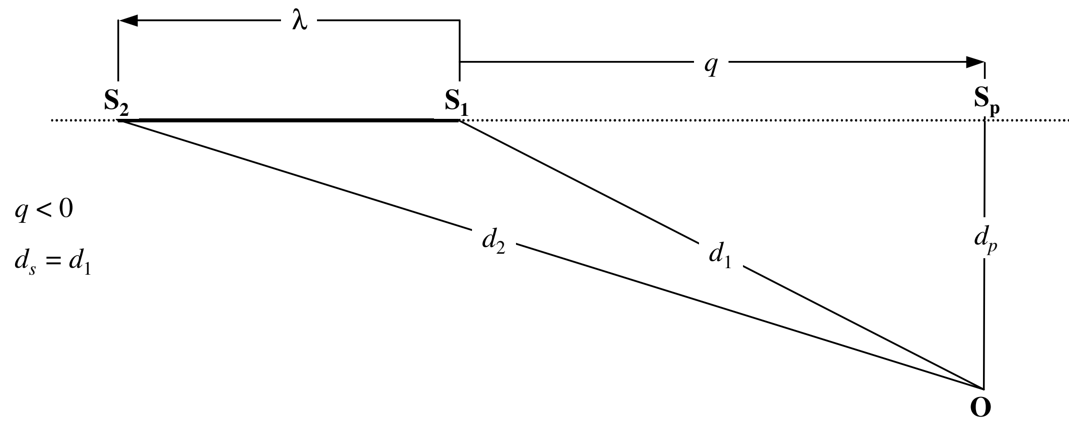

Figure 4-2a: Flight path segment geometry for observer behind segment

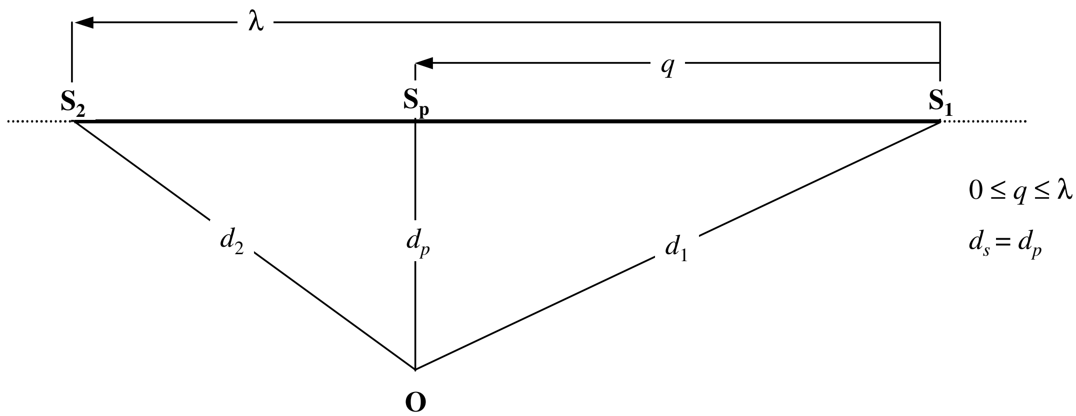

Figure 4-2b: Flight path segment geometry for observer alongside segment

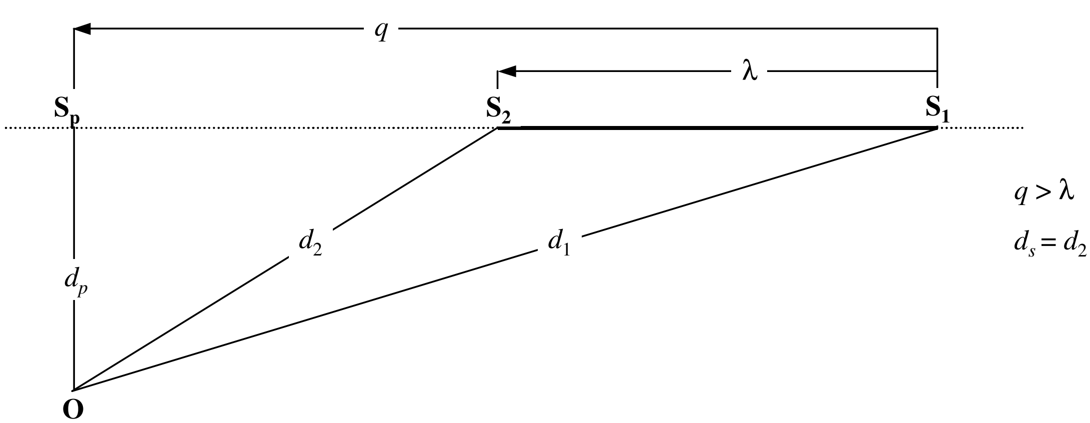

Figure 4-2c: Flight path segment geometry for observer ahead of segment

4.5.2.2 In **Figures 4-2a through 4-2c**, the flight path segment is represented by a bold, solid line. The dotted line represents the *flight path extension* which stretches to infinity in both directions. For airborne segments, when the event metric is an exposure level L_E, the NPD distance parameter d is the distance d_p between $\mathbf{S_p}$ and the observer, called the *minimum slant range* (i.e. the perpendicular distance from the observer to the segment or its extension, in other words to the (hypothetical) infinite flight path of which the segment is considered to be part).

4.5.2.3 <u>However, for exposure level metrics where observer locations are behind the ground segments during the take-off roll and locations ahead of ground segments during the landing roll, the NPD distance parameter d becomes the distance d_s, the shortest distance from the observer to the segment (i.e. the same as for maximum level metrics).</u>

4.5.2.4 For maximum level metrics, the NPD distance parameter d is d_s, the shortest distance from the observer to the segment.

4.5.3 Segment power P

4.5.3.1 The tabulated NPD data describe the noise of an aeroplane in steady straight flight on an infinite flight path, i.e. at constant engine power P. The recommended methodology breaks actual flight paths, along which speed and direction vary, into a number of finite segments, each of which is then taken to be part of a uniform, infinite flight path for which the NPD data are valid. However, the methodology provides for changes of power along the length of a segment; it is taken to change linearly with distance from P_1 at its start to P_2 at its end. It is therefore necessary to define an equivalent steady segment value P. This is taken to be the value at the point on the segment that is closest to the observer. If the observer is alongside the segment (**Figure 4-2b**) it is obtained by interpolation as given by equation 3-3d between the end values, i.e.

$$P = \sqrt{P_1^2 + \frac{q}{\lambda}\cdot\left(P_2^2 - P_1^2\right)} \qquad (4\text{-}9)$$

4.5.3.2 If the observer is behind or ahead of the segment, it is that at the nearest end point, P_1 or P_2.

4.6 SEGMENT EVENT LEVEL CORRECTION TERMS

4.6.1 The NPD data define noise event levels as a function of distance perpendicularly beneath an idealised straight level path of infinite length along which the aeroplane flies with steady power at a fixed reference speed[19]. The event level interpolated from the NPD table for a specific power setting and slant distance is thus described as a *baseline level*. It applies to an infinite flight path and has to be corrected to account for the effects of non-reference speed, engine installation effects (lateral directivity), lateral attenuation, finite segment length and longitudinal directivity behind start of roll on take-off - see equations 4-6.

4.6.2 The duration correction Δ_V (Exposure levels L_E only)

4.6.2.1 This correction[20] accounts for a change in exposure levels if the actual segment groundspeed is different to the aeroplane reference speed V_{ref} to which the basic NPD-data relate. Like engine power, speed varies along the segment (groundspeed varies from V_1 to V_2) and it is necessary to define an equivalent segment speed V_{seg} remembering that the segment is inclined to the ground; i.e.

$$V_{seg} = V/\cos\gamma \qquad (4\text{-}10a)$$

where here V is an equivalent segment groundspeed and

$$\gamma = \tan^{-1}\left(\frac{z_2 - z_1}{s_2 - s_1}\right) \qquad (4\text{-}10b)$$

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[19] NPD specifications require that the data be based on measurements of steady *straight* flight, not necessarily level; to create the necessary flight conditions, the test aeroplane flight path can be inclined to the horizontal. However, as will be seen, inclined paths lead to computational difficulties and, when using the data for modelling, it is convenient to visualise the source paths as being both straight and level.

[20] This is known as the *duration correction* because it makes allowance for the effects of aeroplane *speed* on the duration of the sound event - implementing the simple assumption that, other things being equal, duration, and thus received event sound energy, is inversely proportional to source velocity.

4.6.2.2 For airborne segments, V is taken to be the groundspeed at the closest point of approach **S** - interpolated between the segment end-point values assuming it varies linearly with time; i.e. if the observer is alongside the segment:

$$V = \sqrt{V_1^2 + \frac{q}{\lambda} \cdot \left(V_2^2 - V_1^2\right)} \qquad \text{(4-10c)}$$

4.6.2.3 If the observer is behind or ahead of the segment, it is the speed at the nearest end point, V_1 or V_2.

4.6.2.4 For runway segments (parts of the take-off or landing ground rolls for which $\gamma = 0$) V_{seg} is taken to be simply the average of the segment start and end speeds; i.e.

$$V_{seg} = (V_1 + V_2)/2 \qquad \text{(4-10d)}$$

4.6.2.5 In either case the additive duration correction is then

$$\Delta_V = 10 \cdot \log(V_{ref} / V_{seg}) \qquad \text{(4-11)}$$

4.6.3 Sound propagation geometry

Figure 4-3 shows the basic geometry in the plane normal to the aeroplane flight path. The ground line is the intersection of the normal plane and the level ground plane. (If the flight path is level the ground line is an end view of the ground plane.) The parameters involved are:

a) the aeroplane bank angle ε measured counter-clockwise about its roll axis (i.e. starboard wing up). It is therefore positive for left turns and negative for right turns.

b) the *elevation angle* β (between 0 and 90°) between the direct sound propagation path and the level ground line[21]. This determines, together with the flight path inclination and the lateral displacement ℓ of the observer from the ground track, the lateral attenuation. This is explained in **Sections 4.6.4 and 4.6.5**.

c) the *depression angle* φ between the wing plane and the propagation path. This determines the engine installation effects. With respect to the convention for the bank angle $\varphi = \beta \pm \varepsilon$, with the sign positive for observers to starboard (right) and negative for observers to port (left).

4.6.4 Engine installation correction Δ_I

4.6.4.1 An aeroplane in flight is a complex sound source. Not only are the engine (and airframe) sources complex in origin, but the airframe configuration, particularly the location of the engines, influences the noise radiation patterns through the processes of reflection, refraction and scattering by the solid surfaces and aerodynamic flow fields. This results in a non-uniform directionality of sound radiated laterally about the roll axis of the aeroplane, referred to here as *lateral directivity*.

4.6.4.2 There are significant differences in lateral directivity between aeroplanes with fuselage-mounted and underwing-mounted engines

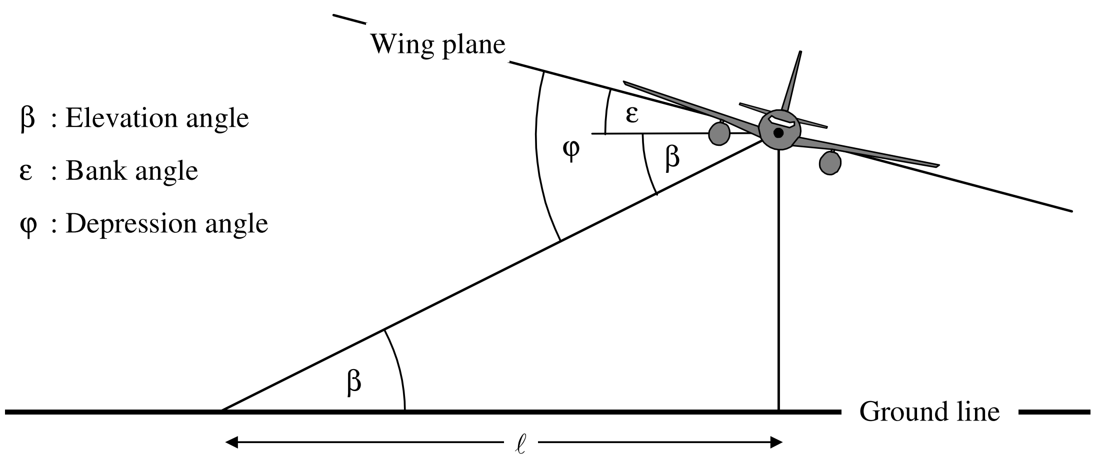

Figure 4-3: Aircraft-observer angles in plane normal to flight path

sections 2.4 and 3.3). In the event that, due to ground elevation, the receiver point is above the aircraft, elevation angle β is set equal to zero.

and these are allowed for in the following expression:

$$\Delta_I(\varphi) = 10 \cdot \log\left[\frac{\left(a \cdot \cos^2 \varphi + \sin^2 \varphi\right)^b}{\left(c \cdot \sin^2 2\varphi + \cos^2 2\varphi\right)}\right] \text{ dB} \tag{4-12}$$

where $\Delta_I(\varphi)$ is the correction, in dB, at depression angle φ (see **Figure 4-3**) and

a = 0.00384, b = 0.0621, c = 0.8786 for wing-mounted engines and

a = 0.1225, b = 0.3290, c = 1 for fuselage-mounted engines.

4.6.4.3 For propeller aeroplanes directivity variations are negligible and for these it may be assumed that

$$\Delta_I(\varphi) = 0 \tag{4-13}$$

4.6.4.4 **Figure 4-4** shows the variation of $\Delta_I(\varphi)$ about the aeroplane roll axis for the three engine installations. These empirical relationships have been derived by the SAE from experimental measurements made mainly beneath the wing [ref. 8]. Until above-wing data have been analysed it is recommended that, for negative φ, $\Delta_I(\varphi) = \Delta_I(0)$ for all installations.

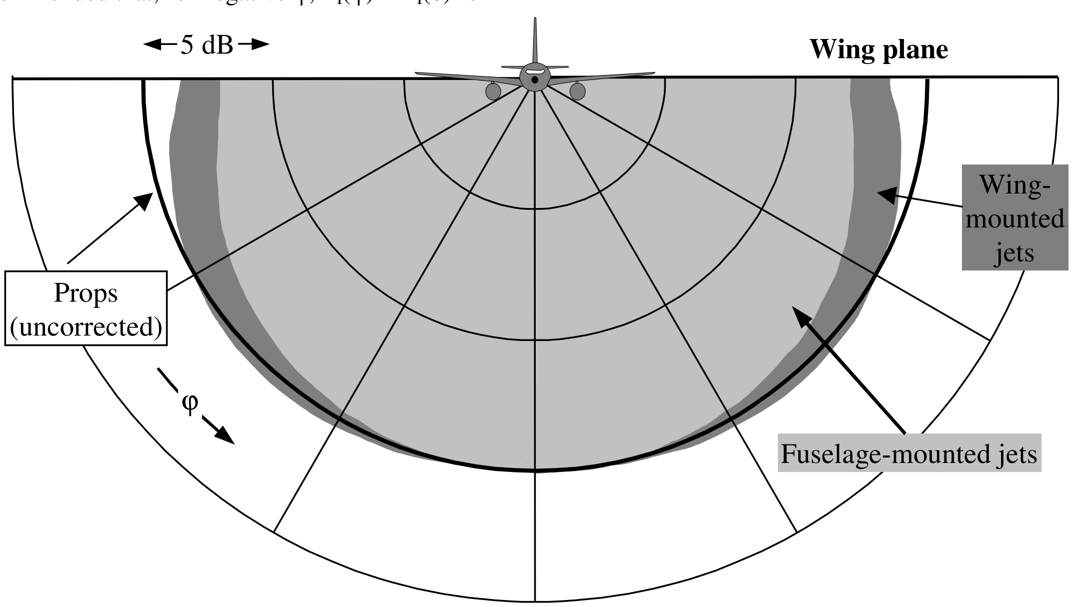

Figure 4-4: Lateral directivity of installation effects

4.6.4.5 It is assumed that $\Delta_I(\varphi)$ is two-dimensional; i.e. it does not depend on any other parameter - and in particular that it does not vary with the longitudinal distance of the observer from the aeroplane. This is for modelling convenience until there is a better understanding of the mechanisms; in reality, installation effects are bound to be substantially three-dimensional. Despite that, a two-dimensional model is justified by the fact that event levels tend to be dominated by noise radiated sideways from the nearest segment.

4.6.5 Lateral attenuation $\Lambda(\beta,\ell)$ (infinite flight path)

4.6.5.1 Tabulated NPD event levels relate to steady level flight and are generally based on measurements made 1.2m over soft level ground beneath the aeroplane; the distance parameter is effectively height above the surface. Any effect of the surface on event noise levels beneath the aeroplane, that might cause the tabulated levels to differ from free-field values[22], is assumed to be inherent in the data (i.e. in the shape of the level vs. distance relationships).

4.6.5.2 To the side of the flight path, the distance parameter is the minimum slant distance – the length of the normal from the receiver to the flight path. At any lateral position the noise level will generally be less than at the same distance immediately below the aeroplane. Apart from

[22] A ‘free-field’ level is that which would be observed if the ground surface were not there.

lateral directivity or 'installation effects' described in **Section 4.6.4** this is due to an excess *lateral attenuation* which causes the sound level to fall more rapidly with distance than indicated by the NPD curves. A previous, widely used method for modelling lateral propagation of aeroplane noise was developed by the Society of Automotive Engineers (SAE) in AIR-1751 [ref. 9] and the algorithms described below are based on improvements SAE now recommends AIR-5662 [ref. 8]. Lateral attenuation is a reflection effect, due to interference between directly radiated sound and that which reflects from the surface. It depends on the nature of the surface and can cause significant reductions in observed sound levels at low elevation angles. It is also very strongly affected by sound refraction, steady and unsteady, caused by wind and temperature gradients and turbulence which are themselves attributable to the presence of the surface[23]. The mechanism of surface reflection is well understood and, for uniform atmospheric and surface conditions, it can be described theoretically with some precision. However, atmospheric and surface non-uniformities - which are not amenable to simple theoretical analysis - have a profound effect on the reflection effect, tending to 'spread' it to higher elevation angles; thus the theory is of limited applicability. SAE work to develop a better understanding of surface effects is continuing and this is expected to lead to better models. Until these are developed, the following methodology, described in AIR-5662, is recommended for calculating lateral attenuation. It is confined to the case of sound propagation over soft level ground which is appropriate for the great majority of civil airports. Adjustments to account for the effects of a hard ground surface (or, acoustically equivalent, water) are still under development.

4.6.5.3 The methodology is built on the substantial body of experimental data on sound propagation from aeroplanes with fuselage-mounted engines in straight (non-turning), steady, level flight reported originally in AIR-1751. Making the assumption that, for level flight, air-to-ground attenuation depends on (i) elevation angle β measured in the vertical plane and (ii) lateral displacement from the aeroplane ground track ℓ, the data were analysed to obtain an empirical function for the *total* lateral adjustment $\Lambda_T(\beta,\ell)$ (= lateral event level minus the level at the same distance beneath the aeroplane).

[23] The wind and temperature gradients and turbulence depend in part upon the roughness and heat transfer characteristics of the surface.

4.6.5.4 As the term $\Lambda_T(\beta,\ell)$ accounted for lateral directivity as well as lateral attenuation, the latter can be extracted by subtraction. Describing lateral directivity by equation 4-12, with the fuselage-mount coefficients and with φ replaced by β (appropriate to non-turning flight), the lateral attenuation becomes:

$$\Lambda(\beta,\ell) = \Lambda_T(\beta,\ell) - \Delta_I(\beta) \qquad (4\text{-}14)$$

where β and ℓ are measured as depicted in **Figure 4-3** in a plane normal to the infinite flight path which, for level flight, is also vertical.

4.6.5.5 Although $\Lambda(\beta,\ell)$ could be calculated directly using equation 4-14 with $\Lambda_T(\beta,\ell)$ taken from AIR-1751, a more efficient relationship is recommended. This is the following empirical approximation adapted from AIR-5662:

$$\Lambda(\beta,\ell) = \Gamma(\ell)\cdot\Lambda(\beta) \qquad (4\text{-}15)$$

where $\Gamma(\ell)$ is a distance factor given by

$$\Gamma(\ell) = 1.089\cdot\left[1-\exp(-0.00274\,\ell)\right] \quad \text{for} \quad 0 \le \ell \le 914 \text{ m} \qquad (4\text{-}16a)$$

$$\Gamma(\ell) = 1 \quad \text{for} \quad \ell > 914 \text{ m} \qquad (4\text{-}16b)$$

and $\Lambda(\beta)$ is long-range air-to-ground lateral attenuation given by

$$\Lambda(\beta) = 1.137 - 0.0229\beta + 9.72\cdot\exp(-0.142\beta) \quad \text{for} \quad 0° \le \beta \le 50° \qquad (4\text{-}16c)$$

$$\Lambda(\beta) = 0 \quad \text{for } 50° \le \beta \le 90° \qquad (4\text{-}16d)$$

4.6.5.6 The expression for lateral attenuation $\Lambda(\beta,\ell)$, equation 4.15, which is assumed to hold good for all aeroplanes, propeller aeroplanes as well as fuselage-mount and wing-mount jets, is shown graphically in **Figure 4-5**.

4.6.5.7 Under certain circumstances (with terrain), it is possible for β to be less than zero. In such cases it is recommended that $\Lambda(\beta) = 10.57$.

4.6.6 Finite Segment Lateral Attenuation

4.6.6.1 Equations 4.16 describe the lateral attenuation $\Lambda(\beta,\ell)$ of sound arriving at the observer from an aeroplane in steady flight along an infinite, level flight path. When applying them to finite path segments that are not level, the attenuation has to be calculated for an *equivalent* level path - as the closest point on a simple extension of the inclined

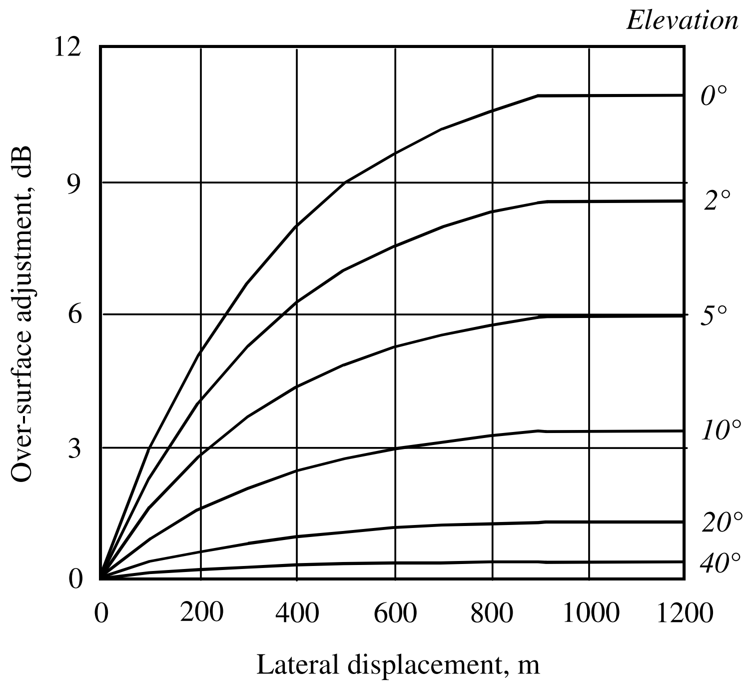

Figure 4-5: Variation of lateral attenuation Λ(β, ℓ) with elevation angle and distance

segment (that passes through the ground surface at some point) generally does not yield an appropriate elevation angle β.

4.6.6.2 The determination of lateral attenuation for finite segments differs markedly for L_{max} and L_E metrics. Segment maximum levels L_{max} are determined from NPD data as a function of propagation distance d from the nearest point on the segment; no corrections are required to account for the dimensions of the segment. Likewise, lateral attenuation of L_{max} is assumed to depend only on the elevation angle of, and ground distance to, the same point. Thus only the coordinates of that point are required. But for L_E, the process is more complicated.

4.6.6.3 The baseline event level $L_E(P,d)$ that is determined from the NPD data, even though for finite segment parameters, applies nevertheless to an infinite flight path. The event exposure level from a segment, $L_{E,seg}$, is of course less than the baseline level - by the amount of the finite segment correction defined later. That correction, a function of the geometry of triangles OS_1S_2 in **Figure 4-2**, defines what proportion of the total infinite path noise energy received at O comes from the segment; the same correction applies, whether or not there is any lateral attenuation. But any lateral attenuation must be calculated for the infinite flight path, i.e. as a function of its displacement and elevation, not those of the finite segment.

4.6.6.4 Adding the corrections Δ_V and Δ_I, and subtracting lateral attenuation $\Lambda(\beta,\ell)$ from the NPD *baseline level* gives the adjusted event noise level for equivalent steady *level* flight on an adjacent, infinite straight path. But the actual flight path segments being modelled, those that affect the noise contours, are rarely level; aeroplanes are usually climbing or descending.

4.6.6.5 **Figure 4-6** illustrates a departure segment $\mathbf{S_1S_2}$ - the aeroplane is climbing at an angle γ - but the considerations remain very similar for an arrival. The remainder of the 'real' flight path is not shown; suffice it to state that $\mathbf{S_1S_2}$ represents just a part of the whole path (which in general will be curved). In this case, the observer **O** is alongside, and to the left of, the segment. The aeroplane is banked (anti-clockwise about the flight path) at an angle ε to the lateral horizontal axis. The depression angle φ from the wing plane, of which the installation effect Δ_I is a function (Equation 4-14), lies in the plane normal to the flight path in which ε is defined. Thus $\varphi = \beta - \varepsilon$ where $\beta = \tan^{-1}(h/\ell)$ and ℓ is the perpendicular distance **OR** from the observer to the ground track; i.e. the lateral displacement of the observer[24]. The aeroplane's closest point of approach to the

[24] For an observer located on the right side to the segment φ would become $\beta + \varepsilon$ (see section 4.5.2).

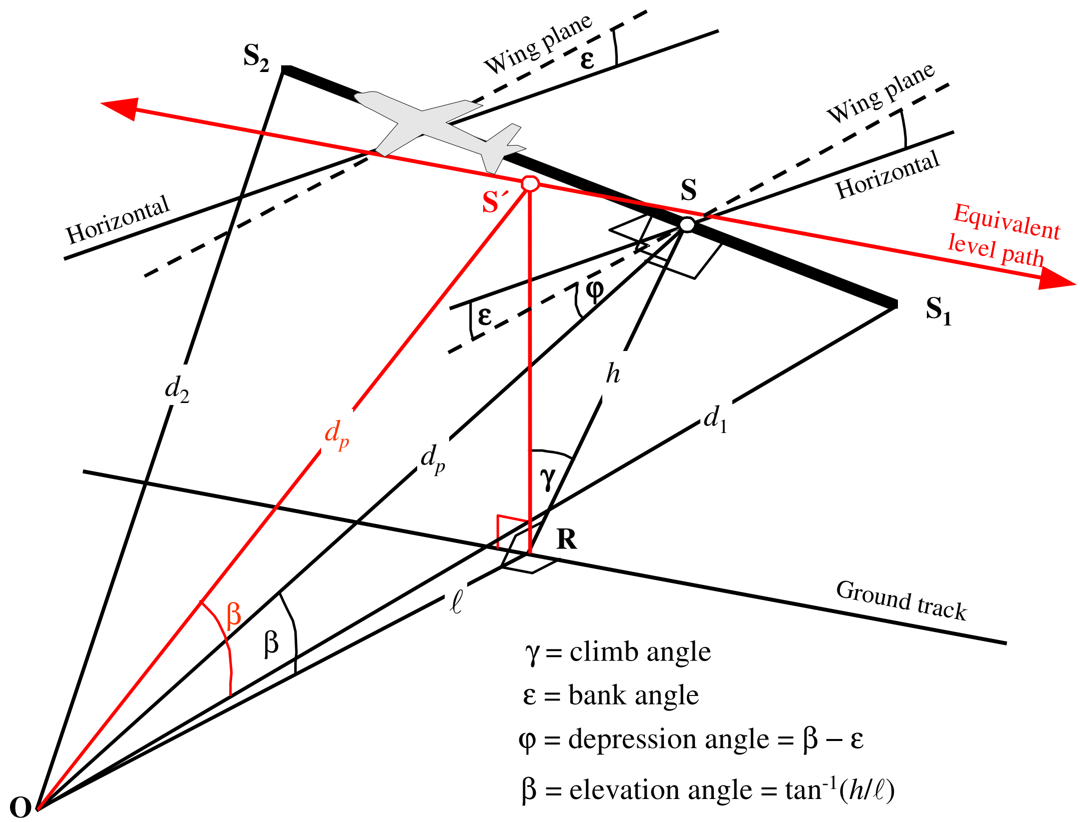

Figure 4-6: Observer alongside segment

observer, **S**, is defined by the perpendicular **OS**, of length (slant distance) d_p. The triangle $\mathbf{OS_1S_2}$ accords with **Figure 4-2b**, the geometry for calculating the segment correction Δ_F.

4.6.6.6 To calculate the lateral attenuation using equation 4.15 (where β is measured in a vertical plane), an *equivalent level flight path* is defined in the vertical plane through $\mathbf{S_1S_2}$ and with the same perpendicular slant distance d_p from the observer. This is visualised by rotating the triangle **ORS**, and its attached flight path about **OR** (see **Figure 4-6**) through angle γ thus forming the triangle **ORS´**. The elevation angle of this equivalent level path (now in a vertical plane) is $\beta = \tan^{-1}(h/\ell)$ (ℓ remains unchanged). In this case, observer alongside, the lateral attenuation $\Lambda(\beta,\ell)$ is the same for L_E and L_{max} metrics.

4.6.6.7 **Figure 4.7** illustrates the situation when the observer point **O** lies *behind the finite segment*, not alongside. Here the segment is observed as a more distant part of an infinite path; a perpendicular can only be drawn to point $\mathbf{S_p}$ on its extension. The triangle $\mathbf{OS_1S_2}$ accords with **Figure 4-2a** which defines the segment correction Δ_F. But in this case the parameters for lateral directivity and attenuation are less obvious.

4.6.6.8 Remembering that, as conceived for modelling purposes, lateral directivity (installation effect) is two-dimensional, the defining depression angle φ is still measured laterally from the aeroplane wing plane. (The baseline event level is still that generated by the aeroplane traversing the infinite flight path represented by the extended segment.) Thus the depression angle is determined at the closest point of approach, i.e. $\varphi = \beta_p - \varepsilon$ where β_p is angle $\mathbf{S_pOC}$.

4.6.6.9 For maximum level metrics, the NPD distance parameter is taken as the shortest distance to the segment, i.e. $d = d_1$. For exposure level metrics, it is the shortest distance d_p from **O** to $\mathbf{S_p}$ on the extended flight path; i.e. the level interpolated from the NPD table is $L_{E\infty}(P_1, d_p)$.

4.6.6.10 The geometrical parameters for lateral attenuation also differ for maximum and exposure level calculations. For *maximum level* metrics the adjustment $\Lambda(\beta,\ell)$ is given by equation 4.15 with $\beta = \beta_1 = \sin^{-1}(z_1 / d_1)$ and $\ell = \mathbf{OC_1} = \sqrt{d_1^2 - z_1^2}$ where β_1 and d_1 are defined by the triangle $\mathbf{OC_1S_1}$ in the vertical plane through **O** and $\mathbf{S_1}$.

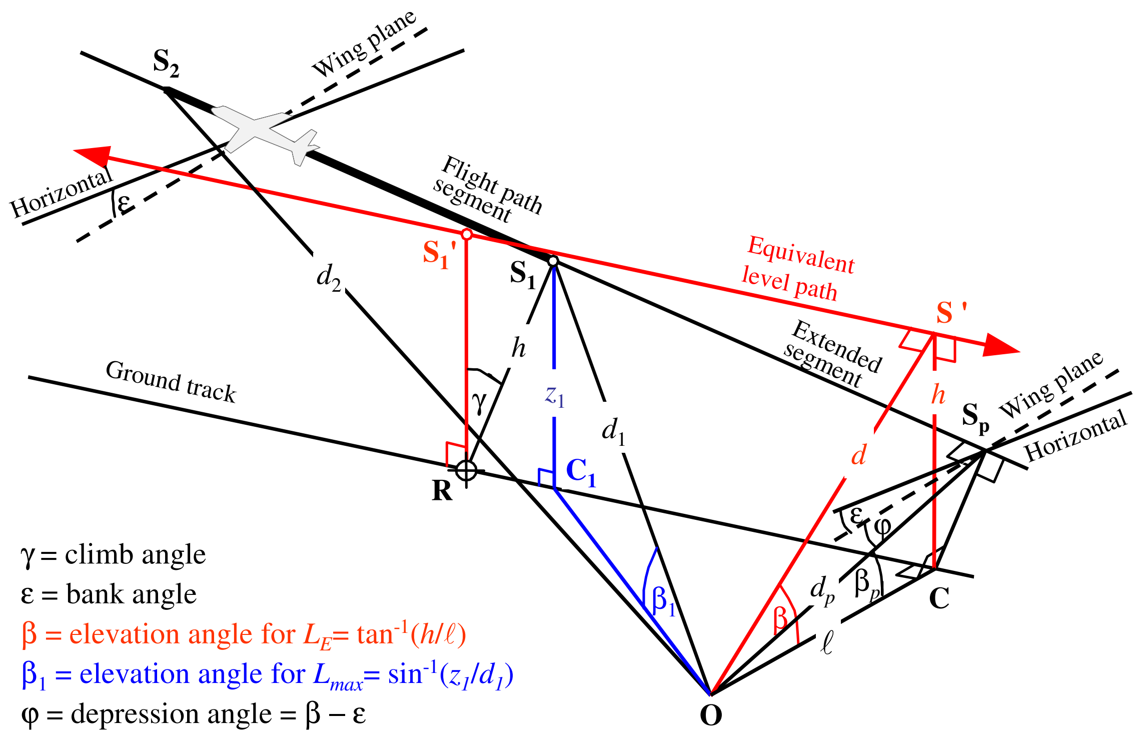

Figure 4-7: Observer behind segment

4.6.6.11 When calculating the lateral attenuation for airborne segments only and *exposure level* metrics, ℓ remains the shortest lateral displacement from the segment extension (**OC**). However, to define an appropriate value of β it is again necessary to visualise an (infinite) *equivalent level flight path* of which the segment can be considered part. This is drawn through **S_1'**, height *h* above the surface, where h is equal to the length of **RS_1** the perpendicular from the ground track to the segment. This is equivalent to rotating the actual extended flight path through angle γ about point **R** (see **Figure 4-7**). Insofar as **R** is on the perpendicular to **S_1**, the point on the segment that is closest to **O**, the construction of the equivalent level path is the same as when **O** is alongside the segment.

4.6.6.12 The closest point of approach of the equivalent level path to the observer **O** is at **S´**, slant distance *d*, so that the triangle **OCS´** so formed in the vertical plane then defines the elevation angle $\beta = \cos^{-1}(\ell / d)$. Although this transformation might seem rather convoluted, it should be noted that the basic source geometry (defined by d_1, d_2 and φ) remains untouched, the sound travelling from the segment *towards* the observer is simply what it would be if the entire flight along the infinitely extended inclined segment (of which for modelling purposes the segment forms part) were at constant speed *V* (Equation 4-13b) and power P_1. The lateral attenuation of sound from the segment *received* by the observer, on the other hand, is related not to β_p, the elevation angle of the extended path, but to β, that of the equivalent level path.

4.6.6.13 The case of an observer ahead of the segment is not described separately; it is evident that this is essentially the same as the case of the observer behind.

4.6.6.14 <u>However, for exposure level metrics where observer locations are behind ground segments during the take-off roll and locations ahead of ground segments during the landing roll, the value of β becomes the same as that for maximum level metrics, i.e. $\beta = \beta_1 = \sin^{-1}(z_1/d_1)$ and $\ell = OC_1 = \sqrt{d_1^2 - z_1^2}$</u>

4.6.7 The finite segment correction Δ_F (Exposure levels L_E only)

4.6.7.1 The adjusted baseline noise exposure level relates to an aeroplane in continuous, straight, steady level flight (albeit with a bank angle ε that is inconsistent with straight flight). Applying the (negative) *finite segment correction* $\Delta_F = 10{\cdot}\log(F)$, where F is the *energy fraction*, further adjusts the level to what it would be if the aeroplane traversed the finite segment only.

4.6.7.2 The energy fraction term accounts for the pronounced longitudinal directivity of aeroplane noise and the angle subtended by the segment at the observer position. Although the processes that cause the directionality are very complex, studies have shown that the resulting contours are quite insensitive to the precise directional characteristics assumed. The expression for Δ_F below is based on a fourth-power 90-degree dipole model of sound radiation. It is assumed to be unaffected by lateral directivity and attenuation. The derivation of this correction is described in detail in **Appendix F**.

4.6.7.3 The energy fraction F is a function of the 'view' triangle $\mathbf{OS_1S_2}$ defined in **Figures 4-2a to 4-2c** such that:

$$\Delta_F = 10 \cdot \log \times \left[\frac{1}{\pi}\left(\frac{\alpha_2}{1+\alpha_2^2} + \tan^{-1}\alpha_2 - \frac{\alpha_1}{1+\alpha_1^2} - \tan^{-1}\alpha_1\right)\right] \tag{4-17}$$

with

$$\alpha_1 = -\frac{q}{d_\lambda}; \quad \alpha_2 = -\frac{q-\lambda}{d_\lambda};$$
$$d_\lambda = d_0 \cdot 10^{[L_{E\infty}(P,d_p) - L_{max}(P,d_p)]/10};$$
$$d_0 = \frac{2}{\pi} \cdot V_{ref} \cdot t_0$$

where d_λ is known as the 'scaled distance' (see **Appendix F**). Note that $L_{max}(P, d_p)$ is the maximum level, from NPD data, for perpendicular distance d_p, NOT the segment L_{max}.

4.6.7.4 For the observer locations behind <u>every</u> take-off ground-roll segment and locations ahead of the every landing ground-roll segment a special form of noise fraction is used instead of Equation 4-17. This is computed using

$$\Delta_F' = 10 \log[(1/\pi)\,[\alpha_2/(1+\alpha_2^2) + \tan^{-1}\alpha_2]\,10^{\Delta SOR/10}] \tag{4-18}$$

where $\alpha_2 = \lambda / d_\lambda$ and Δ_{SOR} is the start-of-roll directivity function defined in Section 4.6.7.

4.6.8 The start-of-roll directivity function Δ_{SOR}

4.6.8.1 The noise of jet aeroplanes – especially those equipped with lower by-pass ratio engines – exhibits a lobed radiation pattern in the rearward arc, which is characteristic of jet exhaust noise. This pattern is the more pronounced the higher the jet velocity and the lower the aeroplane speed. This is of special significance for observer locations behind the start of roll, where both conditions are fulfilled. This effect is taken into account by a directivity function Δ_{SOR}.

4.6.8.2 **Figure 4-8** shows the relevant geometry. The azimuth angle ψ between the aeroplane longitudinal axis and the vector to the observer is defined by

$$\psi = \cos^{-1}\left(\frac{q}{d_{SOR}}\right) \tag{4-19}$$

4.6.8.3 The relative distance q is negative (see **Figure 4-2a**) so that ψ ranges from 0° in the direction of the aeroplane forward heading to 180° in the reverse direction.

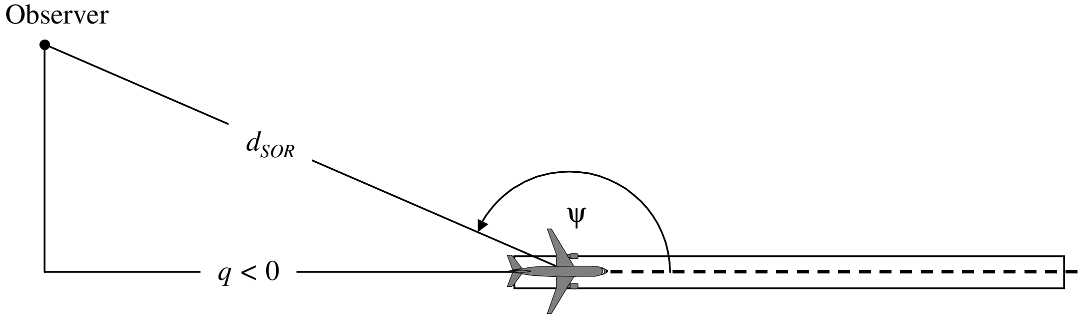

Figure 4-8: Aircraft-observer geometry at for estimation of directivity correction

4.6.8.4 The parameters, d_{SOR} and ψ are calculated relative to the start of the each individual ground roll segment, not to the Start-of-Roll point.

4.6.8.5 The function Δ_{SOR} is applied at positions behind the start of roll, i.e. for $90° < \psi \leq 180°$, to the partial event level generated by all noise emanating from the take-off ground roll:

$$L_{TGR}(d_{SOR}, \psi) = L_{TGR}(d_{SOR}, 90°) + \Delta_{SOR}(d_{SOR}, \psi) \tag{4-20}$$

where $L_{TGR}(d_{SOR},90°)$ is the event level generated by all take-off ground roll segments at the point distance d_{SOR} to the side of the SOR. The SOR directivity function is given by

if $90° \leq \psi < 148.4°$ then

$$\Delta^0_{SOR} = 51.47 - 1.553 \cdot \psi + 0.015147 \cdot \psi^2 - 0.000047173 \cdot \psi^3 \tag{4-21a}$$

and if $148.4° \leq \psi \leq 180°$ then

$$\Delta^0_{SOR} = 339.18 - 2.5802 \cdot \psi - 0.0045545 \cdot \psi^2 + 0.000044193 \cdot \psi^3 \tag{4-21b}$$

4.6.8.6 If the distance d_{SOR} exceeds the normalising distance $d_{SOR,0}$ of 762 m (2500 ft), the directivity correction is multiplied by a correction factor to account for the fact that the directivity becomes less pronounced for greater distances from the aeroplane; i.e.

$$\Delta_{SOR} = \Delta^0_{SOR} \tag{4-22a}$$

if $d_{SOR} \leq d_{SOR,0}$

and

$$\Delta_{SOR} = \Delta^0_{SOR} \cdot \frac{d_{SOR,0}}{d_{SOR}} \tag{4-22b}$$

if $d_{SOR} > d_{SOR,0}$

Chapter 5

Calculation of Cumulative Levels

5.1 INTRODUCTION

5.1.1 **Chapter 4** describes the calculation of the event sound noise level of a single aeroplane movement at a single observer location. The total noise exposure at that location is calculated by accumulating the event levels of all noise-significant aeroplane movements, i.e. all movements, inbound or outbound, that influence the cumulative level. Some of the basic measures of cumulative noise are outlined below; for a general description of noise scales, metrics and indices, see **Appendix A**.

5.2 WEIGHTED EQUIVALENT SOUND LEVELS

5.2.1 Time-weighted equivalent sound levels, which account for all significant aeroplane sound energy received, can be expressed in a generic manner by the formula

$$L_{eq,W} = 10 \cdot \log\left[\frac{t_0}{T_0} \cdot \sum_{i=1}^{N} g_i \cdot 10^{L_{E,i}/10}\right] + C \qquad \text{(5-1a)}$$

5.2.2 The summation is performed over all N noise events during the time interval T_0 to which the noise index applies. $L_{E,i}$ is the single event noise exposure level of the i-th noise event. g_i is a time-of-day dependent weighting factor (usually defined for day, evening and night periods). Effectively g_i is a multiplier for the number of flights occurring during the specific periods. The constant C can have different meanings (normalising constant, seasonal adjustment etc.).

5.2.3 Using the relationship:

$$g_i = 10^{\Delta_i/10}$$

where Δ_i is the decibel weighting for the i-th period, equation 5-1a can be rewritten as

$$L_{eq,W} = 10 \cdot \log\left[\frac{t_0}{T_0} \sum_{i=1}^{N} 10^{(L_{E,i}+\Delta_i)/10}\right] + C \qquad \text{(5-1b)}$$

i.e. the time-of-day weighting is expressed by an additive level offset.

5.2.4 Some noise indices are based on maximum noise event levels rather than on time integrated metrics. An example is the average maximum sound level:

$$\overline{L_{max}} = 10 \cdot \log\left[\frac{1}{N} \sum_{i=1}^{N} 10^{L_{max,i}/10}\right] \qquad \text{(5-2)}$$

5.2.5 Common applications are situations with a relative low equivalent sound level but high maximum levels (e.g. aerodromes with a relatively small number of jet operations).

5.2.6 Some indices account for both $\overline{L_{max}}$ and event numbers N by a relationship of the form

$$\text{Index} = \overline{L_{max}} + K \cdot \log N \qquad \text{(5-3)}$$

where the constant K defines the relative weight given to event numbers.

5.2.7 A special index is the *"Number Above Threshold"*, NAT. NAT_X is the number of noise events with maximum sound levels reaching or exceeding a threshold value X (dB). NAT-criteria can be defined for specific times of day (e.g. $NAT_{Night,70}$).

5.3 THE WEIGHTED NUMBER OF OPERATIONS

5.3.1 The cumulative noise level is estimated by summing the contributions from all different types or categories of aeroplane using the different flight routes appropriate to the airport.

5.3.2 To describe this summation process the following subscripts are introduced:

i index for aeroplane type or category;

j index for flight track or subtrack (if subtracks are defined); and

k index for flight track segment

5.3.3 Many noise indices include time-of-day weighting factors g_i in their definition (equation 5.1). For average maximum levels (equation 5.2) the weighting factors g_i are usually 1 or 0, depending of whether the metric covers specific times of the day or the whole 24 hours.

5.3.4 The summation process can be simplified by introducing a 'weighted number of operations'

$$M_{ij} = \left(g_{day} \cdot N_{ij,day} + g_{evening} \cdot N_{ij,evening} + g_{night} \cdot N_{ij,night}\right) \tag{5-4}$$

where the values N_{ij} represent the numbers of operations of aeroplane type/category *i* on track (or subtrack) *j* during the day, evening and night period respectively[25].

5.3.5 From equation.(5-1b) the (generic) cumulative equivalent sound level L_{eq} at the observation point *(x,y)* is

$$L_{eq,W}(x,y) = 10 \cdot \log\left[\frac{t_0}{T_0} \cdot \sum_i \sum_j \sum_k M_{ij} \cdot 10^{L_{E,ijk}(x,y)/10}\right] + C \tag{5-5}$$

where T_0 is the reference time period, and $L_{E,ijk}$ is the single event noise level contribution from segment k of track or subtrack j for an operation of aeroplane of category i. The estimation of $L_{E,ijk}$ is described in detail in **Chapter 4**.

5.4 ESTIMATION OF CUMULATIVE MAXIMUM LEVEL BASED METRICS

5.4.1 Calculating a cumulative equivalent sound level is a straightforward aggregation of the event levels L_E of all noise-significant aeroplane movements. Cumulative maximum level metrics are less straightforward. By definition a maximum sound level is tied to a single noise event. However, a single aeroplane movement can generate more than one sound event at a given observer location (when its flight path causes more than one rise and fall in the received sound intensity).

5.4.2 Additionally different metrics assign different meanings to the generic expression "maximum sound level" as illustrated by the following alternative definitions:

a) The average maximum sound level, defined by equation 5-2, of <u>all noise events</u> occurring at the observer location;

b) The average maximum sound level, defined by equation 5-2, of all noise events exceeding a specified threshold level L_T at the observer location; or

c) The absolute maximum level (i.e. the "maximum maximum" level). In this case <u>only one noise event</u> contributes.

This indicates the need for metric-specific aggregation of the maximum sound levels.

5.4.3 With no threshold, the average maximum sound level [a) above] occurring at the observer location *(x,y)* can be expressed as

$$\overline{L_{max}}(x,y) = 10 \cdot \log\left[\sum_i \sum_j \sum_k 10^{L_{max,ijk}/10} \cdot u(k)\right] - 10 \cdot \log\left[\sum_i \sum_j \sum_k M_{ij} \cdot u(k)\right] \tag{5-6a}$$

where

$$u(k) = \begin{Bmatrix} 0 \\ 1 \end{Bmatrix} \quad \text{if} \quad L_{max,ijk} \begin{Bmatrix} \text{is not} \\ \text{is} \end{Bmatrix} \text{the maximum level of a noise event} \tag{5-6b}$$

where the function u(*k*) determines whether the maximum segment level $L_{max,ijk}$ is the maximum level of a noise event or not (the derivation this function is described in detail in **Appendix F**)

5.4.4 With a threshold L_T, the average maximum sound level [b) above]

$$\overline{L_{max}}(x,y) = 10 \cdot \log\left[\sum_i \sum_j \sum_k 10^{L_{max,ijk}/10} \cdot v(k)\right] - 10 \cdot \log\left[\sum_i \sum_j \sum_k M_{ij} \cdot v(k)\right] \tag{5-7a}$$

where

$$v(k) = \begin{Bmatrix} 0 \\ 1 \end{Bmatrix} \quad \text{if} \quad \begin{Bmatrix} L_{max,ijk} < L_T \\ L_{max,ijk} \geq L_T \end{Bmatrix} \tag{5-7b}$$

which guarantees that only noise events with maximum levels reaching or exceeding the threshold value L_T are included into the summation process.

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25 The time periods may differ from these three, depending on the definition of the noise index used.

5.4.5 If only the highest maximum level [c) above] of all noise events occurring at the observation point has to be calculated the corresponding equation is quite simple:

$$L_{max}(x,y) = \max\left(L_{max,ijk}\right) \qquad (5\text{-}8)$$

5.4.6 The equation for estimation of a number above threshold criterion is similar to that for an average maximum sound level. However the weighted operations have to be summed rather than the level contributions:

$$NAT_{L_T}(x,y) = \sum_i \sum_j \sum_k M_{ij} \cdot \mathrm{u}(k) \cdot \mathrm{v}(k) \quad (5\text{-}9)$$

5.5 THE USE OF LEVEL DISTRIBUTIONS FOR MAXIMUM LEVEL METRICS

5.5.1 The methodology described in **Chapter 4** yields the same maximum sound level for all movements of the same aeroplane type on the same track[26]. This can lead to unrealistic discontinuities in $\overline{L_{max}}$ and *NAT* contours. In reality there are no sharp changes; the calculated $\overline{L_{max}}$ is just an estimated average of event levels that are scattered about a central value L_0. This scatter can be realistically described by a Gaussian distribution function with a standard deviation S:

$$w(L_{max}, L_0, S) = \frac{1}{\sqrt{2\pi} \cdot S} \cdot \exp\left[-\frac{1}{2}\left(\frac{L_{max} - L_0}{S}\right)^2\right] \qquad (5\text{-}10)$$

5.5.2 **Figure 5-1** shows a sketch of such a level distribution.

5.5.3 It must be noted that the median value L_0 of the distribution function is generally not equal to the value $\overline{L}$ stored in NPD-databases as that is normally derived from measurements by decibel averaging. This is higher than the median value of the distribution by an amount which depends on the standard deviation:

$$\overline{L} = L_0 + \frac{S^2 \cdot \ln 10}{20} = L_0 + 0.115 \cdot S^2 \qquad (5\text{-}11)$$

5.5.4 A characteristic type-specific value for the standard deviation *S* is observed from operational measurements to be around 2 dB[27]. This results in a level difference between logarithmic and arithmetic averages of about 0.5 dB.

5.5.5 For similar reasons, distributed levels should be taken into account when estimating *NAT* values. The reason is clear from **Figure 5-1**: for this case both L_0 and $\overline{L}$ are less than the threshold level L_T. If the distribution is not taken into account, the contribution to *NAT* will equal zero. However with distributed levels some are higher than the threshold and thus contribute to the total *NAT*. To account for the distribution, equation 5-9

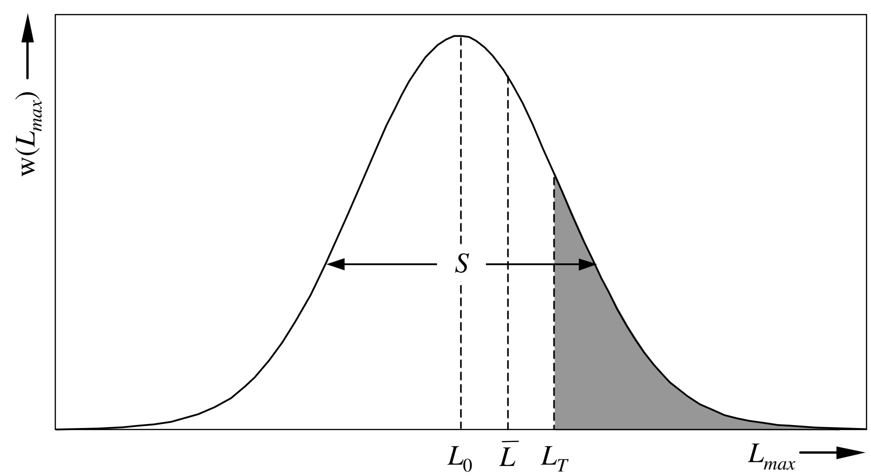

Figure 5-1: Maximum sound level distribution

[26] Assuming the same operating procedures and weight.

[27] Rather lower scatter is achieved in certification tests.

has to be modified by replacing the discrete step represented by the function v(*k*) by an integral over a continuous distribution function:

$$NAT_{L_T}(x,y) = \sum_i \sum_j \sum_k \left[\begin{array}{l} M_{ij} \cdot u(k) \\ \cdot \int_{L_T}^{\infty} w\left(L_{max,ijk}, L_{0,k}, s\right) dL_{max,ijk} \end{array} \right] \quad (5\text{-}12)$$

Polynomial approximations of this integral for programming purposes can be found in mathematical handbooks [e.g. ref. 10].

5.5.6 It should be noted that the arithmetic mean $L_{0,k}$ has to be derived according to equation 5-11 if, as in the ANP database the maximum values are estimated from measured data by logarithmic averaging.

Chapter 6

Calculation of noise contours

6.1 STANDARD GRID CALCULATION AND REFINEMENT

6.1.1 When noise contours are obtained by interpolation between index values at rectangularly spaced grid points, their accuracy depends on the choice of the grid spacing (or mesh size) Δ_G, especially within cells where large gradients in the spatial distribution of the index cause tight curvature of the contours (see **Figure 6-1**). Interpolation errors are reduced by reducing the grid spacing, but as this increases the number of grid points, the computation time is increased. Optimising a regular grid mesh involves balancing modelling accuracy and run time.

6.1.2 A marked improvement in computing efficiency which also delivers more accurate results is to use an irregular grid to refine the interpolation in critical cells. The technique, depicted in **Figure 6-1**, is to tighten the mesh locally, leaving the bulk of the grid unchanged. This is very straightforward and achieved by the following steps:

a) Define a refinement threshold difference ΔL_R for the noise index.

b) Calculate the basic grid for a spacing Δ_G.

c) Check the differences ΔL of the index values between adjacent grid nodes.

d) If there are any differences $\Delta L > \Delta L_R$, define a new grid with a spacing $\Delta_G/2$ and estimate the levels for the new nodes in the following way:

$$\text{If } \begin{cases} \Delta L \leq \Delta L_R \\ \Delta L > \Delta L_R \end{cases} \text{ calculate the new value } \begin{cases} \text{by linear interpolation from the adjacent ones.} \\ \text{completely anew from the basic input data.} \end{cases}$$

e) Repeat steps a) through d) until all differences are less than the threshold difference.

f) Estimate the contours by linear interpolation.

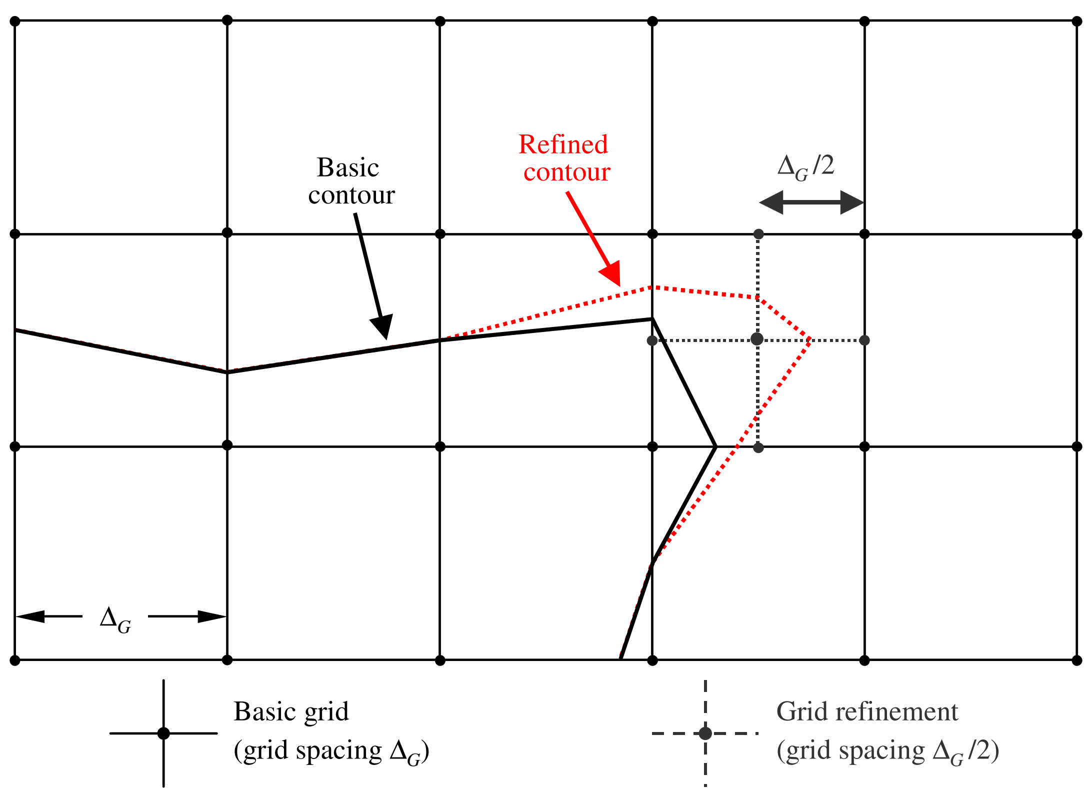

Figure 6-1: Standard grid and grid refinement

6.1.3 If the array of index values is to be aggregated with others (e.g. when calculating weighted indices by summing separate day, evening and night contours) care is required to ensure that the separate grids are identical.

6.2 USE OF ROTATED GRIDS

6.2.1 In many practical cases, the true shape of a noise contour tends to be symmetrical about a ground track. However if the direction of this track is not aligned with the calculation grid, this can cause result in an asymmetric contour shape.

6.2.2 The straightforward way to avoid this effect is to tighten the grid. However this increases computation time. A more elegant solution is to rotate the computation grid so that its direction is parallel to the main ground tracks (i.e. usually parallel to the main runway). **Figure 6-2** shows the effect of such a grid rotation on the contour shape.

6.3 TRACING OF CONTOURS

6.3.1 A very time-efficient algorithm that eliminates the need to calculate a complete grid array of index values at the expense of a little more computational complexity is to trace the path of the contour, point by point. This option requires two basic steps to be performed and repeated (see **Figure 6-3**):

6.3.2 Step 1 is to find a first point $\mathbf{P_1}$ on the contour. This is done by calculating the noise index levels L in equidistant steps along a 'search ray' that is expected to cross the required contour of level L_C. When the contour is crossed, the difference $\delta = L_C - L$ changes sign. If this happens, the step-width along the ray is halved and the search direction is reversed. This is done until δ is smaller than a pre-defined accuracy threshold.

6.3.3 Step 2, which is repeated until the contour is sufficiently well defined, is to find the

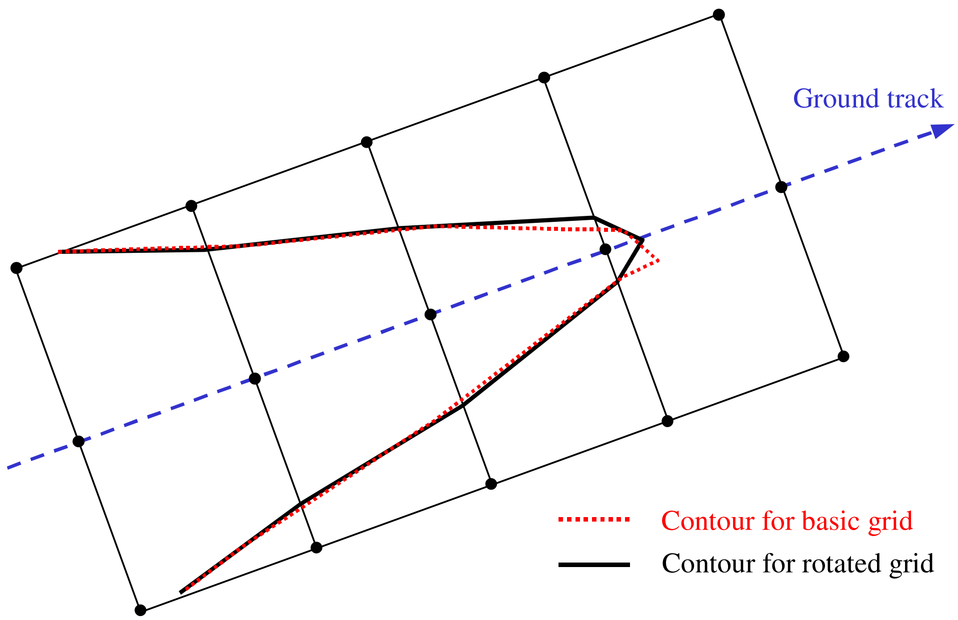

Figure 6-2: Use of a rotated grid

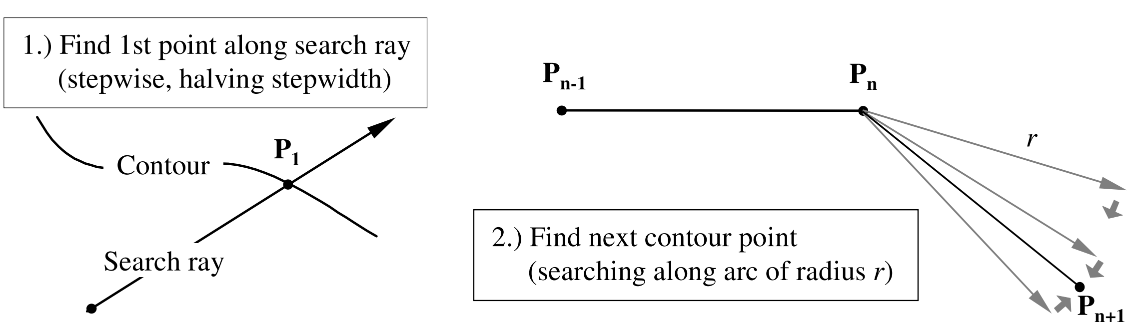

Figure 6-3: Concept of tracing algorithm

next point on the contour L_C - which is at a specified straight line distance r from the current point. During consecutive angular steps, index levels and differences δ are calculated at the ends of vectors describing an arc with radius r. By similarly halving and reversing the increments in the directions of the vector, the next contour point is determined.

6.3.4 Some constraints should be imposed to guarantee that the contour is estimated with a sufficient degree of accuracy (see **Figure 6-4**):

a) The length of the chord Δc (the distance between two contour points) should be within an interval [Δc_{min}, Δc_{max}], e.g. [10 m, 200 m].

b) The length ratio between two adjacent chords of lengths Δc_n and Δc_{n+1} should be limited, e.g. $0.5 < \Delta c_n / \Delta c_{n+1} < 2$.

c) With respect to a good fit of the chord length to the contour curvature the following condition should be fulfilled:

$$\phi_n \cdot \max(\Delta c_{n-1}, \Delta c_n) \leq \varepsilon \quad (\varepsilon \approx 15\text{ m})$$

where ϕ_n is the difference in the chord headings.

6.3.5 Experience with this algorithm has shown that, on an average, between 2 and 3 index values have to be calculated to determine a contour point with an accuracy of better than 0.01 dB.

6.3.6 This algorithm speeds up computation time dramatically, especially when large contours have to be calculated. However it should be noted that its implementation requires experience, especially when a contour breaks down into separate islands.

6.4 POST-PROCESSING

6.4.1 Commonly the post-processing of calculated noise indices involves the following:

a) Interpolation and – if necessary – smoothing of noise contours (if the index was estimated for a grid).

b) Performing grid operations such as merging, adding, subtracting or converting.

c) Plotting (including representation of contours, runways, tracks, specific observer locations and/or topography).

d) Integration of noise data into geographic information systems (GIS) (e.g. to estimate enclosed population numbers).

6.4.2 Currently several post-processing tools and standardised data formats are in use, which are suitable for processing data from aeroplane noise calculation programs. Examples of such tools are:

a) NMPLOT: this program is designed for viewing and editing geo-referenced data sets such as noise data stored in grids; and

b) GIS-software such as ESRI ArcView or MicroStation GeoGraphics (usually commercial software).

6.4.3 Data formats which are widely used are:

a) ArcView shapefile format.

b) AutoCAD data exchange format DXF.

c) Intergraph and MicroStation standard file format ISFF (also known as DGN).

d) Noise model grid format NMGF. The NMGF-format was originally developed for use in conjunction with different noise models. It is used by NMPLOT.

6.4.4 A lot of possibilities for the definition of interfaces therefore exist. This should be taken into account when a computer model based on this document is developed.

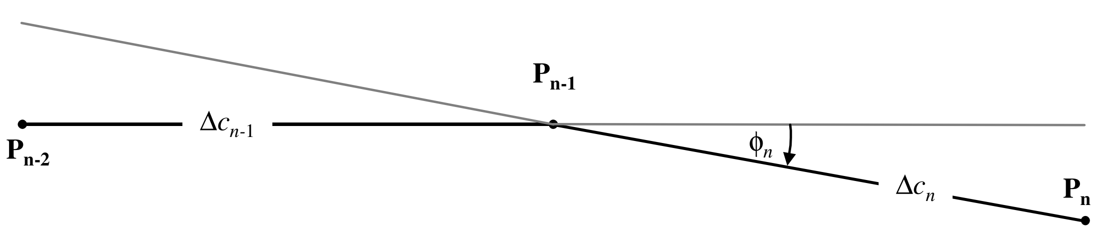

Figure 6-4: Geometric parameters defining conditions for the tracing algorithm

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[1] Society of Automotive Engineers: *Procedure for the Calculation of Aircraft Noise in the Vicinity of Airports.* SAE AIR-1845 (1986) (currently under revision).

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[15] International Organization for Standardization*: Acoustics – Procedure for describing aircraft noise heard on the ground.* ISO 3891 (1978).

Appendix A

Noise Indices in use in ICAO States

Individual Contracting States **have** selected different noise indices for national use. **The** formulations of current **indices** are as follows:

A.1 Day-evening-night sound level, L_{DEN}

$$L_{DEN} = 10\log(1/24)\times \left[12\times 10^{L_D/10} + 4\times 10^{(L_E+5)/10} + 8\times 10^{(L_N+10)/10}\right]$$

where $\mathbf{L_D}$, $\mathbf{L_E}$ and $\mathbf{L_N}$ are the equivalent continuous **A**-weighted sound pressure levels[28] over, respectively, the **12-hour** daytime period 0700 to 1900 hours, the **4-hour** evening period 1900 to 2300 hours and the **8-hour** night period 2300 to 0700 hours[29].

A.2 Day-night average sound level, L_{DN}

$$L_{DN} = 10\log(1/24)\left[15\times 10^{L_D/10} + 9\times 10^{(L_N+10)/10}\right]$$

where $\mathbf{L_D}$ and $\mathbf{L_N}$ are the equivalent continuous A-weighted sound pressure levels over, respectively, the **15-hour** daytime period 0700 to 2200 hours and the **9-hour** night period 2200 to 0700 hours.

A.3 Equivalent continuous A-weighted sound pressure level, $L_{A,eq}$, as defined in Austria:

$$L_{Aeq} = 10\log\left[(1/t_{eq})\int_0^{t_{eq}} 10^{L_A(t)/10}dt\right]$$

where $\mathbf{L_A}(\boldsymbol{t})$ is the instantaneous A-weighted sound pressure level and t_{eq} is the evaluation period in seconds; $L_{A,eq}$ is evaluated separately over the 16-hour daytime period 0600 to 2200 hours and the 8-hpur night period 2200 to 0600 hours.

A.4 Noise exposure forecast, NEF

$$NEF = 10\log\sum_i\sum_j 10^{NEF_{ij}/10}$$

where $\mathbf{NEF_{ij}}$ is a partial value for a specific class of aeroplanes, **i**, on a flight path, **j**, defined as follows:

$$NEF_{ij} = L_{EPNij} + 10\log(n_{Dij} + 16.67n_{Nij}) - 88$$

where, in turn, $\mathbf{L_{EPNij}}$ is the Effective Perceived Noise Level at the observation point considered, for the aeroplanes and flight path concerned, $\mathbf{n_{Dij}}$ is the number of operations during the 15-hour day (0700 to 2200 hours) and $\mathbf{n_{Nij}}$ is the number during the 9-hour night (2200 to 0700 hours).

A.5 Noise exposure index, B

$$B = 20\log\sum_i\left[n\left(10^{L_p/15}\right)\right] - 157$$

Where $\boldsymbol{L_p}$ is the maximum A-weighted sound pressure level of an aeroplane fly-past and ***n*** is a weighting factor which varies with different times during the day and night.

A.6 Weighted equivalent continuous perceived noise level, WECPNL, as defined in Japan:

$$WECPNL = \left(10\log\left[(1/n)\sum_i 10^{L_i/10}\right] + 10\log N\right) - 27$$

where $\boldsymbol{L_i}$ is the maximum A-weighted sound pressure level of an aeroplane fly-past ***i***, ***n*** is the number of operations within a 24-hour period, and **N** is based upon the number with weightings for the numbers during the daytime (0700 to 1900 hours), evening (1900 to 2200 hours) and night (2200 to 0700 hours).

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[28] The equivalent continuous A-weighted sound pressure level is usually given the symbol $\mathbf{L_{A,eq,\Gamma}}$ (see Reference 1 to main text). The symbols $\mathbf{L_D}$, $\mathbf{L_E}$ and $\mathbf{L_N}$ used here are intended to indicate the time periods over which the levels are evaluated. This quantity is defined as follows:

$$L_{A,eq,\Gamma} = 10\log\left\{[1/(t_2 - t_1)]\times\int_{t_1}^{t_2}\left[p^2{}_A(t/p^2{}_0)\right]dt\right\}$$

where $\mathbf{L_{A,eq,\Gamma}}$ is the equivalent continuous **A-weighted sound pressure level** determined over a time interval **T** starting at $\mathbf{t_1}$ and ending at $\mathbf{t_2}$. $\mathbf{p_A(t)}$ is the instantaneous A-weighted sound pressure of the sound signal and $\mathbf{p_0}$ is the reference sound pressure (20 µPa).

[29] The L_{DEN} time periods are different in the U.S.A.: the **12-hour** daytime period 0700 to 1900 hours, the **3-hour** evening period 1900 to 2200 hours and the **9-hour** night period 2200 to 0700 hours.

A.7 Australian noise exposure forecast, ANEF

$\text{ANEF} = 10\log\sum_i\sum_j 10^{\text{ANEF}_{ij}/10}$ where $\mathbf{ANEF_{ij}}$ is a partial value for a specific class of aeroplanes, ***i***, on a flight path, ***j***, defined as follows:

$$\text{ANEF}_{ij} = L_{\text{EPN}ij} + 10\log\left(n_{\text{D}ij} + 4n_{\text{N}ij}\right) - 88$$

where, in turn $\mathbf{L_{EPN\mathit{iJ}}}$ is the Effective Perceived Noise Level at the observation point considered for the aeroplane and flight path concerned, $\mathbf{n_{D\mathit{ij}}}$ is the number of operations during the 11-hour day (0700 to 1900 hours) and $\mathbf{n_{N\mathit{ij}}}$ is the number during the 12-hour night (1900 to 0700 hours).

A.8 Application of EPNL based indices

Historically the EPNL data required for calculating certain indices has not been widely available from aircraft manufacturers. As a result the approximation presented in **Appendix B** has been used instead. However, with the development of the ANP database, EPNL based noise-power-distance (NPD) data is now much more widely available and it is recommended that EPNL NPD data is used directly in the calculation of indices based on EPNL. It is recognised that this may change the shape and size of contours; hence Appendix B is retained, where its continued use may be relevant to maintain continuity.

Appendix B

Approximate Methods for Determining Effective Perceived Noise Level (EPNL)

B.1 INTRODUCTION

Approximate methods for arriving at the effective perceived noise level at a specified location from actual noise level measurementsare provided herewith.

B.2 APPROXIMATIONS TO OBTAIN TONE CORRECTED PERCEIVED NOISE LEVEL (PNLTJ (AS DEFINED IN ANNEX 16. VOLUME I))

a) Approximation by use of PNL derived from octave band measurements

Use the sound pressure level in each octave band as given in step 1 of Annex 16, Volume I, 4.2.1 and for step2, use the factor 0.3 instead of 0.15. Omit the "Correction for Spectral Irregularities" given in Annex 16, Volume I, 4.3. For approximate tone corrections, see Table B-1 below (from PNL to PNLT).

b) Approximation by D- and A-weighted over all sound pressure level

PNLT may be approximated by means of recordings with direct measuring equipment if an additional element is inserted in the measuring chain such that the over-all frequency response of the measuring chain is:

1) equal to the inverse of the 40 noy curve as described in Annex 16, Volume I, Appendix 5, Table 5-1: or

2) equal to the A-Weighting as defined in IEC Recommendation 179.[30]

The addition of correction constant K to such measurements gives an approximation to PNLT. See Table B-1 below for approximate values for K.

[30] This publication was first issued in 1965 by the Bureau central de la Commission electrotechnique internationale, 1 rue de Varembe, Geneva, Switzerland.

Table B-1 Correction Constant K to be added to D-weighted and A-weighted over-all sound pressure measurements and to PNL values to obtain approximate PNLT values.

Aeroplane		Constant K to be added to obtain				
		PNL from		PNLT from		
		dB(A)	dB(D)	dB(A)	dB(D)	PNL
Turbofan	Take-off	13	7	13	7	0
	Landing	13	7	15	9	2
Turbojet	Take-off	13	7	13	7	0
	Landing	13	7	13	7	0
Noise from unknown aeroplanes		13	7	13	7	0

The values in this table are considered the best available guidance at the present time and are to be used unless more nearly exact constants K for the particular application, such as aeroplane type, distance from flight paths, etc., are known. If values other than the ones in the table are used in approximate method b) above, the value used for K must be stated.

Note. – It is realized that the exact correction constant depends on such factors as aeroplane type, operational characteristics, meteorological conditions and the distance from the aeroplane flight path. The figures in the above table are based on a considerable number of observations. In one study the correction constant was found to range from 13 to 8 for obtaining PNL from dB(A) and from 8.5 to 4 from dB(D) respectively, the higher value being for a distance of 500m from the flight path, the lower for 3,500m. In another study[31] averaging more than 4,000 flyovers measured in an area within a 19.3km radius of an aerodrome, the

[31] W.K. Connor, Community Reactions to Aircraft Noise Measurements, in : *Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft*, National Aeronautics and Space Administration, Washington D.C., 1968 (NASA SP-189).

following standard deviations for constants were found (see **Table B-2**):

Table B-2 STANDARD DEVIATIONS FOR K VALUES

PNL from		PNLT from	
dB(A)	dB(D)	dB(A)	dB(D)
2.2	1.8	3.0	2.6

B.3 APPROXIMATION TO OBTAIN DURATION CORRECTION D

An approximation to the duration allowance is given by the expression

$$D = 10\log\{[t(2) - t(1)]/T(0)\}$$

where:

T(0) is a normalizing constant of 20s; and *[t(2) – t(1)]* is the time interval during which a recording of PNLT (or an approximation thereto) is within 10 dB of its maximum value. If the maximum value is less than 10 dB above the background level (or other limiting value such as that recommended in Annex 16, Volume 1, Appendix 1, 4.5), the time it exceeds the background level or other limiting value is taken into account.

In case of discrepancies between the various approximations, total noise exposure levels based on measurements made with a frequency weighting equal to the inverse of the 40 noy curve (D-weighting) are to be considered closer approximations to EPNL than measurements made with A-weighting. Total noise exposure levels derived from PNL determinations from octave band measurements are to be considered closer approximations to EPNL than determinations based either on D- or A- weighted measurements.

Appendix C

Flight performance calculations

C.1 TERMS AND SYMBOLS

C.1.1 The terms and symbols used in this appendix are consistent with those conventionally used by aeroplane performance engineers. Some basic terms are explained briefly below for the benefit of users not familiar with them. To minimise conflict with the main body of the document, symbols are mostly defined separately within this appendix. Quantities that are referenced in the main body are assigned common symbols; a few that are used differently in this appendix are marked with an asterix (*). There is some juxtaposition of US and SI units; again this is to preserve conventions that are familiar to users from different disciplines.

C.1.1 Terms

Break point	See Flat Rating
Calibrated airspeed	(Otherwise termed equivalent or indicated airspeed.) The speed of the aeroplane relative to the air as indicated by a calibrated instrument on the aeroplane. The true airspeed, which is normally greater, can be calculated from the calibrated airspeed knowing the air density.
Corrected net thrust	Net thrust is the propulsive force exerted by an engine on the airframe. At a given power setting (*EPR* or N_1) this falls with air density as altitude and temperature increase; corrected net thrust is equivalent to the thrust at sea level in ISA conditions.
Flat rating	For specific maximum component temperatures, the engine thrust falls as the ambient air temperature rises - and *vice-versa*. This means that there is a critical air temperature above which the *rated thrust* cannot be achieved. For most modern engines this is called the 'flat rated temperature' because, at lower air temperatures the thrust is automatically limited to the rated thrust to maximise service life. The thrust falls anyway at temperatures above the flat rated temperature - which is often called the *break point* or *break temperature*.
Speed	Magnitude of aeroplane velocity vector (relative to aerodrome coordinate system)
Rated thrust	The service life of an aeroplane engine is very dependent upon the operating temperatures of its components. The greater the power or trust generated, the higher the temperatures and the shorter the life. To balance performance and life requirements flat rated engines are assigned *thrust ratings* for take-off, climb and cruise which define normal maximum power settings.
Thrust setting parameter	Since thrust cannot be measured directly in flight it is necessary to set and control thrust through the use of an alternative parameter which can be displayed in the cockpit. This is usually either the engine pressure ratio (*EPR*) or low-pressure rotor (or fan) rotational speed (N_1).

C.1.2 Symbols

C.1.2.1 Quantities are dimensionless unless otherwise stated. Symbols and abbreviations not listed below are used only locally and defined in the text. Subscripts 1 and 2 denote conditions at the start and end of a segment respectively. Overbars denote segment mean values, i.e. average of start and end values.

a	Average acceleration, ft/s^2
a_{max}	Maximum acceleration available, ft s^2
A, B, C, D	Flap coefficients
E, F, $G_{A,B}$, H	Engine thrust constants or coefficients for temperatures below the engine flat rating

	temperature at the thrust rating in use (on the current segment of the take-off/climb-out or approach flight path), lb.s/ft, lb/ft, lb/ft^2, lb/°C respectively. Obtainable from the ANP database.
F_n	Net thrust per engine, lbf
F_n/δ	Corrected net thrust per engine, lbf
G	Climb gradient
G´	Engine-out climb gradient
G_R	Mean runway gradient, positive uphill
g	Gravitational acceleration, ft/s^2
ISA	International Standard Atmosphere
N	No of engines supplying thrust
N_1	Rotational speed of the engine's low-pressure compressor (or fan) and turbine stages, %
R	Drag-to-lift ratio C_D/C_L
ROC	Segment rate of climb (ft/min)
s	Ground distance covered along ground track, ft
s_{TO8}	Take-off distance into an 8 kt headwind, ft
s_{TOG}	Take-off distance corrected for w and G_R, ft
s_{TOw}	Take-off distance into headwind w, ft
T	Ambient air temperature in which the aeroplane is operating, °C
T_B	Breakpoint temperature, °C
V	Groundspeed, kt
V_C	Calibrated airpeed, kt
V_T	True airspeed, kt
W	Aeroplane weight, lb
w	Headwind speed, kt
Δs	Still air segment length projected onto ground track, ft
Δs_w	Segment length ground projection corrected for headwind, ft
δ	p/p_O, the ratio of the ambient air pressure at the aeroplane to the standard air pressure at mean sea level: p_O = 101.325 kPa (or 1013.25 mb) [ref. 11]
ε	Bank angle, radians
γ	Climb/descent angle, radians
θ	$(T + 273.15)/(T_0 + 273.15)$ the ratio of the air temperature at altitude to the standard air temperature at mean sea level: T_0 = 15.0 °C [ref. 11]
σ	ρ/ρ_0 = Ratio of air density at altitude to mean sea level value (also, $\sigma = \delta/\theta$)

C.2 INTRODUCTION

C.2.1 Flight path synthesis

C.2.1.1 In the main, this appendix recommends procedures for calculating an aeroplane flight profile, based on specified aerodynamic and powerplant parameters, aeroplane mass, atmospheric conditions, ground track and operating procedure (flight configuration, power setting, forward speed, vertical speed etc). The operating procedure is described by a set of *procedural steps* that prescribe how to fly the profile.

C.2.1.2 The flight profile, for take-off or approach, is represented by a series of straight-line segments, the ends of which are termed *profile points*. It is calculated using aerodynamic and thrust equations containing numerous coefficients and constants which must be available for the specific combination of airframe and engine. This calculation process is described in the text as the process of flight path *synthesis*.

C.2.1.3 Apart from the aeroplane performance parameters, which can be obtained from the ANP database (See **Appendix H**), these equations require specification of (1) aeroplane gross weight, (2) the number of engines, (3) air temperature, (4) runway elevation and atmospheric pressure, and (5) the procedural steps (expressed in terms of power settings, flap deflections, airspeed and, during acceleration, average rate-of-climb/descent) for each segment during take-off and approach. Each segment is then classified as a ground roll, take-off or landing, constant speed climb, power cutback, accelerating climb with or without flap retraction, descent with or without deceleration and/or flap deployment, or final landing approach. The flight profile is built up step by step, the starting parameters for each segment being equal to those at the end of the preceding segment.

C.2.1.4 The aerodynamic-performance parameters in the ANP database are intended to yield a reasonably accurate representation of an aeroplane's actual flight path for the specified reference conditions (see **Section 2.5**). But the aerodynamic parameters and engine coefficients have been shown to be adequate for air temperatures up to 43 °C, aerodrome altitudes up to 4 000ft and across the range of weights specified in the ANP database. The equations thus permit the calculation of flight paths for other conditions; i.e. non-reference aeroplane weight, wind speed, air temperature, and runway elevation (air pressure), normally with sufficient accuracy for computing contours of average sound levels around an airport.

C.2.1.5 **Section C-4** explains how the effects of turning flight are taken into account for departures. This allows bank angle to be accounted for when calculating the effects of lateral directivity (installation effects). Also, during turning flight, climb gradients will generally be reduced depending in the radius of the turn and the speed of the aeroplane. (The effects of turns during the landing approach are more complex and are not covered at present. However these will rarely influence noise contours significantly.)

C.2.1.6 **Sections C-5** to **C-9** describe the recommended methodology for generating departure flight profiles, based on ANP database coefficients and procedural steps.

C.2.1.7 **Sections C-10** and **C-11** describe the methodology used to generate approach flight profiles, based on ANP database coefficients and flight procedures.

C.2.1.8 **Section C-12** provides worked examples of the calculations.

C.2.1.9 Separate sets of equations are provided to determine the net thrust produced by jet engines and propellers respectively. Unless noted otherwise, the equations for aerodynamic performance of an aeroplane apply equally to jet and propeller-powered aeroplanes.

C.2.1.10 Mathematical symbols used are defined at the beginning of this appendix and/or where they are first introduced. *In all equations the units of coefficients and constants must of course be consistent with the units of the corresponding parameters and variables. For consistency with the ANP database, the conventions of aeroplane performance engineering are followed in this appendix; distances and heights in feet (ft), speed in knots (kt), mass in pounds (lb), force in pounds-force (lbf), and so on - even though some dimensions (e.g. atmospheric ones) are expressed in SI units. Modellers using other unit systems should be very careful to apply appropriate conversion factors when adopting the equations to their needs.*

C.2.2 Flight path analysis

C.2.2.1 In some modelling applications the flight path information is provided not as procedural steps but as coordinates in position and time, usually determined by analysis of radar data. This is discussed in **Chapter 3** of the text. In this case the equations presented in this Appendix are used 'in reverse'; the engine thrust parameters are derived from the aeroplane motion rather than vice-versa. In general, once the flight path data has been averaged and reduced to segment form, each segment being classified by climb or descent, acceleration or deceleration, and thrust and flap changes, this is relatively straightforward by comparison with synthesis which often involves iterative processes.

C.3 ENGINE THRUST

C.3.1 The propulsive force produced by each engine is one of five quantities that need to be defined at the ends of each flight path segment (the others being height, speed, power setting and bank angle). Net thrust represents the component of engine gross thrust that is available for propulsion. For aerodynamic and acoustical calculations, the net thrust is referred to standard air pressure at mean sea level. This is known as *corrected net thrust, F_n/δ.*

C.3.2 This will be either the net thrust available when operating at a specified *thrust rating*, or the net thrust that results when the *thrust-setting parameter* is set to a particular value. For a turbojet or turbofan engine operating at a specific thrust rating, corrected net thrust is given by the equation

$$F_n / \delta = E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 + H \cdot T \qquad \text{(C-1)}$$

C.3.3 Data are also provided in the ANP database to allow calculation of non-rated thrust as a function of a thrust setting parameter. This is defined by some manufacturers as engine pressure ratio *EPR*, and by others as low-pressure rotor speed, or fan speed, N_1. When that parameter is *EPR*, Equation C-1 is replaced by

$$\begin{aligned} F_n / \delta = {} & E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 \\ & + H \cdot T + K_1 \cdot EPR + K_2 \cdot EPR^2 \end{aligned} \qquad \text{(C-2)}$$

where K_1 and K_2 are coefficients, from the ANP database that relate corrected net thrust and engine pressure ratio in the vicinity of the engine pressure ratio of interest for the specified aeroplane Mach number.

C.3.4 When engine rotational speed N_1 is the parameter used by the cockpit crew to set thrust, the generalised thrust equation becomes

$$\begin{aligned} F_n / \delta = {} & E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 \\ & + H \cdot T + K_3 \cdot \left(\frac{N_1}{\sqrt{\theta}} \right) + K_4 \cdot \left(\frac{N_1}{\sqrt{\theta}} \right)^2 \end{aligned} \qquad \text{(C-3)}$$

where

$\frac{N_1}{\sqrt{\theta}}$	is the corrected low pressure rotor speed, %; and
K_3, K_4	are constants derived from installed engine data encompassing the N_1 speeds of interest.

Note that for a particular aeroplane E, F, G_A, G_B and *H* in equations C-2 and C-3 might have different values from those in equation C-1.

C.3.5 Not every term in the equation will always be significant. For example, for flat-rated engines operating in air temperatures below the break point (typically 30°C), the temperature term may not be required. For engines not flat rated, ambient temperature must be considered when designating rated thrust. Above the engine flat rating temperature, a different set of engine thrust coefficients (E, F, G_A, G_B and $H)_{high}$ must be used to determine the thrust level available. Normal practice would then be to compute F_n/δ using both the low temperature and high temperature coefficients and to use the higher thrust level for temperatures *below* the flat rating temperature and use the lower calculated thrust level for temperature *above* the flat rating temperature.

C.3.6 Where only low temperature thrust coefficients are available, the following relationship may be used:

$$\begin{aligned} (F_n / \delta)_{high} = {} & F \cdot V_C + (E + H \cdot T_B) \\ & \cdot (1 - 0.006 \cdot T)/(1 - 0.006 \cdot T_B) \end{aligned} \qquad \text{(C-4)}$$

where

$(F_n/\delta)_{high}$	high-temperature corrected net thrust (pounds),
T_B	breakpoint temperature (in the absence of a definitive value assume a default value of 30 °C).

C.3.7 The ANP database provides values for the constants and coefficients in equations C-1 to C-4.

C.3.8 For propeller driven aeroplanes, corrected net thrust per engine should be read from graphs or calculated using the equation

$$F_n / \delta = (326 \cdot \eta \cdot P_p / V_T) / \delta \qquad \text{(C-5)}$$

where

η	is the propeller efficiency for a particular propeller installation and is a function of propeller rotational speed and aeroplane flight speed
V_T	is the true airspeed, kt
P_p	is net propulsive power for the given flight condition, e.g. max take-off or max climb power, hp

C.3.9 Parameters in Equation C-5 are provided in the ANP database for maximum take-off thrust and maximum climb thrust settings.

C.3.10 True airspeed V_T is estimated from the calibrated airspeed V_C using the relationship

$$V_T = V_C / \sqrt{\sigma} \qquad \text{(C-6)}$$

where σ is the ratio of the air density at the aeroplane to the mean sea-level value.

C3.1 Guidance on operation with reduced take-off thrust

C.3.1.1 Often, aeroplane take-off masses are below maximum allowable and/or the available runway field length exceeds the minimum required with the use of maximum take-off thrust. In these cases, it is common practice to reduce engine thrust below maximum levels in order to prolong engine life and, sometimes, for noise abatement purposes. Engine thrust can only be reduced to levels that maintain a required margin of safety. The calculation procedure used by airline operators to determine the amount of thrust reduction is regulated accordingly: it is complex and takes into account numerous factors including take-off weight, ambient air temperature, declared runway distances, runway elevation and runway obstacle clearance criteria. Therefore the amount of thrust reduction varies from flight to flight.

C.3.1.2 As they can have a profound effect upon departure noise contours, modellers should take reasonable account of reduced thrust operations and, to make best possible provision, to seek practical advice from operators.

C.3.1.3 If such advice is not available it is still advisable to make some allowance by alternative means. It is impractical to mirror the operators' calculations for noise modelling purposes; nor would they be appropriate alongside the conventional simplifications and approximations which are made for the purposes of calculating long term average noise levels. As a practicable alternative the following guidance is provided. It should be emphasised that considerable research is ongoing in this area and thus, this guidance is subject to change.

C.3.1.4 Analysis of FDR data has shown that the level of thrust reduction is strongly correlated with ratio of the actual take-off weight to the Regulated Take-off Weight (RTOW), down to a fixed lower limit[32]; i.e.

$$F_n / \delta = \left(F_n / \delta\right)_{max} \cdot W / W_{RTOW} \qquad \text{(C-7)}$$

where $(F_n/\delta)_{max}$ is the maximum rated thrust, W is the actual gross take-off weight and W_{RTOW} is the Regulated Take-off Weight.

C3.1.5 The RTOW is the maximum take-off weight that can be safely used, whilst satisfying take-off field length, engine-out and obstacle requirements. It is a function of the available runway length, airfield elevation, temperature, headwind, and flap angle. This information can be obtained from operators and should be more readily available than data on actual levels of reduced thrust. Alternatively, it may be computed using data contained in aeroplane flight manuals.

C.3.2 Reduced Climb Thrust

C.3.2.1 When employing reduced take-off thrust, operators often, but not always, reduce climb thrust from below maximum levels[33]. This prevents situations occurring where, at the end of the initial climb at take-off thrust, power has to be increased rather than cut back. However, it is more difficult to establish a rationale for a common basis here. Some operators use fixed detents below maximum climb thrust, sometimes referred to as Climb 1 and Climb 2, typically reducing climb thrust by 10 and 20 percent respectively relative to maximum. It is recommended that whenever reduced take-off thrust is used, climb thrust levels also be reduced by 10 percent.

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[32] Airworthiness authorities normally stipulate a lower thrust limit, often 25 percent below maximum.

[33] To which thrust is reduced after the initial climb at take-off power.

C.4 VERTICAL PROFILES OF AIR TEMPERATURE, PRESSURE, DENSITY AND WINDSPEED

C.4.1 For the purposes of this document, the variations of temperature, pressure and density with height above mean sea level are taken to be those of the International Standard Atmosphere [ref. 11]. The methodologies described below have been validated for aerodrome altitudes up to 4 000 ft above sea level and for air temperatures up to 43 °C (109 °F).

C.4.2 Although, in reality, mean wind velocity varies with both height and time, it is not usually practicable to take account of this for noise contour modelling purposes. Instead, the flight performance equations given below are based on the common assumption that the aeroplane is heading directly into a (default) headwind of 8 kt at all times - regardless of compass bearing (although no explicit account of mean wind velocity is taken in sound propagation calculations). Methods for adjusting the results for other headwind speeds are provided.

C.5 THE EFFECTS OF TURNS

C.5.1 The remainder of this appendix explains how to calculate the required properties of the segments joining the profile points *s*,*z* that define the two-dimensional flight path in the vertical plane above the flight track. Segments are defined in sequence in the direction of motion. At the end of any one segment (or at the start of roll in the case of the first for a departure) where the operational parameters and the next procedural step are defined, the need is to calculate the climb angle and track distance to the point where the required height and/or speed are reached.

C.5.2 If the track is straight, this will be covered by a single profile segment, the geometry of which can then be determined directly (albeit sometimes with a degree of iteration). But if a turn starts or ends, or changes in radius or direction, before the required end-conditions are reached, a single segment would be insufficient because the aeroplane lift and drag change with bank angle. <u>To account for the effects of the turn on the climb</u>, additional profile segments are required to implement the procedural step - as follows.

C.5.3 The construction of the ground track is described in **Section 3.6.1** of the text. This is done independently of any aeroplane flight profile (although with care not to define turns that could not be flown under normal operating constraints). But as the flight profile - height and speed as a function of track distance - is affected by turns so that the flight profile cannot be determined independently of the ground track.

C.5.4 To maintain speed in a turn the aerodynamic wing lift has to be increased, to balance centrifugal force as well as the aeroplane mass. This in turn increases drag and, consequently the propulsive thrust required. The effects of the turn are expressed in the performance equations as functions of bank angle ε which, for an aeroplane in level flight turning at constant speed on a circular path, is given by

$$\varepsilon = \tan^{-1}\left\{\frac{2.85 \cdot V^2}{r \cdot g}\right\} \qquad \text{(C-8)}$$

where V is the groundspeed, kt
r is the turn radius, ft
and g is the acceleration due to gravity, ft/s^2

C.5.5 All turns are assumed to have a constant radius and second-order effects associated with non-level flight paths are disregarded; bank angles are based on the turn radius *r* of the ground track only.

C.5.6 To implement a procedural step a provisional profile segment is first calculated using the bank angle ε at the start point - as defined by Equation C-8 for the track segment radius *r*. If the calculated length of the provisional segment is such that it does not cross the start or end of a turn, the provisional segment is confirmed and attention turns to the next step.

C.5.7 But if the provisional segment crosses one or more starts or ends of turns (where ε changes)[34], the flight parameters at the first such point are estimated by interpolation (see **Section 3.6.2**), saved along with its coordinates as end-point values, and the segment truncated. The second part of the procedural step is then applied from that point - once more assuming provisionally that it can be completed in a single segment with the same end conditions but with the new start point and new bank angle. If this second segment

[34] To avoid contour discontinuities caused by instantaneous changes of bank angle at the junctions between straight and turning flight, sub-segments are introduced into the noise calculations to allow linear transitions of bank angle over the first and last 5° of the turn. These are not necessary in the performance calculations; the bank angle is always given by equation B-8.

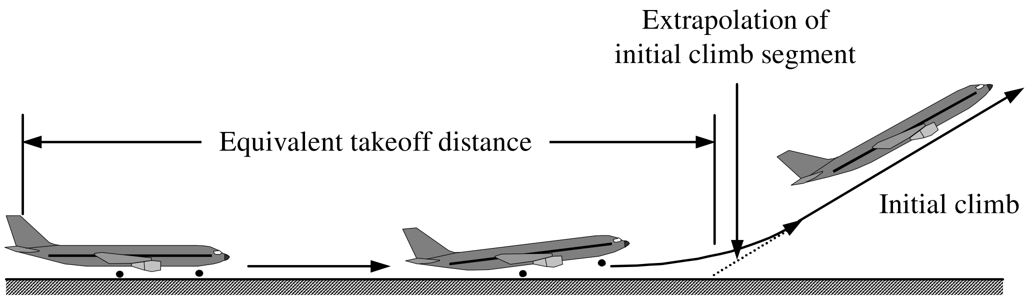

Figure C-1: Equivalent take-off distance

then passes another change of turn radius/direction, a third segment will be required - and so on until the end-conditions are achieved.

C.5.1 Approximate method

C.5.1.1 It will be apparent that accounting fully for the effects of turns, as described above, involves considerable computational complexity because the climb profile of any aeroplane has to be calculated separately for each ground track that it follows. But changes to the vertical profile caused by turns usually have a markedly smaller influence on the contours than the changes of bank angle, and some users may prefer to avoid the complexity - at the cost of some loss of precision - by disregarding the effects of turns on profiles while still accounting for the bank angle in the calculation of lateral sound emission (see **Sections 4.5.2 and 4.5.3**). Under this approximation profile points for a particular aeroplane operation are calculated once only, assuming a straight ground track (for which $\varepsilon = 0$).

C.6 TAKE-OFF GROUND ROLL

C.6.1 Take-off thrust accelerates the aeroplane along the runway until lift-off. Calibrated airspeed is then assumed to be constant throughout the initial part of the climb-out. Landing gear, if retractable, is assumed to be retracted shortly after lift-off.

C.6.2 For the purpose of this document, the actual take-off ground-roll is approximated by an equivalent take-off distance (into a default headwind of 8 kt), s_{TO8}, defined as shown in **Figure C-1**, as the distance along the runway from brake release to the point where a straight line extension of the initial landing-gear-retracted climb flight path intersects the runway.

C.6.3 On a level runway, the equivalent take-off ground-roll distance s_{TO8} in feet is determined from

$$s_{TO8} = \frac{B_8 \cdot \theta \cdot (W/\delta)^2}{N \cdot (F_n/\delta)} \qquad \text{(C-9)}$$

where

B_8 is a coefficient appropriate to a specific aeroplane/flap-deflection combination for the ISA reference conditions, including the 8-knot headwind, ft/lbf

W is the aeroplane gross weight at brake release, lbf

N is the number of engines supplying thrust.

Note: Since equation C-9 accounts for variation of thrust with airspeed and runway elevation, for a given aeroplane the coefficient B_8 depends only on flap deflection.

C.6.4 For headwind other than the default 8kt, the take-off ground-roll distance is corrected by using:

$$s_{TOw} = s_{TO8} \cdot \frac{(V_C - w)^2}{(V_C - 8)^2} \qquad \text{(C-10)}$$

where

S_{TOw} is the ground-roll distance corrected for headwind w, ft

V_C (in this equation) is the calibrated speed at take-off rotation, kt

w is the headwind, kt

C.6.5 The take-off ground-roll distance is also corrected for runway gradient as follows:

$$s_{TOG} = s_{TOw} \cdot \frac{a}{(a - g \cdot G_R)} \qquad \text{(C-11)}$$

where

S_{TOG}	is the ground-roll distance (ft) corrected for headwind and runway gradient,
a	is the average acceleration along the runway, equal to $(V_C \cdot \sqrt{\sigma})^2 / (2 \cdot s_{TOw})$, ft/s^2
G_R	is the runway gradient; positive when taking-off uphill

C.7 CLIMB AT CONSTANT SPEED

C.7.1 This type of segment is defined by the aeroplane's calibrated airspeed, flap setting, and the height and bank angle at its end, together with the headwind speed (default 8 kt). As for any segment, the segment start parameters including corrected net thrust are put equal to those at the end of the preceding segment - there are no discontinuities (except of flap angle and bank angle which, in these calculations, are allowed to change in steps). The net thrusts at the segment end are first calculated using the appropriate equation from C-1 to C-5. The average geometric climb angle γ (see **Figure C-1**) is then given by

$$\gamma = \arcsin\left(K \cdot \left[N \cdot \frac{\overline{F_n / \delta}}{\overline{W / \delta}} - \frac{R}{\cos \varepsilon}\right]\right) \qquad \text{(C-12)}$$

where the over-bars denote mid-segment values (= average of start-point and end-point values - generally the mid-segment values) and

K	is a speed-dependent constant equal to 1.01 when $V_C \leq 200$ kt or 0.95 otherwise. This constant accounts for the effects on climb gradient of climbing into an 8-knot headwind and the acceleration inherent in climbing at constant calibrated airspeed (true speed increases as air density diminishes with height).
R	is the ratio of the aeroplane's drag coefficient to its lift coefficient appropriate to the given flap setting. The landing gear is assumed to be retracted.
ε	Bank angle, radians

C.7.2 The climb angle is corrected for headwind w using:

$$\gamma_w = \gamma \cdot \frac{(V_C - 8)}{(V_C - w)} \qquad \text{(C-13)}$$

where γ_w is the average climb angle corrected for headwind.

C.7.3 The distance that the aeroplane traverses along the ground track, Δs, while climbing at angle γ_w, from an initial altitude h_1 to a final altitude h_2 is given by

$$\Delta s = \frac{(h_2 - h_1)}{\tan \gamma_w} \qquad \text{(C-14)}$$

C.7.4 As a rule, two distinct phases of a departure profile involve climb at constant airspeed. The first, sometime referred to as the *initial climb segment* is immediately after lift-off, where safety requirements dictate that the aeroplane is flown at a minimum airspeed of least the take-off safety speed. This is a regulated speed and should be achieved by 35ft above the runway during normal operation. However, it is common practice to maintain a initial climb speed slightly beyond the take-off safety speed, usually by 10-20kt, as this tends to improve the initial climb gradient achieved. The second is after flap retraction and initial acceleration, referred to as *continuing climb.*

During the initial climb, the airspeed is dependent on the take-off flap setting and the aeroplane gross weight. The calibrated initial climb speed V_{CTO} is calculated using the first order approximation:

$$V_{CTO} = C \cdot \sqrt{W} \qquad \text{(C-15)}$$

where C is a coefficient appropriate to the flap setting (kt/√lbf), read from the ANP database.

C.7.5 For continuing climb after acceleration, the calibrated airspeed is a user input parameter.

C.8 POWER CUTBACK (TRANSITION SEGMENT)

C.8.1 Power is reduced, or *cut back*, from take-off setting at some point after take-off in order to extend engine life and often to reduce noise in certain areas. Thrust is normally cut back during either a constant speed climb segment (**Section C.6**) or an acceleration segment (**Section C.8**). As it is a relatively brief process, typically of only 3 - 5 seconds duration, is it modelled by adding a 'transition segment' to the primary segment. This is usually taken to cover a horizontal ground distance of 1000 ft (305 m).

C.8.1 Amount of thrust reduction

C.8.1.1 n normal operation the engine thrust is reduced to the maximum climb thrust setting. Unlike the take-off thrust, climb thrust can be sustained indefinitely, usually in practice until the aeroplane has reached its initial cruise altitude. The maximum climb thrust level is determined with equation C-1 using the manufacturer supplied maximum thrust coefficients. However, noise abatement requirements may call for additional thrust reduction, sometimes referred to as a deep cutback. For safety purposes the maximum thrust reduction is limited[35] to an amount determined by the performance of the aeroplane and the number of engines.

C.8.1.2 The minimum "reduced-thrust" level is sometimes referred to as the engine-out "reduced thrust":

$$(F_n / \delta)_{engine.out} = \frac{(W / \delta_2)}{(N-1)} \cdot \left[\frac{\sin\left(\tan^{-1}(0.01 \cdot G')\right)}{K} + \frac{R}{\cos\varepsilon} \right] \quad \text{(C-16)}$$

where

δ_2 is the pressure ratio at altitude h_2

G' is the engine-out percentage climb gradient:

= 0% for aeroplanes with automatic thrust restoration systems; otherwise,

= 1.2% for 2-engine aeroplane

= 1.5% for 3-engine aeroplane

= 1.7% for 4-engine aeroplane

C.8.2 Constant speed climb segment with cutback

C.8.2.1 The climb segment gradient is calculated using equation C-12, with thrust calculated using either C-1 with maximum climb coefficients, or C-16 for reduced thrust. The climb segment is then broken into two sub-segments, both having the same climb angle. This is illustrated in **Figure C-2**.

C.8.2.2 The first sub-segment is assigned a 1000 ft (304 m) ground distance, and the corrected net thrust per engine at the end of 1000 ft is set equal to the cutback value. (If the original horizontal distance is less than 2000 ft, one half of the segment is used to cutback thrust.) The final thrust on the second sub-segment is also set equal to the cutback thrust. Thus, the second sub-segment is flown at constant thrust.

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35 "Noise Abatement Procedures", ICAO Document 8168 "PANS-OPS" Vol.1 Part V, Chapter 3, ICAO 2004.

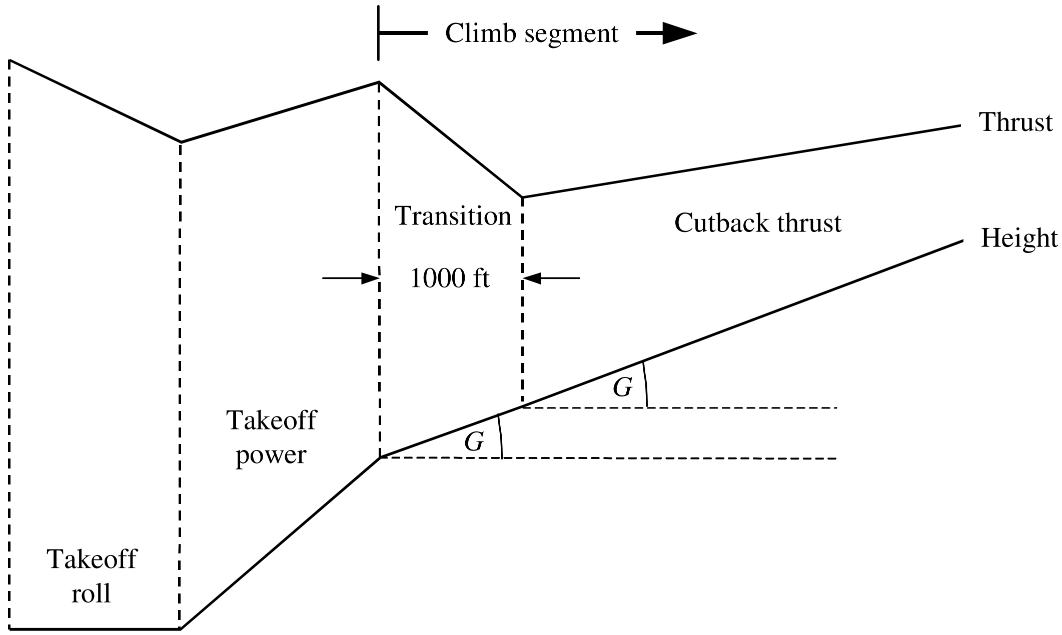

Figure C-2: Constant speed climb segment with cutback (illustration – not to scale)

C.9 ACCELERATING CLIMB AND FLAP RETRACTION

C.9.1 This usually follows the initial climb. As for all flight segments, the start-point altitude h_1, true airspeed V_{T1}, and thrust $(F_n/\delta)_1$ are those from the end of the preceding segment. The end-point calibrated airspeed V_{C2} and the average climb rate ROC are user inputs (bank angle ε is a function of speed and radius of turn). As they are interdependent, the end altitude h_2, end true airspeed V_{T2}, end thrust $(F_n/\delta)_2$ and segment track length Δs have to be calculated by iteration; the end altitude h_2 is guessed initially and then recalculated repeatedly using equations C-16 and C-17 until the difference between successive estimates is less than a specified tolerance, e.g. one foot. A practical initial estimate is $h_2 = h_1 + 250$ ft.

C.9.2 The segment track length (horizontal distance covered) is estimated as:

$$s_{seg} = 0.95 \cdot k^2 \cdot (V_{T2}^2 - V_{T1}^2) / 2(a_{max} - G \cdot g) \qquad \text{(C-17)}$$

where

0.95 is a factor to account for effect of 8 kt headwind when climbing at 160 kt

k is a constant to convert kt to ft/sec = 1.688 ft/s per kt

V_{T2} = true airspeed at segment end, kt: $V_{T2} = V_{C2} / \sqrt{\sigma_2}$

where σ_2 = air density ratio at end altitude h_2

a_{max} = maximum acceleration in level flight (ft/s^2)

$= g[\, N \cdot \overline{F_n / \delta} / (\overline{W / \delta}) - R / \cos\varepsilon \,]$

G = climb gradient $\approx \dfrac{ROC}{60 \cdot k \cdot \overline{V_T}}$

where ROC = climb rate, ft/min

C.9.3 Using this estimate of Δs, the end altitude h_2' is then re-estimated using:

$$h_2' = h_1 + s \cdot G / 0.95 \qquad \text{(C-18)}$$

C.9.4 As long as the error $|h_2' - h_2|$ is outside the specified tolerance, the steps C-17 and C-18 are repeated using the current iteration segment-end values of altitude h_2, true airspeed V_{T2}, corrected net thrust per engine $(F_n/\delta)_2$. When the error is within the tolerance, the iterative cycle is terminated and the acceleration segment is defined by the final segment-end values.

Note: If during the iteration process $(a_{max} - G{\cdot}g) < 0.02$g, the acceleration may be too small to achieve the desired V_{C2} in a reasonable distance. In this case, the climb gradient can be limited to $G = a_{max}/g - 0.02$, in effect reducing the desired climb rate in order to maintain acceptable acceleration. If $G < 0.01$ it should be concluded there is not enough thrust to achieve the acceleration and climb specified; the calculation should be terminated and the procedure steps revised[36].

C.9.5 The acceleration segment length is corrected for headwind *w* by using:

$$\Delta s_w = \Delta s \cdot \frac{(V_T - w)}{(V_T - 8)} \qquad \text{(C-19)}$$

C.9.1 Accelerating segment with cutback

C.9.1.1 Thrust cutback is inserted into an acceleration segments in the same way as for a constant speed segment; by turning its first part into a transition segment. The cutback thrust level is calculated as for the constant-speed cutback thrust procedure, using equation C-1 only. Note it is not generally possible to accelerate and climb whilst maintaining the minimum engine-out thrust setting. The thrust transition is assigned a 1000 ft (305 m) ground distance, and the corrected net thrust per engine at the end of 1000 ft is set equal to the cutback value. The speed at the end of the segment is determined by iteration for a segment length of 1000 ft. (If the original horizontal distance is less than 2000 ft, one half of the segment is used for thrust change.) The final thrust on the second sub-segment is also set equal to the cutback thrust. Thus, the second sub-segment is flown at constant thrust.

C.10 ADDITIONAL CLIMB AND ACCELERATION SEGMENTS AFTER FLAP RETRACTION

C.10.1 If additional acceleration segments are included in the climb-out flight path, equations C-12 to C-19 should be used again to calculate the ground-track distance, average climb angle, and height gain for each. As before, the final segment height must be estimated by iteration.

[36] In either case the computer model should be programmed to inform the user of the inconsistency.

C.11 DESCENT AND DECELERATION

C.11.1 Approach flight normally requires the aeroplane to descend and decelerate in preparation for the final approach segment where the aeroplane is configured with approach flap and gear down. The flight mechanics are unchanged from the departure case; the main difference is that the height and speed profile is generally known, and it is the engine thrust levels that must be estimated for each segment. The basic force balance equation is:

$$F_n / \delta = W \cdot \frac{R \cdot \cos\gamma + \sin\gamma + a/g}{N \cdot \delta} \qquad \text{(C-20)}$$

C.11.2 Equation C-20 may be used in two distinct ways. First the aeroplane speeds at the start and end of a segment may be defined, along with a descent angle (or level segment distance) and initial and final segment altitudes. In this case the deceleration may be calculated using:

$$a = \frac{(V_2 / \cos\gamma)^2 - (V_1 / \cos\gamma)^2}{(2 \cdot \Delta s / \cos\gamma)} \qquad \text{(C-21)}$$

where Δs is the ground distance covered and V_1 and V_2 and are the initial and final groundspeeds calculated using

$$V = \frac{V_C \cdot \cos\gamma}{\sqrt{\sigma}} - w \qquad \text{(C-22)}$$

C.11.3 Equations C-20, C-21 and C-22 confirm that whilst decelerating over a specified distance at a constant rate of descent, a stronger headwind will result in more thrust being required to maintain the same deceleration, whilst a tailwind will require less thrust to maintain the same deceleration.

C.11.4 In practice most, if not all decelerations during approach flight are performed at idle thrust. Thus for the second application of Equation C-20, thrust is defined at an idle setting and the equation is solved iteratively to determine (1) the deceleration and (2) the height at the end of the deceleration segment - in a similar manner to the departure acceleration segments. In this case, deceleration distance can be very different with head and tail winds and it is sometimes necessary to reduce the descent angle in order to obtain reasonable results.

C.11.5 For most aeroplanes, idle thrust is not zero and, for many, it is also a function of flight speed. Thus, Equation C-20 is solved for the deceleration by inputting an idle thrust; the idle thrust is calculated using an equation of the form:

$$(F_n/\delta)_{idle} = E_{idle} + F_{idle} \cdot V_C + G_{A,idle} \cdot h + G_{B,idle} \cdot h^2 + H_{idle} \cdot T \qquad \text{(C-23)}$$

where (E_{idle}, F_{idle}, $G_{A,idle}$, $G_{B,idle}$ and H_{idle}) are idle thrust engine coefficients available in the ANP database.

C.12 LANDING APPROACH

C.12.1 The landing approach calibrated airspeed, V_{CA}, is related to the landing gross weight by an equation of the same form as Equation C-11, namely

$$V_{CA} \approx D \cdot \sqrt{W} \qquad \text{(C-24)}$$

where the coefficient *D* (kt/√lbf) corresponds to the landing flap setting.

C.12.2 The corrected net thrust per engine during descent along the approach glideslope is calculated by solving equation C-12 for the landing weight *W* and a drag-to-lift ratio *R* appropriate for the flap setting with landing gear extended. The flap setting should be that typically used in actual operations. During landing approach, the glideslope descent angle γ may be assumed constant. For jet-powered and multi-engine propeller aeroplanes, γ is typically −3°. For single-engine, propeller-powered aeroplanes, γ is typically −5°.

C.12.3 The average corrected net thrust is calculated by inverting equation C-12 using K=1.03 to account for the deceleration inherent in flying a descending flight path into an 8-knot reference headwind at the constant calibrated airspeed given by equation C-24, i.e.

$$\overline{F_n/\delta} = \frac{\overline{W/\delta}}{N} \cdot \left(R + \frac{\sin\gamma}{1.03}\right) \qquad \text{(C-25)}$$

For headwinds other than 8kt, average corrected net thrust becomes

$$\left(\overline{F_n/\delta}\right)_w = \overline{F_n/\delta} + 1.03 \cdot \overline{W/\delta} \cdot \frac{\sin\gamma \cdot (w-8)}{N \cdot V_{CA}} \qquad \text{(C-26)}$$

The horizontal distance covered is calculated by:

$$\Delta s = \frac{(h_2 - h_1)}{\tan\gamma} \qquad \text{(C-27)}$$

(positive since $h_1 > h_2$ and γ is negative).

C.13 WORKED EXAMPLES

C.13.1 The following worked examples for the Boeing 737-300 illustrate how the various equations are used with parameters defining aeroplane departure and approach ‘procedures’ to construct flight profiles together with power settings.

Departure Profile

Boeing 737-300: take-off mass of 53,968 kg (119,000 lb), ISA conditions at sea-level, headwind component 8kt.

The procedural steps are:

(1) Take-off, flap 5, full take-off thrust

(2) Maintain take-off power, Climb at V_2 + 10 kt to 1000ft

(3) Maintain take-off power, accelerate to 185 kt CAS, climbing at 1544 ft/min

(4) Maintain take-off power, select flap 1, accelerate to 190 kt CAS, climbing at 1544 ft/min.

(5) Reduce thrust to maximum climb thrust, select zero flap, accelerate to 220 kt CAS, climbing at 1000 ft/min

(6) Maintain maximum climb thrust, 220 kt CAS, zero flap and climb to 3000 ft.

(7) Maintain maximum climb thrust, accelerate to 250 kt CAS, climbing at 1000 ft/min

(8) Maintain maximum climb thrust and 250 kt CAS, zero flap and climb to 5500 ft

(9) Maintain maximum climb thrust, 250 kt CAS, zero flap and climb to 7500 ft[37]

(10) Maintain maximum climb thrust, 250 kt CAS, zero flap and climb to 10000 ft

C.13.2 The calculation steps and results are shown in **Table C-1**. Note that step 5 is split into

[37] Although apparently redundant as Step 10 supplants it, Step 9, like much ANP content, dates from a time when models had to be less sophisticated. In this particular case the original need was to reduce the risk of using excessively long segments. Modern tools designed for more capable computers can be designed to warn of such risks automatically.

two parts, the initial part including a 1000 ft long segment to account for thrust reduction. The length of the segment following acceleration at the specified climb rate determines the end speed for this segment.

Approach Profile

Boeing 737-300: landing mass 46,636 kg (102600 lb), ISA conditions at sea-level, 8 kt headwind. Relatively conventional approach with a long decelerating segment in level flight.

The procedural steps are:

(1) Descend from 6000 ft to 3000 ft with a descent angle of 3°, whilst maintaining 250 kt CAS, flap code zero.

(2) At 3000 ft, level off, select flap code 5 and decelerate to 170 kt CAS over a distance of 21000 ft.

(3) Maintain altitude of 3000 ft, flap code 5 and decelerate to 148.6 kt CAS over a distance of 5000 ft.

(4) Descend at 3°, select flap code D-15 and decelerate to 139 kt CAS by an altitude of 2500 ft.

(5) Descend at 3°, select flap code D-30 and maintain 139 kt (reference landing speed).

(6) Touchdown roll out for 294 ft, decelerate to 132.1 kt.

(7) Touchdown roll for 2940 ft, thrust at 60% maximum.

(8) End of procedure, speed at 30 kt, thrust at 10% maximum.

Note: The approach example features a level flight segment at 3000ft along which speed is reduced and illustrates how the improved methodology may be applied. However the specified ‘procedural steps’ are not at present tabulated in the ANP database[38]. Data for the Boeing 737-300 were generated some years ago when the SAE data specification called only for a continuous 3° descent from 6000ft to touchdown, whilst continuously decelerating. Such a flight profile is rarely typical of operations at most airports. Although the aerodynamic coefficients necessary to calculate more realistic approach profiles have still not been provided, more recent data entries remedy the problem via tabulations of ‘profile points’ data for an approach with a 3000ft level flight segment. (A remaining difficulty with ‘profile points’ is that they are fixed; alternative profiles cannot be created.) In future, the methodology described in **Section C-10** will enable the provision of ‘procedural steps’ data for profiles incorporating level flight segments and deceleration.

[38] However it is consistent with the current ANP database ‘procedural steps’ to the extent that the flap deployment has been sequenced based on the same speeds.

Table C-1: Example Departure Profile

Segment		Start of roll	Take-off ground roll	Climb to 1000ft	Accelerate to 185kt	Accelerate to 190kt	Thrust cutback (Accelerate to 220 kt)	Accelerate to 220kt	Climb to 3000ft	Accelerate to 250kt	Climb to 5500ft	Climb to 7500ft	Climb to 10000ft
Start speed (CAS)	(kt)		0	164.6	164.6	185.0	190.0	196.7	220.0	220.0	250.0	250.0	250.0
End speed (CAS)	(kt)		164.6	164.6	185.0	190.0	196.7	220.0	220.0	250.0	250.0	250.0	250.0
Start height	(ft)		-	-	-	-	-	-	-	-	-	-	-
End height	(ft)		-	1000	1331	1408	1461	1646	3000	3268	5500	7500	10000
Input climb rate	(ft/min)		-	-	1544	1544	1000	1000	-	1000	-	-	-
Flap	(°)		5	5	5	1	zero	zero	zero	zero	zero	zero	zero
Thrust rating	(-)		Max take-off	Max take-off	Max take-off	Max take-off	Max climb	Max climb	Max climb	Max climb	Max climb	Max climb	Max climb
Start FN/δ	(lb/eng)	18745	18745	15433	15837	15561	14376	14269	13894	14105	13627	13974	14286
End FN/δ	(lb/eng)	-	15433	15837	15561	15492	14269	13894	14105	13627	13974	14286	14675
Start θ	(-)	1.000	1.000	1.000	0.993	0.991	0.990	0.990	0.989	0.979	0.978	0.962	0.948
End θ	(-)	1.000	1.000	0.993	0.991	0.990	0.990	0.989	0.979	0.978	0.962	0.948	0.931
Start δ	(-)	1.000	1.000	1.000	0.964	0.953	0.950	0.948	0.942	0.896	0.887	0.817	0.757
End δ	(-)	1.000	1.000	0.964	0.953	0.950	0.948	0.942	0.896	0.887	0.817	0.757	0.688
Start σ	(-)	1.000	1.000	1.000	0.971	0.962	0.959	0.958	0.953	0.915	0.908	0.849	0.798
End σ	(-)	1.000	1.000	0.971	0.962	0.959	0.958	0.953	0.915	0.908	0.849	0.798	0.738
Weight/δ (mean)	(lb)	119000	119000	121173	124140	125067	125365	125910	129509	133435	139768	151324	164882
Climb factor	(-)	-	-	1.01	1.01	1.01	1.01	0.95	0.95	0.95	0.95	0.95	0.95
Climb gradient	(-)	-	-	0.1817	0.1765	0.1748	0.1690	0.1542	0.1470	0.1390	0.1291	0.1188	0.1082
Wind adjustment	(-)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Eq. take-off distance	(ft)	-	5506	-	-	-	-	-	-	-	-	-	-
Start VTAS	(kt)	0.0	0.0	164.6	167.1	188.7	194.0	201.0	225.4	230.0	262.4	271.4	279.8
End VTAS	(kt)	-	164.6	167.1	188.7	194.0	201.0	225.4	230.0	262.4	271.4	279.8	290.9
Sector distance gain	(ft)	0	5506	5441	3671	926	999	3801	9143	6357	17197	16757	23021
Sector height gain	(ft)	0	0	1000	331	78	53	185	1354	268	2232	2000	2500
Total distance gain	(ft)	0	5506	10947	14618	15544	16543	20344	29487	35844	53041	69798	92818
Total height gain	(ft)	0	0	1000	1331	1408	1461	1646	3000	3268	5500	7500	10000

Table C-2: Example approach profile

	Units	Step 1	Step 2		Step 3		Step 4		Step 5		Step 6	Step 7	Step 8
Flap code		zero	5	5	5	5	D-15	D-15	D-15	D-30	D-30	D-30	D-30
D		0	0	0	0	0	0	0	0	0.434	0.434	0.434	0.434
R		0.062	0.0791	0.0791	0.0791	0.0791	0.1103	0.1103	0.1103	0.1247	0.1247	0.1247	0.1247
Segment:		Descend	Level	Level	Level	Level	Descend	Descend	Descend	Descend	Land	Decelerate	Decelerate
Descent angle	(°)	-3	-	-	-	-	-3	-3	-3	-3	-3	-	-
Distance	(ft)		1000	20000	1000	4000	-	-	-	-	294	2940	0
Ground thrust	(%)	-	-	-	-	-	-	-	-	-	-	40	10
Start:													
CAS	(kt)	250.0	250.0	246.2	170.0	165.7	148.6	147.6	139.0	139.0	139.0	132.1	30.0
Altitude (h)	(ft)	6000	3000	3000	3000	3000	3000	2948	2500	2448	0	0	0
Δ h	(ft)	3000	0	0	0	0	52.4	447.6	52.4	2447.6	0	0	0
θ	(-)	0.959	0.979	0.979	0.979	0.979	0.979	0.980	0.983	0.983	1.000	1.000	1.000
δ	(-)	0.801	0.896	0.896	0.896	0.896	0.896	0.898	0.913	0.915	1.000	1.000	1.000
σ	(-)	0.836	0.915	0.915	0.915	0.915	0.915	0.917	0.929	0.930	1.000	1.000	1.000
TAS	(kt)	273.4	261.3	257.4	177.7	173.2	155.3	154.2	144.2	144.1	139.0	132.1	30.0
GSP	(kt)	265.5	253.3	249.4	169.7	165.2	147.3	146.2	136.2	136.1	131.0	0.0	0.0
RoD (ft/min)	(ft/min)	-1258.6	0.0	0.0	0.0	0.0	-745.6	-721.4	-699.8	-699.8	0.0	0.0	0.0
Mid-values:													
θ	(-)	0.969	0.979	0.979	0.979	0.979	0.980	0.981	0.983	0.992	1.000	1.000	1.000
δ	(-)	0.849	0.896	0.896	0.896	0.896	0.897	0.905	0.914	0.957	1.000	1.000	1.000
σ	(-)	0.875	0.915	0.915	0.915	0.915	0.916	0.923	0.930	0.965	1.000	1.000	1.000
Calculation:													
Segment length (ft)	(ft)	57243	1000	20000	1000	4000	1000	8541	1000	46703	-294	-2940	0
Deceleration (m/s²)	(m/s²)	-0.048	-0.731	-0.731	-0.731	-0.615	0.000	-0.143	-0.143	0.000	-	-	-
Track distance	(ft)	140487	83243	82243	62243	61243	57243	56243	47703	46703	0	-294	-3234
FN/δ	(lb/eng)	302.1	260.8	260.8	260.8	936.5	936.5	2467.6	2427.3	4144.0	3790.4	8000.0	2000.0

Note: Underlined figures are inputs procedural step values, other number are calculated

Appendix D

Modelling of lateral ground track spreading

D.1 It is recommended that, in the absence of radar data, lateral ground track dispersion be modelled on the assumption that the spread of tracks perpendicular to the backbone track follows a Gaussian normal distribution. Experience has shown that this assumption is a reasonable one in most cases.

D.2 Assuming a Gaussian distribution with a standard deviation S, illustrated in **Figure D-1**, about 98.8 percent of all movements fall within boundaries of $\pm 2.5 \cdot S$ (i.e. within a swathe of width of $5 \cdot S$).

D.3 A Gaussian distribution can normally be modelled adequately using 7 discrete sub-tracks evenly spaced between the $\pm 2.5 \cdot S$ boundaries of the swathe as shown in **Figure D-1**.

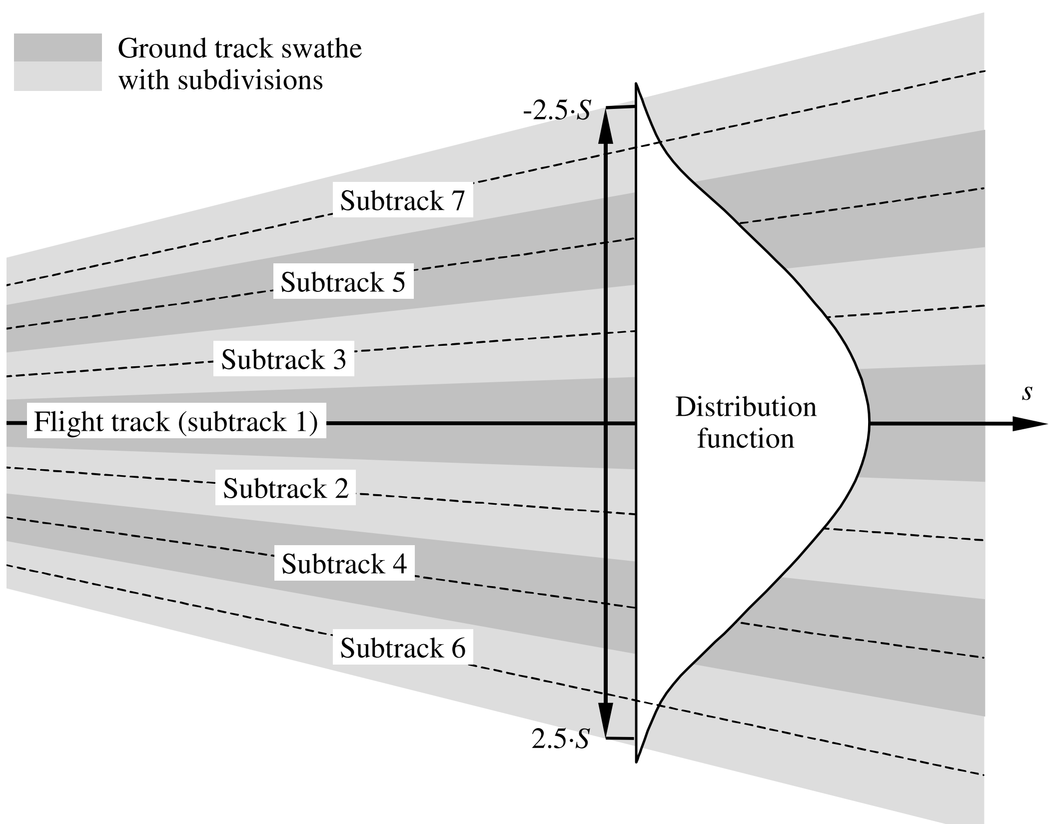

Figure D-1: Subdivision of a ground track into 7 subtracks. The width of the swathe is 5 times the standard deviation of the flight track spreading.

D.4 However, the adequacy of the approximation depends on the relationship of the sub-track track separation to the heights of the aeroplanes above. There may be situations (very tight or very dispersed tracks) where a different number of subtracks is more appropriate. Too few subtracks cause ‘fingers’ to appear in the contour. **Tables D-1** and **D-2** show the parameters for a subdivision into between 5 and 13 subtracks. **Table D-1** shows the location of the particular subtracks, **Table D-2** the corresponding percentage of movements on each subtrack.

Table D-1: Location of 5, 7, 9, 11 or 13 subtracks. The overall width of the swathe (containing 98% of all movements) is 5 times the standard deviation

Subtrack number	Location of subtracks for subdivision into				
	5 subtracks	7 subtracks	9 subtracks	11 subtracks	13 subtracks
12 / 13					$\pm 2.31 \cdot S$
10 / 11				$\pm 2.27 \cdot S$	$\pm 1.92 \cdot S$
8 / 9			$\pm 2.22 \cdot S$	$\pm 1.82 \cdot S$	$\pm 1.54 \cdot S$
6 / 7		$\pm 2.14 \cdot S$	$\pm 1.67 \cdot S$	$\pm 1.36 \cdot S$	$\pm 1.15 \cdot S$
4 / 5	$\pm 2.00 \cdot S$	$\pm 1.43 \cdot S$	$\pm 1.11 \cdot S$	$\pm 0.91 \cdot S$	$\pm 0.77 \cdot S$
2 / 3	$\pm 1.00 \cdot S$	$\pm 0.71 \cdot S$	$\pm 0.56 \cdot S$	$\pm 0.45 \cdot S$	$\pm 0.38 \cdot S$
1	0	0	0	0	0

Table D-2: Percentage of movements on 5, 7, 9, 11 or 13 subtracks. The overall width of the swathe (containing 98% of all movements) is 5 times the standard deviation

Subtrack number	Percentage of movements on subtrack for subdivision into				
	5 subtracks	7 subtracks	9 subtracks	11 subtracks	13 subtracks
12 / 13					1.1 %
10 / 11				1.4 %	2.5 %
8 / 9			2.0 %	3.5 %	4.7 %
6 / 7		3.1 %	5.7 %	7.1 %	8.0 %
4 / 5	6.3 %	10.6 %	12.1 %	12.1 %	11.5 %
2 / 3	24.4 %	22.2 %	19.1 %	16.6 %	14.4 %
1	38.6 %	28.2 %	22.2 %	18.6 %	15.6 %

Appendix E

Recalculation of NPD-data for non-reference conditions

E.1 The noise level contributions from each segment of the flight path are derived from the NPD-data stored in the international ANP database. However it is important to note that these data have been normalised using average atmospheric attenuation rates defined in SAE AIR-1845 [ref. 1]. Those rates are averages of values determined during aeroplane noise certification testing in Europe and the USA. The wide variation of atmospheric conditions (temperature and relative humidity) in those tests is shown in **Figure E-1** (taken from [ref. 12]).

E.2 The curves overlaid on **Figure E-1**, calculated using an industry standard atmospheric attenuation model ARP 866A [ref. 13], illustrate that across the test conditions a substantial variation of high frequency (8kHz) sound absorption would be expected (although the variation of overall absorption would be rather

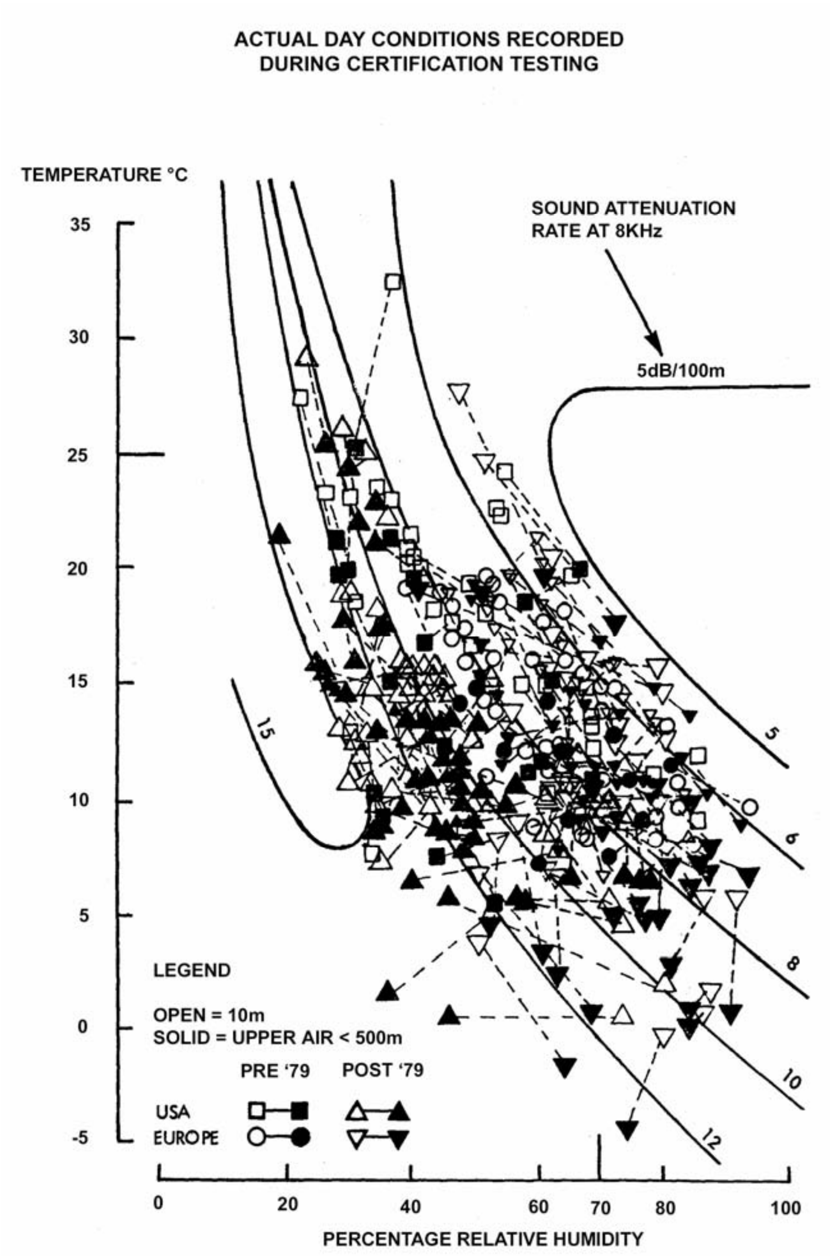

Figure E-1: Meteorological conditions recorded during noise certification tests

less).

E.3 Because the attenuation rates [ref. 1], given in **Table E-1**, are arithmetic averages, the complete set cannot be associated with a single reference atmosphere (i.e. with specific values of temperature and relative humidity). They should be thought of as properties of a purely notional atmosphere - referred to as the 'AIR-1845 atmosphere'.

Table E-1: Average atmospheric attenuation rates used to normalise NPD data in the ANP database [ref. 1]

Centre frequency of 1/3-octave band [Hz]	Attenuation rate [dB/100m]	Centre frequency of 1/3-octave band [Hz]	Attenuation rate [dB/100m]
50	0.033	800	0.459
63	0.033	1 000	0.590
80	0.033	1 250	0.754
100	0.066	1 600	0.983
125	0.066	2 000	1.311
160	0.098	2 500	1.705
200	0.131	3 150	2.295
250	0.131	4 000	3.115
315	0.197	5 000	3.607
400	0.230	6 300	5.246
500	0.295	8 000	7.213
630	0.361	10 000	9.836

E.4 The attenuation coefficients in **Table E-1** should be considered valid over reasonable ranges of temperature and humidity. However, to check whether adjustments may be necessary, ARP-866A [ref. 13] should be used to calculate average atmospheric absorption coefficients for the average airport temperature *T* and relative humidity *RH*. If a comparison of these attenuation rates with those in **Table E-1** indicates that adjustment is required, the following methodology should be used.

E.5 The ANP database provides the following NPD data for each power setting:

- maximum sound level versus slant distance, $L_{max}(d)$
- time integrated level versus distance for the reference airspeed, $L_E(d)$, and
- unweighted reference sound spectrum at a slant distance of 305 m (1000 ft), $L_{n,ref}(d_{ref})$ where *n* = frequency band (ranging from 1 to 24 for 1/3-octave bands with centre frequencies from 50Hz to 10kHz),

all data being normalised to the AIR-1845 atmosphere.

E.6 Adjustment of the NPD curves to user-specified conditions *T* and *RH* is performed in three steps:

1. First the reference spectrum is corrected to remove the SAE AIR-1845 atmospheric attenuation $\alpha_{n,ref}$:

$$L_n\left(d_{ref}\right) = L_{n,ref}\left(d_{ref}\right) + \alpha_{n,ref} \cdot d_{ref} \qquad \text{(E-1)}$$

where $L_n(d_{ref})$ is the unattenuated spectrum at d_{ref} = 305m and $\alpha_{n,ref}$ is the coefficient of atmospheric absorption for the frequency band *n* taken from **Table E-1** (but expressed in dB/m).

2. Next the corrected spectrum is adjusted to each of the ten standard NPD distances[39] d_i using attenuation rates for both (1) the SAE AIR-1845 atmosphere and (2) the user-specified atmosphere (based on SAE ARP-866A).

(1) For the SAE AIR-1845 atmosphere:

$$L_{n,ref}(d_i) = L_n\left(d_{ref}\right) - 20.\lg(d_i / d_{ref}) - \alpha_{n,ref} \cdot d_i \qquad \text{(E-2)}$$

(2) For the user atmosphere:

$$L_{n,866A}(T, RH, d_i) = L_n\left(d_{ref}\right) - 20.\lg(d_i / d_{ref}) - \alpha_{n,866A}(T, RH) \cdot d_i \qquad \text{(E-3)}$$

where $\alpha_{n,866A}$ is the coefficient of atmospheric absorption for the frequency band *n* (expressed in dB/m) calculated using SAE ARP-866A with temperature *T*, and relative humidity *RH*.

[39] The NPD distances are 200, 400, 630, 1 000, 2 000, 4 000, 6 300, 10 000, 16 000 and 25 000 ft.

3. At each NPD distance d_i the two spectra are A-weighted and decibel-summed to determine the resulting A-weighted levels $L_{A,866A}$ and $L_{A,ref}$ - which are then subtracted arithmetically:

$$\Delta L(T,RH,d_i) = L_{A,866A} - L_{A,ref}$$
$$= 10 \cdot \lg \sum_{n=1}^{24} 10^{(L_{n,866A}(T,RH,d_i) - A_n)/10}$$
$$-10 \cdot \lg \sum_{n=1}^{24} 10^{(L_{n,ref}(d_i) - A_n)/10} \qquad \text{(E-4)}$$

E.7 The increment ΔL is the difference between the NPDs in the user-specified atmosphere and the reference atmosphere. This is added to the ANP database NPD data value to derive the adjusted NPD data.

E.8 Applying ΔL to adjust both L_{max} and L_E NPDs effectively assumes that different atmospheric conditions affect the reference spectrum only and have no effect on the shape of the level-time-history. This may be considered valid for typical propagation ranges and typical atmospheric conditions.

E.9 The following is an example of the application of the NPD Spectral Adjustment**:** Adjust standard NPD data to the atmosphere 10 °C and 80% relative humidity.

E.9.1 Using the SEL NPD data presented in **Appendix H** for the V2527A, the matching spectral classes in the ANP database are 103 and 205 for departure and arrival respectively. The spectra data are tabulated in **Table E-2**.

E.9.2 First the spectrum levels (referenced to 305 m/1000 ft) are corrected back to the source to remove the SAE AIR-1845 atmosphere, ignoring spherical spreading effects. This is done using equation E-1. The corresponding spectra at source are also tabulated in **Table E-2**.

Table E-2: Spectra for V2527 NPD from ANP database and calculated source spectra

	At 1,000 ft		At Source	
Freq (Hz)	**DEP_103 (dB)**	**ARR_205 (dB)**	**DEP_103 (dB)**	**ARR_205 (dB)**
50	56.7	68.3	57.0	68.6
63	66.1	60.7	66.4	61.0
80	70.1	64.6	70.4	64.9
100	72.8	67.4	73.5	68.1
125	76.6	78.4	77.3	79.1
160	73.0	74.8	74.0	75.8
200	74.5	71.4	75.8	72.7
250	77.0	72.4	78.3	73.7
315	75.3	72.0	77.3	74.0
400	72.2	72.4	74.5	74.7
500	72.2	71.6	75.2	74.6
630	71.2	72.0	74.8	75.6
800	70.2	71.0	74.8	75.6
1000	70.0	70.0	75.9	75.9
1250	69.6	68.9	77.1	76.4
1600	71.1	67.2	80.9	77.0
2000	70.6	65.8	83.7	78.9
2500	67.1	64.4	84.2	81.5
3150	63.4	63.0	86.4	86.0
4000	63.5	62.0	94.7	93.2
4500	58.2	60.6	94.3	96.7
6300	51.5	54.4	104.0	106.9
8000	42.3	48.5	114.4	120.6
10000	37.7	39.0	136.1	137.4

E.9.3 The source spectra data are then propagated out to the standard NPD data distances using equations E-2 and E-3, together with the absorption coefficients in **Table E-1** for the AIR-1845 atmosphere and using absorption coefficients calculated using SAE ARP-866A (Ref 15) for the atmosphere, 10 °C, 80 % relative humidity. The two sets of absorption coefficients are listed in **Table E-3**.

Table E-3: AIR-1845 absorption coefficients (from Table E-1) and coefficients for 10 °C/80 % relative humidity calculated using ARP-866A.

Frequency (Hz)	AIR-1845 Absorption (dB/100 m)	ARP866A 10 °C/80 %RH (dB/100 m)
50	0.033	0.021
63	0.033	0.027
80	0.033	0.034
100	0.066	0.043
125	0.066	0.053
160	0.098	0.068
200	0.131	0.086
250	0.131	0.107
315	0.197	0.135
400	0.230	0.172
500	0.295	0.216
630	0.361	0.273
800	0.459	0.349
1000	0.590	0.439
1250	0.754	0.552
1600	0.983	0.738
2000	1.311	0.985
2500	1.705	1.322
3150	2.295	1.853
4000	3.115	2.682
4500	3.607	3.216
6300	5.246	4.580
8000	7.213	6.722
10000	9.836	9.774

E.9.4 At each NPD distance, the 1/3-octave band levels are A-weighted and decibel-summed to give the overall A-weighted level at each distance. This is repeated for both the departure spectrum (103) and the approach spectrum (205). For each NPD distance the A-weighted levels are then subtracted to give the increment, ΔL. The A-weighted levels and increments ΔL are shown in **Table E-4**.

Table E-4: A-weighted levels for reference and ARP866A atmosphere and difference between each atmosphere, ΔL.

	DEP_103			ARR_103		
Distance (ft)	$L_{A,ref}$ (dBA)	$L_{A,866A}$ (dBA)	ΔL (dB)	$L_{A,ref}$ (dBA)	$L_{A,866A}$ (dBA)	ΔL (dB)
200	127.6	127.7	+0.0	129.1	127.7	-1.4
400	121.7	121.8	+0.1	123.2	121.8	-1.4
630	114.9	115.0	+0.2	116.4	115.0	-1.4
1000	104.1	104.5	+0.4	105.9	104.5	-1.4
2000	85.5	87.4	+1.9	85.1	87.4	+2.3
4000	79.0	81.1	+2.1	77.8	81.1	+3.3
6300	75.7	77.8	+2.1	74.7	77.8	+3.1
10000	72.3	74.5	+2.2	71.2	74.5	+3.3
16000	68.5	71.0	+2.5	67.1	71.0	+3.9
25000	64.2	67.2	+3.0	62.8	67.2	+4.4

E.9.5 The departure and approach increments shown in **Table E-4** are then added to the departure and approach ANP database NPD thrust levels (**Table E-5a**) to construct the new NPD shown in **Table E-5b**.

Table E-5a: Original NPD data

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	L_200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
V2527A	SEL	A	2000	93.1	89.1	86.1	82.9	77.7	71.7	67.1	61.9	55.8	49.2
V2527A	SEL	A	2700	93.3	89.2	86.2	83.0	77.7	71.8	67.2	62.0	55.8	49.3
V2527A	SEL	A	6000	94.7	90.5	87.4	83.9	78.5	72.3	67.7	62.5	56.3	49.7
V2527A	SEL	D	10000	95.4	90.7	87.3	83.5	77.7	71.1	66.3	60.9	54.6	47.4
V2527A	SEL	D	14000	100.4	96.1	93.0	89.4	83.5	77.0	72.2	66.7	60.1	53.0
V2527A	SEL	D	18000	103.2	99.1	96.2	92.9	87.4	81.1	76.5	71.1	64.9	57.9
V2527A	SEL	D	22500	105.1	101.2	98.5	95.4	90.3	84.3	79.9	74.8	68.7	62.0

Table E-5b: Revised NPD data

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	L_200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
V2527A	SEL	A	2000	91.7	87.7	84.7	81.5	80.0	75.0	70.2	65.2	59.7	53.6
V2527A	SEL	A	2700	91.9	87.8	84.8	81.6	80.0	75.1	70.3	65.3	59.7	53.7
V2527A	SEL	A	6000	93.3	89.1	86.0	82.5	80.8	75.6	70.8	65.8	60.2	54.1
V2527A	SEL	D	10000	95.4	90.8	87.5	83.9	79.6	73.2	68.4	63.1	57.1	50.4
V2527A	SEL	D	14000	100.4	96.2	93.2	89.8	85.4	79.1	74.3	68.9	62.6	56.0
V2527A	SEL	D	18000	103.2	99.2	96.4	93.3	89.3	83.2	78.6	73.3	67.4	60.9
V2527A	SEL	D	22500	105.1	101.3	98.7	95.8	92.2	86.4	82.0	77.0	71.2	65.0

Appendix F

The finite segment correction

F.1 INTRODUCTION

F.1.1 This appendix outlines the derivation of the finite segment correction and the associated energy fraction algorithm described in **Section 4.5.6**.

F.2 GEOMETRY

F.2.1 The energy fraction algorithm is based on the sound radiation of a 'fourth-power' 90-degree dipole sound source. This has directional characteristics, which approximate those of jet aeroplane sound, in the angular region that most influences sound event levels beneath and to the side of the aeroplane flight path.

F.2.2 **Figure F-1** illustrates the geometry of sound propagation between the flight path and the observer location **O**. The aeroplane at **P** is flying in still uniform air with a constant speed on a straight, level flight path. Its closest point of approach to the observer is $\mathbf{P_p}$. The parameters are:

d	distance from the observer to the aeroplane
d_p	perpendicular distance from the observer to the flight path (slant distance)
q	distance from **P** to $\mathbf{P_p}$ = $-V\cdot\tau$
V	speed of the aeroplane
t	time at which the aeroplane is at point **P**
t_p	time at which the aeroplane is located at the point of closest approach $\mathbf{P_p}$
τ	flight time = time relative to time at $\mathbf{P_p}$ = $t - t_p$
ψ	angle between flight path and aeroplane-observer vector

F.2.3 It should be noted that, since the flight time τ relative to the point of closest approach is negative when the aeroplane is before the observer position (as shown in **Figure F-1**), the relative distance *q* to the point of closest approach becomes positive in that case. If the aeroplane is ahead of the observer, *q* becomes negative.

F.3 ESTIMATION OF THE ENERGY FRACTION

F.3.1 The basic concept of the energy fraction is to express the noise exposure *E* produced at the observer position from a flight path segment $\mathbf{P_1P_2}$ (with a start-point $\mathbf{P_1}$ and an end-point $\mathbf{P_2}$) by multiplying the exposure E_∞ from the whole infinite path flyby by a simple factor – the *energy fraction* factor *F*:

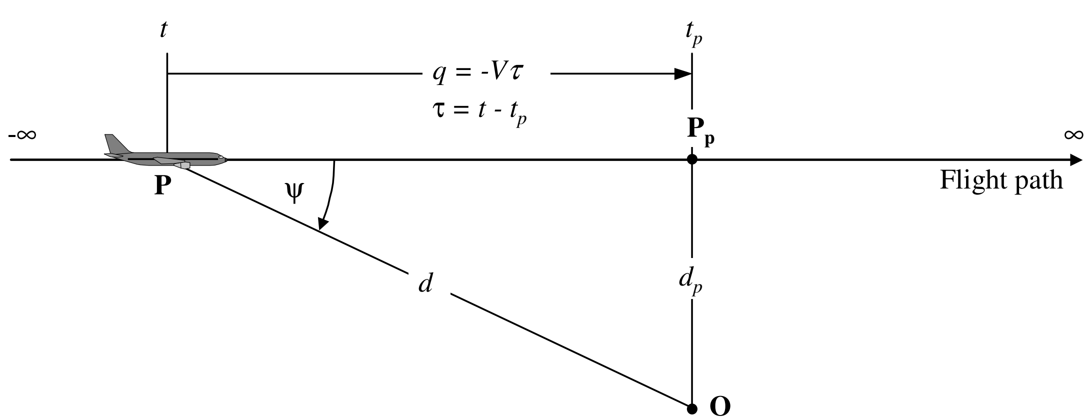

Figure F-1: Geometry between flight path and observer location O

$$E = F \cdot E_\infty \tag{F-1}$$

F.3.2 Since the exposure can be expressed in terms of the time-integral of the mean-square (weighted) sound pressure level, i.e.

$$E = \text{const} \cdot \int p^2(\tau) d\tau \tag{F-2}$$

the mean-square pressure has to be expressed as a function of the known geometric and operational parameters. For a 90° dipole source,

$$p^2 = p_p^2 \cdot \frac{d_p^2}{d^2} \cdot \sin^2 \psi = p_p^2 \cdot \frac{d_p^4}{d^4} \tag{F-3}$$

where p^2 and $p_p{}^2$ are the observed mean-square sound pressures produced by the aeroplane as it passes points **P** and $\mathbf{P_p}$.

F.3.3 This relationship has been found to provide a good simulation of jet aeroplane noise, even though the real mechanisms involved are extremely complex. The term $d_p{}^2/d^2$ in Equation F-3 describes just the mechanism of spherical spreading appropriate to a point source, an infinite sound speed and a uniform, non-dissipative atmosphere. All other physical effects - source directivity, finite sound speed, atmospheric absorption, Doppler-shift etc. - are implicitly covered by the $sin^2\psi$ term. This factor causes the mean square pressure to decrease inversely as d^4; whence the expression "fourth power" source.

F.3.4 By introducing the substitutions

$$d^2 = d_p^2 + q^2 = d_p^2 + (V \cdot \tau)^2$$

and $$\left(\frac{d}{d_p}\right)^2 = 1 + \left(\frac{V \cdot \tau}{d_p}\right)^2$$

the mean-square pressure can be expressed as a function of time (again disregarding sound propagation time):

$$p^2 = p_p^2 \cdot \left(1 + \left(\frac{V \cdot \tau}{d_p}\right)^2\right)^{-2} \tag{F-4}$$

F.3.5 By putting this into equation (F-2) and performing the substitution

$$\alpha = \frac{V \cdot \tau}{d_p} \tag{F-5}$$

the sound exposure at the observer from the flypast between the time interval $[\tau_1, \tau_2]$ can be expressed as

$$E = \text{const} \cdot p_p^2 \cdot \frac{d_p}{V} \cdot \int_{\alpha_1}^{\alpha_2} \frac{1}{(1+\alpha^2)^2} d\alpha \tag{F-6}$$

F.3.6 The solution of this integral is:

$$E = \text{const} \cdot p_p^2 \cdot \frac{d_p}{V} \cdot \frac{1}{2}\left(\frac{\alpha_2}{1+\alpha_2^2} + \tan^{-1}\alpha_2 - \frac{\alpha_1}{1+\alpha_1^2} - \tan^{-1}\alpha_1\right) \tag{F-7}$$

F.3.7 Integration over the interval [-∞,+∞] (i.e. over the whole infinite flight path) yields the following expression for the total exposure E_∞:

$$E_\infty = \text{const} \cdot \frac{\pi}{2} \cdot p_p^2 \cdot \frac{d_p}{V} \tag{F-8}$$

and hence the energy fraction according to Equation F-1 is

$$F = \frac{1}{\pi}\left(\frac{\alpha_2}{1+\alpha_2^2} + \tan^{-1}\alpha_2 - \frac{\alpha_1}{1+\alpha_1^2} - \tan^{-1}\alpha_1\right) \tag{F-9}$$

F.4 CONSISTENCY OF MAXIMUM AND TIME INTEGRATED METRICS – THE SCALED DISTANCE

F.4.1 A consequence of using the simple dipole model to define the energy fraction is that it implies a specific theoretical difference ΔL between the event noise levels L_{max} and L_E. If the contour model is to be internally consistent, this needs to equal the difference of the values determined from the NPD curves. A problem is that the NPD data are derived from actual aeroplane noise measurements - which do not necessarily comply with the simple theory. The theory therefore needs an added element of flexibility. But in principal the variables α_1 and α_2 are determined by geometry and aeroplane speed – thus leaving no further degrees of freedom. A solution is provided by the concept of a *scaled distance* d_λ as follows.

F.4.2 The exposure level $L_{E,\infty}$ as tabulated as a function of d_p in the ANP database for a reference speed V_{ref}, can be expressed as

$$L_{E,\infty}(V_{ref}) = 10 \cdot \log\left[\frac{\int_{-\infty}^{\infty} p^2.dt}{p_0^2 \cdot t_{ref}}\right] \tag{F-10}$$

where p_0 is a standard reference pressure and t_{ref} is a reference time (= 1 s for SEL). For the actual speed V it becomes

$$L_{E,\infty}(V) = L_{E,\infty}(V_{ref}) + 10 \cdot \log\left(\frac{V_{ref}}{V}\right) \tag{F-11}$$

F.4.3 Similarly the maximum event level L_{max} can be written

$$L_{max} = 10 \cdot \log\left[\frac{p_p^2}{p_0^2}\right] \tag{F-12}$$

F.4.4 For the dipole source, using equations F-8, F-11 and F-12, noting that (equations F-2 and F-8)

$$\int_{-\infty}^{\infty} p^2 \cdot dt = \frac{\pi}{2} \cdot p_p^2 \cdot \frac{d_p}{V}$$

the difference ΔL can be written:

$$\Delta L = L_{E,\infty} - L_{max}$$
$$= 10 \cdot \log\left[\frac{V}{V_{ref}} \cdot \left(\frac{\pi}{2} p_p^2 \frac{d_p}{V}\right) \cdot \frac{1}{p_0^2 \cdot t_{ref}}\right] - 10 \cdot \log\left[\frac{p_p^2}{p_0^2}\right] \tag{F-13}$$

F.4.5 This can only be equated to the value of ΔL determined from the NPD data if the slant distance d_p used to calculate the energy fraction is substituted by a *scaled distance* d_λ given by

$$d_\lambda = \frac{2}{\pi} \cdot V_{ref} \cdot t_{ref} \cdot 10^{(L_{E,\infty} - L_{max})/10} \tag{F-14}$$

F.4.6 Replacing d_p by d_λ in equation F-5 and using the definition $q = V\tau$ from **Figure F-1** the parameters α_1 and α_2 in equation F-9 can be written (putting $q = q_1$ at the start-point and q–λ = q_2 at the endpoint of a flight path segment of length λ) as

$$\alpha_1 = \frac{-q_1}{d_\lambda} \quad \text{and} \quad \alpha_2 = \frac{-q_1 + \lambda}{d_\lambda} \tag{F-15}$$

F.4.6 Having to replace the slant actual distance by scaled distance diminishes the simplicity of the fourth-power 90 degree dipole model. But as it is effectively calibrated using data derived from measurements, the energy fraction algorithm can be regarded as semi-empirical rather than a pure theoretical.

Appendix G

Maximum level of noise events

G.1 In **Chapter 5**, equation 5-9 introduces a step-function u(k) which determines whether the maximum level contribution from flight path segment k is the maximum level of a noise event or not:

$$u(k) = \begin{Bmatrix} 0 \\ 1 \end{Bmatrix}$$

$$\text{if } L_{max,k} \begin{Bmatrix} \text{is not} \\ \text{is} \end{Bmatrix} \text{the maximum level of a noise event}$$

G.2 In **Figure G-1** a flow-diagram shows the steps by which this function can be estimated for each aeroplane type and ground track (or subtrack).

G.3 The procedure uses four variables:

k is the number of the current track (or subtrack) segment.

$L_{max,k}$ is the maximum level from the current track

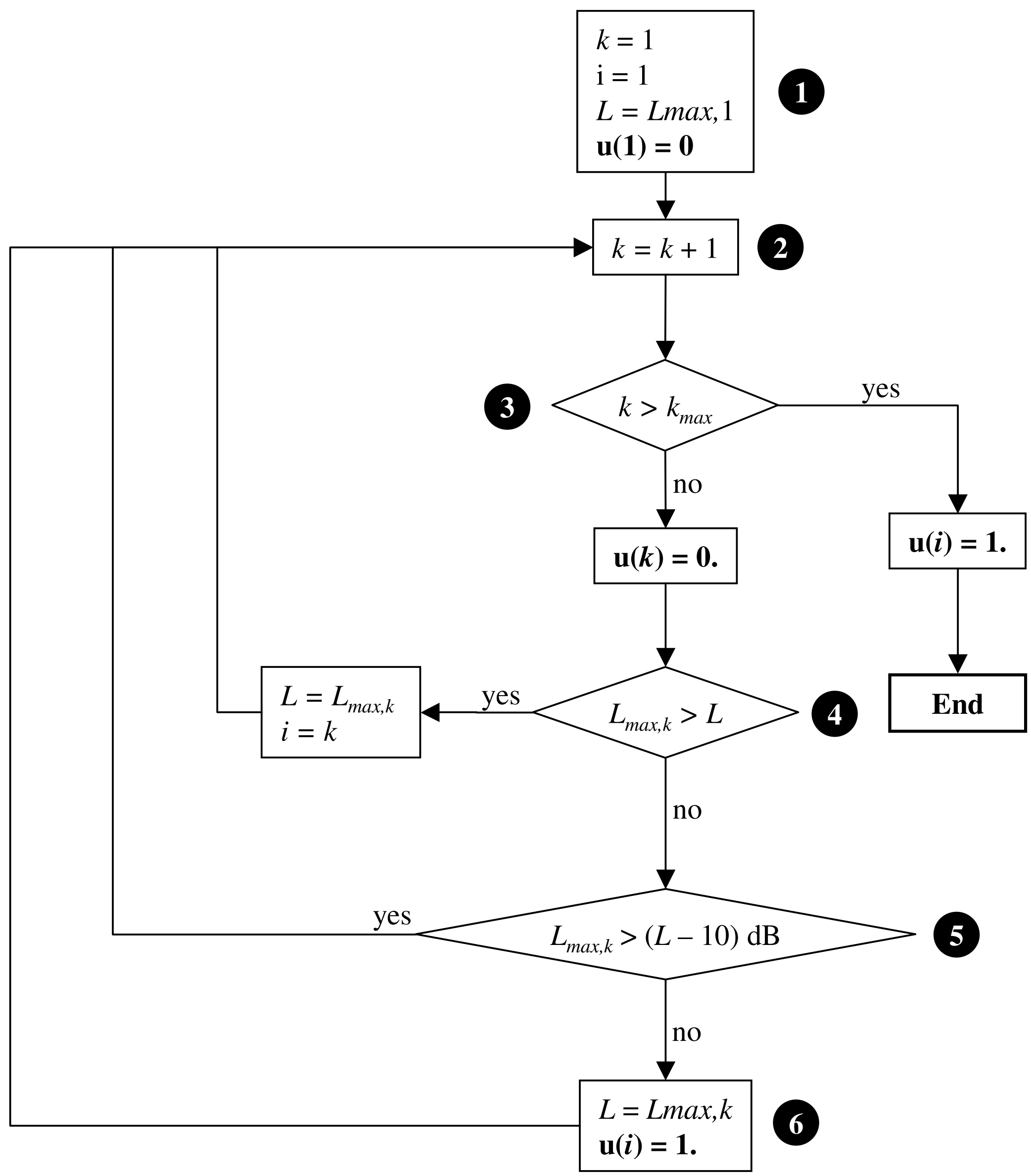

Figure G-1: Flow-diagram for the estimation of the function u(k)

(or subtrack) segment.

L is the maximum level of the actual noise event.

i is a pointer to the segment which produces the maximum level L.

G.4 The procedure is presented below:

❶ Initialise the variables: set the subtrack counter k to one, set the pointer i to the actual maximum event level to one and set the variable L representing the maximum level of the actual noise event to $L_{max,1}$. This means that the to the maximum level of the first track segment is to be assumed the maximum level of the first noise event. Additionally initialise the variable u(1) with zero.

❷ Perform a loop over all segments of the actual ground (sub)track increasing the segment number by one.

❸ If the last segment is processed, leave the loop. Set the variable u(i) for the last marked maximum level to one. If the current segment is not the last one, set the variable u(k) for this segment to zero (i.e. initialise it).

❹ Check if the maximum level $L_{max,k}$ from the actual segment is higher than the maximum level L of the current noise event. If so, set $L = L_{max,k}$ and set the marker i to the current segment number ($i = k$). Then branch to the next segment (i.e. to step❷).

❺ Estimate the difference between the maximum level L of the current noise event and the maximum level of the current segment. If it is less than 10 dB, the event is not yet finished - branch to step ❷.

❻ The actual noise event is finished. Start a new event by setting the maximum level of this new event to $L = L_{max,k}$ and set the counter $i = k$. This is similar to step ❶.

G.5 Steps ❺ and ❻ are not necessary if only the highest maximum level produced by the actual aeroplane type on the actual (sub)track has to be estimated. In this case branch directly from step ❹ to step ❷.

Appendix H

The International Aircraft Noise and Performance (ANP) database

H.1 INTRODUCTION

H.1.1 To support the development of accurate aeroplane noise contour models, an on-line aircraft noise and performance (ANP) database has been established, accessible at www.aircraftnoisemodel.org.

Data sources

H.1.2 The data accord with specifications and formats laid down by the international Society of Automotive Engineers (SAE) in AIR 1845 [ref. 1] that are designed to achieve best practicable levels of data quality and consistency. By preference, entries are supplied by the aeroplane manufacturers and these cover most of the larger, modern aeroplane models and variants in the world's airline fleets and that therefore govern the noise at most major airports. Those entries usually include noise data acquired during noise certification tests carried out under stringent internationally standardised procedures that are regulated by national certification agencies. Data for some other aeroplanes, mainly those of less general noise significance, have been obtained from other sources, principally controlled tests, similar to those of certification, undertaken by national noise modelling agencies in various countries.

Aeroplane coverage

H.1.3 With respect to aeroplane entries, the ANP database is identical to that of the INM database, [ref. 4] excluding at present only data that is not covered by this guidance, i.e. military aeroplanes and helicopters.

H.1.4 Aeroplane models and variants that are not presently covered by the database have to be represented by substitutes - aeroplanes with similar noise and performance characteristics that are included in the database that can be adequately scaled (in terms of 'equivalent number of movements') to represent the missing aeroplanes. Instructions for making the necessary substitutions are provided on the website. These involve examining carefully the aeroplane description and associated parameters such as maximum take-off weight and thrust rating to best represent the in-service fleet operating at a given airport. To facilitate the substitution process, the ANP database includes a table mapping currently operating commercial aeroplanes – with detailed airframe-engine combinations - to the aeroplanes listed in the database.

H.1.5 The database continues to be expanded so that the need for substitution can be minimised. Users who consider that their modelling work is compromised by a lack of coverage are urged to communicate their needs to the database managers, via the website.

Data transparency

H.1.6 For each listed aeroplane, the database specifies the source of the data (manufacturer, other), and, sometimes, may provide more detailed information on the process and assumptions, which have been applied to derive the data.

Data scrutiny

H.1.7 With each update the database developers check entries for consistency and reasonableness as resources allow. However, inconsistencies and deficiencies may be discovered by users in their model applications. Users may report these through a process given on the website.

Terms and conditions for accessing the database

H.1.8 Users have to be registered to access the database (the web-site includes an online registration form for new users). Use of data is subject to terms and conditions posted on the website.

Database content

H.1.9 The international ANP data meet in full the requirements of the ICAO contour modelling methodology. The content of the database and the procedures for downloading the data from the ANP website are described below. The data are provided in a near "ready-to-use" format; it is only necessary for the software developer to match the model parameters and variables to those of the data.

H.1.10 The database includes several tables of data that are described in the following sections, as they are at the time of publication of this guidance. The content and format of these tables are likely to evolve with time, depending on the needs of the aviation community.

H.1.11 Users are cautioned that quantities, dimensions and units are those generally used by the data suppliers; modellers must be especially careful to ensure that, where necessary, appropriate conversions are applied at the point of use.

H.2 AIRCRAFT TABLE

H.2.1 This tabulates the aeroplanes represented along with descriptive parameters. Some parameters are required for noise modelling purposes whilst others are for general information only, enabling the user to further classify the aeroplanes according to selected criteria (e.g. source of the data, weight categories, noise certification status, etc.), and to assist with substitutions.

H.2.2 For some aeroplanes, additional technical information, including in particular the assumptions that were made to derive the aeroplane-specific data, is provided in a downloadable PDF document.

H.2.3 The different fields/parameters of the Aircraft Table are listed below. Parameters that are required inputs to the noise contour model are underlined.

- Aircraft Identifier: the aeroplane name which labels the associated performance data and by which it is accessed.
- Description of the aeroplane: manufacturer, airframe, engine, etc.
- Source of the data: manufacturer, other.
- Engine Type: Jet, Turboprop or Piston
- Number of Engines: used in various equations of **Appendix C**
- Weight Class: Small, Large or Heavy
- Owner Category: Commercial or General Aviation
- Maximum Gross Take-off Weight (lb) used to calculate reduced take-off thrust (see **Appendix C**)
- Maximum Gross Landing Weight (lb): default approach profiles are usually provided for 90% of MGLW.
- Maximum Landing Distance (ft)
- Maximum Sea Level Static Thrust (lb): provided for standard day conditions
- Noise Chapter (Noise certification standard)
- NPD Identifier: associates the aeroplane with a set of NPD data, stored in the NPD table. (As NPDs tend to be powerplant related, similar aeroplane types may be assigned the same set of NPD data.)
- Power Parameter: indicates which noise related power parameter is used to access the NPD data (corrected net thrust, shaft horse power, etc.) and the associated unit (pounds, percent, other).
- Spectral Class Identifiers: associate the aeroplane with reference sound spectral shapes, one for approach and one for departure, stored in the Spectral Classes table.
- Lateral Directivity Identifier: Fuselage-mounted, Wing-mounted or Prop. Indicates the engine installation correction to be applied – see **Section 4.6.3**
- Link to any accompanying PDF document.

H.3 AIRCRAFT PERFORMANCE TABLES

H.3.1 These provide the engine and aerodynamic data required to implement the performance equations presented in **Appendix C**. These data (coefficients) may not be available for all the aeroplanes of the database. For aeroplanes with missing coefficients, or for specific flight procedures which cannot be well modelled using the methodology described in **Appendix C**, the database may include a supplementary table providing default fixed-point profiles – a set of height, speed and thrust values as a function of ground distance.

H.3.2 Additionally, the database includes a table providing, for each aeroplane, default take-off weights values as a function of trip length.

H.3.1 Reference conditions for performance data

H.3.1.1 The performance data (engine coefficients) are provided by manufacturers for the following reference conditions:

Atmosphere:	International Standard Atmosphere (ISA) [ref. 11]
Surface Air Temperature:	15 degrees C (59 degrees F)
Wind:	4 m/s (8 kt.) headwind, constant with height above ground
Runway elevation:	Mean Sea Level (MSL)
Runway gradient:	None
Number of engines supplying thrust :	All

H.3.1.2 However, the engine coefficients, along with the thrust equations described in

Appendix C, may be used also for aerodrome conditions other than 15°C, sea level (temperatures up to 43 °C (109 °F) and airport elevations up to 6000 ft above sea level). The database includes high temperature jet coefficients enabling thrust calculations above temperature breakpoint. The flap coefficients are also available for other that reference conditions.

H.3.2 Jet engine coefficients table

H.3.2.1 This table provides, for each aeroplane and for up to five different rated thrusts, the jet coefficients E, F, G_A, G_B and H for use with thrust equation C-1 of **Appendix C**. The thrust ratings encompass Max-Take-off, Hi-Temp Max-Take-off, Max-Climb, Hi-Temp Max-Climb and Idle (the last for approach - see equation C-23).

H.3.2.2 Additionally, the table may provide (depending on the aeroplane) a set of general jet coefficients enabling the calculation of non-rated thrust as a function of either EPR or N1, using equations C-2 and C-3 of **Appendix C**. These general jet coefficients include in particular the additional coefficients K_1, - K_4..

H.3.2.3 The content of a data row in this table is (each parameter occupying a column):

- Aircraft_ID
- Thrust Rating: includes 'General Thrust' for non-rated thrust calculation
- E (lbf)
- F (lbf/kt)
- G_A (lbf/ft)
- G_B (lbf/ft^2)
- H (lbf/ °C)
- K_1 (lbf/EPR)
- K_2 (lbf/EPR^2)
- K_3 (lbf/(N1/$\sqrt{\theta}$))
- K_4 (lbf/(N1/$\sqrt{\theta}$)^2)

Note: Rated thrust coefficients are provided for at least MaxTakeoff and MaxClimb thrust ratings. The general thrust K-coefficients are provided either for EPR ($K_{1,2}$) or N1 ($K_{3,4}$), depending on the aeroplane/engine.

H.3.3 Propeller engine coefficients table

H.3.3.1 This provides propeller efficiency and installed net propulsive power data for the calculation of corrected net thrust for propeller driven aeroplanes (**Appendix C** equation C-5). The data are usually provided for two thrust ratings: MaxTakeoff and MaxClimb.

H.3.3.2 A data row of this table contains:

- Aircraft ID
- Thrust rating: MaxTakeoff or MaxClimb
- η: Propeller Efficiency
- P_p (hp) : Installed Net Propulsive Power

H.3.4 Aerodynamic coefficients table

H.3.4.1 This table provides, for each aeroplane, the aerodynamic coefficients B_8, C/D and R (See **Appendix C**, equations C-9, C-12, C-15 and C-24) associated with different flap settings on arrival and departure. The number of flap settings and the flap identifiers are aeroplane-specific. The flap settings for which aerodynamic data are available normally cover the complete sequence used by aeroplanes under operational conditions (from clean configuration to full landing configuration-gear down during approach for instance). The flap identifiers include – where necessary - an indication on gear position (up or down).

H.3.4.2 Each row of the table contains the following (each parameter representing a column):

- Aircraft ID
- Operation: Arrival (A) or Departure (D)
- Flap ID
- B_8 (ft/lb)
- C (Initial climb speed) or D (landing speed) (kt/$\sqrt{\text{lb}}$)
- R

Note: Coefficients B_8 and C are provided only for take-off flap settings.

H.3.5 Default weights table

H.3.5.1 This provides, for each aeroplane, suggested default take-off weights assigned to different trip- (or stage-) length ranges. These are for use when the operational take-off weights at the studied airport are unknown. The trip length stages are defined as follows:

Stage Length	1	2	3	4
Trip Length Range (nm x 1000)	0-0.5	0.5-1	1-1.5	1.5-2.5
Representative Range (nm)	350	850	1350	2200
Take-off Weight (lb)				

Stage Length	5	6	7	8	9
Trip Length Range (nm x 1000)	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	> 6.5
Representative Range (nm)	3200	4200	5200	6200	
Take-off Weight (lb)					

H.3.5.2 The Representative Range, for which the take-off weight is calculated, is defined as follows:

Representative Range = Min Range + 0.70*(Max Range – Min Range)

H.3.5.3 The assumptions made to arrive at the default take-off weights associated to each of the above representative range may depend on the aeroplane category and/or weight class, and may even vary from one manufacturer to another. Additional information is given on the website.

H.3.5.4 Each row of the table contains the following (each parameter representing a column):

- Aircraft ID
- Stage Length
- Weight (lb)

H.3.6 Default departure procedural steps table

H.3.6.1 This table provides a description of default departure procedures (i.e. description of successive steps, as flown by the crew). It includes all the required parameters which, combined with data from the performance tables, allow calculation of the resulting flight profiles (altitude, speed and thrust as a function of ground distance) using equations described in **Appendix C**.

H.3.6.2 Each row of the table contains the following (each parameter representing a column):

- Aircraft ID
- Profile ID
- Stage Length
- Step Number
- Step Type: Take-off, Climb or Accelerate
- Flap ID: flap settings used on each step
- Thrust Rating: MaxTakeoff, MaxClimb, other
- End Point Altitude (ft): altitude to be reached at the end of the segment
- Rate of Climb (ft/min)
- End Point CAS (kt): calibrated airspeed to be reached at the end of the segment

Note: Each of the last three parameters is assigned a value or not (field ‘empty’), depending on the step type that is flown (example: a rate of climb value is provided only for an acceleration step, the field being empty for the other step types).

H.3.7 Default approach procedural steps table

H.3.7.1 This table, in a similar way as the previous one, provides a description of default approach procedures (normally one default procedure by aeroplane - for 90% of Maximum Gross Landing Weight - using step by step flight instructions.

H.3.7.2 For reasons explained in **Section 3.6.1**, the default approach procedures currently available in the ANP database describe a continuous 3° descent from 6000ft to touchdown. This is not necessarily representative of current operational practice and the data will be progressively replaced by more realistic default procedures, incorporating level flight segments and deceleration. Progress will depend on the availability of the aeroplane performance data required to fully implement the methodology described in **Appendix C** (see also **Appendix H.3.8**).

H.3.8 Default fixed-points profiles table

H.3.7.3 This table provides default fixed-point profiles for aeroplanes, for which the required performance data to calculate flight profiles based on the methodology described in **Appendix C** are unavailable. This too will be phased out (in favour of the procedural profiles) as soon as the aeroplane performance data which are required for a full implementation of **Appendix C** become available.

H.3.7.4 The structure is described below (each parameter representing a column in the table):

- Aircraft_ID
- Operation type: Arrival (A) or Departure (D)
- Profile ID
- Stage Length
- Point Number
- Distance (ft)
- Height above field elevation (ft)
- Speed TAS (kt)
- Corrected Net Thrust (lbf)

Note: Some tables have all the coefficients required to calculate departure profiles but no aerodynamic coefficients enabling the calculation of approach profiles. For these aeroplanes, default fixed-point profiles are provided for approach only.

H.4 AIRCRAFT NOISE TABLES

H.4.1 These provide the acoustic data required to calculate the single event noise as described in **Chapter 4**. For each aeroplane, there are two sets of data: (1) a Noise-Power-Distance (NPD) table and (2) two Spectral Classes - reference sound spectra (used to adjust NPDs for non-reference atmospheric conditions).

H.4.1 NPD table

H.4.1.1 This table provides, for each aeroplane type (through its NPD identifier) and a number of values of the noise-related power parameter (mostly corrected net thrust values), a set of noise event levels at a number of slant distances. Several similar aeroplanes may be assigned the same NPD data set.

H.4.1.2 The noise event levels are given for various single event noise metrics, including at least L_{Amax} and SEL ten slant distances: 200, 400, 630, 1 000, 2 000, 4 000, 6 300, 10 000, 16 000, and 25 000 ft.

H.4.1.3 The power settings span normal operating values, both for approach and departures, in order to avoid the need for large modelling extrapolations. NPD data are distinguished by operating mode (approach or departure) as, due to airframe effects, noise depends on flight configuration as well as power setting.

H.4.1.4 Each table entry (row) contains the following (each parameter representing a column):

- Noise Identifier
- Noise Index: maximum or exposure-based metric
- Operating Mode : ‘A’ or ‘D’
- Noise -related power parameter value
- L_n noise levels at distances d_n for n = 1 to 10

H.4.2 Reference conditions for NPD data

H.4.2.1 NPD data are normalised for the following conditions:

- Atmospheric pressure: 101.325 kPa (1013.25 mb)
- Atmospheric absorption: attenuation rates listed in **Table E-1** of **Appendix E**
- Precipitation: none
- Wind Speed: less than 8 m/s (15 kt)
- Reference Speed (for exposure-based metrics): 160 kt

H.4.3 Spectral classes table

H.4.3.1 Spectral classes represent average noise spectra for groups of aeroplanes that have similar spectral characteristics.

H.4.3.2 The spectral classes represent average spectral shapes at the time of maximum sound level, at a reference distance of 1 000 ft, and for the same reference conditions of air temperature and humidity as the NPDs. They are un-weighted (unlike NPDs) and - for historical reasons - normalized to 70 dB at 1 000 Hz. Sound levels are provided for 24 one-third octave bands, with nominal centre-frequencies from 50 to 10 000 Hz.

H.4.3.3 A detailed description of the method used to develop spectral class data can be found on the web site.

H.4.3.4 The table provides separate spectral shapes for approach and departure conditions. Thus a given aeroplane is assigned two spectral classes (through its two spectral class identifiers).

Each row of this table contains (each parameter representing a column in the table):

- Spectral Class ID
- Operation type: ‘A’ or ‘D’
- Description: general characteristics of the aeroplane family that is assigned this spectral shape
- 24 relative one-third octave band sound levels for the centre-frequencies from 50 to 10 000 Hz.

H.5 HOW TO DOWNLOAD THE DATA

H.5.1 Registered users may download the following aeroplane noise and performance data from the web-site:

- the whole database
- noise and performance tables related to one or several specific aeroplane types
- a specific table

H.5.2 The downloaded data are provided in CSV files, with one file per table.

H.5.3 Additionally, registered users are automatically informed (by e-mail) of any update of the database (new entries).

H.6 EXAMPLE DATA

H.6.1 Example data from the ANP database are provided in **Tables H-1 through H-9**.

H.6 EXAMPLE DATA

Table H-1: Example Aircraft Table

ACFT_ID	Description	Source of data	Engine Type	Number of Engines	Weight Class	Owner Category	Max Gross Take-off Weight (lb)	Max Gross Landing Weight (lb)
737300	Boeing B737-300/CFM56-3B-1 Engines	Manufacturer	Jet	2	Large	Commercial	135000	114000
A32023	Airbus A320-232 / V2527-A5 Engines	Manufacturer	Jet	2	Large	Commercial	162000	142200
SF340	Saab SF340B/CT7-9B Engines	Manufacturer	Turbo Prop	2	Large	Commercial	27300	26500

Table H-1 (continued)

ACFT_ID	Max Landing Distance (ft)	Maximum Sea Level Static Thrust (lb)	Noise Chapter	NPD Identifier	Power Parameter	App Spectral Class Identifier	Dep Spectral Class Identifier	Lateral Directivity Identifier
737300	4580	20000	3	CFM563	CNT (Pounds)	202	102	Wing
A32023	4704	26500	3	V2527A	CNT (Pounds)	205	103	Wing
SF340	3470	4067	3	CT75	SHP (Percent)	211	110	Prop

Table H-2: Example Jet Engine Coefficients Table

ACFT_ID	Thrust Rating	E (lb)	F (lb/kt)	Ga (lb/ft)	Gb (lb/ft^2)	H (lb/ °C)	K1 (lb/EPR)	K2 (lb/EPR^2)	K3 (lb/(N1/√θ))	K4 (lb/(N1/√θ)^2)
A32023	MaxClimb	15390.0	-1.53000	3.04500e-01	-3.52300e-06	0.000e+00				
A32023	MaxClimb HiTemp	15331.9	9.07100	0.00000e+00	0.00000e+00	-1.110e+02				
A32023	MaxTakeoff	24711.4	-24.81300	2.76400e-01	-2.75900e-06	0.000e+00				
A32023	MaxTakeoff HiTemp	29300.3	-24.33000	0.00000e+00	0.00000e+00	-1.331e+02				
A32023	General Thrust	-65083.3	-7.25000	-1.91800e-02	2.57500e-08	0.000e+00	8.78176e+04	-1.86931e+04		
737300	MaxClimb	17448.0	-17.32000	+1.55700e-01	0.00000e+00	0.000e+00				
737300	MaxTakeoff	18745.0	-20.12000	+4.04300e-01	0.00000e+00	0.000e+00				
737300	General Thrust	11106.0	-10.09000	-4.09000e-02	0.00000e+00	0.000e+00			-3.69800e+02	+4.83500e+00

Table H-3: Example Propeller Engine Coefficients Table

ACFT_ID	Thrust Rating	Propeller Efficiency	Installed Net Propulsive Power (hp)
SF340	MaxClimb	0.90	1587.0
SF340	MaxTakeoff	0.90	1763.0

Table H-4: Example Aerodynamic Coefficients Table

ACFT_ID	Op Type	Flap Identifier	B (ft/lb)	C/D (kt/√lb)	R
737300	A	D-15	-	0.463900	0.110300
737300	A	D-30	-	0.434000	0.124700
737300	A	D-40	-	0.421500	0.147100
737300	D	1	0.012600	0.495800	0.076100
737300	D	15	0.011100	0.457200	0.087200
737300	D	5	0.012000	0.477200	0.079100
737300	D	ZERO	-	-	0.062000
A32023	D	1	-	-	0.061500
A32023	D	1+F	0.007858	0.398300	0.072500
A32023	D	ZERO	0.000000	0.000000	0.053900

Table H-5: Example Default Weights Table

ACFT_ID	Stage Length	Weight (lb)
737300	1	96000
737300	2	102000
737300	3	108000
737300	4	119000
A32023	1	135700
A32023	2	141600
A32023	3	147700
A32023	4	158600
A32023	5	162000

Table H-6: Example Default Departure Procedural Profiles Table

ACFT_ID	Profile ID	Stage Length	STEP_NUM	STEP_TYPE	FLAP_ID	THR_RATING	End Point Altitude (ft)	Rate of Climb (ft/min)	End Point CAS (kt)
A32023	ICAO_A	1	1	Take-off	1+F	MaxTakeoff			
A32023	ICAO_A	1	2	Climb	1+F	MaxTakeoff	300.0		
A32023	ICAO_A	1	3	Climb	1+F	MaxTakeoff	1500.0		
A32023	ICAO_A	1	4	Climb	1+F	MaxClimb	3000.0		
A32023	ICAO_A	1	5	Accelerate	1+F	MaxClimb		751.0	187.3
A32023	ICAO_A	1	6	Accelerate	1	MaxClimb		890.0	201.6
A32023	ICAO_A	1	7	Accelerate	ZERO	MaxClimb		1041.0	226.9
A32023	ICAO_A	1	8	Accelerate	ZERO	MaxClimb		1191.0	250.0
A32023	ICAO_A	1	9	Climb	ZERO	MaxClimb	5500.0		
A32023	ICAO_A	1	10	Climb	ZERO	MaxClimb	7500.0		
A32023	ICAO_A	1	11	Climb	ZERO	MaxClimb	10000.0		
737300	STANDARD	4	1	Take-off	5	MaxTakeoff			
737300	STANDARD	4	2	Climb	5	MaxTakeoff	1000.0		
737300	STANDARD	4	3	Accelerate	5	MaxTakeoff		1544.0	185.0
737300	STANDARD	4	4	Accelerate	1	MaxTakeoff		1544.0	190.0
737300	STANDARD	4	5	Accelerate	ZERO	MaxClimb		1000.0	220.0
737300	STANDARD	4	6	Climb	ZERO	MaxClimb	3000.0		
737300	STANDARD	4	7	Accelerate	ZERO	MaxClimb		1000.0	250.0
737300	STANDARD	4	8	Climb	ZERO	MaxClimb	5500.0		
737300	STANDARD	4	9	Climb	ZERO	MaxClimb	7500.0		
737300	STANDARD	4	10	Climb	ZERO	MaxClimb	10000.0		

Table H-7: Example Default Fixed-Points Profiles Table

ACFT_ID	Op Type	Profile ID	Stage Length	Point Number	Distance (ft)	Altitude (ft)	TAS (kt)	Corrected Net Thrust (lb)
A32023	A	STANDARD	1	1	-162381.0	6000.0	272.3	1091.30
A32023	A	STANDARD	1	2	-112299.0	4009.0	264.7	912.70
A32023	A	STANDARD	1	3	-87765.0	3000.0	260.9	802.70
A32023	A	STANDARD	1	4	-61823.0	3000.0	204.6	456.50
A32023	A	STANDARD	1	5	-57240.0	3000.0	190.7	362.50
A32023	A	STANDARD	1	6	-54773.0	2871.0	189.8	358.20
A32023	A	STANDARD	1	7	-51725.0	2711.0	187.5	351.20
A32023	A	STANDARD	1	8	-47460.0	2487.0	177.7	391.40
A32023	A	STANDARD	1	9	-36430.0	1909.0	144.6	654.20
A32023	A	STANDARD	1	10	-35298.0	1850.0	139.6	708.10
A32023	A	STANDARD	1	11	-33710.0	1767.0	130.9	817.50
A32023	A	STANDARD	1	12	-33503.0	1756.0	130.9	4888.50
A32023	A	STANDARD	1	13	-19077.0	1000.0	129.5	4753.10
A32023	A	STANDARD	1	14	-1794.0	94.0	127.8	4598.30
A32023	A	STANDARD	1	15	-954.0	50.0	127.7	4570.80
A32023	A	STANDARD	1	16	0.0	0.0	126.7	4570.80
A32023	A	STANDARD	1	17	470.0	0.0	119.7	10600.00
A32023	A	STANDARD	1	18	4704.0	0.0	30.0	2650.00

Table H-8: Example NPD Table

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	L _200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
V2527A	SEL	A	2000.00	93.1	89.1	86.1	82.9	77.7	71.7	67.1	61.9	55.8	49.2
V2527A	SEL	A	2700.00	93.3	89.2	86.2	83.0	77.7	71.8	67.2	62.0	55.8	49.3
V2527A	SEL	A	6000.00	94.7	90.5	87.4	83.9	78.5	72.3	67.7	62.5	56.3	49.7
V2527A	SEL	D	10000.00	95.4	90.7	87.3	83.5	77.7	71.1	66.3	60.9	54.6	47.4
V2527A	SEL	D	14000.00	100.4	96.1	93.0	89.4	83.5	77.0	72.2	66.7	60.1	53.0
V2527A	SEL	D	18000.00	103.2	99.1	96.2	92.9	87.4	81.1	76.5	71.1	64.9	57.9
V2527A	SEL	D	22500.00	105.1	101.2	98.5	95.4	90.3	84.3	79.9	74.8	68.7	62.0
V2527A	LAmax	A	2000.00	89.3	82.8	78.2	73.4	65.8	57.4	51.2	44.4	36.7	28.6
V2527A	LAmax	A	2700.00	89.5	83.0	78.3	73.5	65.8	57.4	51.3	44.4	36.7	28.6
V2527A	LAmax	A	6000.00	91.6	84.7	79.5	74.2	66.5	58.0	51.9	45.0	37.2	29.1
V2527A	LAmax	D	10000.00	94.5	86.7	81.1	75.1	66.1	56.9	50.3	43.1	35.0	26.5
V2527A	LAmax	D	14000.00	98.0	90.4	85.3	80.1	72.0	63.1	56.6	49.2	40.9	32.0
V2527A	LAmax	D	18000.00	101.9	94.7	89.7	84.3	76.1	67.2	60.7	53.4	45.3	36.7
V2527A	LAmax	D	22500.00	104.1	97.1	92.4	87.4	79.4	70.6	64.4	57.5	49.5	40.5
V2527A	EPNL	A	2000.00	96.9	92.3	88.5	84.6	78.6	71.5	66.3	59.8	51.5	40.7
V2527A	EPNL	A	2700.00	97.0	92.4	88.6	84.7	78.6	71.5	66.3	59.9	51.5	40.8
V2527A	EPNL	A	6000.00	99.0	94.3	90.4	86.2	79.7	72.3	67.0	60.4	52.2	41.6
V2527A	EPNL	D	10000.00	100.7	96.0	92.1	87.6	80.5	72.8	66.0	59.1	49.7	36.8
V2527A	EPNL	D	14000.00	106.1	101.4	97.8	93.4	86.2	78.1	72.2	66.0	57.7	46.9
V2527A	EPNL	D	18000.00	107.7	103.3	99.9	96.1	89.6	82.5	77.2	71.2	63.6	53.8
V2527A	EPNL	D	22500.00	109.8	105.5	102.5	98.9	93.0	86.4	81.2	75.5	68.3	59.3
V2527A	PNLTmax	A	2000.00	103.3	96.5	91.3	85.5	76.9	67.6	60.9	53.0	43.6	32.3
V2527A	PNLTmax	A	2700.00	103.8	96.7	91.1	85.3	76.9	67.7	60.9	53.0	43.6	32.1
V2527A	PNLTmax	A	6000.00	106.3	99.2	93.4	87.0	78.8	68.3	61.4	53.5	44.0	32.6
V2527A	PNLTmax	D	10000.00	112.7	105.0	99.3	92.6	80.9	71.0	59.9	52.0	41.0	27.0
V2527A	PNLTmax	D	14000.00	114.9	107.1	101.4	94.8	84.1	74.0	66.4	58.4	48.6	37.1
V2527A	PNLTmax	D	18000.00	116.6	109.5	104.3	98.5	88.5	78.7	71.2	63.3	54.3	43.5
V2527A	PNLTmax	D	22500.00	118.6	111.4	106.3	100.3	91.5	82.7	76.0	68.4	59.3	48.5

Table H-9: Example Spectral Class Table

Spectral Class Identifier	**Operation Type**	**Description**	**L_50Hz**	**L_63Hz**	**L_80Hz**	**L_100Hz**	**L_125Hz**	**L_160Hz**	**L_200Hz**	**L_250Hz**	**L_315Hz**	**L_400Hz**	**L_500Hz**
103	Departure	Two engine high bypass ratio turbofan	56.7	66.1	70.1	72.8	76.6	73.0	74.5	77.0	75.3	72.2	72.2

Table H-9: Example Spectral Class Table (continued)

Spectral Class Identifier	Operation Type	Description	L_630Hz	L_800Hz	L_1000Hz	L_1250Hz	L_1600Hz	L_2000Hz	L_2500Hz	L_3150Hz	L_4000Hz	L_5000Hz	L_6300Hz	L_8000Hz	L_10000Hz
103	Departure	Two engine high bypass ratio turbofan	71.2	70.2	70.0	69.6	71.1	70.6	67.1	63.4	63.5	58.2	51.5	42.3	37.7

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English only

PROPOSAL FOR A CIRCULAR ON NOISE AND EMISSION EFFECTS FROM PANS-OPS NOISE ABATEMENT DEPARTURE PROCEDURES

CONTENTS

GLOSSARY

Adjusted top of climb	Common mission point after top of climb beyond which the remaining part of flight is common for a set of compared procedures and a given aircraft
AGL	Above Ground Level
A-weighted sound level, L_A	Basic sound/noise level scale used for measuring environmental noise including that from aircraft
Brake release	The point on the runway from which a departing aircraft commences its takeoff
Close-in zone	Zone underneath the flight path, typically extending from the point of initiation of the noise abatement departure procedure up to the crossover point
CO2	Carbon Dioxyde, component of gaseous emissions comprised of one carbon and two oxygen atoms
Crossover point	Point underneath the flight path at which the sign of the difference between noise profiles for two compared departure procedure changes
Cutback	The reduction of engine power from takeoff thrust to a lower thrust setting, usually Climb thrust
dBA	Decibel A-weighted sound level
Distant zone	Zone underneath the flight path, typically extending from the crossover point
FT	Feet
ICAO	International Civil Aviation Organization
ISA	International Standard Atmosphere
KIAS	Knots indicated airspeed
L_{Amax}	Maximum A-weighted sound level
LB	Pound
MCLT	Maximum Climb Thrust, engine setting usually selected for climb-out phase
MTOW	Maximum Takeoff Weight
NADP	Noise Abatement Departure Procedure
NM	Nautical mile
Noise	Noise is defined as unwanted sound. Metrics such as A-weighted sound level used in this document convert a sound level into a noise level.
Noise level	A decibel measure of sound on a scale which indicates its loudness or noisiness
Noise profile	Profile obtained by computing noise levels at regular intervals along the flight track from start of initial climb-out until the point where the aircraft has reached a given altitude
NOx	Nitrogen Oxyde, component of gaseous emissions. Mixture of nitrogen monoxide and nitrogen dioxide
PANS-OPS	Procedures for Air Navigation Services, Operations

Point X	Adjusted top of climb
SAE	Society of Automotive Engineers
SL	Sea level
STD	Standard
TOGA	Takeoff Go-around, maximum takeoff thrust setting
TOW	Takeoff weight
V2	Takeoff safety speed

1. INTRODUCTION

1.1 Purpose

1.1.1 The purpose of this document is to provide information to airports and operators with regard to selection and development of noise abatement departure procedures designed according to the guidance in PANS-OPS, Part V, Chapter 3. Quantitative information regarding effects of noise abatement departure procedures on noise and gaseous emissions are provided below for a limited number of today's commercial transport jet aircraft.

1.1.2 The scope of this document is limited to noise abatement departure procedures that can be operated with aircraft currently in service.

1.1.3 The collection of aircraft for which information is provided in this document includes the main jet aircraft categories, such as business, regional, narrow-body and wide-body aircraft, but is nevertheless limited in number. The data provided for these aircraft is based on common assumptions concerning operational parameters (e.g. takeoff weights, thrust settings, atmospheric conditions) for the different aircraft categories. The usage of this material should be limited to acquiring general insight. For selection of appropriate procedures for a given aircraft type and/or airport situation, further dedicated study is required.

1.2 Guidelines for use of this document

1.2.1 The results of this study should be considered as information to airports and operators with regard to selection and development of noise abatement departure procedures. The usage of this material should be limited to acquiring general insight into noise and emissions effects of departure procedures.

1.2.2 Quantitative results and conclusions mentioned in this study are valid for the aircraft and conditions included in this study and should not be generalized nor extrapolated.

1.2.3 In applying this guidance, users of the data should seek expert noise and emissions advice.

1.2.4 For selection of appropriate procedures for a given airport and/or fleet mix, further dedicated study is required, taking into account particularities such as geographical location and atmospheric conditions.

1.3 Document structure

1.3.1 Section 2 provides a short summary of the PANS-OPS noise abatement departure procedures that can be selected by the operator. It highlights the main parameters relevant for the selection of procedures with regard to environmental criteria due to their supposed influence on noise and gaseous emissions effects.

1.3.2 The environmental effects of departure procedures can be measured in various ways. A description of the predicted noise and emissions effects and their graphical representation is provided in Section 3.

1.3.3 Section 4 provides a description of the noise abatement departure procedures for which noise and emissions effects have been quantified. This section also provides the basis of comparison of the procedures as well as the common assumptions regarding operational flight parameters.

1.3.4 Section 5 provides a synthesis of the noise and emissions effects predicted for the aircraft that are included in this study. The results per aircraft type are available in the appendices to this document.

1.3.5 Section 6 provides the conclusions.

2. NOISE ABATEMENT DEPARTURE PROCEDURES

2.1 Guidance

2.1.1 ICAO PANS-OPS, Part V, Chapter 3 provides guidance with respect to operation of noise abatement departure procedures. The guidance contains recommendations regarding the conditions in which noise abatement procedures can be safely used and the envelope within which main flight parameters defining the procedure can be safely adapted for airport noise mitigation.

2.1.2 The guidance includes two examples of procedures, one to mitigate noise at relatively shorter distances and another at relatively greater distances from the brake release point. These examples are described in the following subsection.

2.1.3 The guidance furthermore states that the number of departure procedures developed and used by the operator for a given aircraft should be limited to two, one identified as the normal procedure and the other to be used for noise abatement. Within these constraints, the operator has to determine which procedures to select.

2.2 PANS-OPS examples of noise abatement procedures

2.2.1 Figure 1 and Figure 2, taken from PANS-OPS, Part V, Chapter 3, provide a schematic description of NADP 1 & 2 procedures. The zones where these procedures are expected to provide noise abatement, respectively close-in and distant relative to the brake release point, are mentioned below the figures.

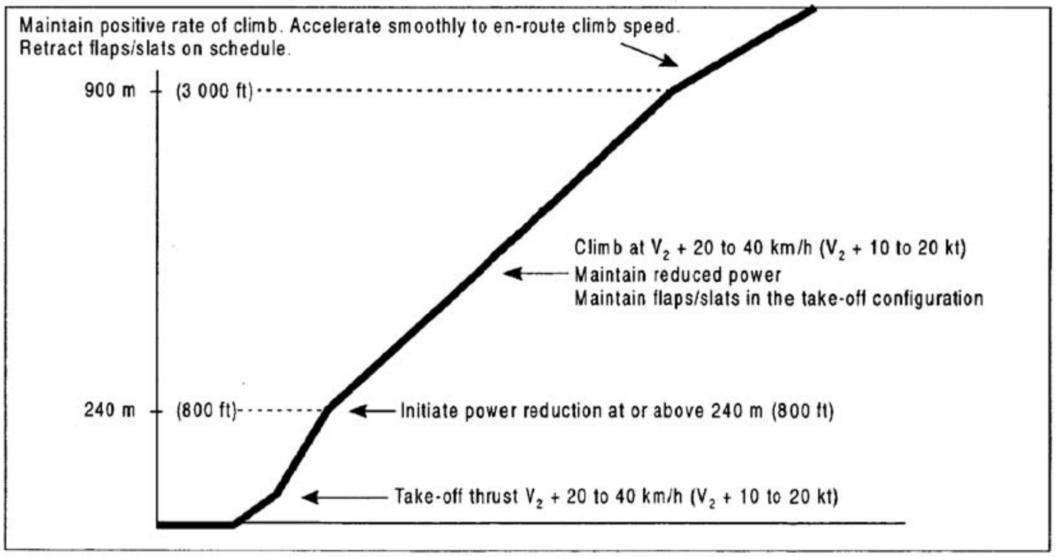


Figure V-3-1. Noise abatement take-off climb — Example of a procedure alleviating noise close to the aerodrome (NADP 1)

Figure 1: ICAO NADP1

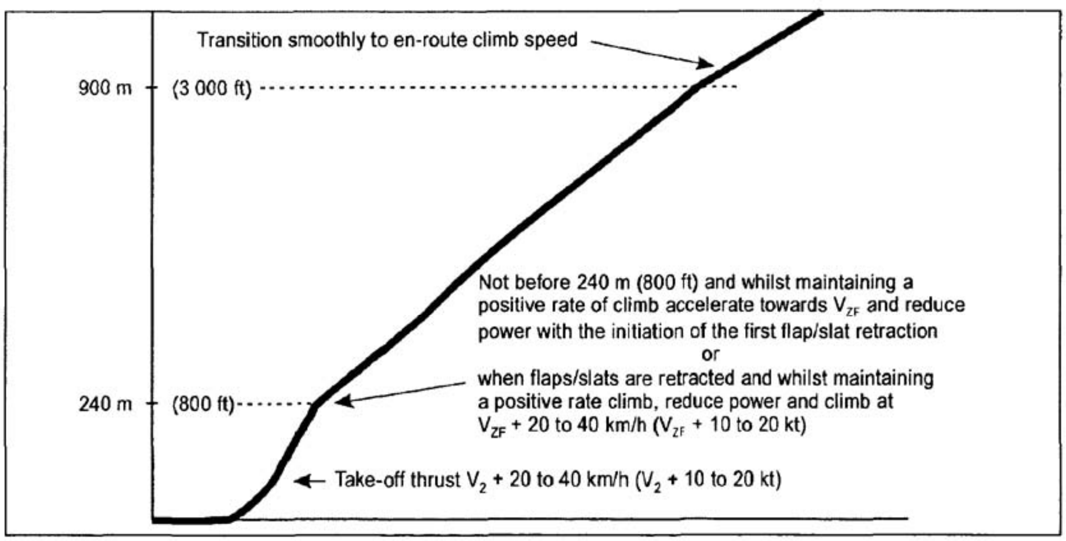


Figure V-3-2. Noise abatement take-off climb — Example of a procedure alleviating noise distant from the aerodrome (NADP 2)

Figure 2: ICAO NADP2

2.2.2 As shown in Figures 1 and 2, the procedures take place between a minimum of 800ft and a maximum of 3000ft AGL, allowing operators to develop specific procedures to suite their local situations. The term used previously in PANS-OPS, ICAO Procedure A, would constitute a specific procedure within the NADP 1 family; similarly ICAO Procedure B constitutes a specific procedure within the NADP 2 family. The flexibility provided in the PANS-OPS guidance remains limited to two procedures.

2.3 Procedure development and appraisal of environmental effects

2.3.1 The PANS-OPS guidance, the main goal of which is to provide recommendations for safe aircraft operations, does not provide quantitative information regarding the zones where the aforementioned procedures provide noise abatement and the size of the noise differences in those zones.

2.3.2 The selection of an appropriate procedure with regard to airport-specific environmental constraints requires the quantification and analysis of the available operational solutions in terms of noise and/or gaseous emissions. The environmental effects of the procedures depend on type of aircraft and operating conditions. The assessment of noise effects as part of procedure development should therefore be based on actual information regarding the airport fleet mix and geographical position of the airport and its runway(s) with regard to noise sensitive areas.

3. NOISE AND GASEOUS EMISSIONS EFFECTS

3.1 Noise effects and metrics

3.1.1 This section explains the main noise effects of operational departure procedures and the method and metrics for quantification of these effects.

3.1.2 For departure operations the main noise source are the aircraft engines. For a given aircraft and a given atmospheric condition, the noise perceived by an observer position on the ground depends mainly on the thrust setting, the height of the aircraft and its speed. The speed of the aircraft affects the duration of the noise event.

3.1.3 The noise perceived on the ground for a single event can be expressed in terms of maximum-level metrics and in terms of total noise exposure metrics. The maximum-level metrics only consider the peak noise level registered during a noise event. Exposure metrics quantify the total amount of noise during the relevant part of the noise event. Whereas the maximum level corresponds to a certain time and position of the aircraft, the exposure level corresponds to noise emitted during a part of the aircraft’s departure.

3.1.4 The noise underneath the flight path is critical for the assessment of noise produced by the different departure procedures. For this study, noise levels are computed at regular intervals along the track from start of initial climb-out until the point where the aircraft has reached 10000 ft AGL, resulting in so-called “noise profiles”.

3.1.5 Establishing a relationship between the development of maximum noise levels below the flight path to events along the flight path (e.g. thrust cutback or transition from climb to acceleration) is relatively straightforward. For exposure-based metrics, this is more difficult due to the integration of noise over a time interval during which several changes in aircraft state and climb performance can occur. For the analysis of procedures in this document, the maximum A-weighted noise level is considered.

3.1.6 Flight profiles have been computed with manufacturer in-house performance engineering software. Noise levels have been computed for these profiles using in-house noise calculation tools, compliant with SAE AIR-1845.

3.2 Emissions effects and metrics

3.2.1 This section explains the main emissions effects considered in this document for operational departure procedures and the method for quantification of these effects.

3.2.2 For departure operations considered in this report, the emissions source is the aircraft main engines. For a given aircraft the operational emissions will depend on the airplane and engine types, engine thrust setting, and operating time to study evaluation altitudes of 1000 ft, 3000 ft, and adjusted top of climb.

3.2.3 The aircraft total NOx emissions produced for each takeoff procedure is presented at 1000 feet, the typical limiting altitude for NO2 concerns, and 3000 feet AGL, the typical boundary layer mixing altitude and ICAO LTO altitude limit. Aircraft total CO2 emissions produced for each takeoff procedure is presented at a common mission point after top of climb (adjusted top of climb, see section 4.1.4).

3.2.4 Emissions calculations were completed by individual airplane manufacturer propriety airplane performance methods (see section 3.1.6) that provided airplane flight path and fuel burn. Aircraft CO2 production is calculated directly from fuel burn. Aircraft NOx production is determined via fuel flow methods and certified engine emissions data.

3.3 Graphic representation of noise and emissions effects

3.3.1 In this section the method for graphic representation of noise and emissions effects of operational departure procedures is explained.

3.3.2 Figure 3 provides an example of the graphical representation of noise and emission effects applied in the Appendices. The graphs show noise and emissions effects per aircraft and per pair of procedures. For this example procedures are named Procedure Y and Procedure Z.

3.3.3 The title of each graph specifies the aircraft type and the assumed takeoff weight.

3.3.4 The noise effects are demonstrated per procedure by means of noise profiles, showing noise underneath the flight path as a function of distance from brake release. These curves provide insight on the decrease of noise levels with increasing distance from brake release. The applied noise metric is the maximum A-weighted noise level (L_{Amax}). A relative scale is used for these curves.

3.3.5 In addition to the noise levels of the two procedures, a third curve providing the difference between these noise levels is included. This curve allows rapid assessment of the amount and sign of difference as function of distance from brake release. The third curve has three distinct characteristics, all of which are important in the selection of noise abatement departure procedures:

- A “Close-in” noise difference zone, typically extending from the point of initiation of the procedure up to the crossover point;
- A “crossover point”, which is generally the point at which the sign of the difference changes,
- A “Distant” noise difference zone, extending from the crossover point.

3.3.6 The maximum close-in noise difference and maximum distant noise difference designated in Figure 3 are included as indicators in the procedure comparisons in Section 5.

3.3.7 The emissions effects are represented by means of bar charts. The charts provide the total amounts of NOx emitted between brake release and altitudes of 1000ft or 3000ft AGL, respectively “1000ft NOx” and “3000ft NOx” in the example. A third quantity provided in the bar chart is the total amount of CO_2 emitted between brake release and the adjusted start of cruise, referred to as “Point ’X‘ CO_2” in the bar chart. All results are given as a percentage relative to the first of the two procedures in the chart. The percentages are printed on the bar charts to facilitate appraisal of the differences.

3.3.8 The appendices also include flight path.

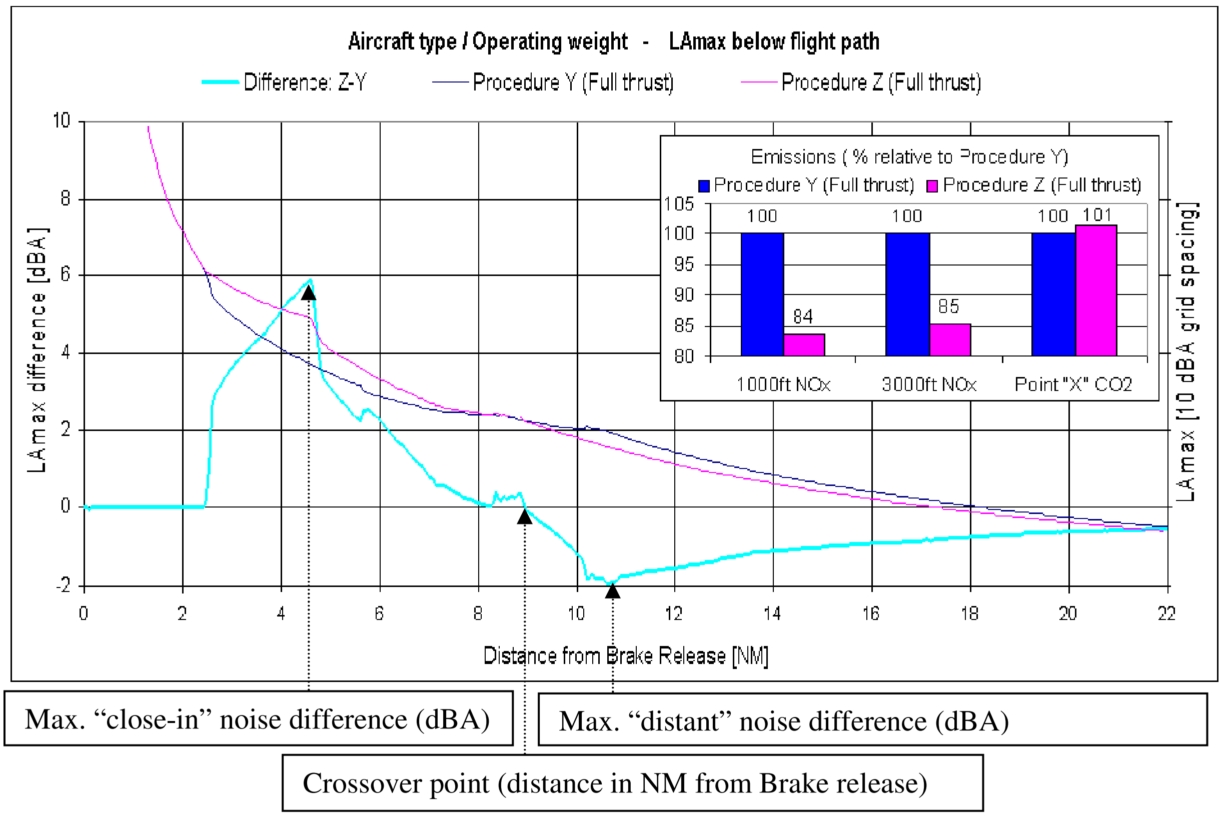


Figure 3: Graphical representation of the noise and emissions effects for two procedures

4. DESCRIPTION OF PROCEDURES USED IN THE ANALYSIS

4.1 Procedure descriptions

4.1.1 This section describes the four variants of departure procedure designed in accordance with PANS-OPS that are evaluated in the document.

4.1.2 Table 1 provides descriptions of these procedures, including two NADP1 variants, Procedures 1 and 2, and two NADP2 variants, Procedures 3 and 4. These descriptions include the takeoff and departure climb up to 10000ft AGL, relevant for the noise assessment. A schematic description of the succeeding climb-out to adjusted top of climb is given after.

4.1.3 Procedures 1 and 2 were selected to illustrate the effect of cutback height. Procedures 3 and 4 were selected to illustrate the effect of thrust cutback at the beginning and end of the acceleration and flap retraction phase. The selected procedures also allow comparison between NADP1 and NADP2. This is described in more detail in Section 4.2.

Procedure 1	**Procedure 2**	**Procedure 3**	**Procedure 4**
Takeoff thrust, lowest flap setting [1]	Takeoff thrust, lowest flap setting [1]	Takeoff thrust, lowest flap setting [1]	Takeoff thrust, lowest flap setting [1]
Climb at V2+15 KIAS [2] to 800 ft AGL	Climb at V2+15 KIAS [2] to 1500 ft AGL	Climb at V2+15 KIAS [2] to 800ft AGL	Climb at V2+15 KIAS [2] to 800ft AGL
Cutback to MCLT	Cutback to MCLT	Accelerate and retract flaps [4]	Cutback to MCLT [3]
		At zero flap cutback to MCLT	Accelerate and retract flaps [4]
Constant speed climb to 3,000 ft AGL	Constant speed climb to 3,000 ft AGL	Constant speed climb to 3000 ft AGL	Constant speed climb to 3,000 ft AGL
Accelerate to 250 KIAS while retracting flaps [4]	Accelerate to 250 KIAS while retracting flaps [4]	Accelerate to 250 KIAS [4]	Accelerate to 250 KIAS [4]
Climb at Constant speed to 10,000ft AGL	Climb at Constant speed to 10,000ft AGL	Climb at Constant speed to 10,000ft AGL	Climb at Constant speed to 10,000ft AGL
End profile at 10,000ft [5]	End profile at 10,000ft [5]	End profile at 10,000ft [5]	End profile at 10,000ft [5]

Table 1: Variants of departure procedures

4.1.4 Following common assumptions have been applied in the development of the vertical profiles corresponding to these procedures:

[1)] Slat/flap setting according to most commonly used flap/slat setting for a given aircraft type;

[2)] V2+15kt considered as default, unless a/c operations manual recommends another takeoff speed;

[3)] The moment at which the cutback is made is compatible with performance of specific aircraft in the study and in line with manufacturer standard operating procedures;

[4)] During the acceleration phases the energy share between acceleration and climb performance is as applied by the manufacturer for given aircraft;

[5)] For noise predictions the profile end is assumed at 10000ft. For the CO2 analysis the profile continues until adapted start of cruise point.

4.1.5 Figure 4 provides a schematic representation of the vertical procedures from brake release until the adjusted top of climb ("Point X"). Takeoff to the adjusted top of climb represents the portion of the flight profile that is dependent on the choice of departure procedure. Flight profiles after the adjusted top of climb are assumed to be common for each airplane type and therefore not modeled in this study.

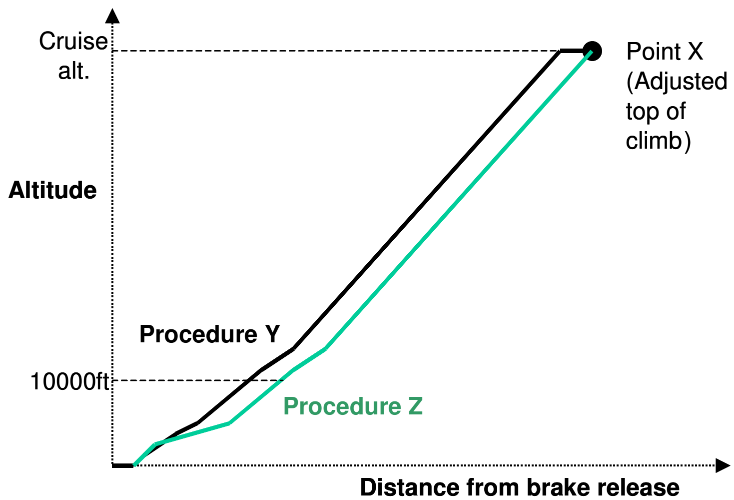


Figure 4: Adjusted top of climb (Point X)

4.2 Comparisons

4.2.1 The procedures described in the preceding subsection are evaluated on a two-by-two basis. For each aircraft type, the four comparisons are made in order to demonstrate effects of type of procedure and the influence of the timing and altitude at which the thrust cutback occurs.

4.2.2 The comparisons and their objectives are as follows:

- Procedure 1 versus 2: demonstrate influence of cutback height for NADP1
- Procedure 1 versus 3: compare NADP1 against NADP2 (NADP2 featuring a late cutback)
- Procedure 1 versus 4: compare NADP1 against NADP2 (NADP2 featuring an early cutback)
- Procedure 3 versus 4: demonstrate influence of cutback moment for NADP2

4.2.3 The comparison of Procedures 1 and 2 assesses the influence of cutback height on noise for a close-in noise abatement departure procedure. Cutback height is varied from 800ft AGL, the minimum height according to the guidance, to 1500ft AGL, the maximum cutback height observed in most of currently applied departure procedures.

4.2.4 The comparisons of Procedure 1 to Procedures 3 and 4 are meant to demonstrate the difference between NADP1 and NADP2 procedures. Two variants of NADP2 procedures are used because these procedures are believed to be quite sensitive to the timing of thrust cutback.

4.2.5 The fourth comparison, between Procedures 3 and 4, is performed to demonstrate the impact on noise and emissions of the timing of thrust cutback in an NADP2 procedure.

4.3 Takeoff thrust settings

4.3.1 The entire study is being performed in parallel for two cases, using different assumptions for takeoff thrust setting and takeoff weight. The objective is to expand the study to real-life operational conditions.

4.3.2 The first case assumes a full thrust takeoff and a maximum takeoff weight.

4.3.3 The second case assumes a reduced takeoff thrust setting and a performance (climb) limited takeoff weight. For this case, the thrust used has to correspond to a level between full takeoff thrust and maximum thrust reduction allowed. In this analysis, the percentage of thrust reduction has been assumed to correspond to either 10% or 12%, and the actual level chosen was believed to be close to the average thrust settings used in daily practice. This portion of the study is restricted to those aircraft for which Max Climb thrust is less than 90% of full takeoff thrust.

4.3.4 Because they are at different weights, comparisons between the two cases are not valid. In practice, takeoff weight is a constraint and takeoff thrust setting is adjusted by the pilot to meet departure performance safety limits in compliance with operator policy.

5. SYNTHESIS OF NOISE AND EMISSIONS EFFECTS

5.1 Introduction

5.1.1 This section provides a synthesis of the NADP noise and emissions data provided in the appendices of this report.

5.1.2 The aircraft aircraft/engine combinations that have been included in the noise and emissions study are presented in Table 2. The dataset includes a range of narrow-body, wide-body, regional and business jet aircraft.

Aircraft category	Aircraft	Engine	MTOW (lbs / tonnes)	Appendix
Narrow body	Airbus A320-214	CFM56-5B4/P	169800 / 77	A
	Boeing 737-700	CFM56-7B24	154500 / 70	B
Wide body	Airbus A330-223	PW4168A	513700 / 233	A
	Airbus A340-642	TRENT 556	811300 / 368	A
	Boeing 767-400	CF6-80C2B8F	450000 / 204	B
	Boeing 777-300	TRENT 892	660000 / 300	B
Regional jet	Bombardier CRJ900ER	CF34-8C5	82500 / 37	C
Business jet	Dassault FALCON 2000EX	PW308C	42200 / 19	D

Table 2: Aircraft types included in the study

5.1.3 In the following four sections the results are summarised per pair of compared procedures. The quantitative results are summarised in tables containing indicators of characteristic noise and emissions differences, as explained in section 4. A qualitative interpretation is given as well.

5.2 **Procedures 1 versus 2**

5.2.1 The comparison of procedures 1 and 2 allows determining the effect of a change in cutback height (respectively 800 and 1500ft AGL) for two NADP1 type procedures. The height profiles in the appendices show the steeper climb profiles for procedure 2 for all cases, due to the delayed cutback.

5.2.2 Table 3 provides the noise and emissions differences per aircraft type for both full and reduced takeoff thrust cases. For the Falcon 2000EX only full takeoff thrust data is available.

5.2.3 The results in the table indicate similar trends for the different aircraft types. The results indicate that performing the cutback at 800ft AGL rather than at 1500ft AGL leads to a noise reduction close-in, which can be attributed to the reduction in engine source noise. The magnitude of this noise reduction varies for the aircraft in this dataset from 0.6 dBA to 5.3 dBA.

5.2.4 For distant zones, the 800ft AGL cutback leads to more noise than the 1500ft cutback, due to the steeper climb-out of the latter. The “distant” noise differences are considerably smaller than the “close-in” differences. After peak differences ranging from –0.2 dBA to –2.0 dBA the noise differences gradually reduce throughout the remainder of the climb-out phase.

5.2.5 The crossover point between the noise profiles varies roughly with aircraft size, ranging from 1.9 NM for the business aircraft to 4.1 NM for the large twinjet at reduced thrust.

5.2.6 The emissions data in Table 2 show that, compared to Procedure 1, Procedure 2 produces differences in NOx of –0.7 to +1.8% through 1000ft and –0.3 to 3.2% through 3000ft AGL. Procedure 2 reduces CO2 by as much as 0.3% through the adjusted top of climb.

Comparison	Aircraft	Takeoff thrust	Max. close-in* noise difference (dBA)	Cross-over* point (NM)	Max. distant* noise difference (dBA)	NOX difference 1000 ft (%)	NOX difference 3000 ft (%)	CO2 difference point X (%)
Procedure 2-1	A320-200	FULL	+5.0	2.5	-1.8	+1.4	+1.4	-0.2
Procedure 2-1	A330-200	FULL	+5.3	3.0	-2.0	+1.8	+3.2	-0.2
Procedure 2-1	A340-600	FULL	+2.4	3.6	-2.0	+1.5	+2.1	-0.3
Procedure 2-1	B737-700	FULL	+0.8	2.6	-0.2	-0.1	+0.5	0.0
Procedure 2-1	B767-400	FULL	+5.0	3.5	-1.8	+1.2	+3.2	-0.1
Procedure 2-1	B777-300	FULL	+3.5	3.9	-2.0	+0.7	+2.8	-0.1
Procedure 2-1	CRJ900ER	FULL	+1.5	2.6	-1.1	+0.3	+0.7	0.0
Procedure 2-1	F2000EX	FULL	+2.0	1.9	-0.9	-0.7	-0.3	-0.3
Procedure 2-1	A320-200	REDUCED	+2.6	2.4	-1.6	+1.2	+0.7	-0.1
Procedure 2-1	A330-200	REDUCED	+4.0	2.6	-1.4	+1.1	+1.8	-0.2
Procedure 2-1	A340-600	REDUCED	+1.5	3.7	-1.2	+0.2	+0.7	-0.2
Procedure 2-1	B737-700	REDUCED	+1.2	3.0	-0.6	+0.3	+1.2	0.0
Procedure 2-1	B767-400	REDUCED	+4.0	3.8	-1.8	+0.9	+1.9	-0.1
Procedure 2-1	B777-300	REDUCED	+2.8	4.1	-2.0	0.0	+1.0	-0.2
Procedure 2-1	CRJ900ER	REDUCED	+0.6	2.3	-0.5	+0.1	+0.2	-0.1

*) Explained in section 3.

Table 3: Noise and emissions differences between procedures 1 and 2

5.3 Procedures 1 versus 3

5.3.1 With the comparison of Procedures 1 and 3 the difference between a NADP1 and NADP2 procedures is determined in terms of noise and emissions effects. Procedure 3 features a cutback at the end of the acceleration and flap retraction phase. The height profiles in the appendices indicate better climb performance for Procedure 1 up to about 3000ft AGL, but better overall climb performance up to 10000ft for Procedure 3.

5.3.2 The results in the following table indicate the "close-in" noise reduction obtained with Procedure 1 compared to Procedure 3. The peak values of noise difference in the "close-in area" before the crossover point vary from 3.5 to 8.1dBA.

5.3.3 In the "distant" area beyond the cross over point noise differences are smaller, with peak differences between –0.2 and –3.7 dBA, and spread out over a larger area.

5.3.4 The crossover point ranges from 5.5 to 8.1NM from brake release for all except the business aircraft, which has its crossover point at 3.3NM.

5.3.5 The emissions data in Table 4 show that Procedure 3 produces up to 17.2% more NOx through 1000ft and up to 19.8% more NOx through 3000ft AGL. Procedure 3 however leads to a reduction of CO2 of as much as 2.7% through the adjusted top of climb.

Comparison	Aircraft	Takeoff thrust	Max. close-in noise difference (dBA)	Cross-over point (NM)	Max. distant noise difference (dBA)	NOX difference 1000 ft (%)	NOX difference 3000 ft (%)	CO2 difference point X (%)
Procedure 3-1	A320-200	FULL	+7.7	7.2	-2.7	+16.6	+13.3	-2.3
Procedure 3-1	A330-200	FULL	+8.1	6.5	-3.0	+16.9	+8.0	-2.2
Procedure 3-1	A340-600	FULL	+5.6	7.7	-3.7	+14.6	+10.2	-2.6
Procedure 3-1	B737-700	FULL	+3.5	7.6	-0.3	+11.2	+7.2	-1.7
Procedure 3-1	B767-400	FULL	+7.0	5.8	-2.0	+9.5	+19.8	-1.8
Procedure 3-1	B777-300	FULL	+4.8	6.5	-2.0	+10.5	+11.7	-1.5
Procedure 3-1	CRJ900ER	FULL	+3.7	7.3	-0.5	+13.5	+0.8	-1.1
Procedure 3-1	F2000EX	FULL	+6.0	3.3	-2.9	+14.8	+4.2	-2.4
Procedure 3-1	A320-200	REDUCED	+6.2	7.0	-2.1	+16.9	+11.2	-2.2
Procedure 3-1	A330-200	REDUCED	+7.2	6.2	-2.2	+17.2	+6.0	-2.5
Procedure 3-1	A340-600	REDUCED	+5.5	7.9	-2.8	+13.9	+8.9	-2.7
Procedure 3-1	B737-700	REDUCED	+3.6	8.1	-0.5	+10.7	+7.7	-1.9
Procedure 3-1	B767-400	REDUCED	+5.0	5.5	-2.0	+9.1	+14.4	-2.0
Procedure 3-1	B777-300	REDUCED	+3.9	8.0	-2.0	+9.9	+8.7	-1.7
Procedure 3-1	CRJ900ER	REDUCED	+3.6	6.5	-0.2	+14.6	+0.3	-1.2

Table 4: Noise and emissions differences between procedures 1 and 3

5.4 Procedures 1 versus 4

5.4.1 As the preceding comparison the comparison between procedure 1 and 4 enables determining noise and emissions differences between a NADP1 and a NADP2 procedure. The NADP2 procedure 4 features a cutback at the beginning of the acceleration and flap retraction phase. Although climbing out less steeper than Procedure 1 in the initial phase, Procedure 4 provides a steeper overall profile up to 10000ft AGL.

5.4.2 The noise effects summarized in the Table 5 indicate similar trends as the effects in the preceding comparison. Procedure 1 provides noise reduction compared to Procedure 4 in the “close-in” area, with peak differences ranging from 3.0 to 7.0 dBA.

5.4.3 In the “distant” area, overall Procedure 4 produces less noise, with peak noise differences reaching –2.6 dBA. For several aircraft, distant noise reduction was marginal and less well developed compared to the case of Procedure 1 versus 3. In the case of the regional jet with reduced thrust, full crossover was not obtained; however, this particular result is only valid for this example and no general conclusion can be drawn. Hence, in this instance a crossover point was chosen by comparing the noise difference plot to those of full thrust and the Procedures 1 versus 3 comparison with both thrust settings - these plots all show strong similarity and the resulting crossover points show similar trends.

5.4.4 The crossover point ranges from 7.8 to 11.0 NM for the wide-body aircraft, is slightly smaller for the regional aircraft and occurs around 3.3NM for the business aircraft. Overall the crossover occurs later than for the comparison between Procedure 3 and 1.

Comparison	Aircraft	Takeoff thrust	Max. close-in noise difference (dBA)	Cross-over point (NM)	Max. distant noise difference (dBA)	NOX difference 1000 ft (%)	NOX difference 3000 ft (%)	CO2 difference point X (%)
Procedure 4-1	A320-200	FULL	+7.0	8.1	-1.6	+14.6	+9.9	-2.0
Procedure 4-1	A330-200	FULL	+4.3	9.7	-1.7	+12.3	+2.1	-2.0
Procedure 4-1	A340-600	FULL	+5.9	9.2	-2.2	+11.0	+4.3	-2.3
Procedure 4-1	B737-700	FULL	+3.1	8.0	-0.1	+10.2	+5.7	-1.7
Procedure 4-1	B767-400	FULL	+4.0	9.5	-0.5	+6.0	+8.5	-1.7
Procedure 4-1	B777-300	FULL	+4.0	9.0	-0.8	+6.1	+5.7	-1.3
Procedure 4-1	CRJ900ER	FULL	+3.0	7.7	-0.2	+9.6	+0.5	-0.6
Procedure 4-1	F2000EX	FULL	+3.5	3.3	-2.6	+8.1	+1.9	-1.8
Procedure 4-1	A320-200	REDUCED	+6.6	7.8	-1.3	+15.5	+9.7	-2.0
Procedure 4-1	A330-200	REDUCED	+6.0	8.3	-1.4	+14.4	+2.8	-2.3
Procedure 4-1	A340-600	REDUCED	+6.1	9.1	-2.0	+12.5	+6.3	-2.4
Procedure 4-1	B737-700	REDUCED	+3.0	9.0	-0.2	+9.7	+5.3	-1.9
Procedure 4-1	B767-400	REDUCED	+4.0	10.0	-0.5	+6.7	+7.8	-1.8
Procedure 4-1	B777-300	REDUCED	+4.0	11.0	-0.8	+7.0	+5.7	-1.5
Procedure 4-1	CRJ900ER	REDUCED	+3.3	6.6	0.0	+12.8	-0.1	-0.8

Table 5: Noise and emissions differences between procedures 1 and 4

5.4.5 The emissions data in Table 5 show that Procedure 4 produces up to 15.5% more NOx through 1000ft and up to 9.9% more NOx through 3000ft AGL. Procedure 4 however leads to a reduction of CO2 of as much as 2.4% through the adjusted top of climb.

5.5 **Procedures 3 versus 4**

5.5.1 The comparison of Procedures 3 versus 4 enables determining the effect of the timing of cutback during the acceleration and flap retraction phase for a NADP2 procedure. Procedure 3 features a cutback to climb thrust at the end of the acceleration and flap retraction phase whereas procedure 4 has a cutback at the beginning. This results overall in a steeper climb-out profile for Procedure 3.

5.5.2 The results in the Table 6 show that performing the cutback to climb thrust at the beginning of the acceleration phase is always better for close-in noise reduction but always worse for distant noise reduction. The noise reduction obtained “close-in” with Procedure 4 ranges from –0.8 to –5.5 dBA and can be attributed to a reduced engines noise level.

5.5.3 The maximum noise differences in the “distant” zone vary between 0.4 and 4.2 dBA and can be attributed to differences in height profile. Unlike the trade-off in close-in and distant noise reductions when comparing Procedures 1 to 2, 3 or 4, here the magnitude of peak of close-in and distant noise differences are very similar.

Comparison	Aircraft	Takeoff thrust	Max. close-in noise difference (dBA)	Cross-over point (NM)	Max. distant noise difference (dBA)	NOX difference 1000 ft (%)	NOX difference 3000 ft (%)	CO2 difference point X (%)
Procedure 4-3	A320-200	FULL	-5.4	3.7	+4.2	-1.7	-2.9	+0.3
Procedure 4-3	A330-200	FULL	-5.5	3.6	+4.1	-4.0	-5.4	+0.2
Procedure 4-3	A340-600	FULL	-2.5	4.9	+4.2	-3.1	-5.3	+0.3
Procedure 4-3	B737-700	FULL	-0.8	3.5	+0.6	-0.9	-1.4.	0.0
Procedure 4-3	B767-400	FULL	-4.8	5.5	+3.8	-3.3	-9.5	+0.1
Procedure 4-3	B777-300	FULL	-3.8	5.0	+3.5	-3.9	-5.4	+0.2
Procedure 4-3	CRJ900ER	FULL	-1.6	2.7	+1.2	-3.4	-0.3	+0.5
Procedure 4-3	F2000EX	FULL	-4.4	2.4	+0.6	-5.8	-2.2	+0.7
Procedure 4-3	A320-200	REDUCED	-2.9	3.5	+2.6	-1.2	-1.3	+0.2
Procedure 4-3	A330-200	REDUCED	-3.9	3.1	+2.8	-2.4	-3.0	+0.2
Procedure 4-3	A340-600	REDUCED	-1.3	5.4	+2.7	-1.2	-2.4	+0.2
Procedure 4-3	B737-700	REDUCED	-1.3	3.6	+1.3	-0.9	-2.3	0.0
Procedure 4-3	B767-400	REDUCED	-4.0	5.5	+3.5	-2.1	-5.8	+0.2
Procedure 4-3	B777-300	REDUCED	-3.0	5.0	+3.8	-2.6	-2.8	+0.3
Procedure 4-3	CRJ900ER	REDUCED	-0.6	2.5	+0.4	-1.6	-0.4	+0.4

Table 6: Noise and emissions differences between procedures 3 and 4

5.5.4 The crossover point ranges from 2.4 to 5.5 NM and is in fact located close to the point where cutback for Procedure 3 takes place.

5.5.5 The emissions data in Table 6 show that Procedure 4 produces up to 5.8% less NOx through 1000ft and up to 9.5% less NOx through 3000ft AGL. Procedure 4 however leads to an increase of CO2 of as much as 0.7% through the adjusted top of climb.

6. CONCLUSIONS

6.1 Noise and emissions effects of noise abatement departure procedures designed according to PANS-OPS guidance have been analyzed for eight commercial jet aircraft. The following conclusions are valid for these eight aircraft.

6.2 The procedures evaluated included two NADP1 and two NADP2 variants. The analysis confirmed that NADP1 procedures minimize noise in a zone relatively close to the brake release point, whereas NADP2 minimizes noise in the zone further away from brake release.

6.3 Close-in noise differences between NADP1 and NADP2 are generally bigger than distant noise differences.

6.4 The point where the noise difference changes sign is called the crossover point and was shown to occur between 5.5 to 11NM distance from brake release for regional and wide-body aircraft.

6.5 The cutback height has a significant influence on noise, for both NADP1 and NADP2 procedures. It determines both the location of noise reduction areas and amount of noise reduction in those areas.

6.6 The magnitudes of the noise differences for the procedures using full thrust are larger than those with reduced thrust. However, the use of full thrust and maximum takeoff weight will not be encountered frequently in operation.

6.7 NADP2 tends to produce less CO2 and more NOx compared to NADP1.

6.8 In terms of accumulated NOx up to 3000ft above ground level, NADP2 appears to produce between 5 to 20% more NOX than NADP1 for wide-body aircraft. For regional and business aircraft differences were smaller.

6.9 In terms of accumulated CO2 up to adjusted top of climb, NADP2 variants appear to produce 0.6 to 2.7% less CO2 than NADP1.

6.10 The results presented indicate that of the procedures included in this study no single departure procedure minimizes overall noise and emissions simultaneously. Depending on local airport requirements tradeoffs must be made between close-in versus distant noise, NOx versus CO2 emissions and finally noise versus gaseous emissions.

APPENDIX A: RESULTS AIRBUS

Aircraft studied:

A320-214, CFM56-5B4/P
- Take-Off in CONF 2
- Climb at V2+10 kt IAS
- Takeoff thrust / weight cases:
  - Full thrust (TOGA) / MTOW = 77t
  - 12% Reduced Thrust / TOW = 71t

A330-223, PW4168A
- Take-Off in CONF 2
- Climb at V2+15 kt IAS
- Takeoff thrust / weight cases:
  - Full thrust (TOGA) / MTOW = 233t
  - 12% Reduced Thrust / TOW = 200t

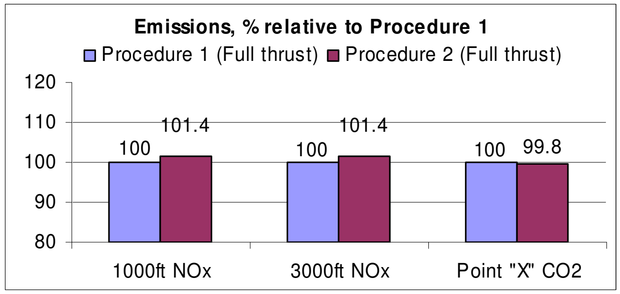
A340-642, RR Trent 556
- Take-Off in CONF 3
- Climb at V2+10 kt IAS
- Takeoff thrust / weight cases:
  - Full thrust (TOGA) / MTOW = 368t
  - 12% Reduced Thrust / TOW = 348t

Atmospheric conditions:

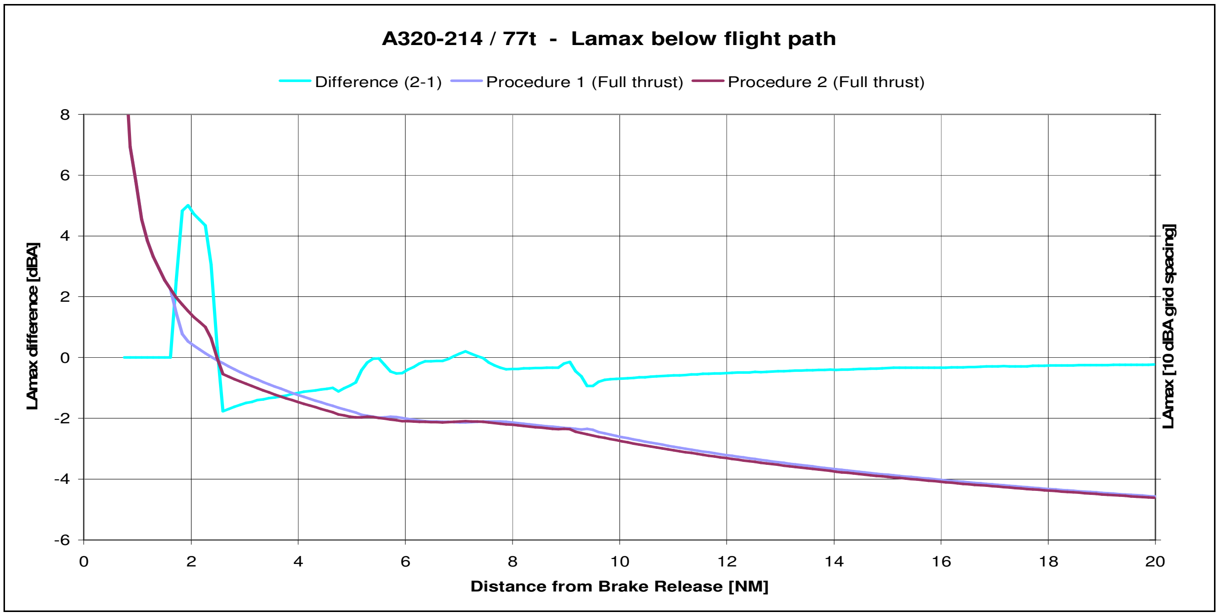
Temperature:	ISA
Relative Humidity:	70%
Wind:	No wind
Runway elevation:	Sea Level

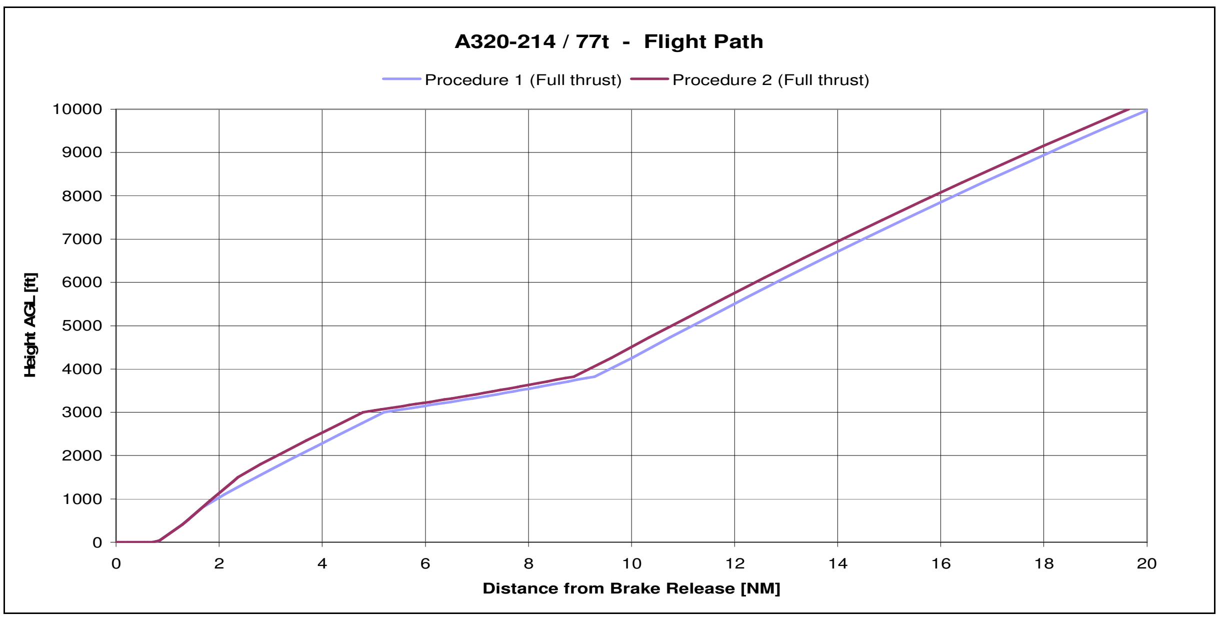
A320-214, CFM56-5B4/P

- **Full thrust (TOGA)**
- **MTOW = 169,800lbs**



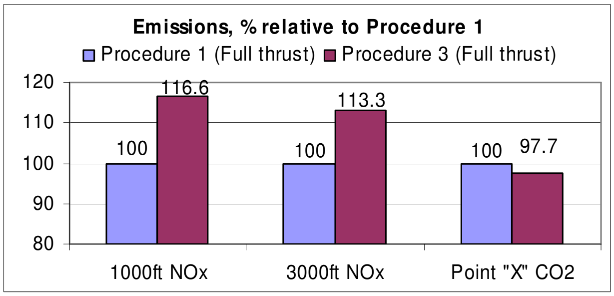
Comparison of Procedures 1 and 2





A320-214, CFM56-5B4/P

- **Full thrust (TOGA)**
- **MTOW = 169,800 lbs**



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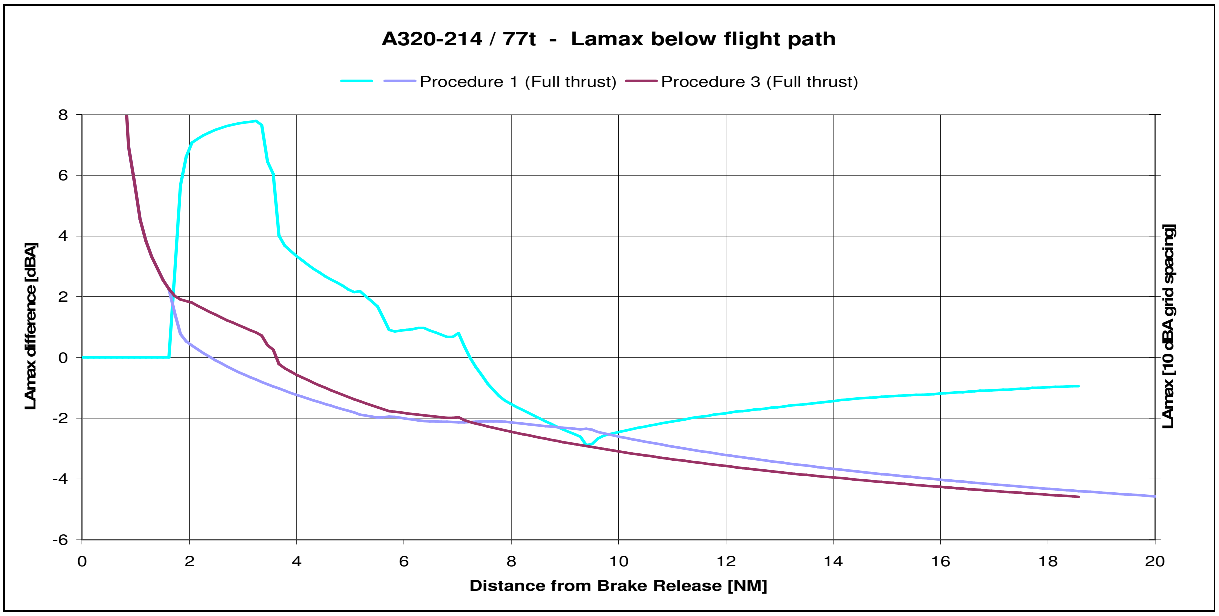
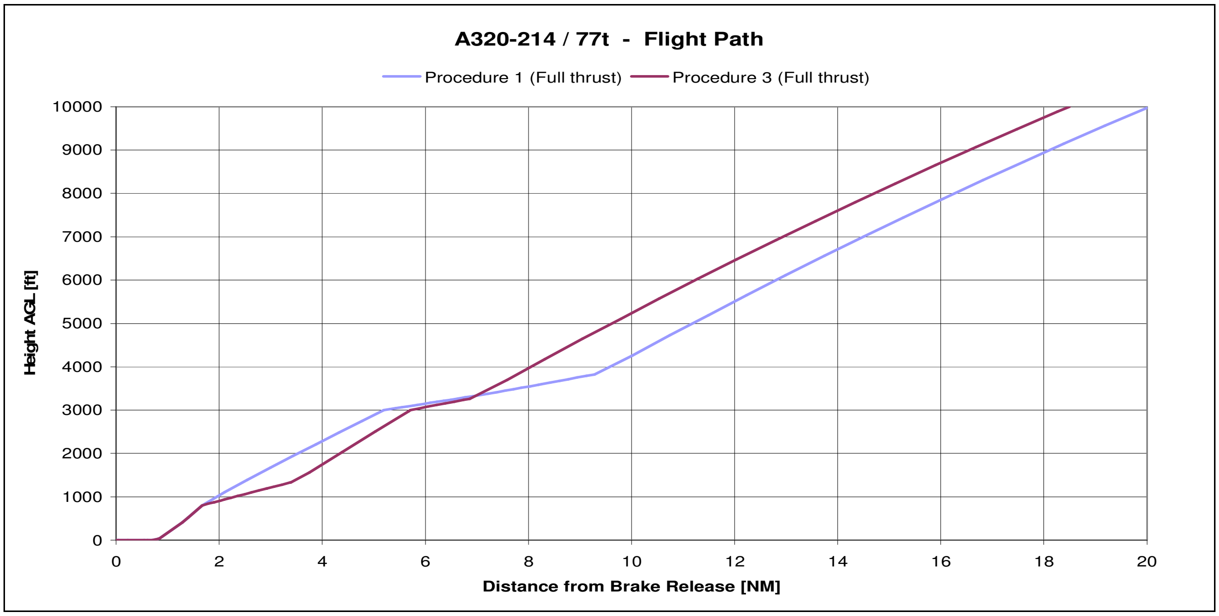
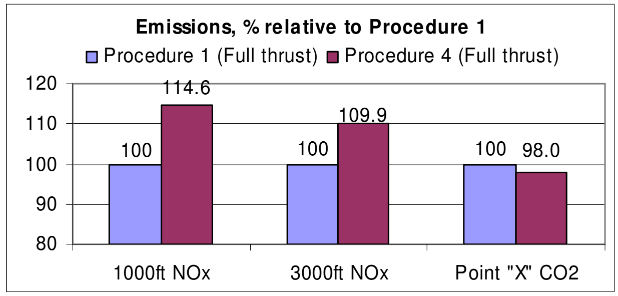


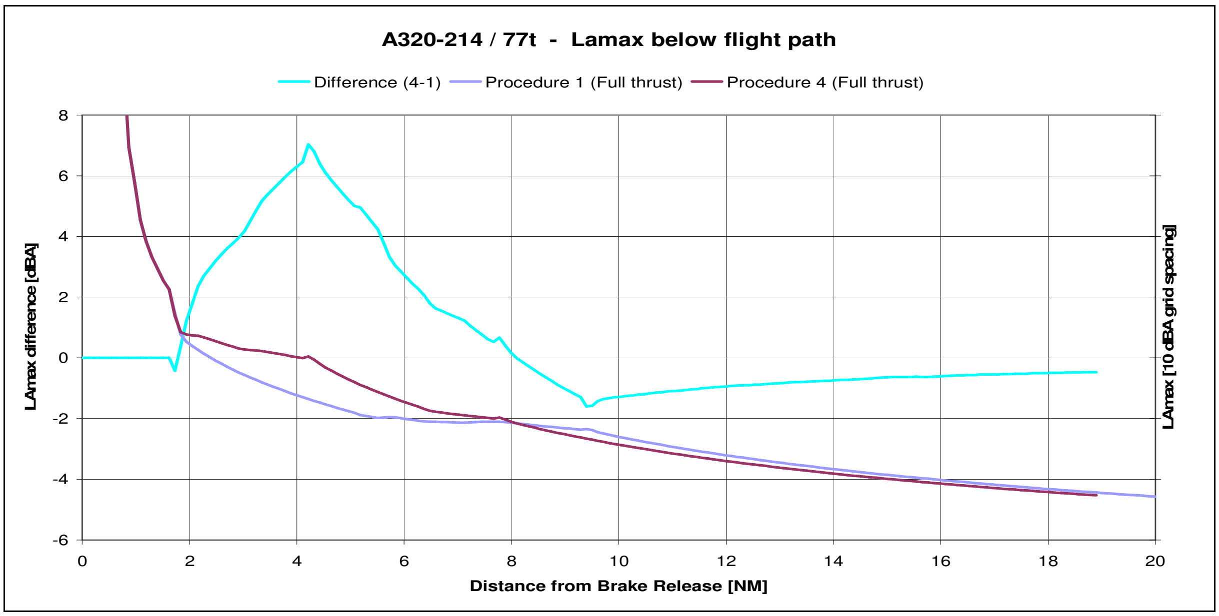


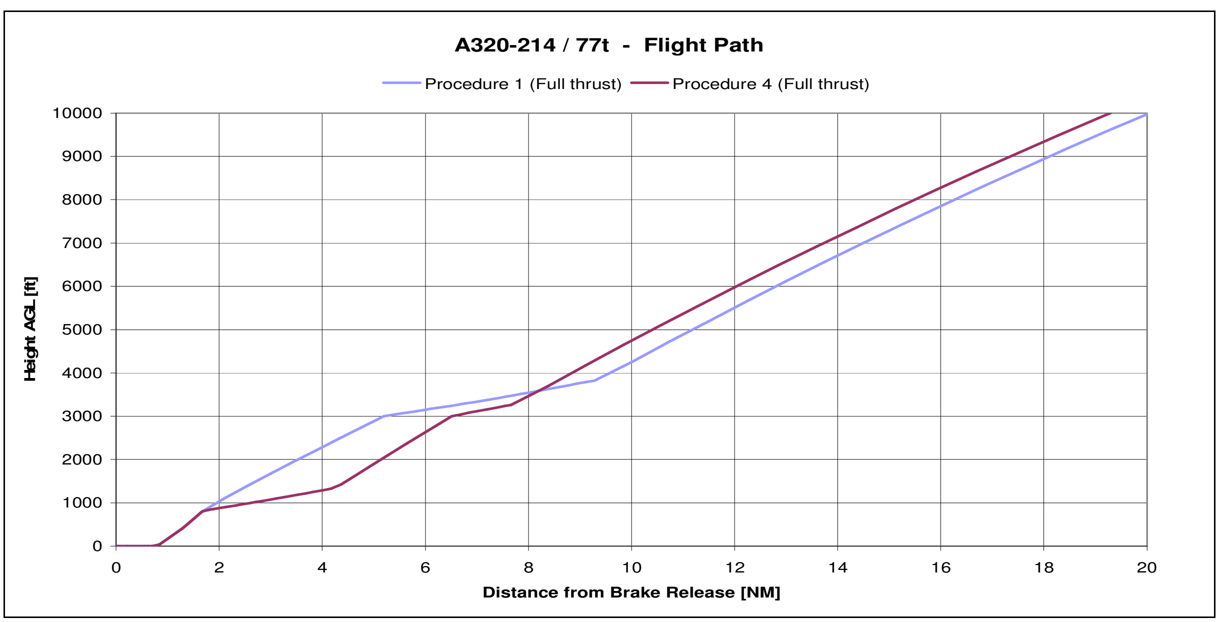
A320-214, CFM56-5B4/P

- **Full thrust (TOGA)**
- **MTOW = 169,800lbs**



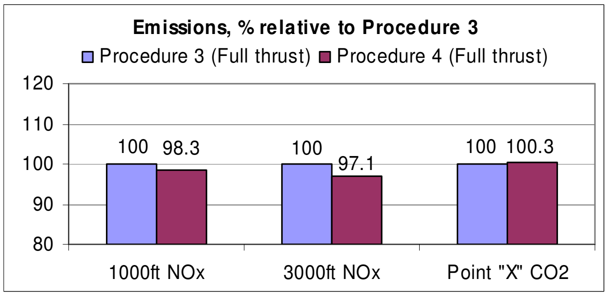
Comparison of Procedures 1 and 4





A320-214, CFM56-5B4/P

- **Full thrust (TOGA)**
- **MTOW = 169,800lbs**



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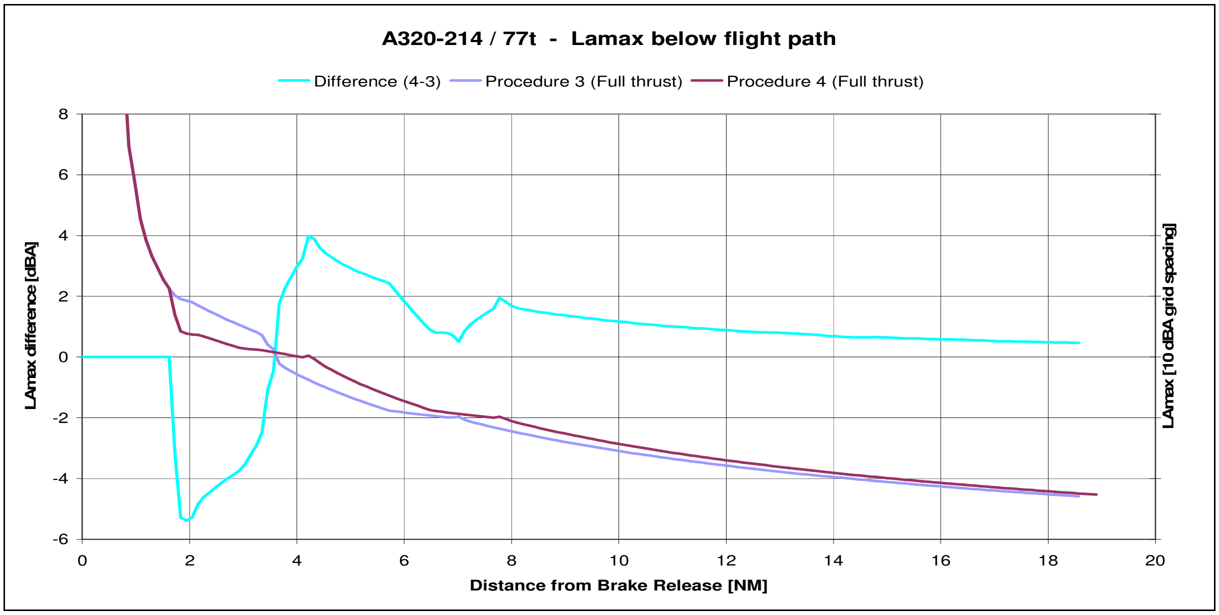
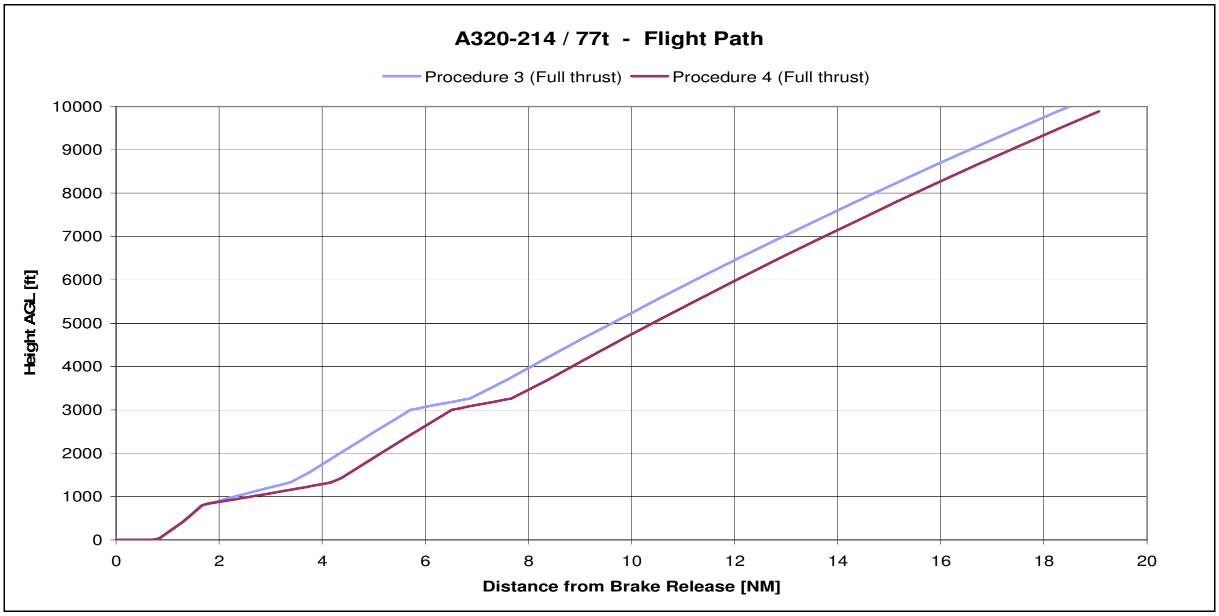
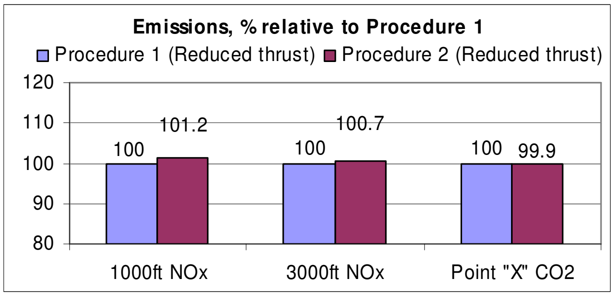


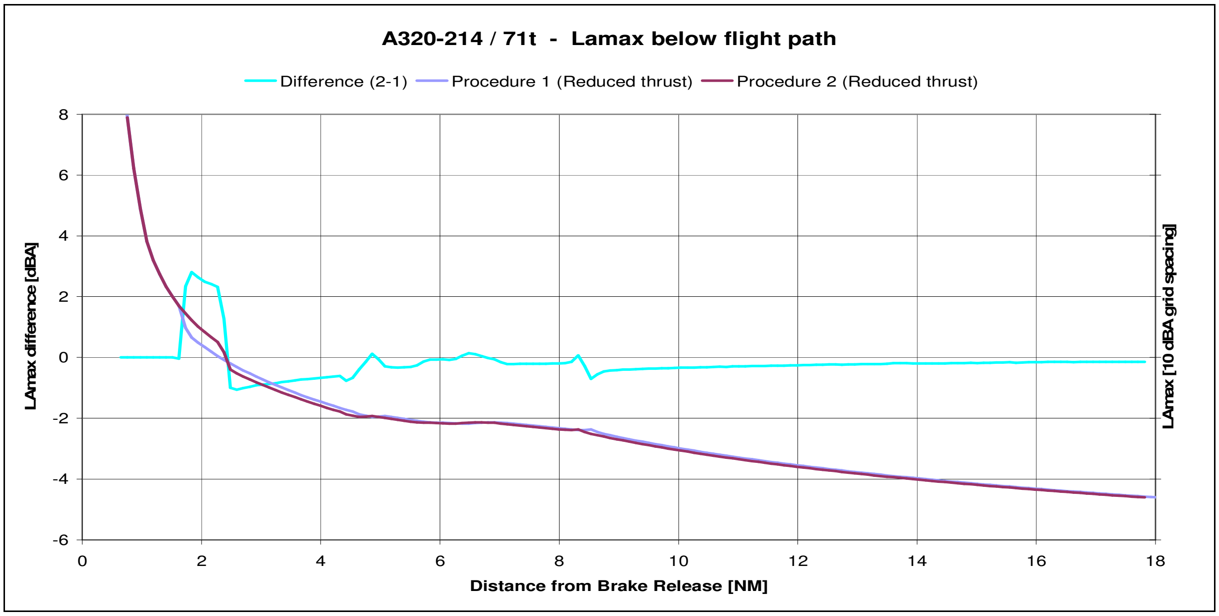


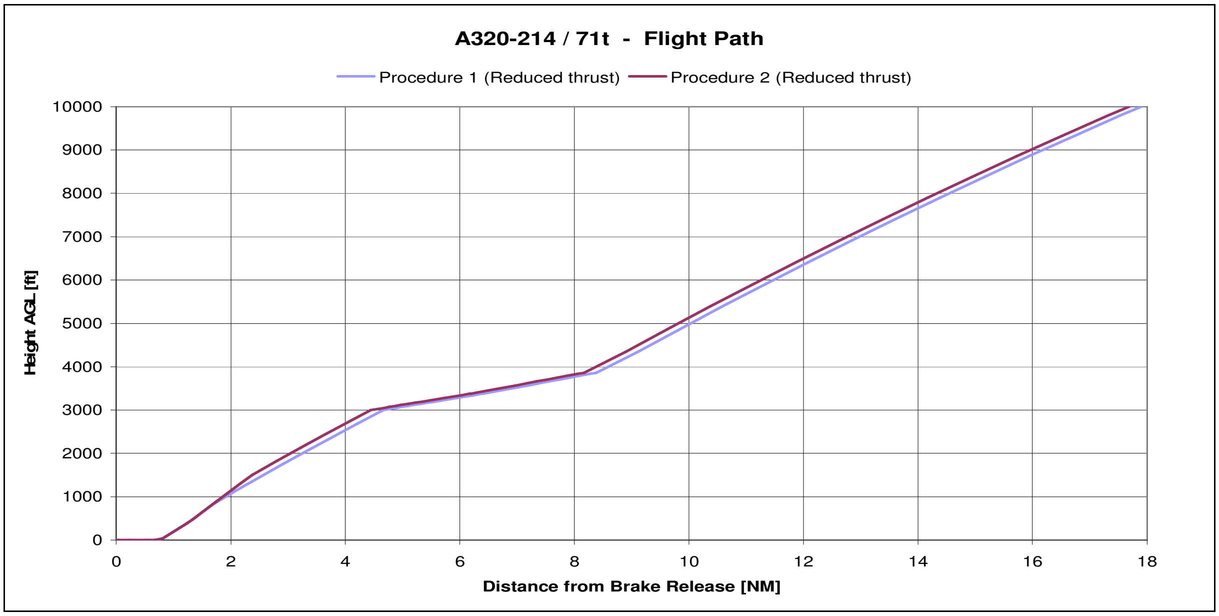
A320-214 / CFM56-5B4/P

- **12% Reduced Thrust**
- **TOW = 156,600lbs**



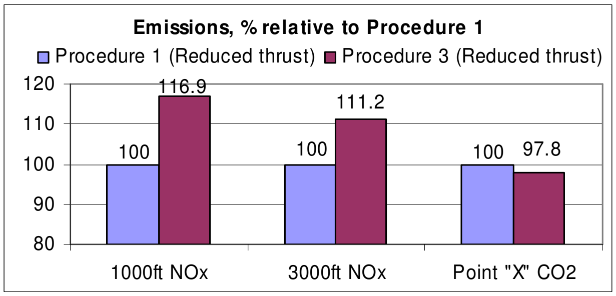
Comparison of Procedures 1 and 2



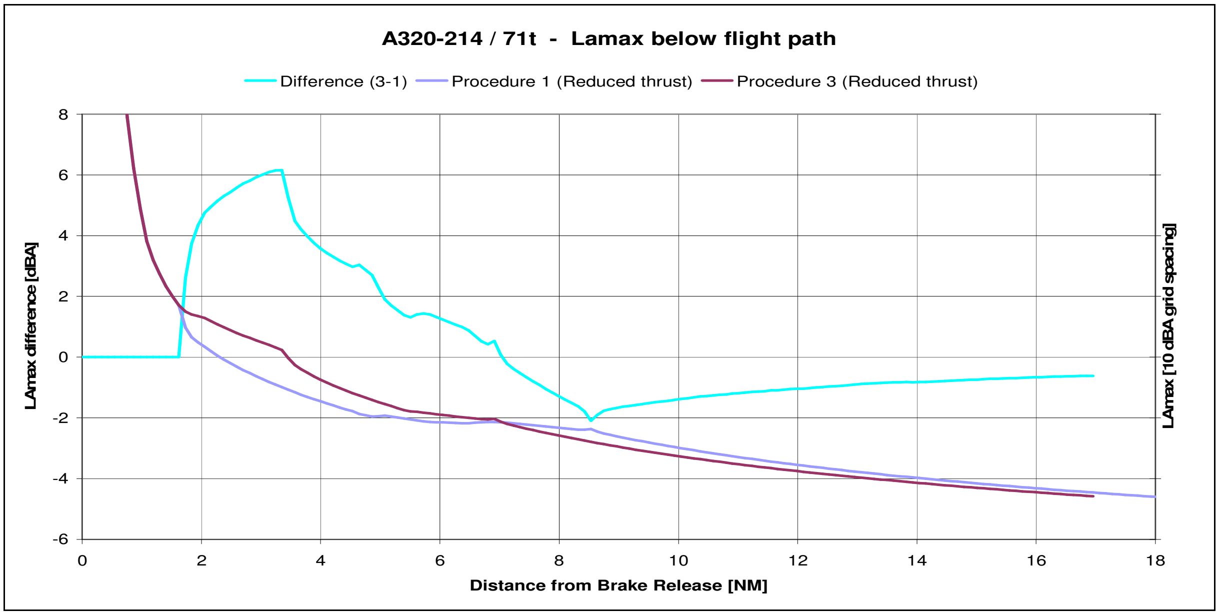


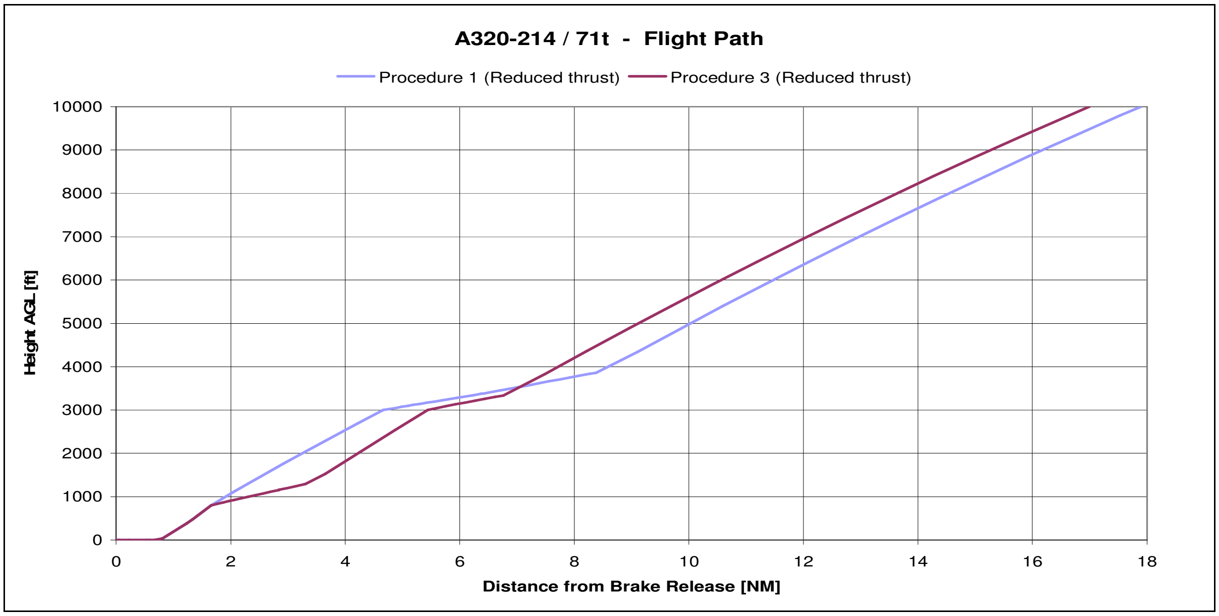
A320-214 / CFM56-5B4/P

- **12% Reduced Thrust**
- **TOW = 156,600lbs**



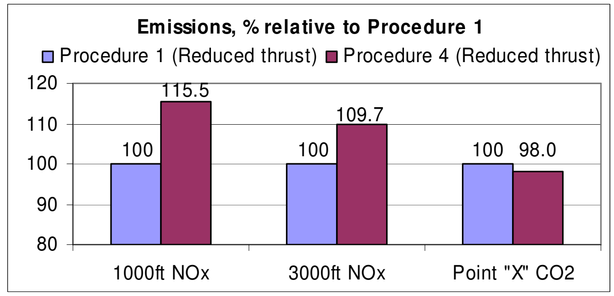
Comparison of Procedures 1 and 3



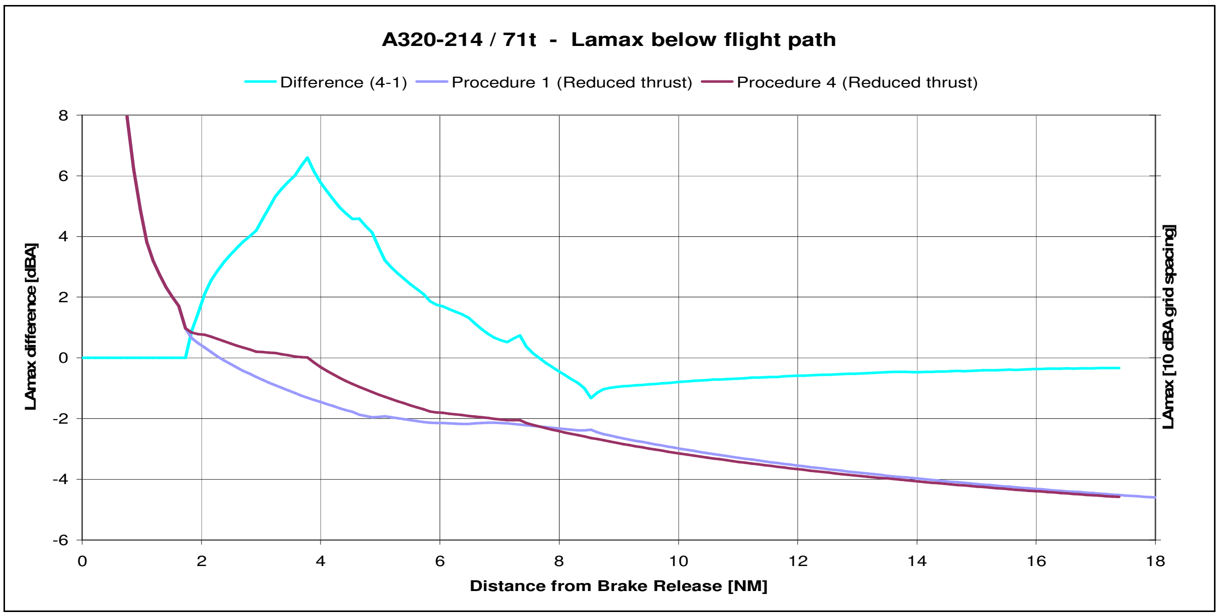


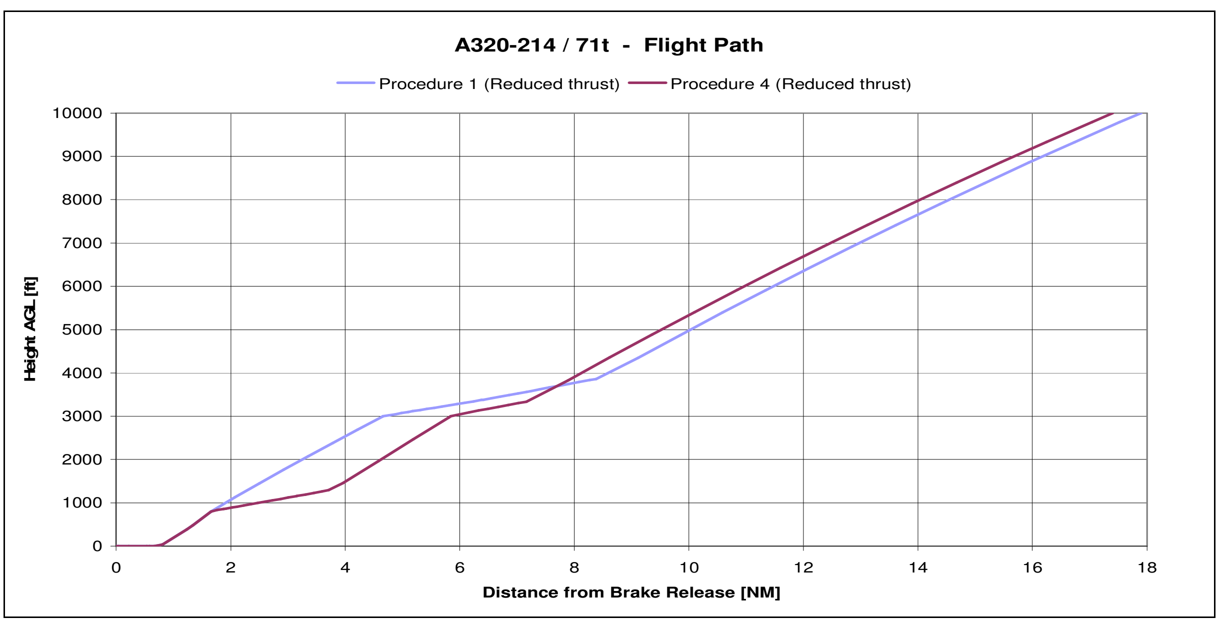
A320-214 / CFM56-5B4/P

- **12% Reduced Thrust**
- **TOW = 156,600lbs**



Comparison of Procedures 1 and 4

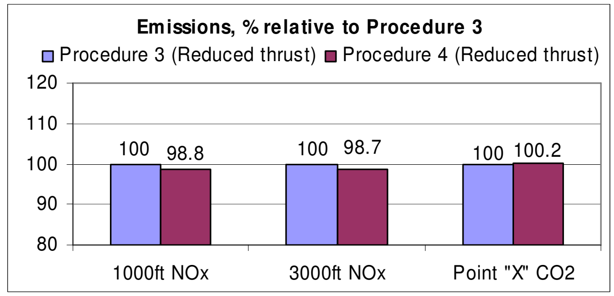


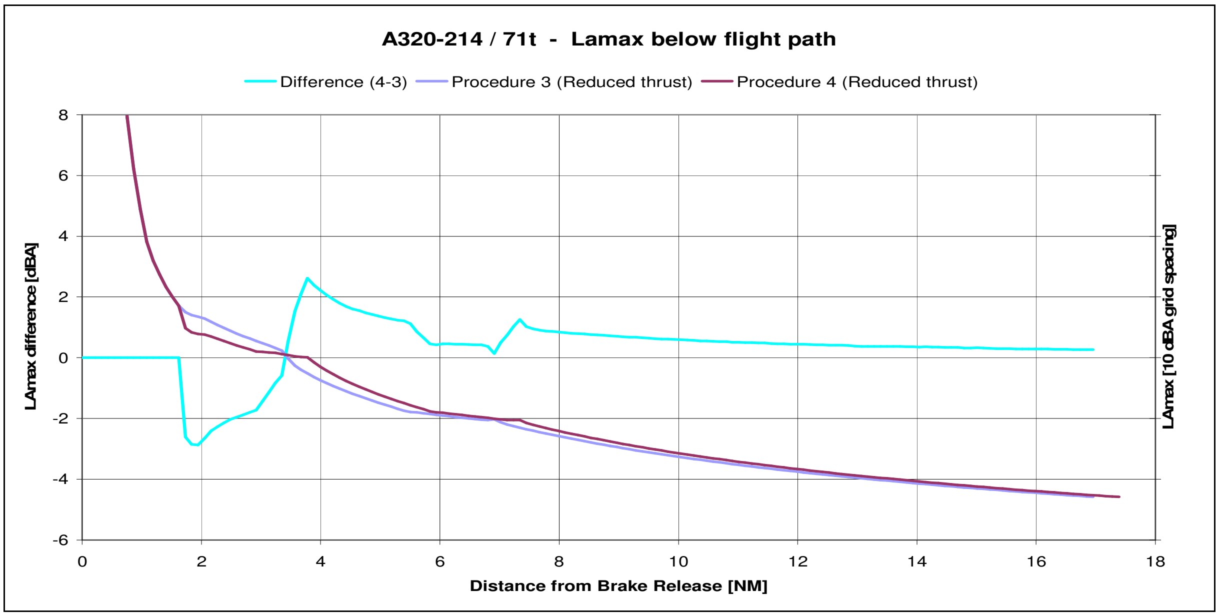


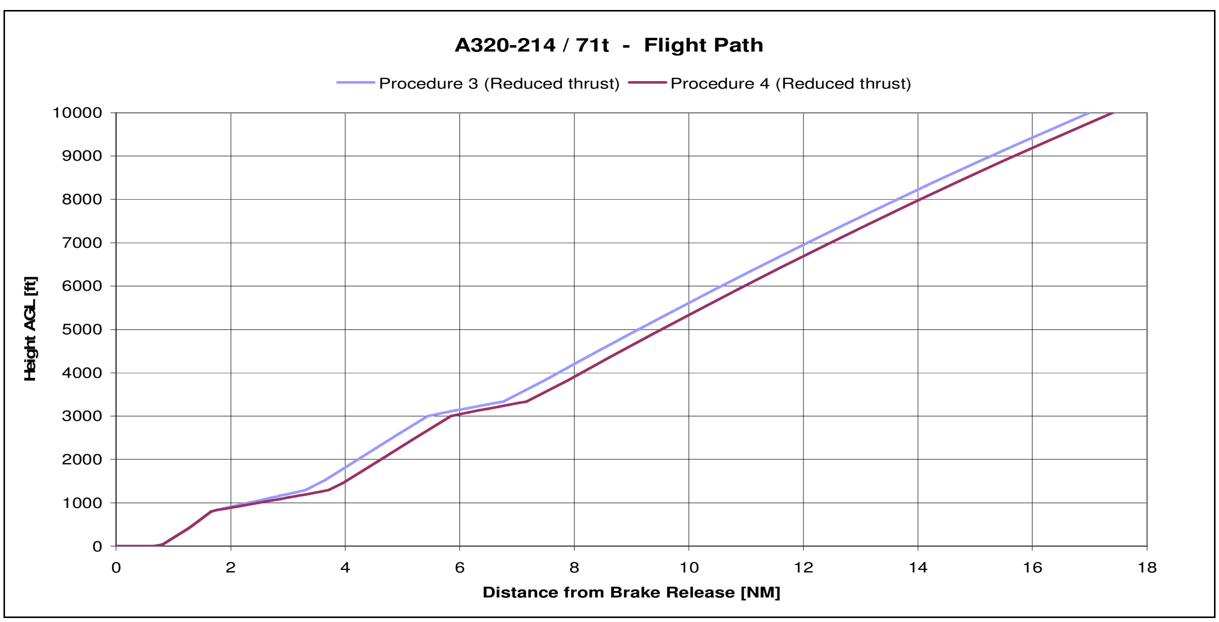
A320-214 / CFM56-5B4/P

- **12% Reduced Thrust**
- **TOW = 156,600lbs**

Comparison of Procedures 3 and 4

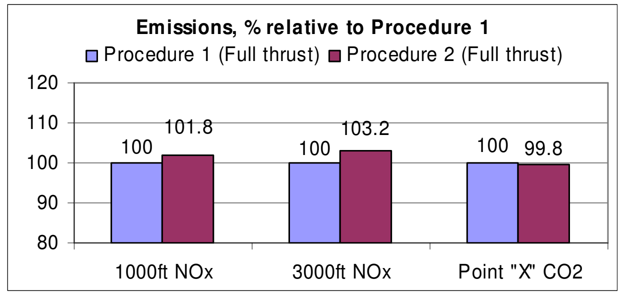




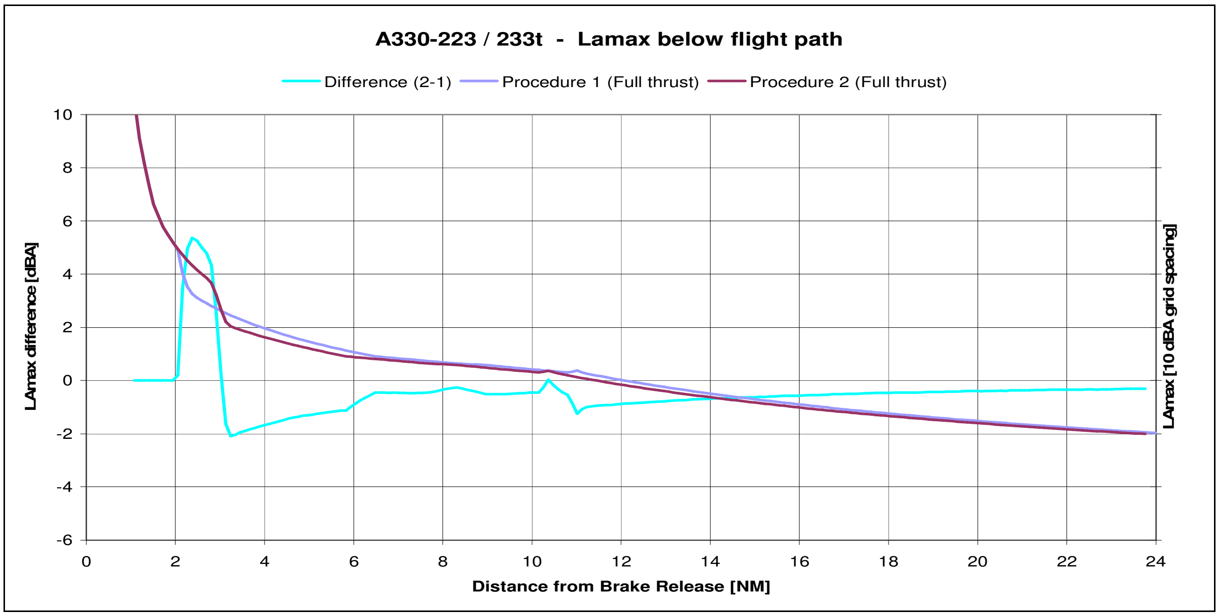


A330-223, PW4168A

- **Full thrust (TOGA)**
- **MTOW = 513,700lbs**



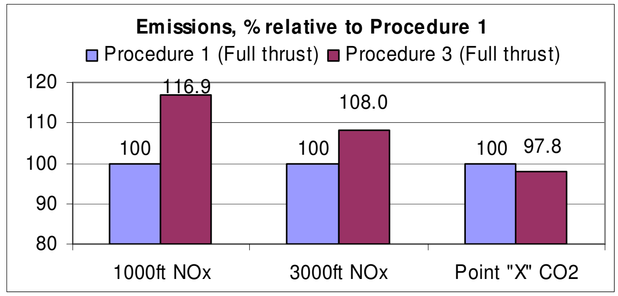
Comparison of Procedures 1 and 2

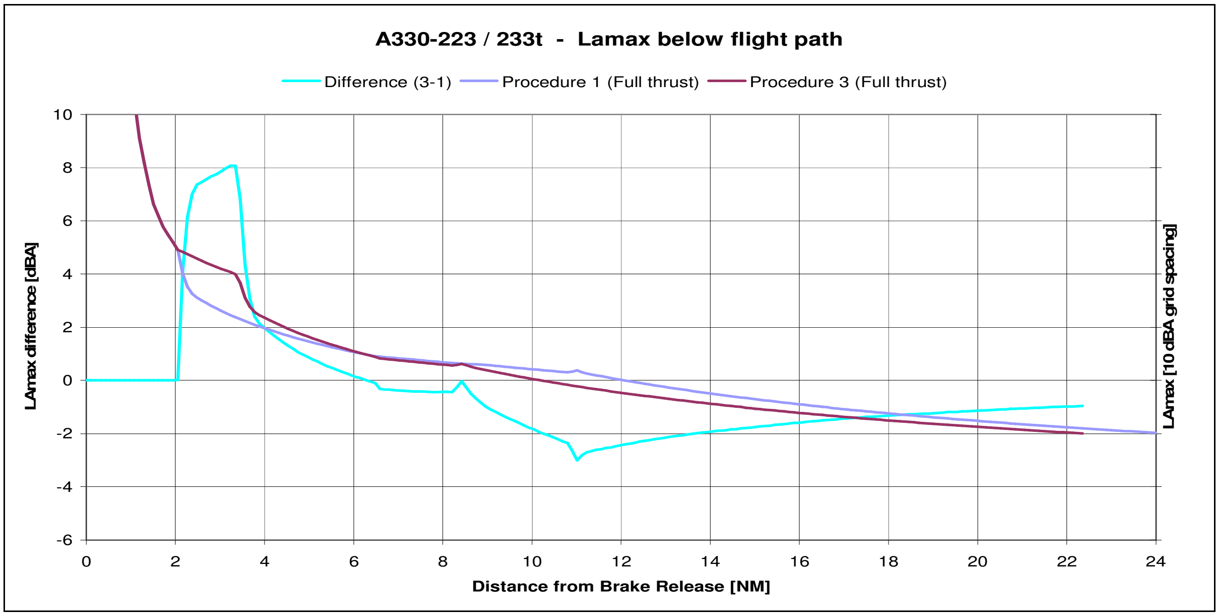


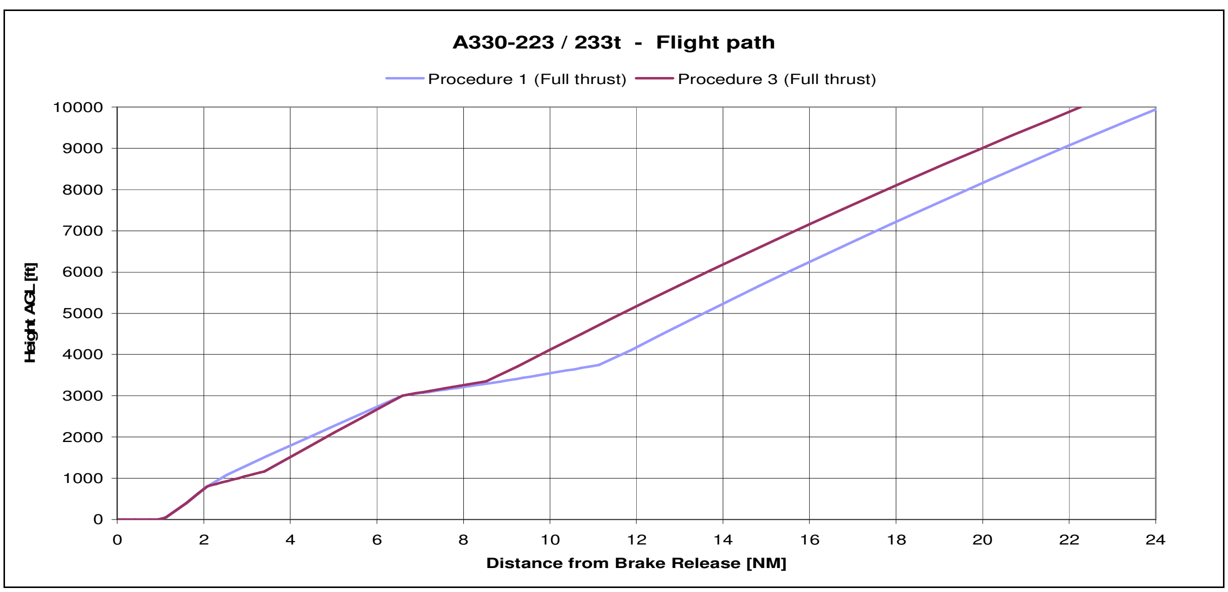
A330-223, PW4168A

- **Full thrust (TOGA)**
- **MTOW = 513,700lbs**

Comparison of Procedures 1 and 3

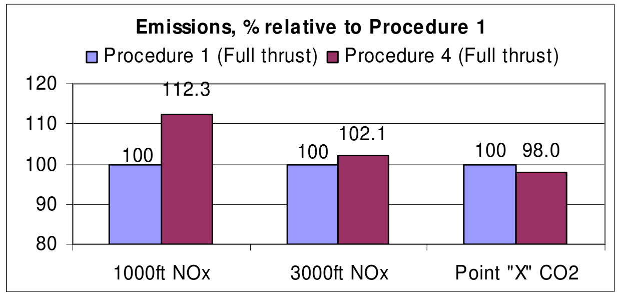




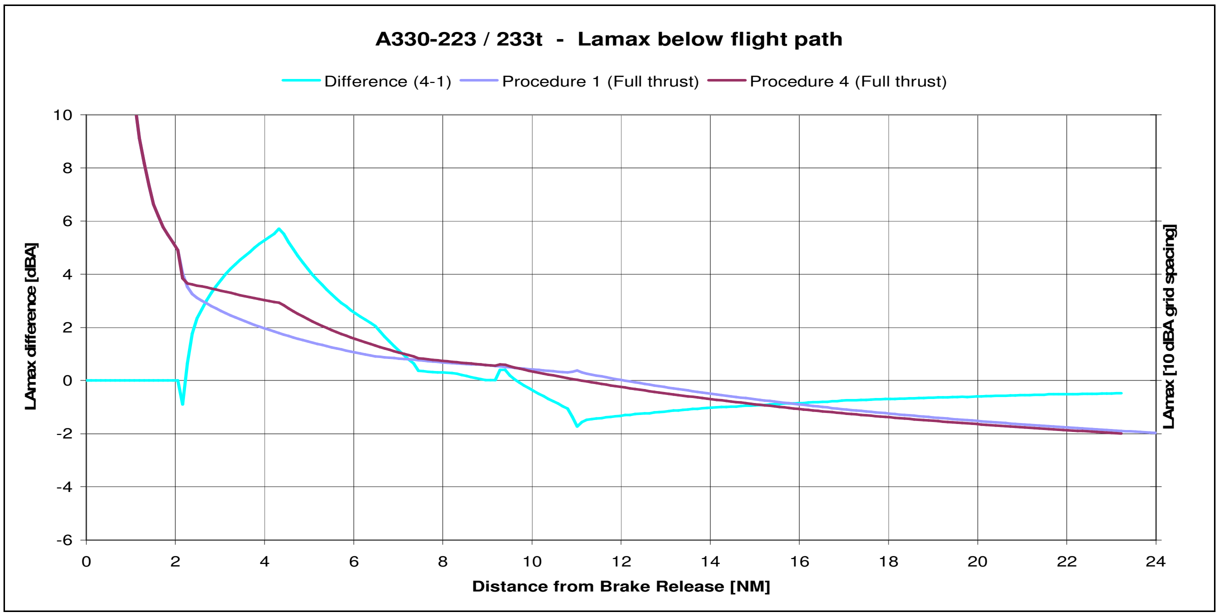


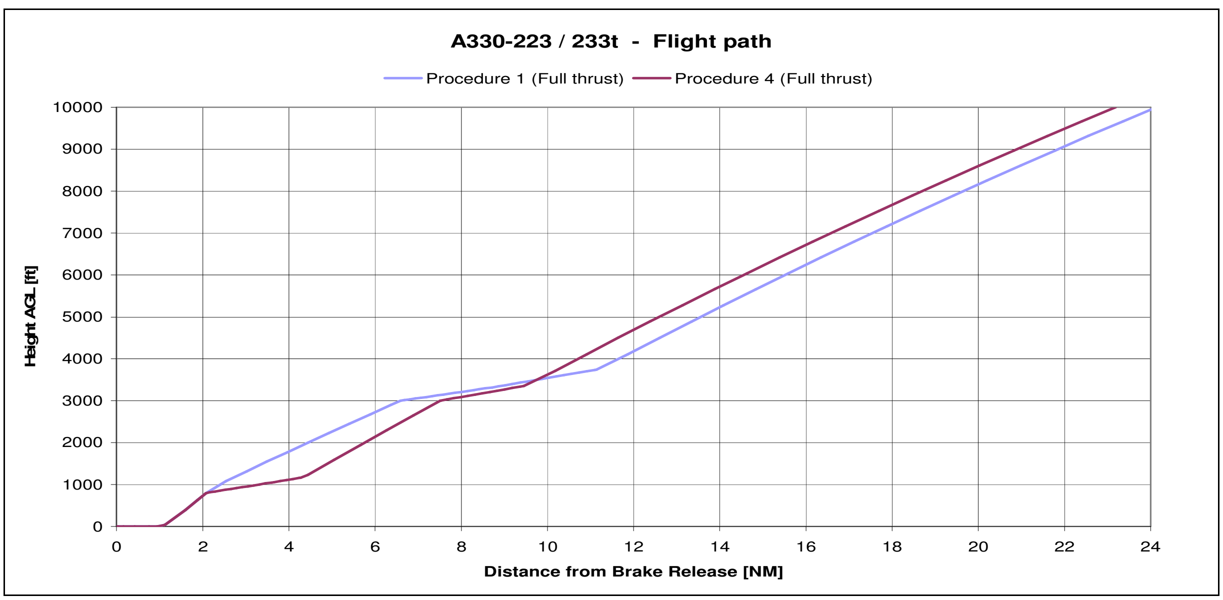
A330-223, PW4168A

- **Full thrust (TOGA)**
- **MTOW = 513,700lbs**



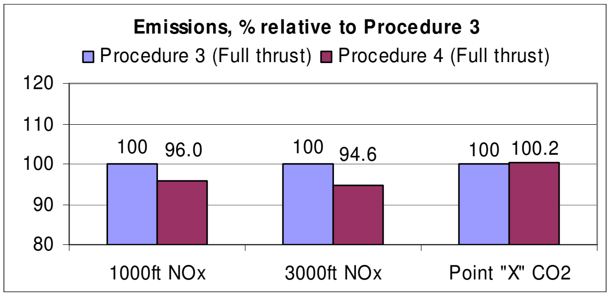
Comparison of Procedures 1 and 4



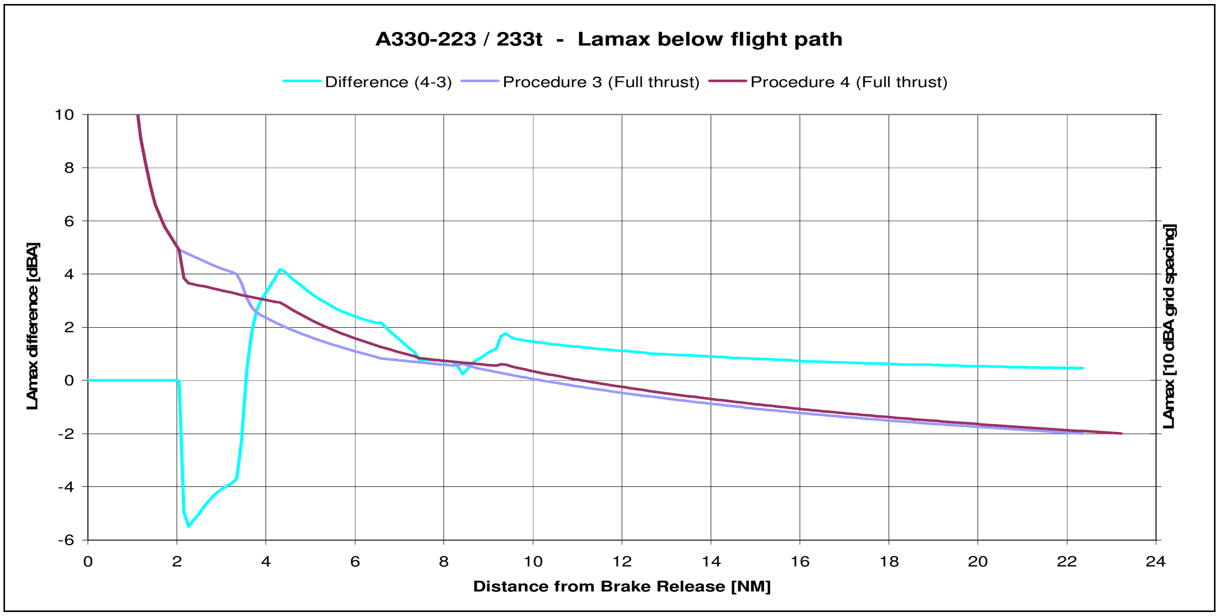


A330-223, PW4168A

- **Full thrust (TOGA)**
- **MTOW = 513,700lbs**

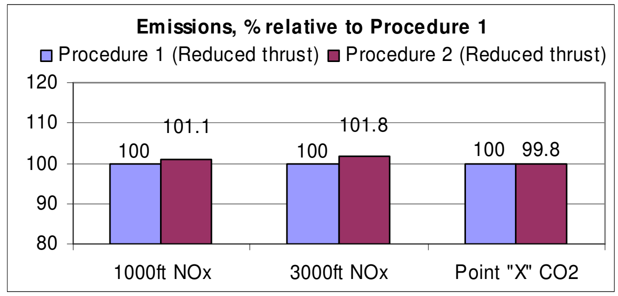


Comparison of Procedures 3 and 4

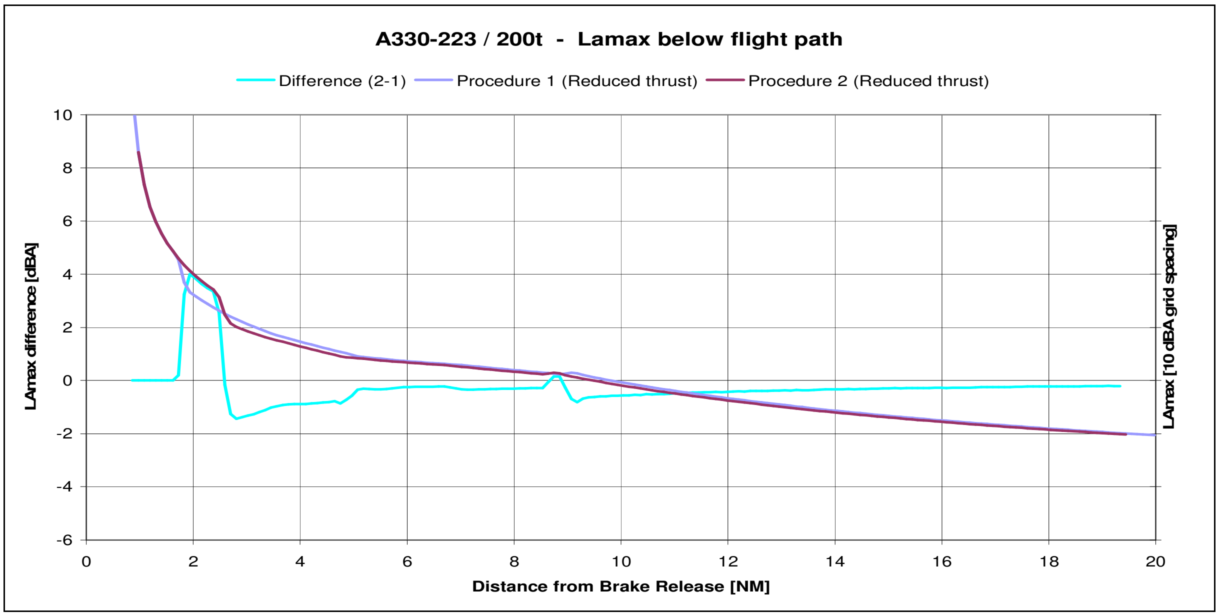


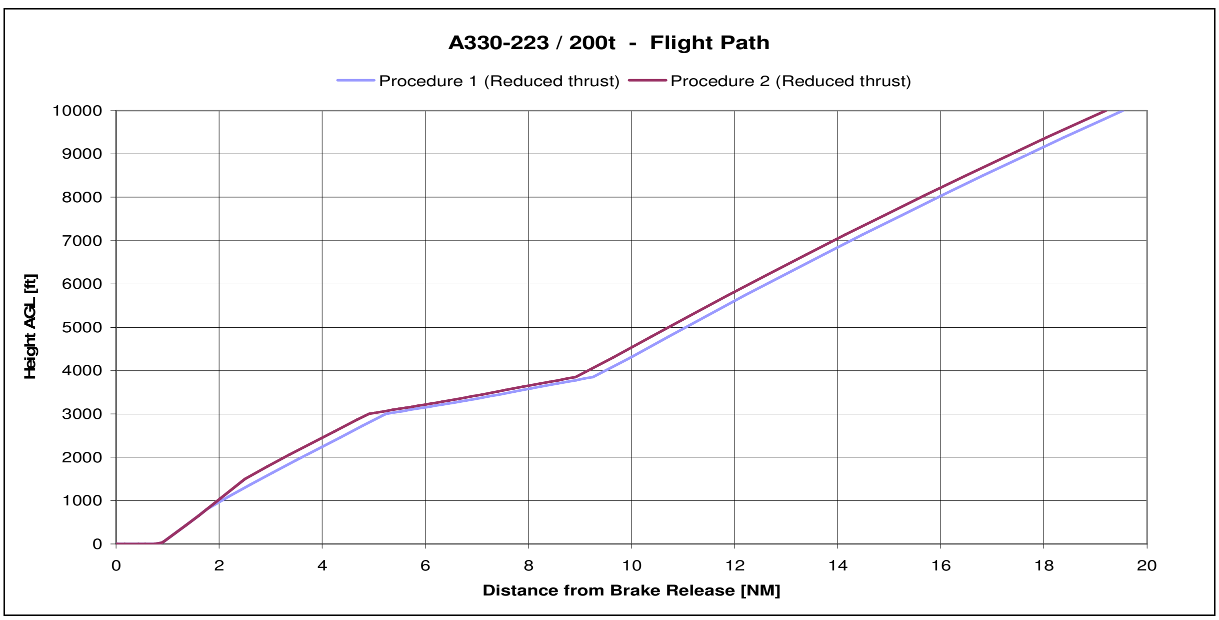
A330-223, PW4168A

- **12% Reduced Thrust**
- **TOW = 441,000lbs**



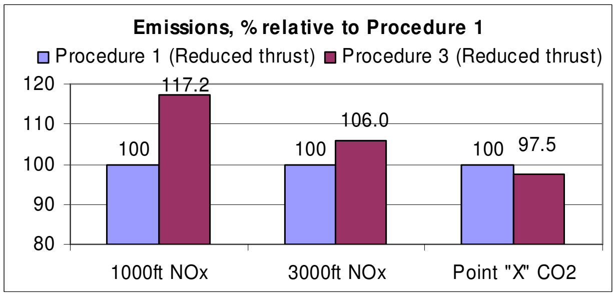
Comparison of Procedures 1 and 2



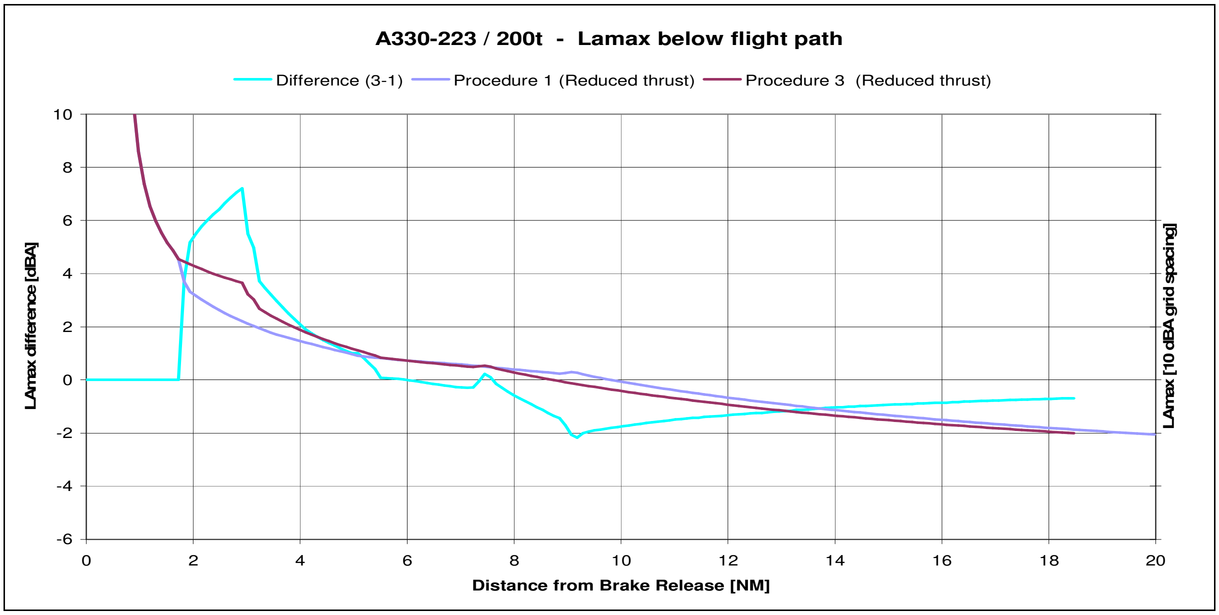


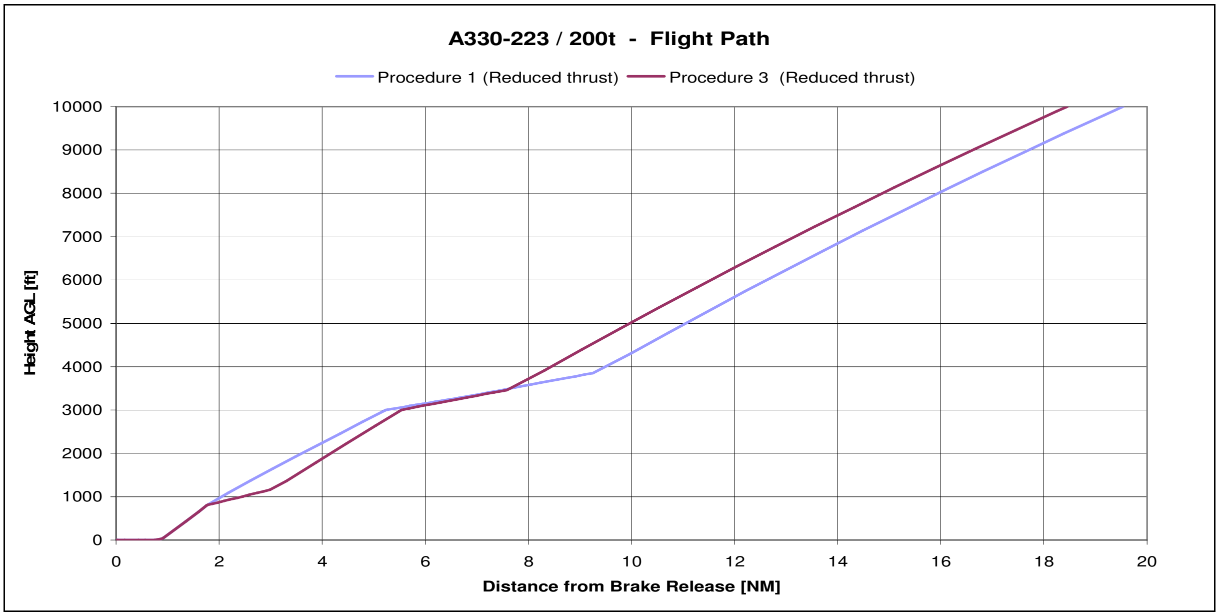
A330-223, PW4168A

- **12% Reduced Thrust**
- **TOW = 441,000lbs**

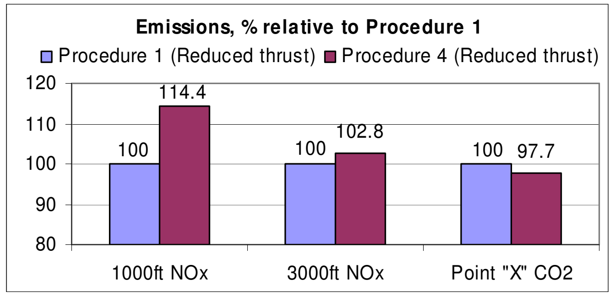


Comparison of Procedures 1 and 3

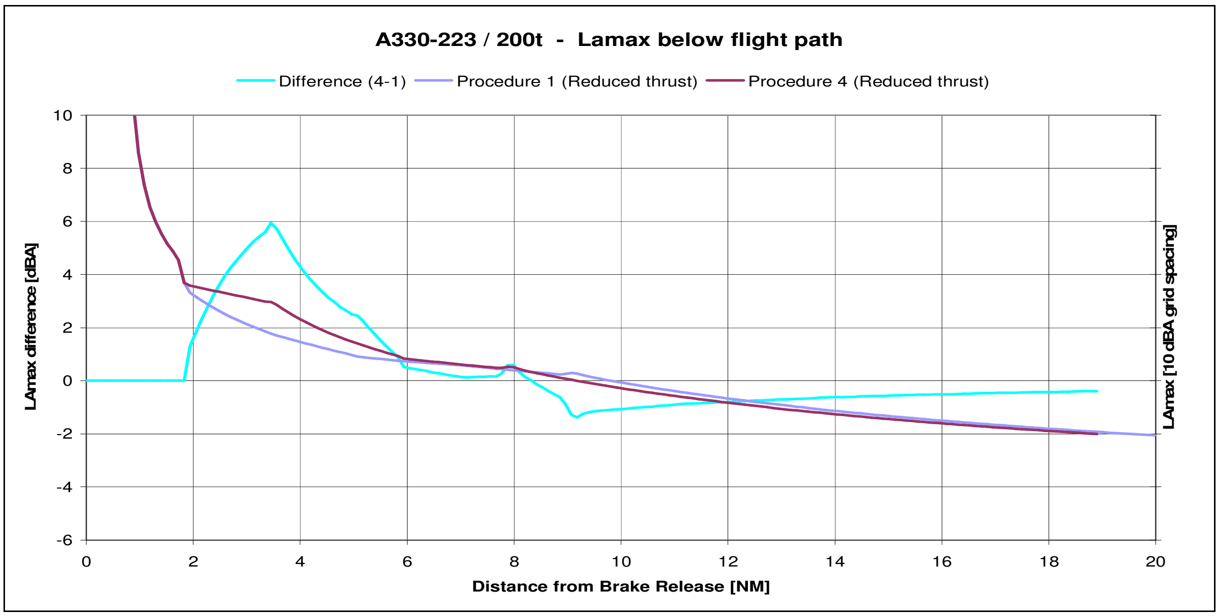


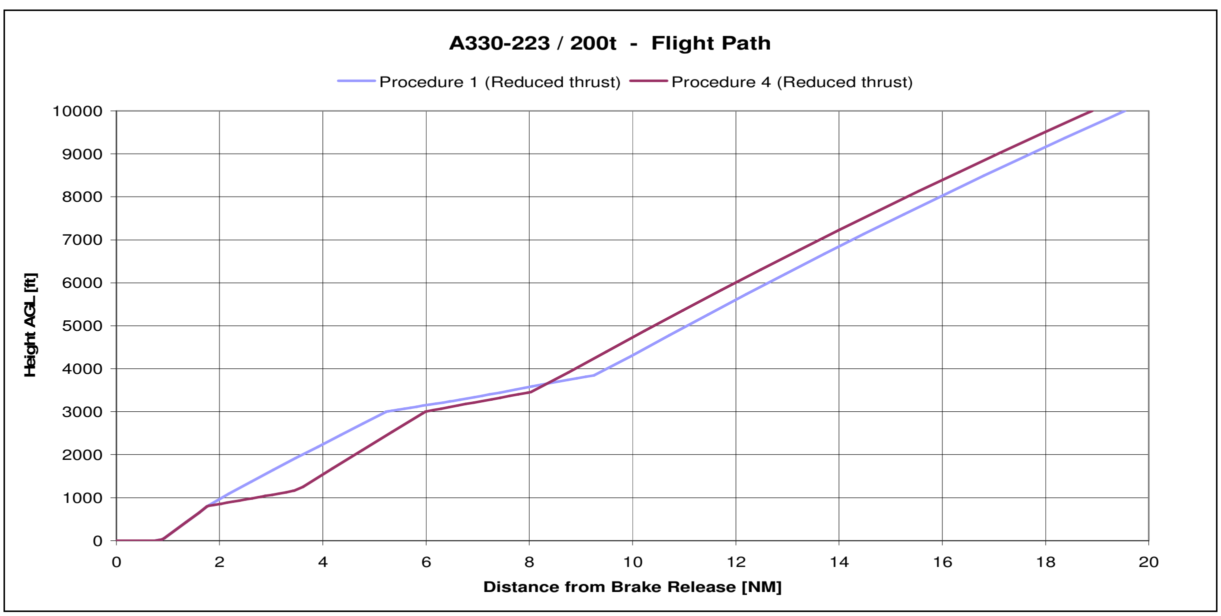


A330-223, PW4168A
- **12% Reduced Thrust**
- **TOW = 441,000lbs**



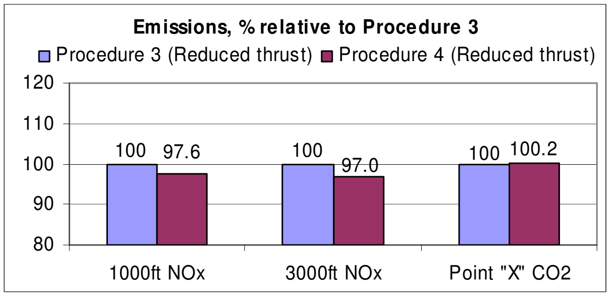
Comparison of Procedures 1 and 4



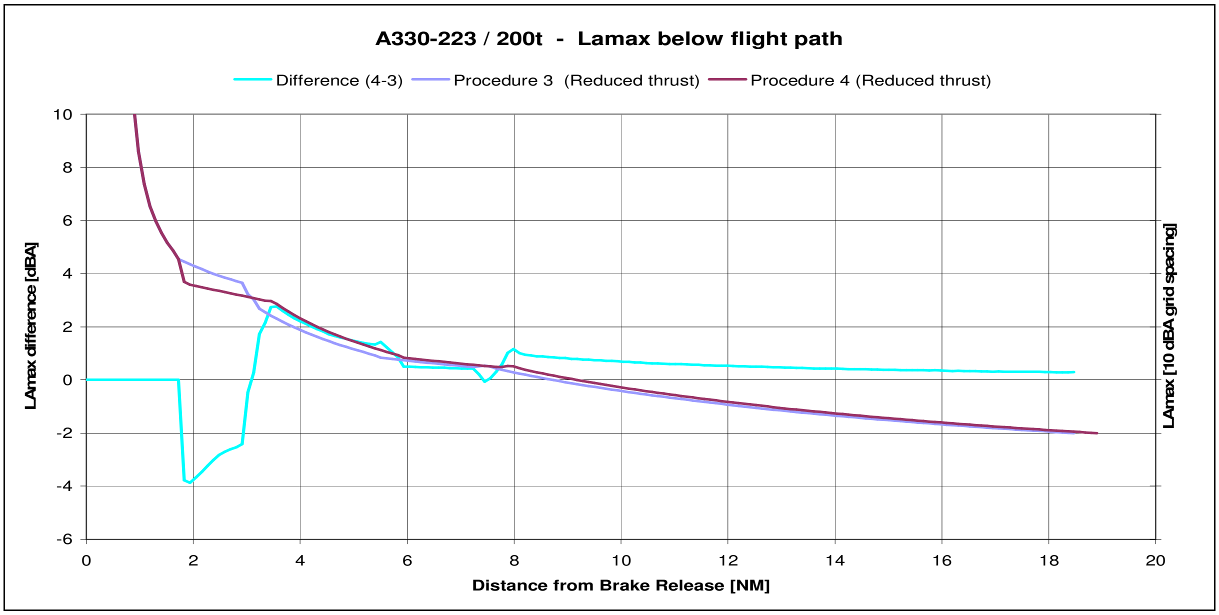


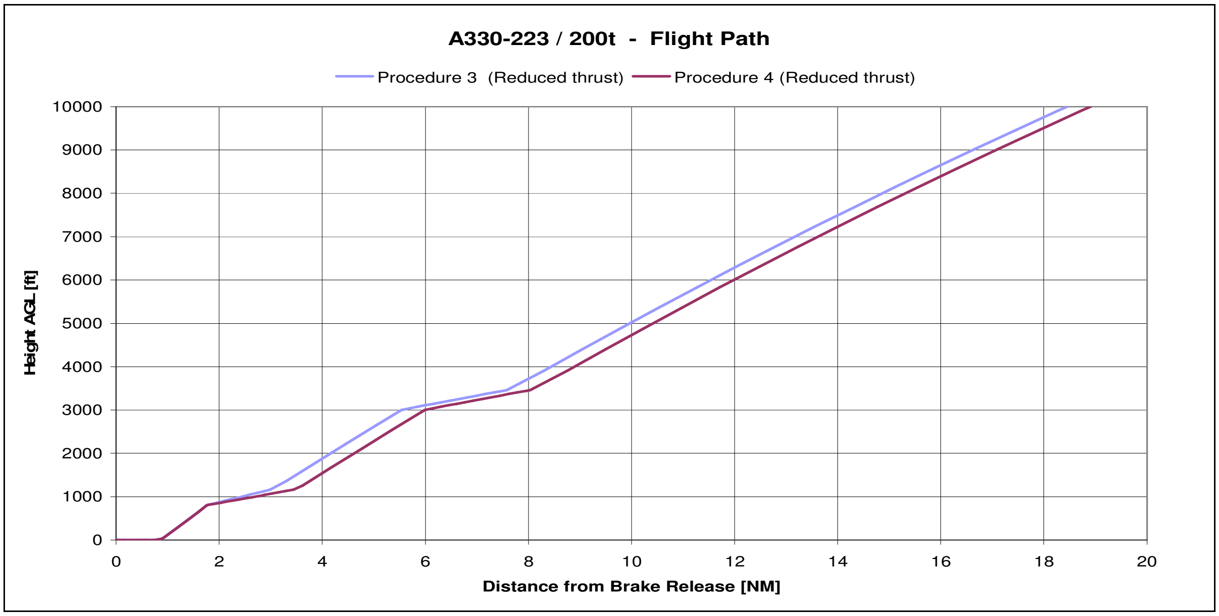
A330-223, PW4168A

- **12% Reduced Thrust**
- **TOW = 441,000lbs**



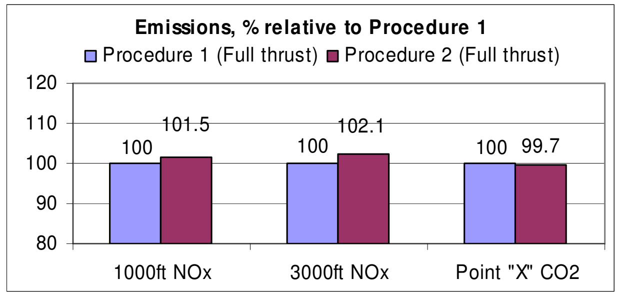
Comparison of Procedures 3 and 4



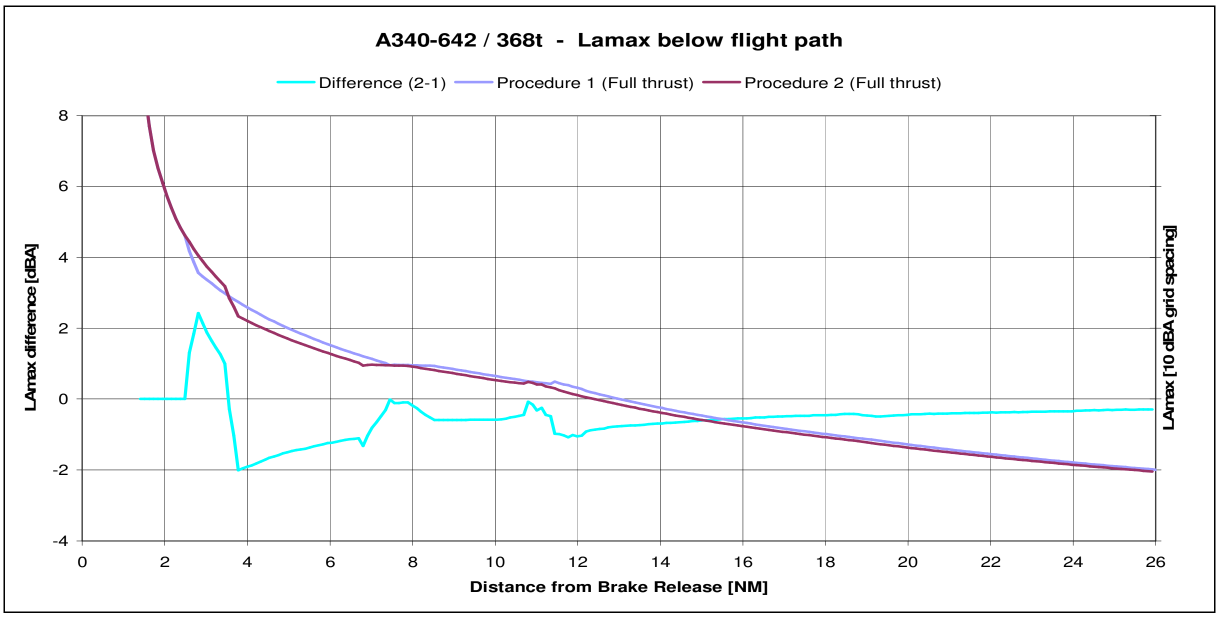


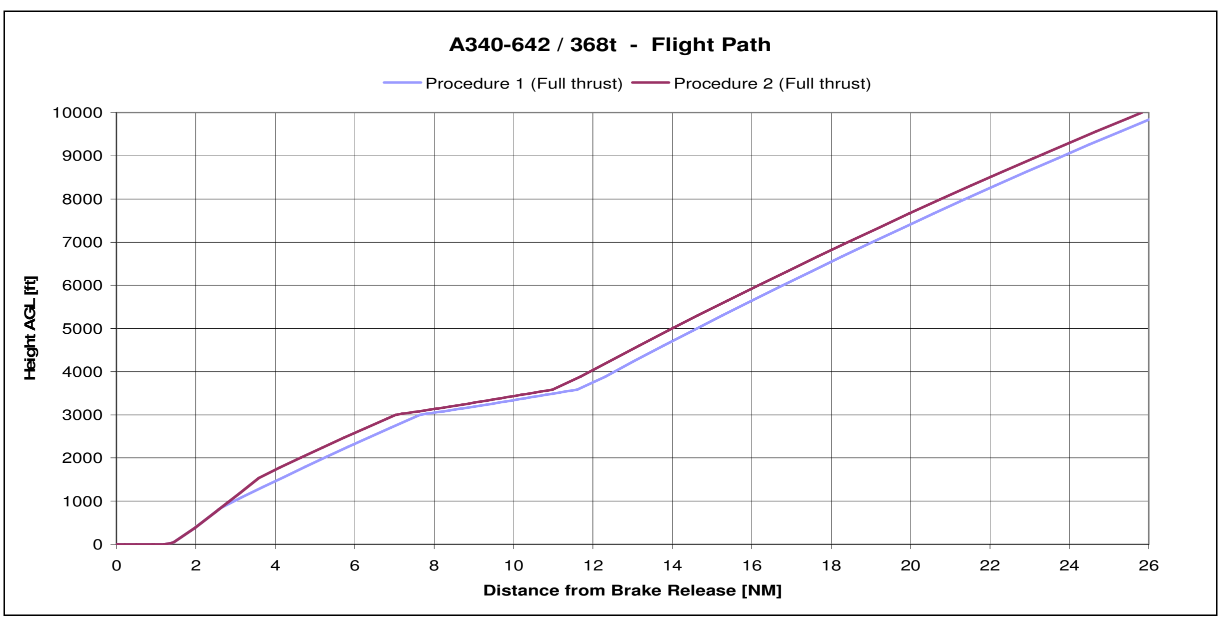
A340-642, RR Trent 556

- **Full thrust (TOGA)**
- **MTOW = 811,300lbs**



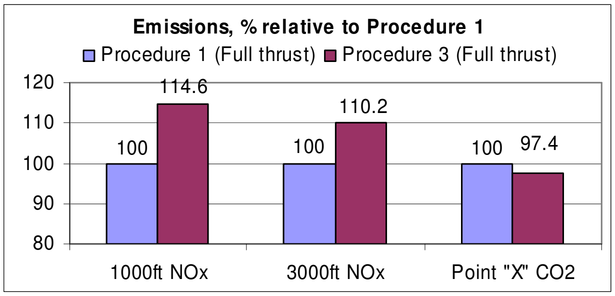
Comparison of Procedures 1 and 2



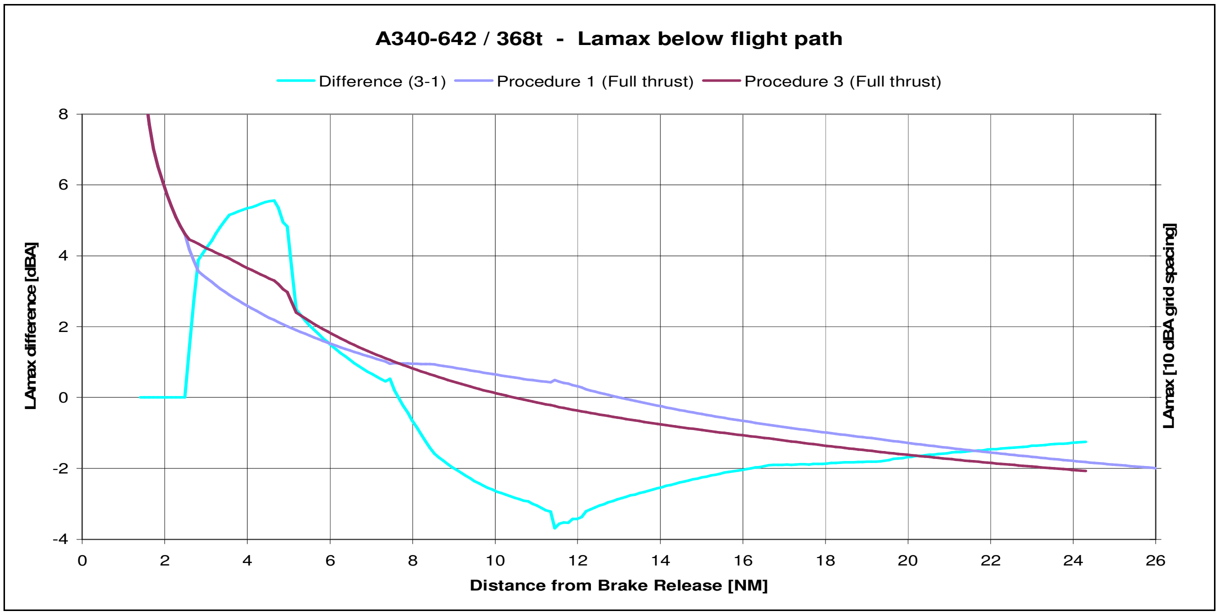


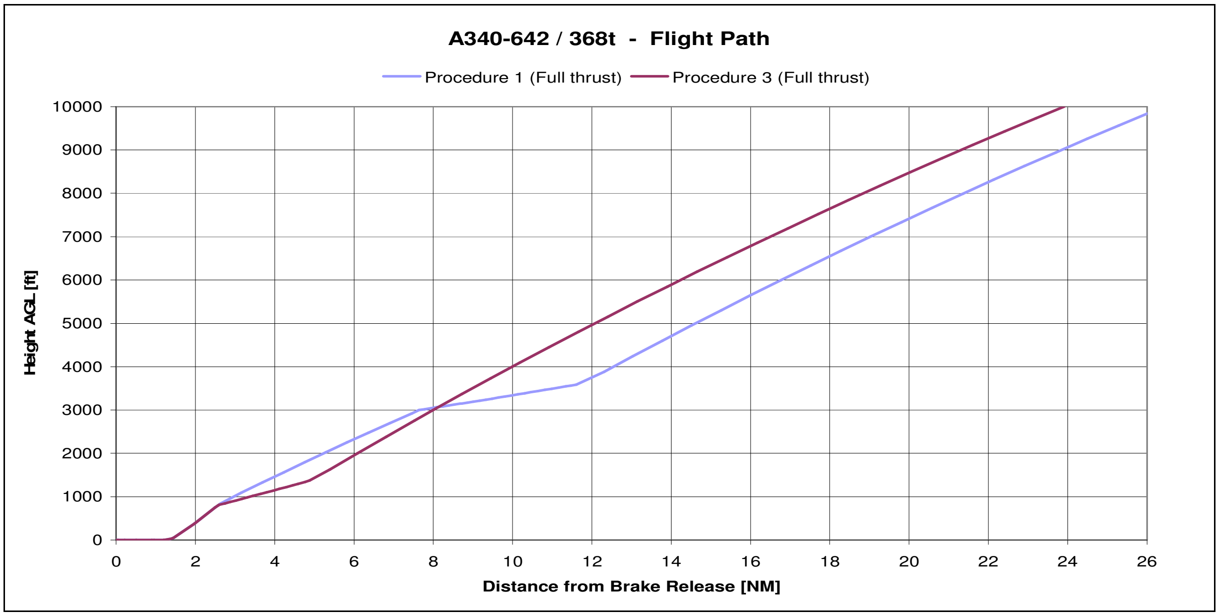
A340-642, RR Trent 556

- **Full thrust (TOGA)**
- **MTOW = 811,300lbs**

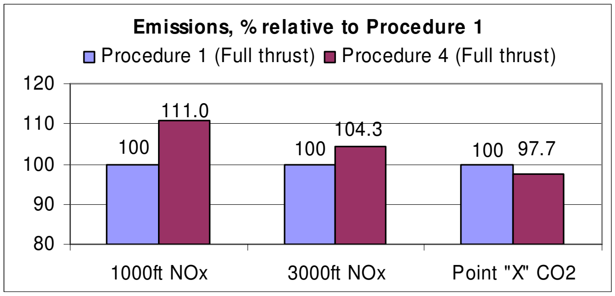


Comparison of Procedures 1 and 3

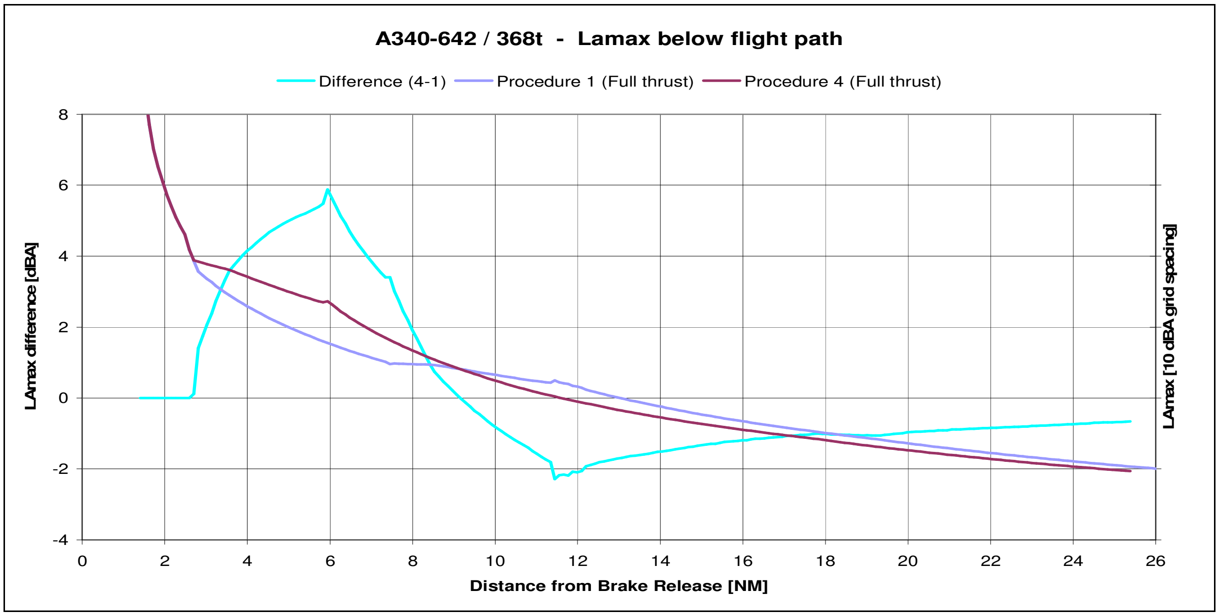


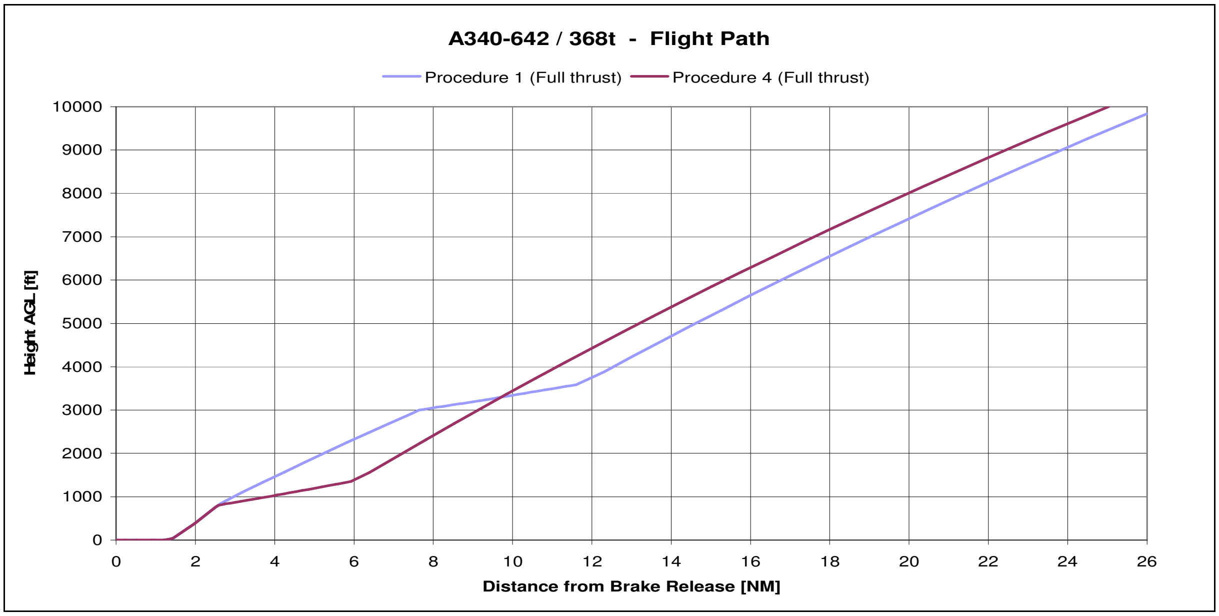


A340-642, RR Trent 556
- **Full thrust (TOGA)**
- **MTOW = 811,300lbs**



Comparison of Procedures 1 and 4

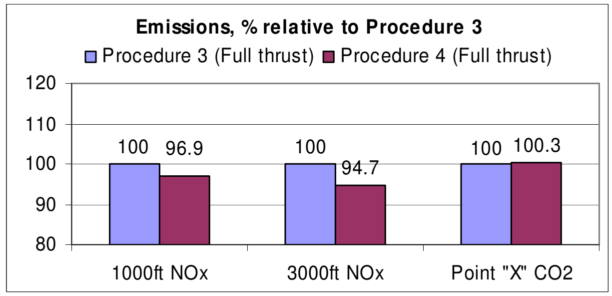


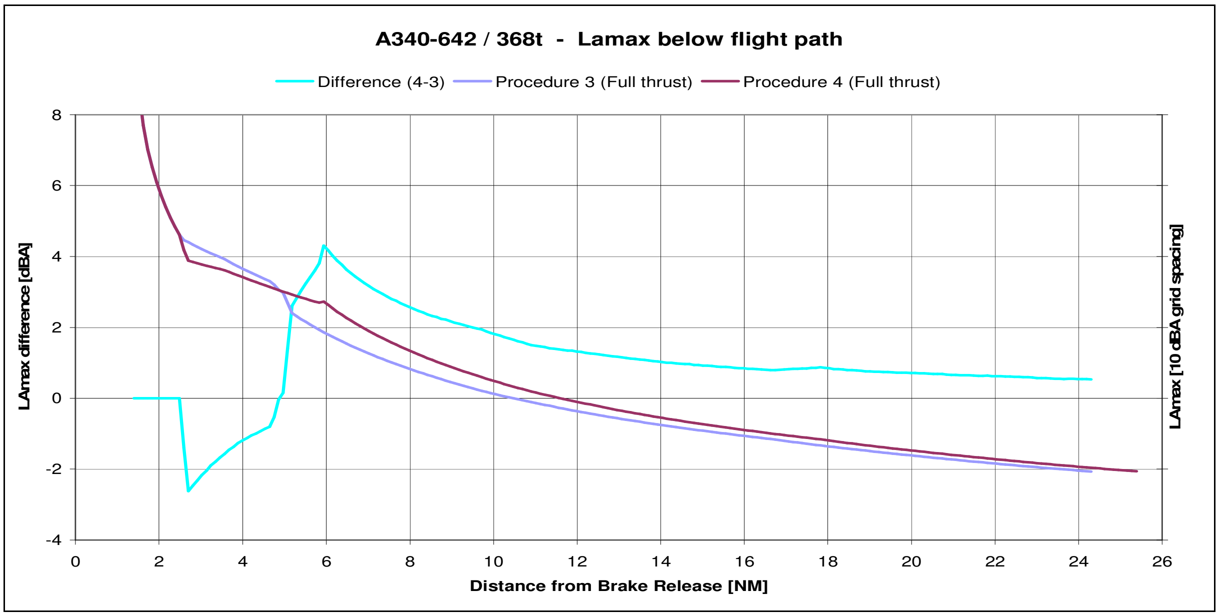


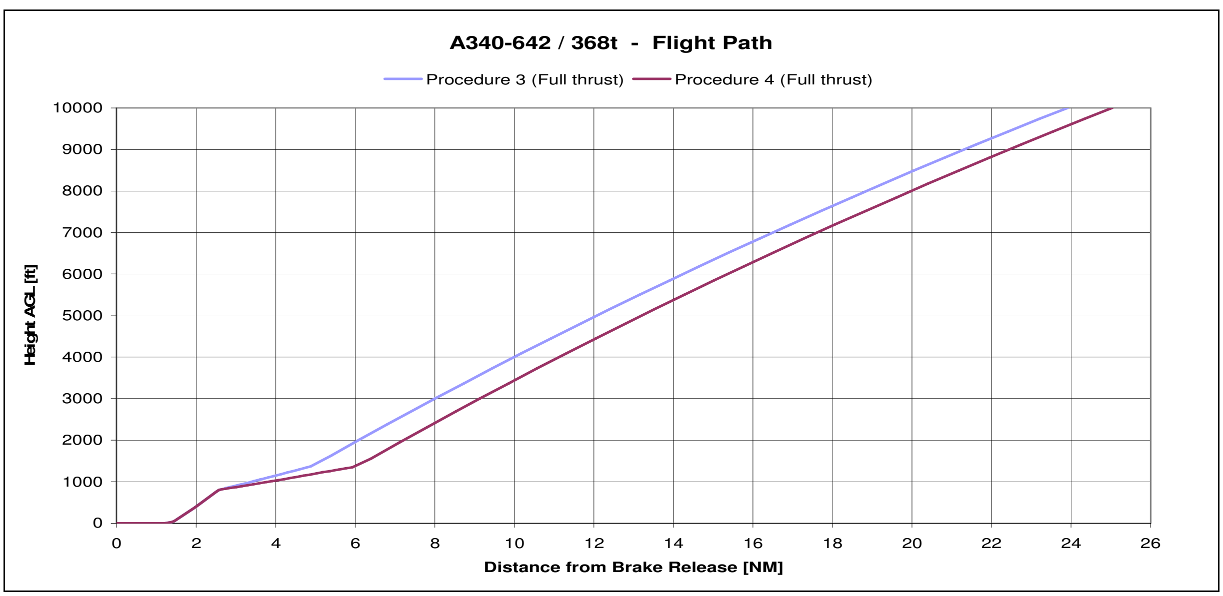
A340-642, RR Trent 556

- **Full thrust (TOGA)**
- **MTOW = 811,300lbs**

Comparison of Procedures 3 and 4



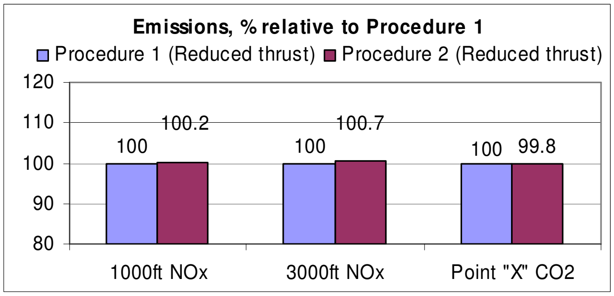


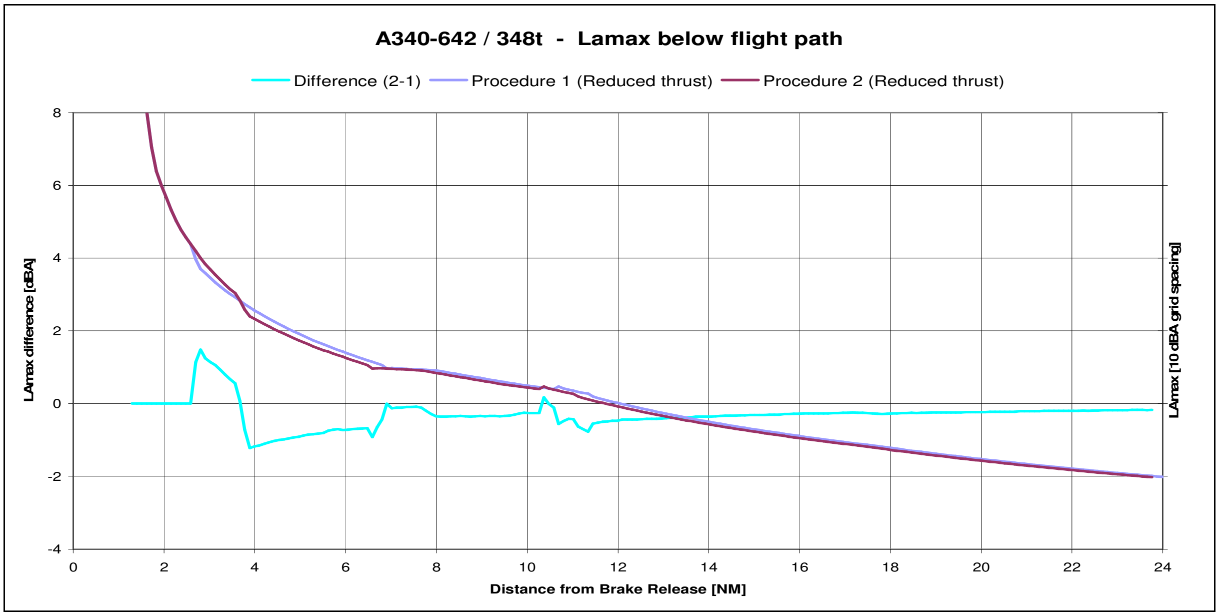


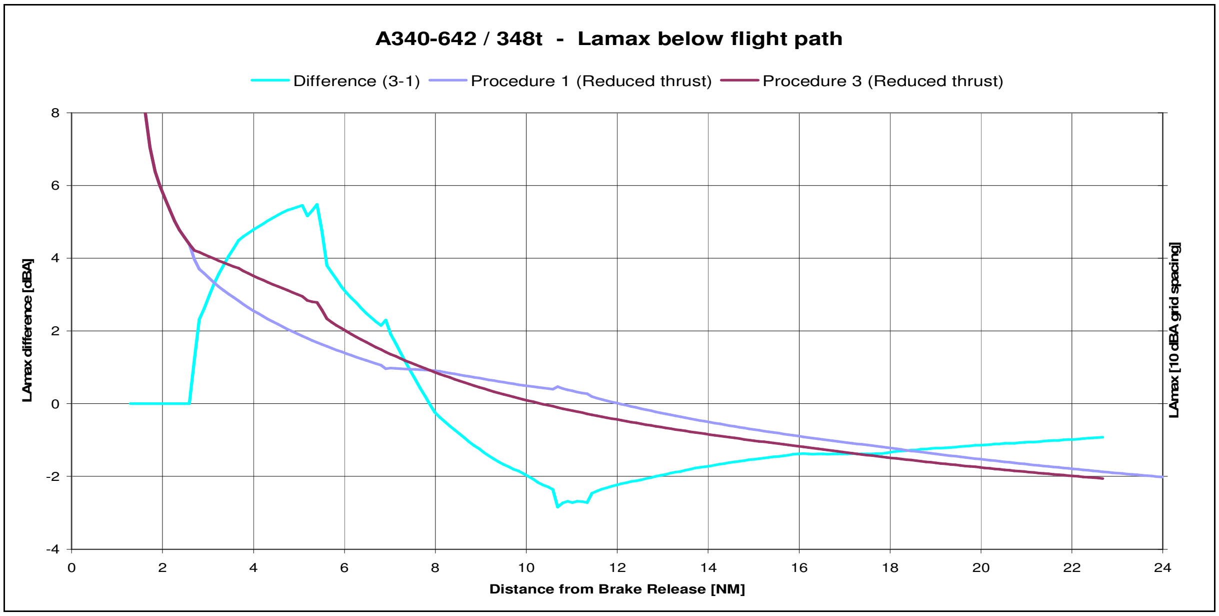
A340-642, RR Trent 556

- **12% Reduced Thrust**
- **TOW = 769,500lbs**

Comparison of Procedures 1 and 2

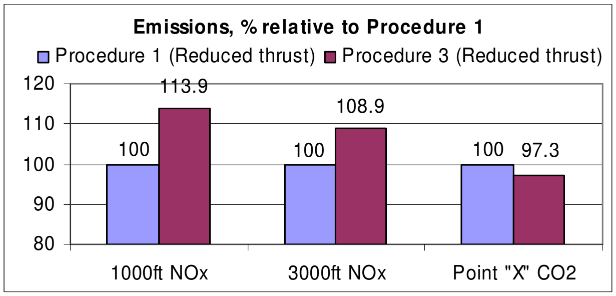




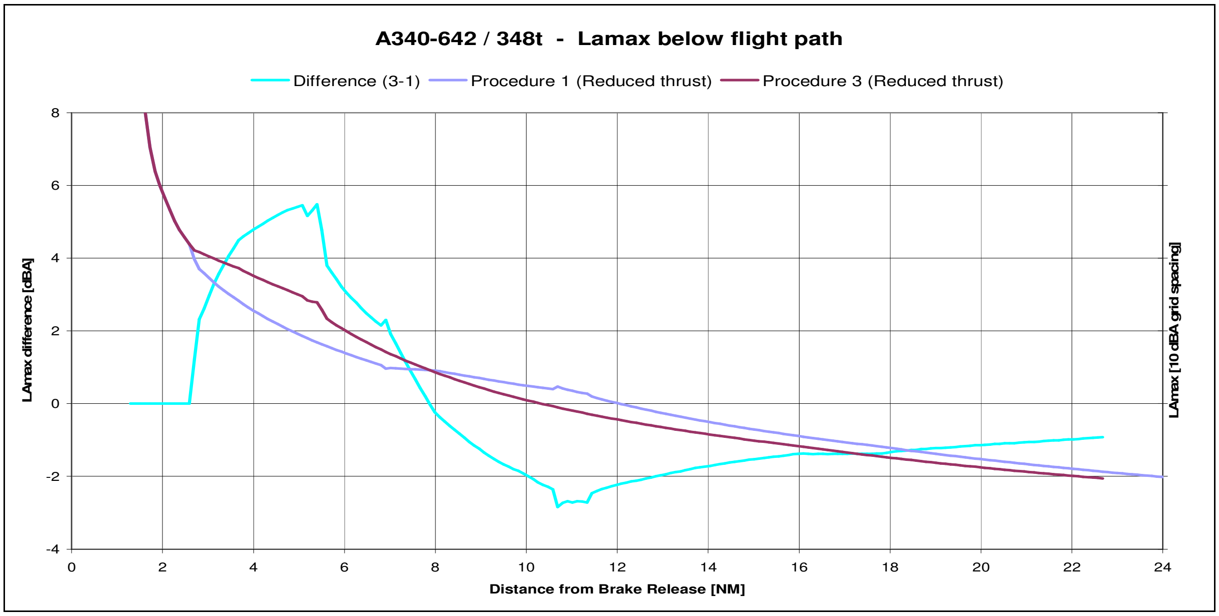


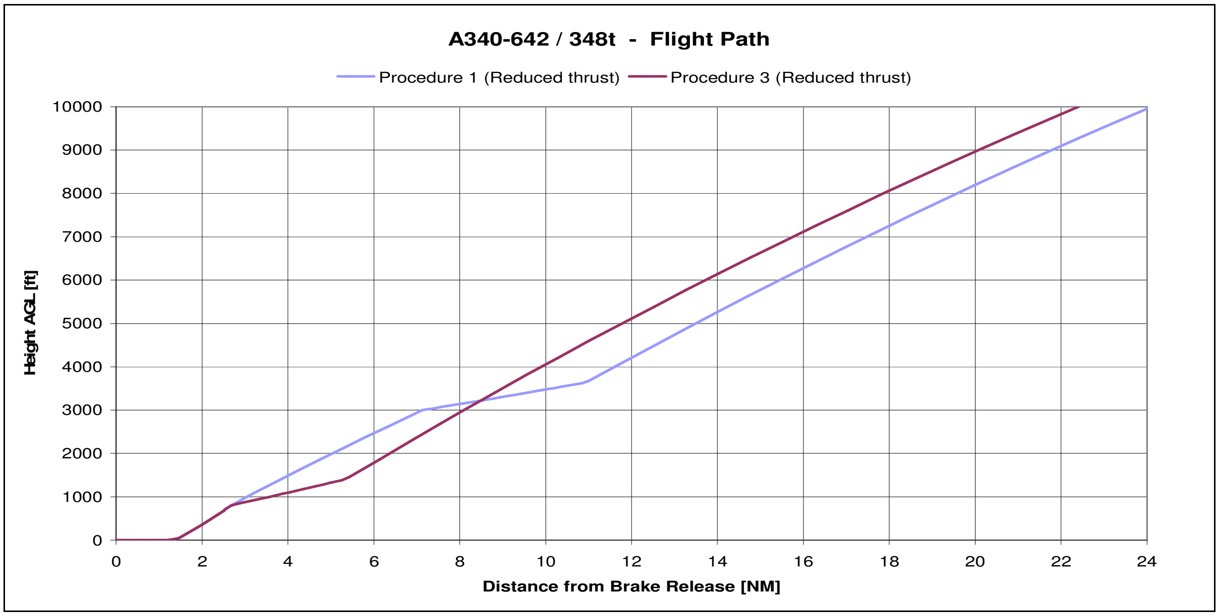
A340-642, RR Trent 556

- **12% Reduced Thrust**
- **TOW = 769,500lbs**



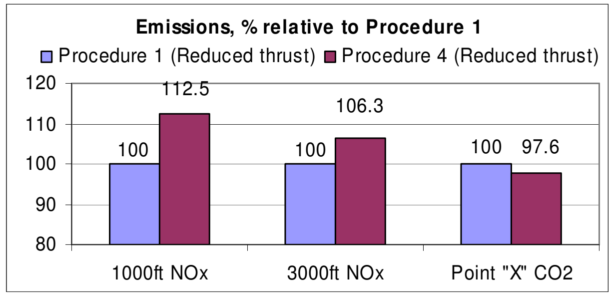
Comparison of Procedures 1 and 3



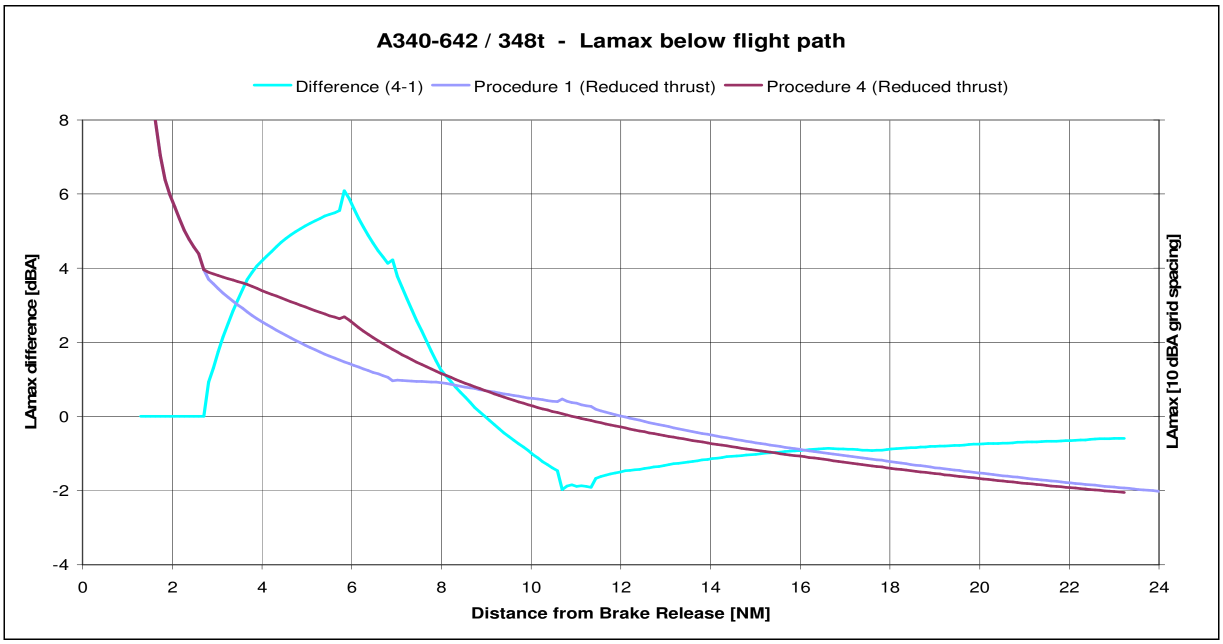


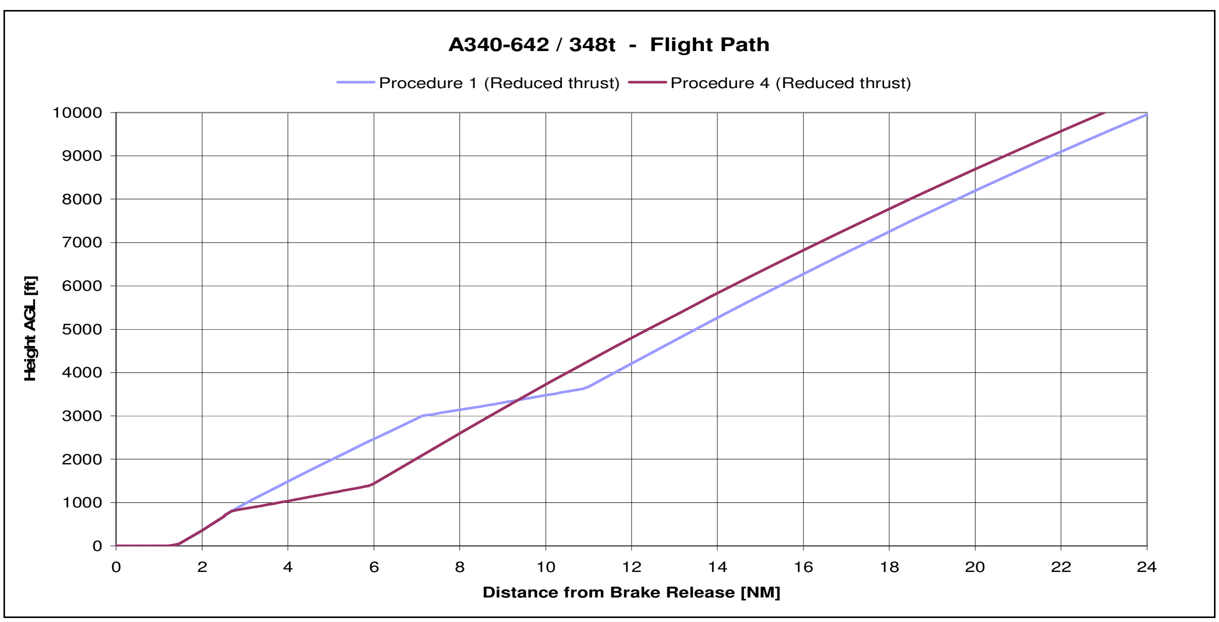
A340-642, RR Trent 556

- **12% Reduced thrust**
- **TOW = 769,500lbs**



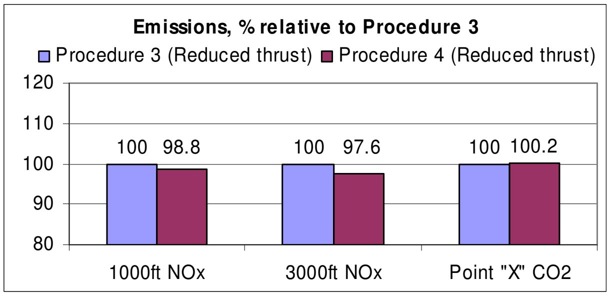
Comparison of Procedures 1 and 4



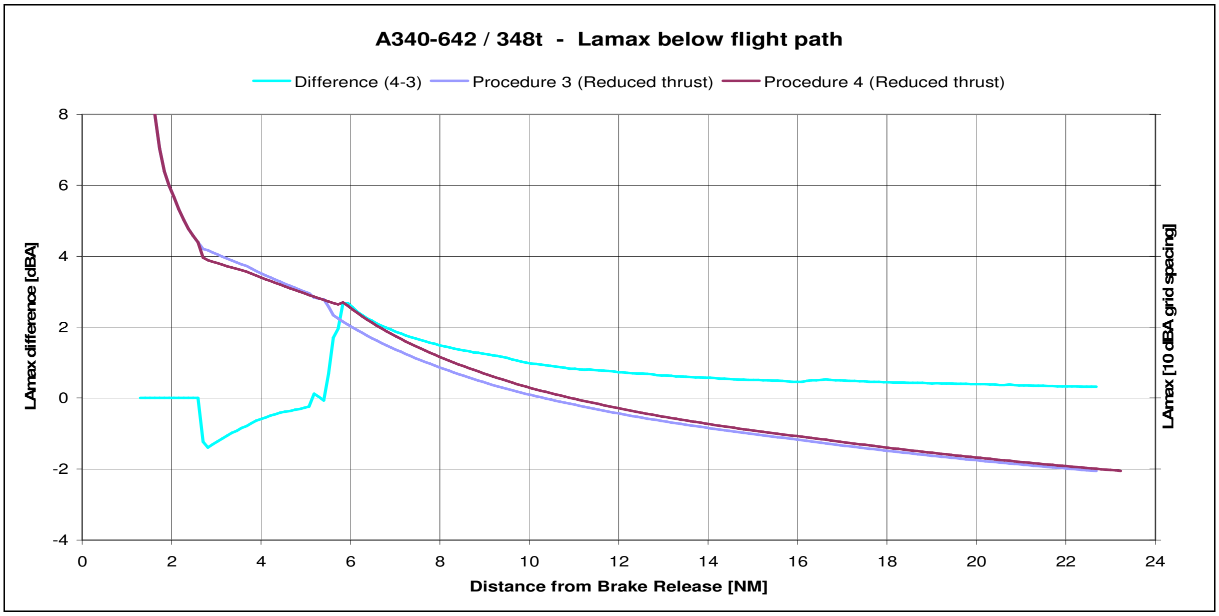


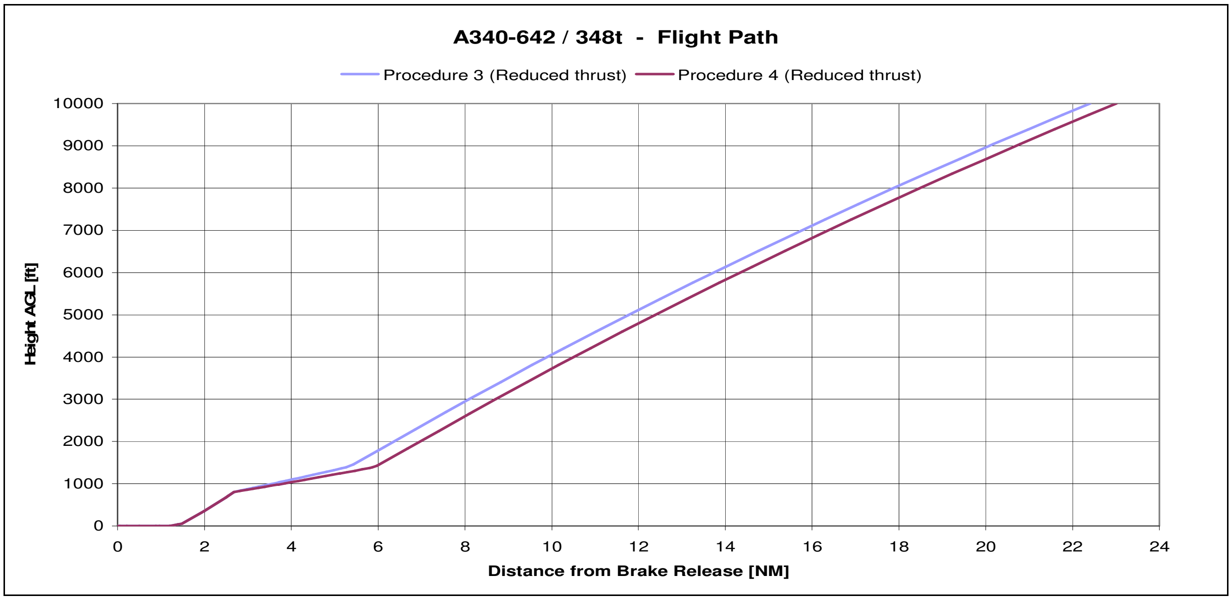
A340-642, RR Trent 556

- **12% Reduced Thrust**
- **TOW = 769,500lbs**



Comparison of Procedures 3 and 4





APPENDIX B: RESULTS BOEING

Aircraft Studied

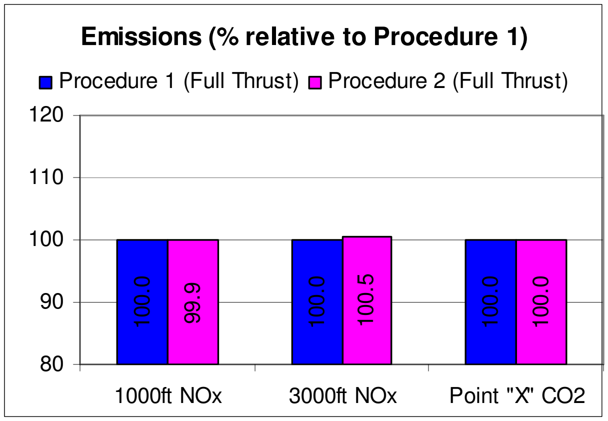
- **737-700/CFM56-7B24**
  - Climb Limit Weight with Flap5, SL/STD Day
  - Max T/O Rating = 154,500 LB
  - 10% Reduced Thrust = 152,100 LB

- **767-400ER/CF6-80C2B8F**
  - Climb Limit Weight with Flap5, SL/STD Day
  - Max T/O Thrust = 450,000 LB
  - 10% Reduced Thrust = 440,000 LB

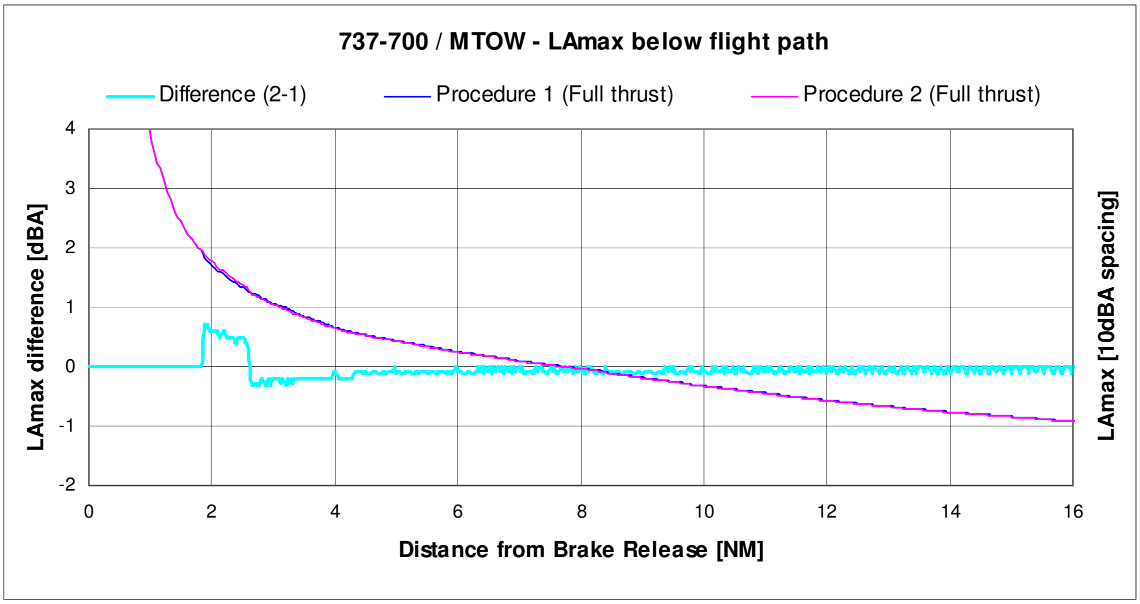
- **777-300/Trent892**
  - Climb Limit Weight with Flap5, SL/STD Day
  - Max T/O Thrust = 660,000 LB
  - 10% Reduced Thrust = 629,100 LB

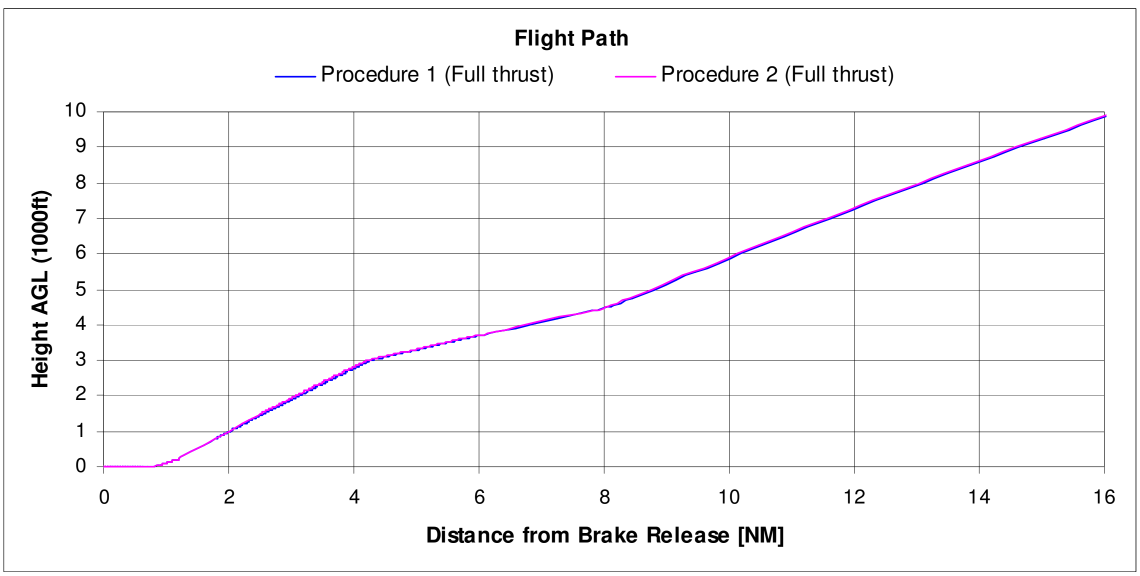
737-700/CFM56-7B24

- **Full Power Thrust**
- **MTOW = 154,500lbs**



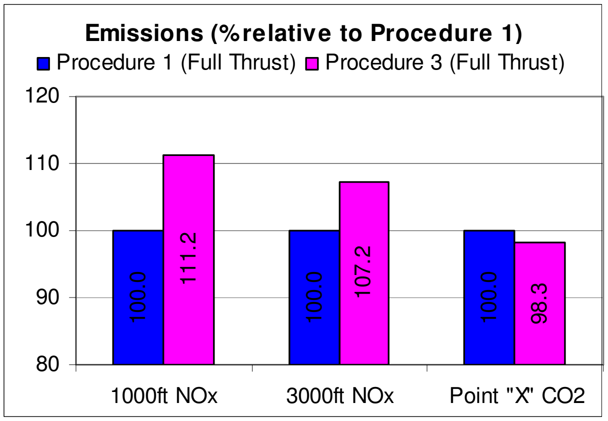
Comparison of Procedure 1 to procedure 2



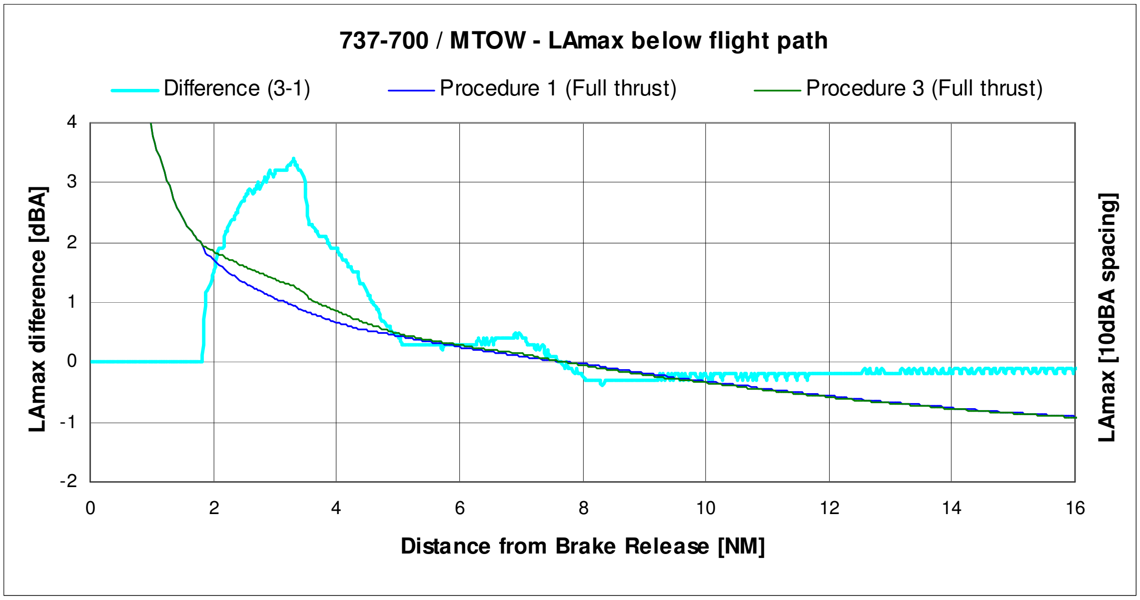


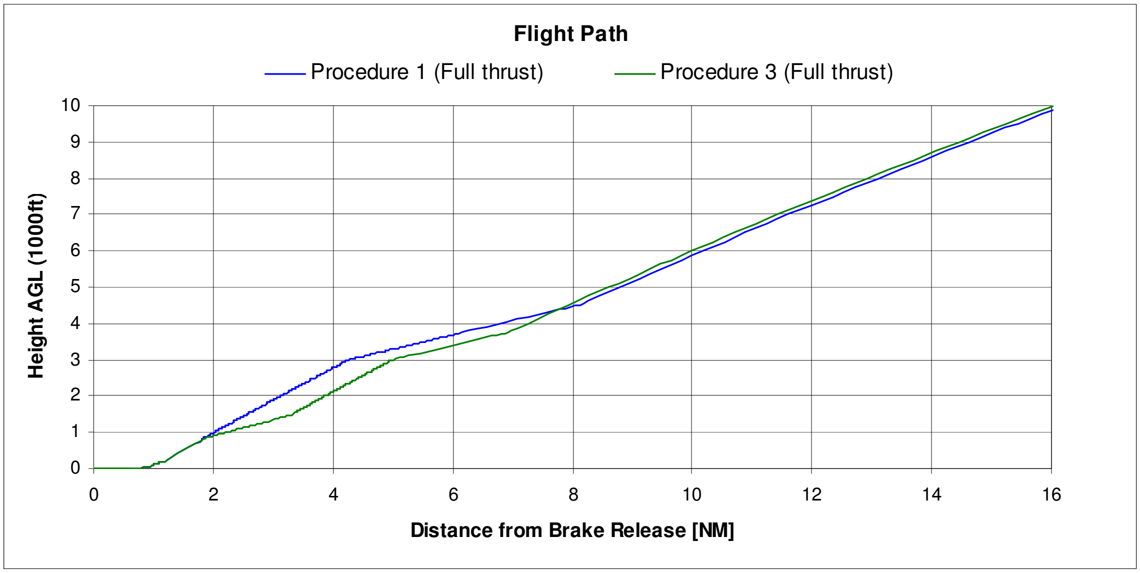
737-700/CFM56-7B24

- **Full Power Thrust**
- **MTOW = 154,500lbs**



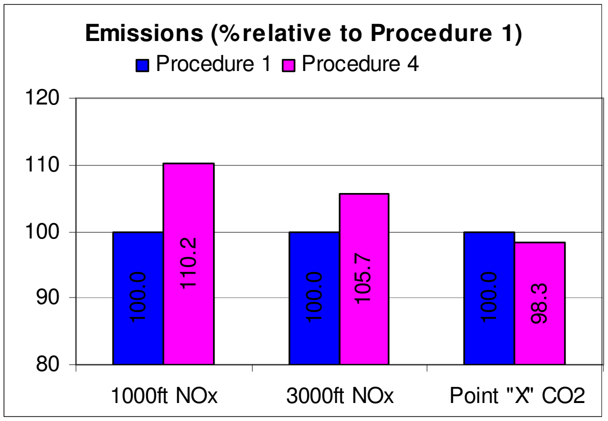
Comparison of Procedure 1 to Procedure 3



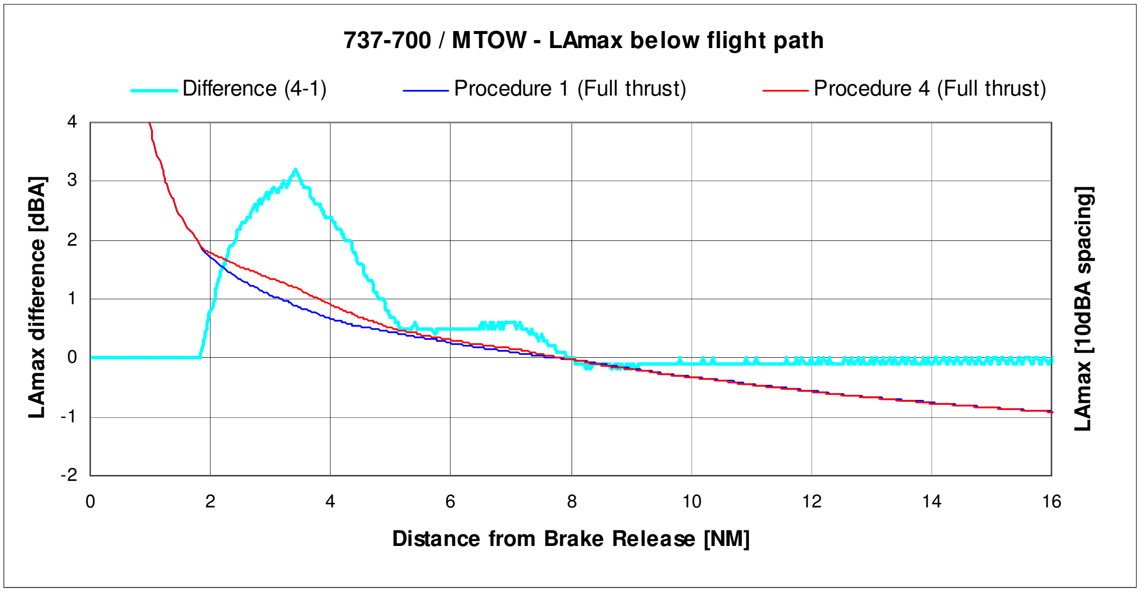


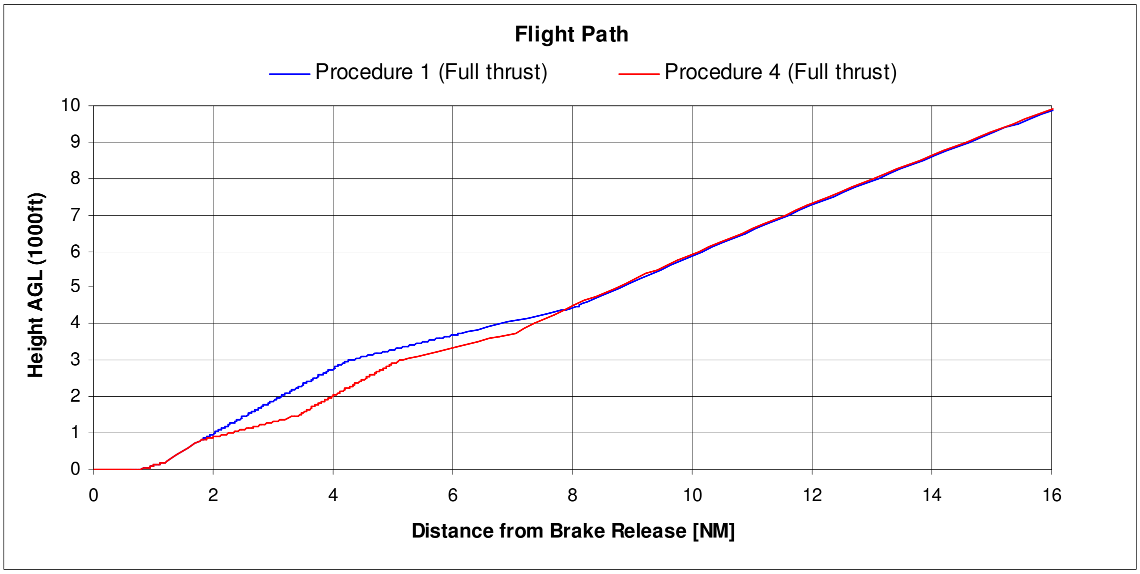
737-700/CFM56-7B24

- **Full Power Thrust**
- **MTOW = 154,500lbs**



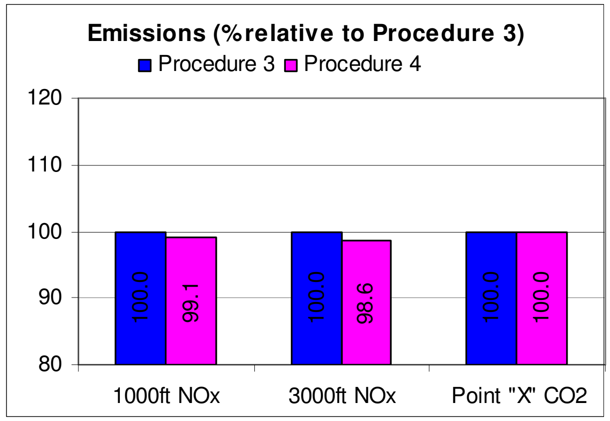
Comparison of Procedure 1 to Procedure 4



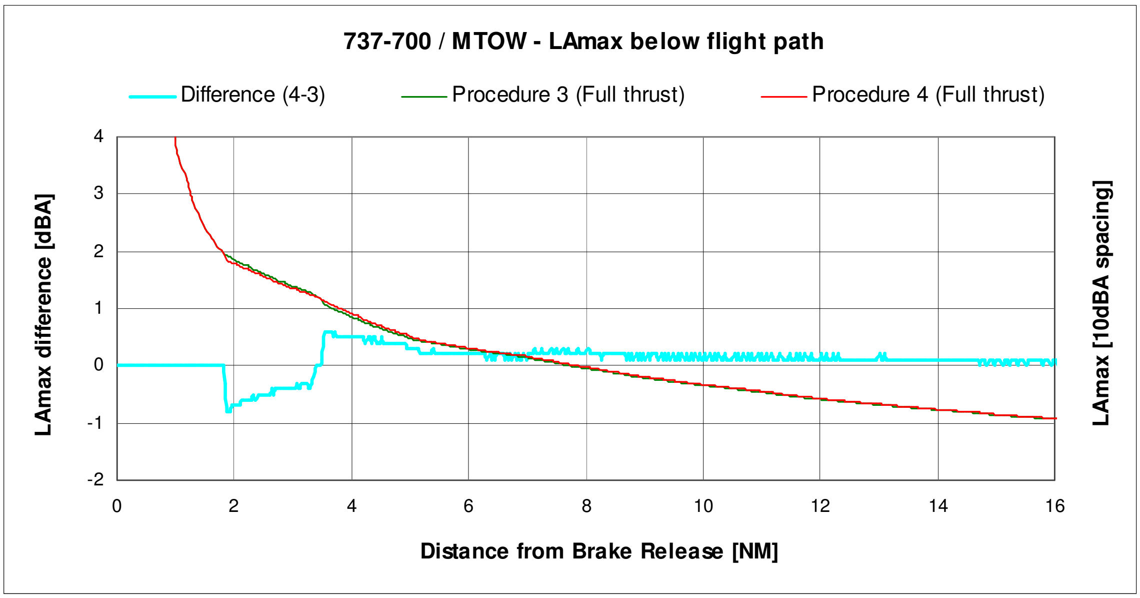


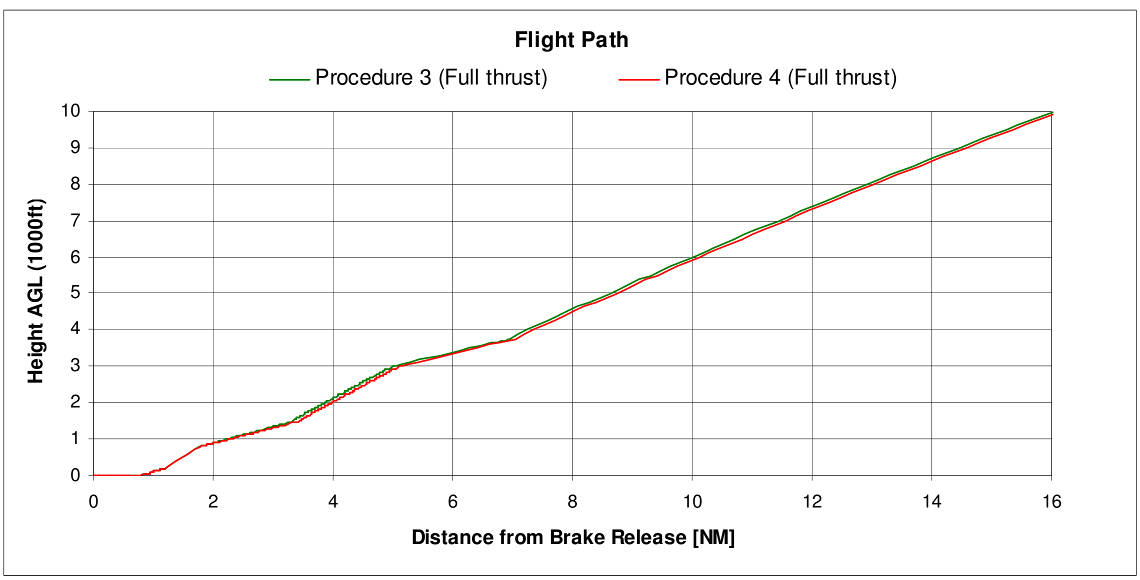
737-700/CFM56-7B24

- **Full Power Thrust**
- **MTOW = 154,500lbs**



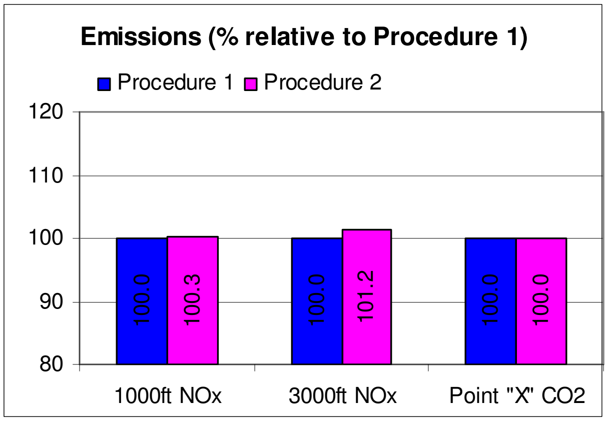
Comparison of Procedure 3 to Procedure 4



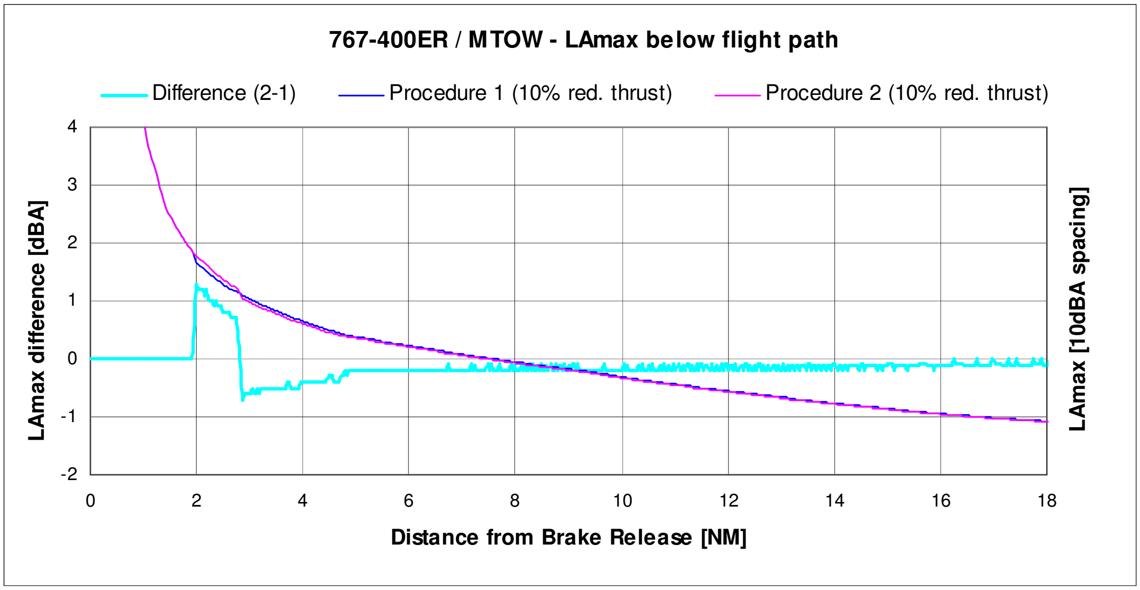


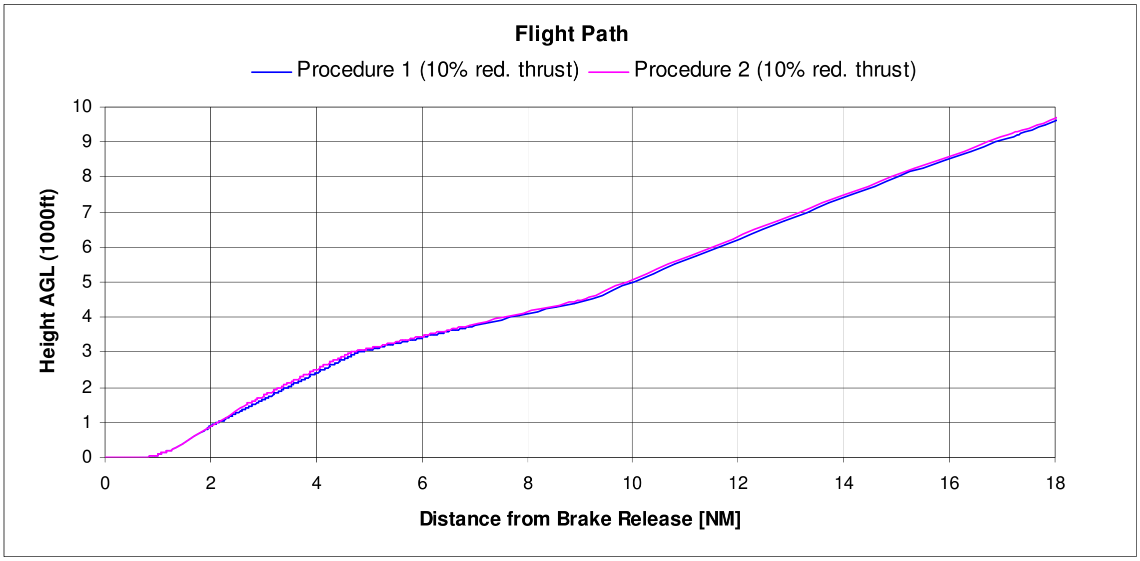
737-700/CFM56-7B24

- **10% Reduced Thrust**
- **MTOW = 152,100lbs**



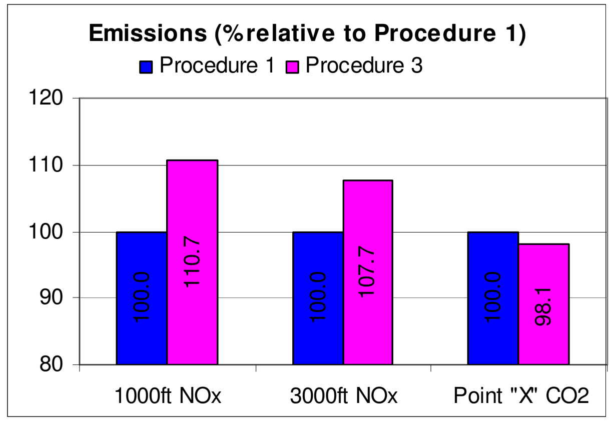
Comparison of Procedure 1 to Procedure 2



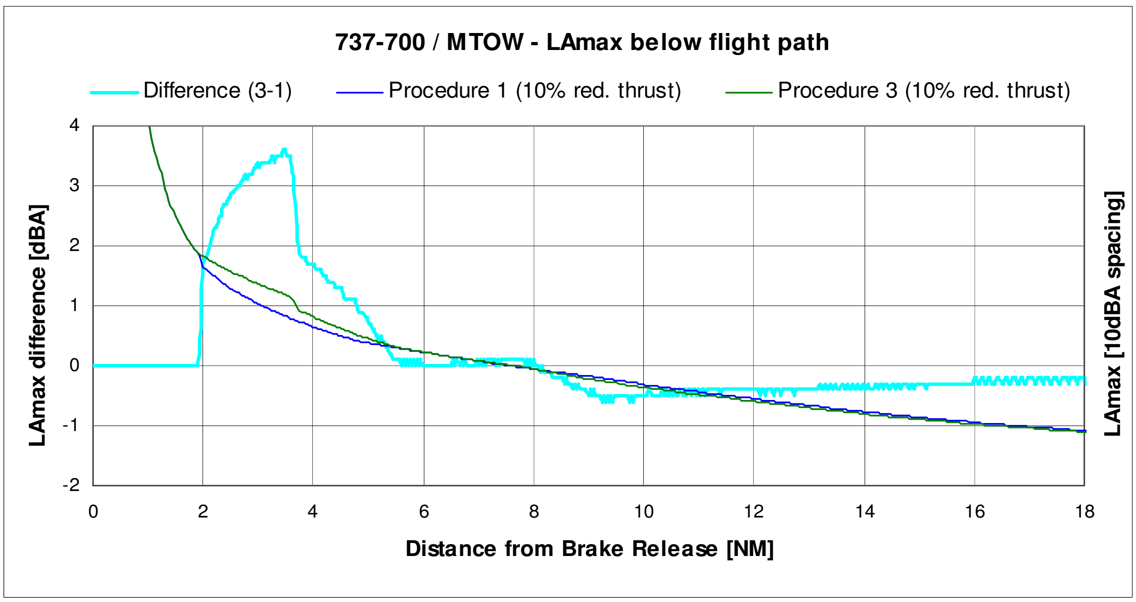


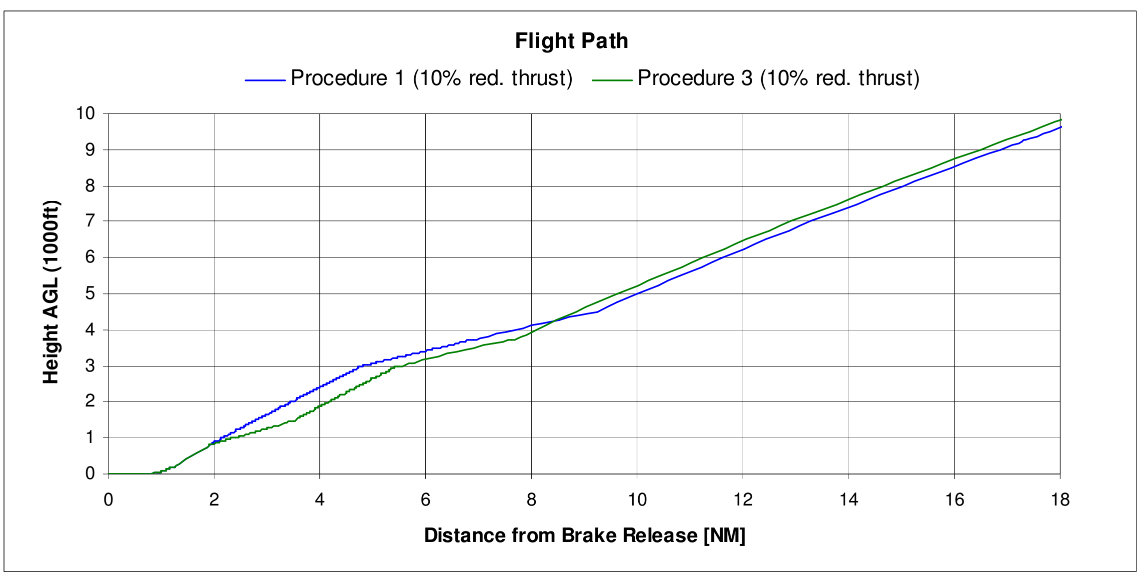
737-700/CFM56-7B24

- **10% Reduced Thrust**
- **MTOW = 152,100lbs**



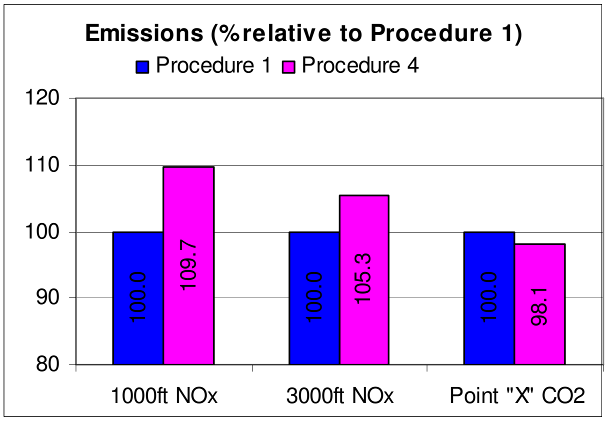
Comparison of Procedure 1 to Procedure 3



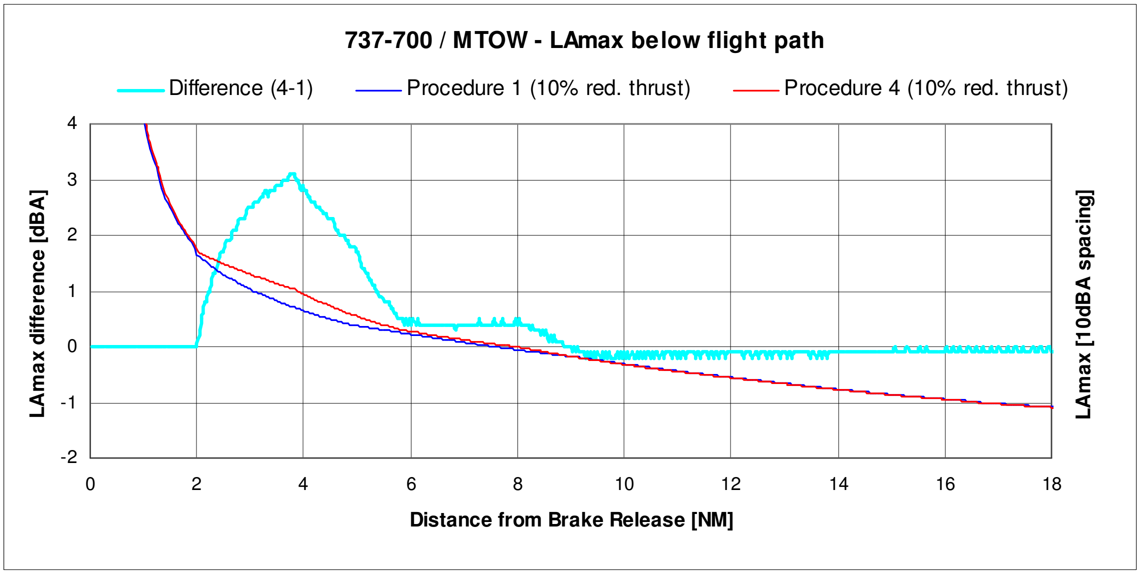


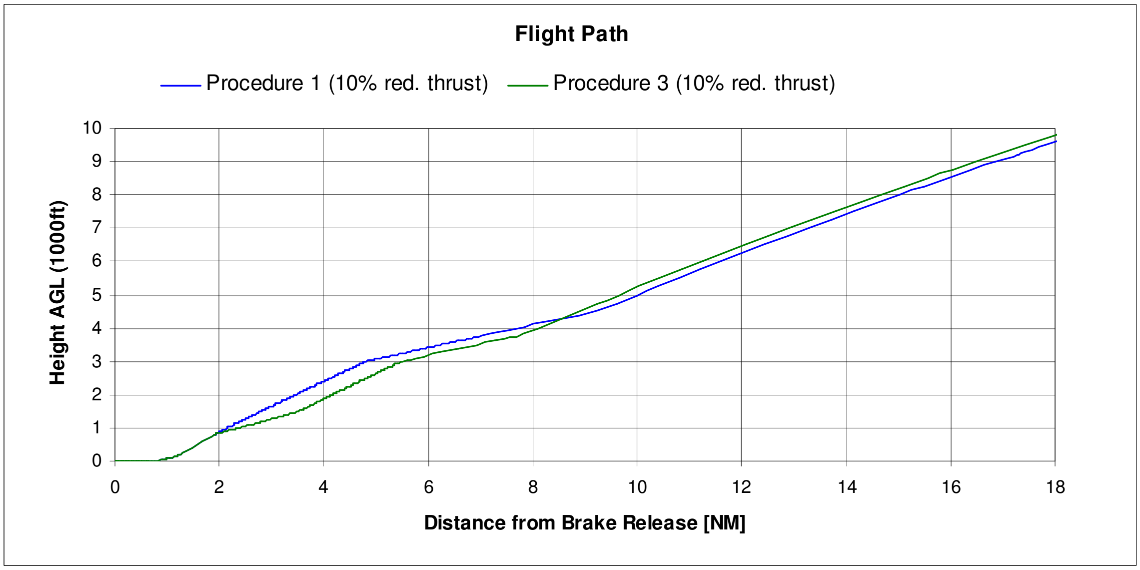
737-700/CFM56-7B24

- **10% Reduced Thrust**
- **MTOW = 152,100lbs**



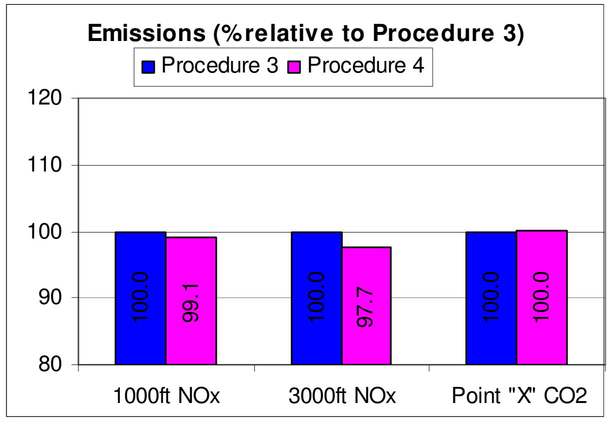
Comparison of Procedure 1 to Procedure 4



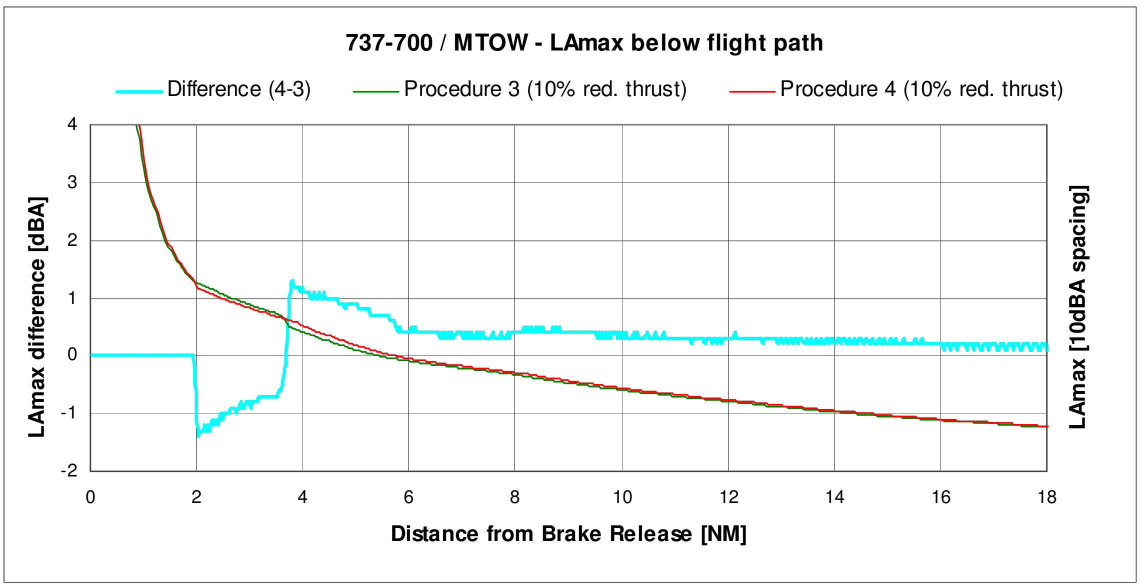


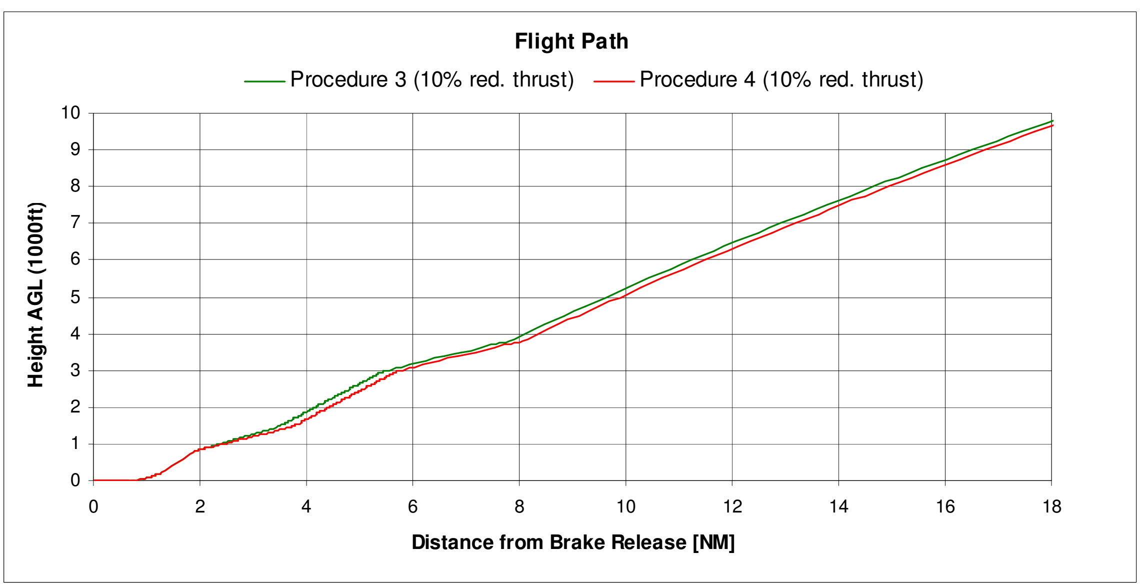
737-700/CFM56-7B24

- **10% Reduced Thrust**
- **MTOW = 152,100lbs**



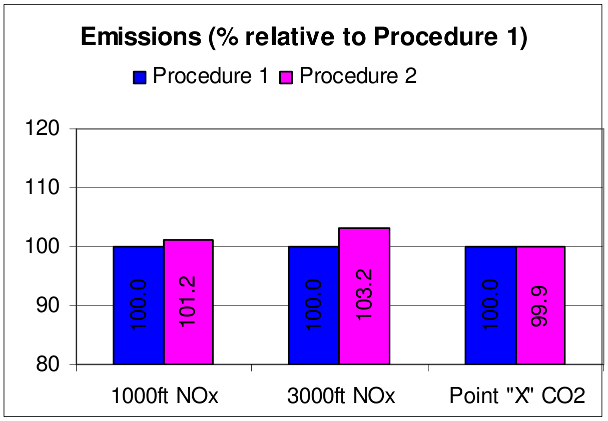
Comparison of Procedure 3 to Procedure 4



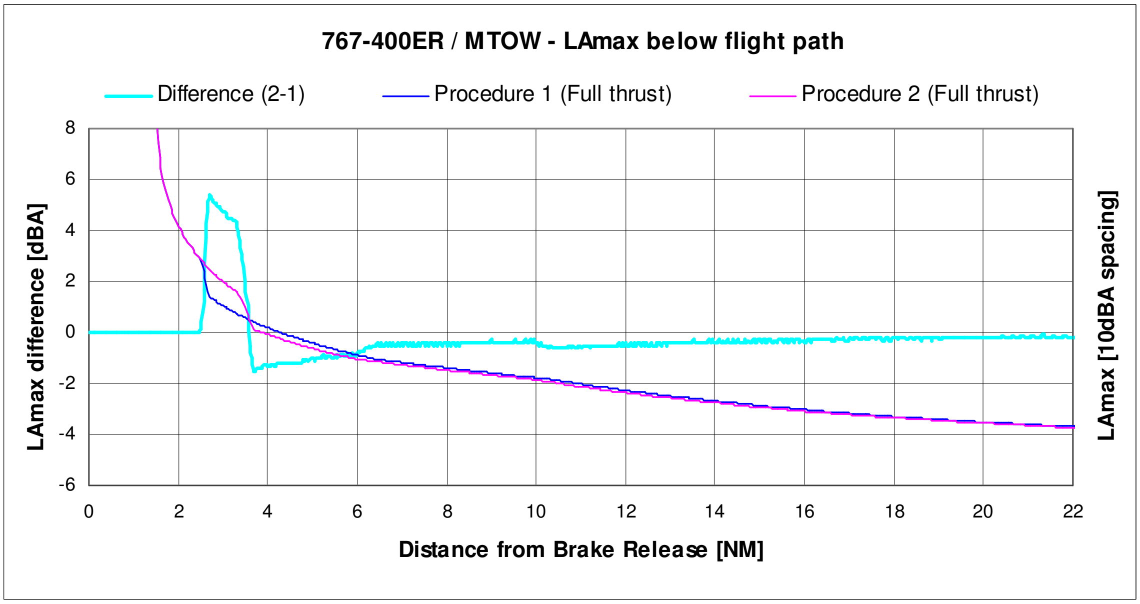


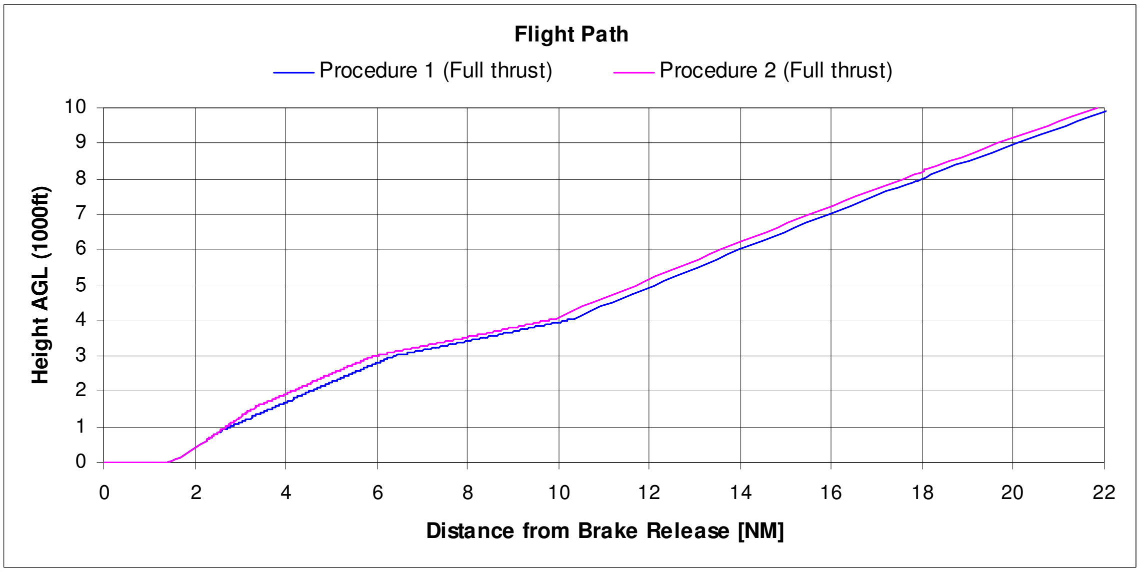
767-400ER/CF6-80C2B8F

- **Full Power Thrust**
- **MTOW = 450,000lbs**



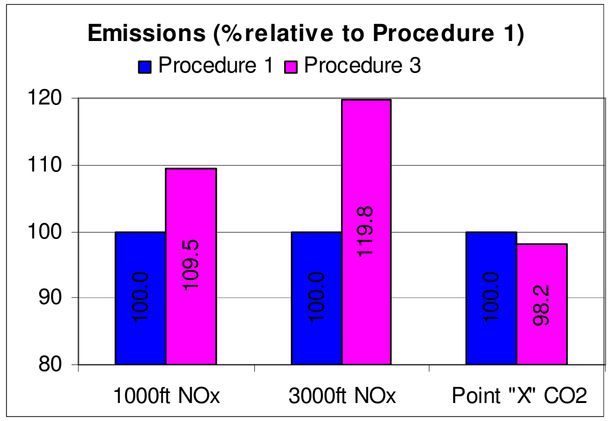
Comparison of Procedure 1 to Procedure 2



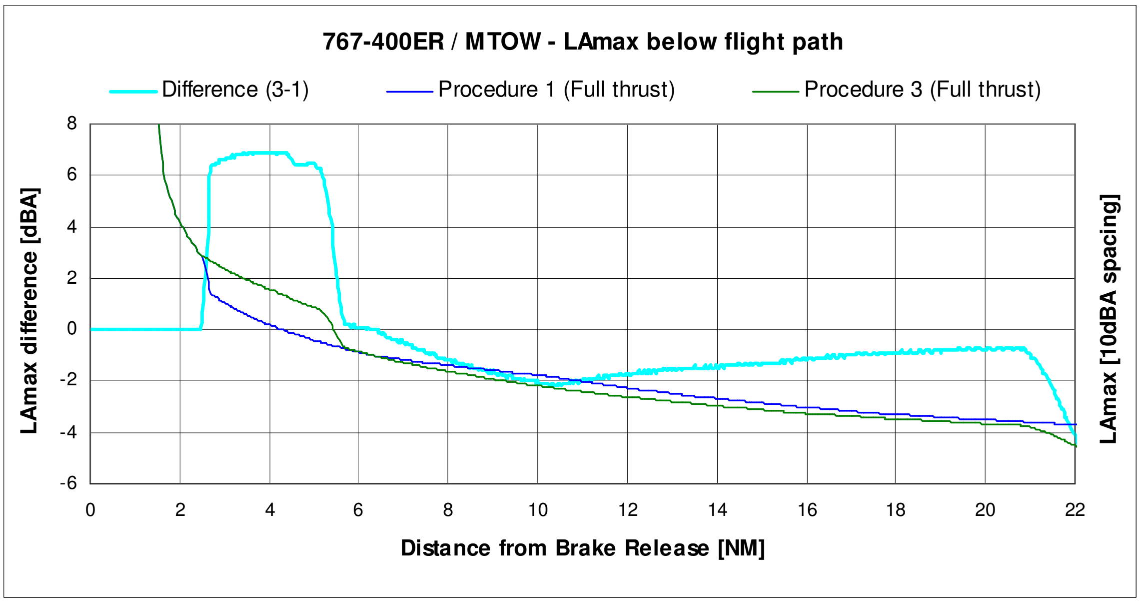


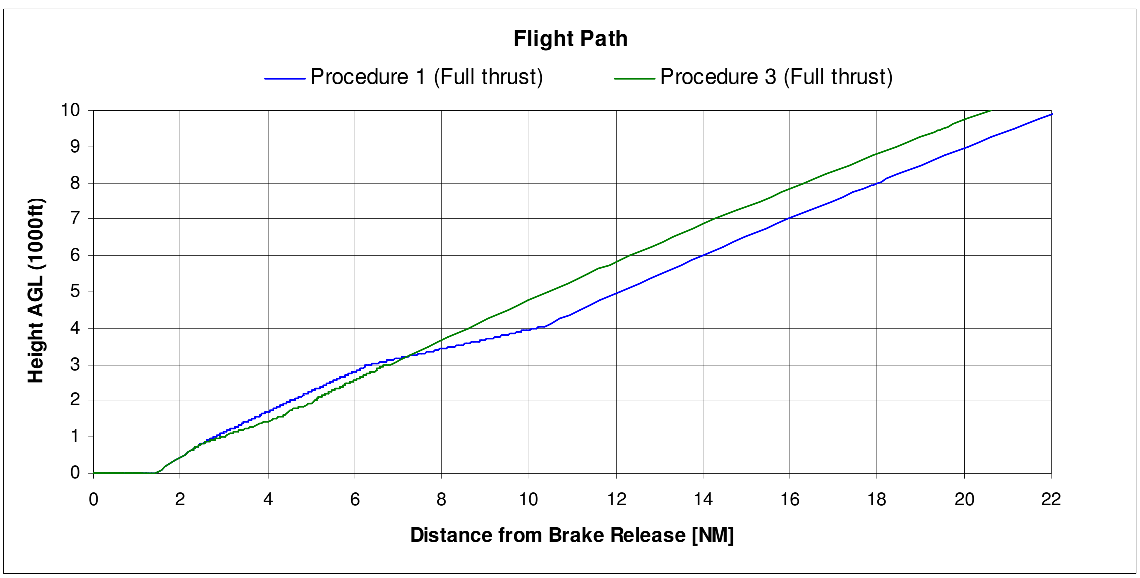
767-400ER/CF6-80C2B8F

- **Full Power Thrust**
- **MTOW = 450,000lbs**



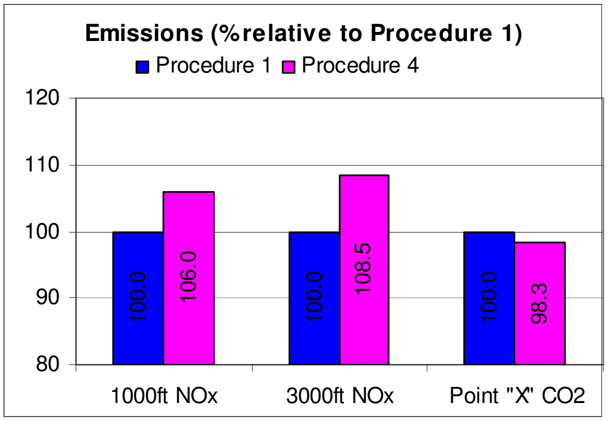
Comparison of Procedure 1 to Procedure 3



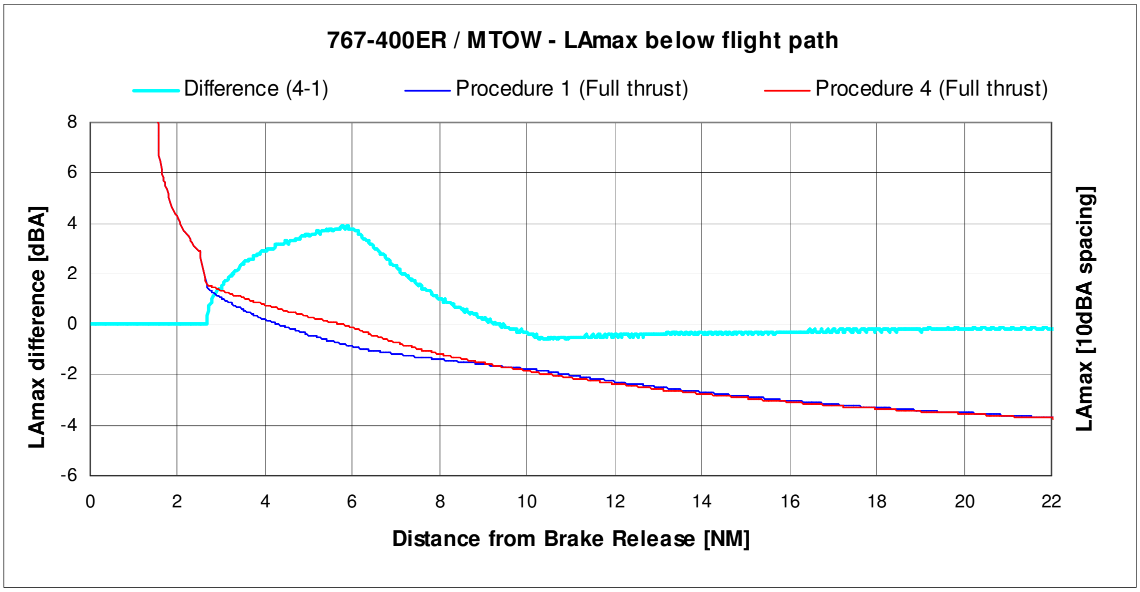


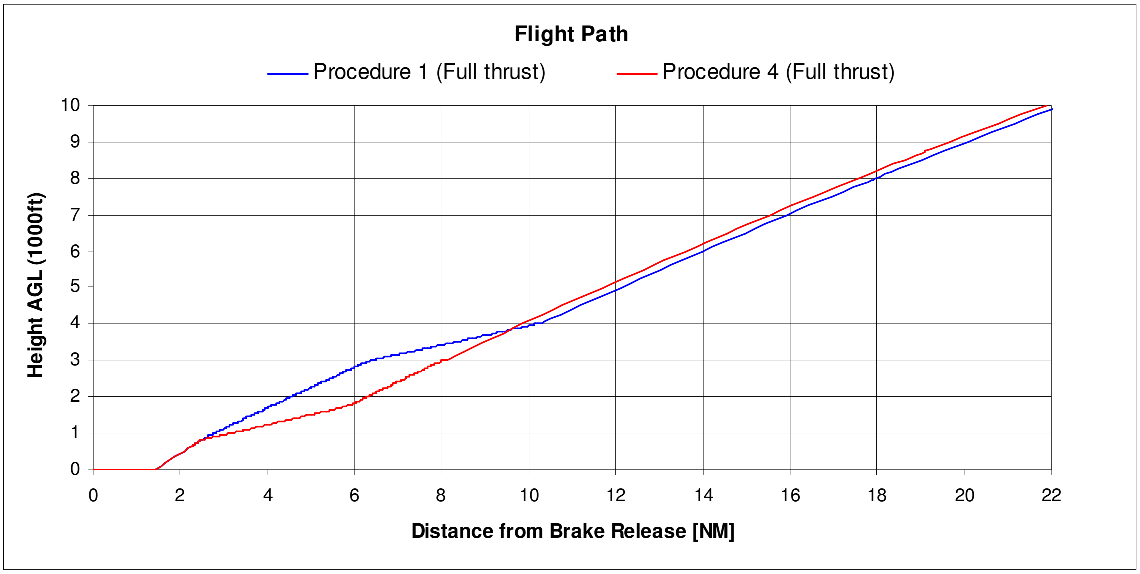
767-400ER/CF6-80C2B8F

- **Full Power Thrust**
- **MTOW = 450,000lbs**



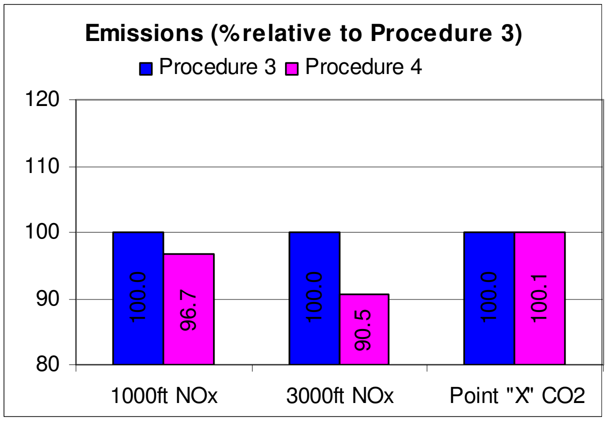
Comparison of Procedure 1 to Procedure 4



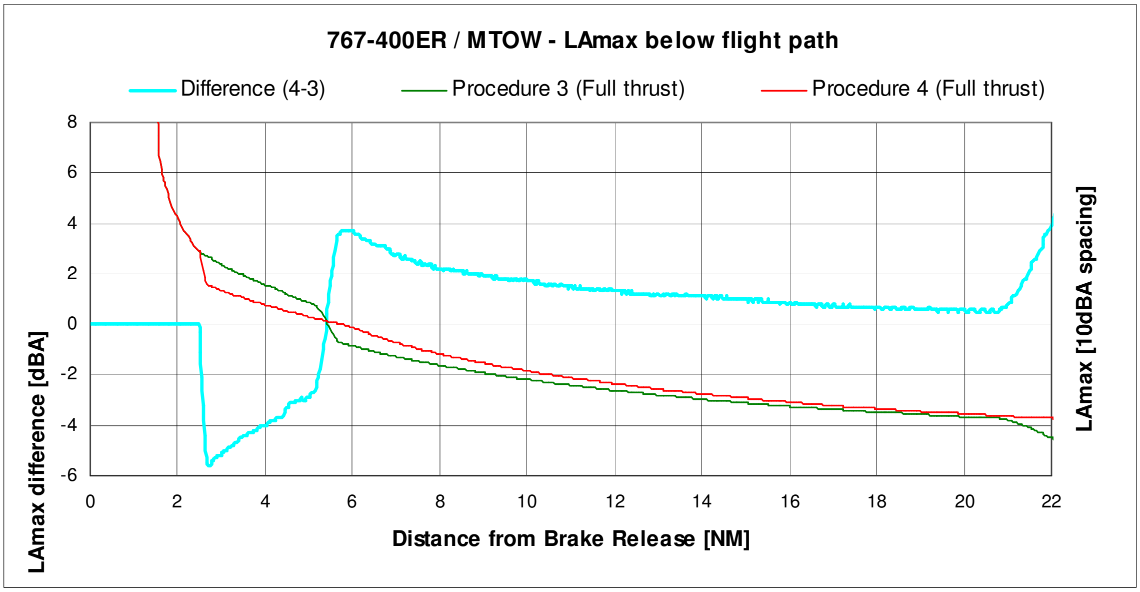


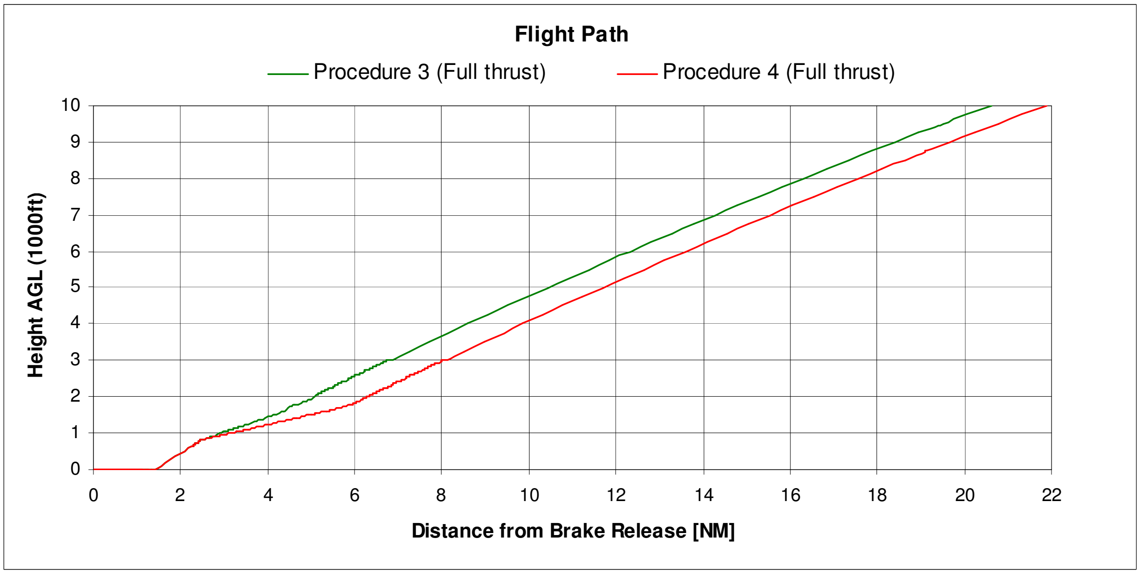
767-400ER/CF6-80C2B8F

- **Full Power Thrust**
- **MTOW = 450,000lbs**



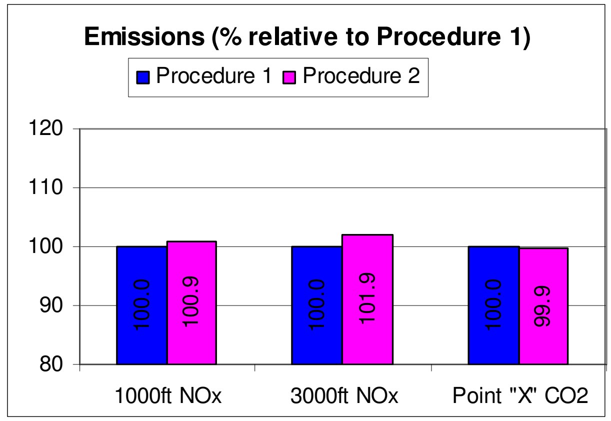
Comparison of Procedure 3 to Procedure 4



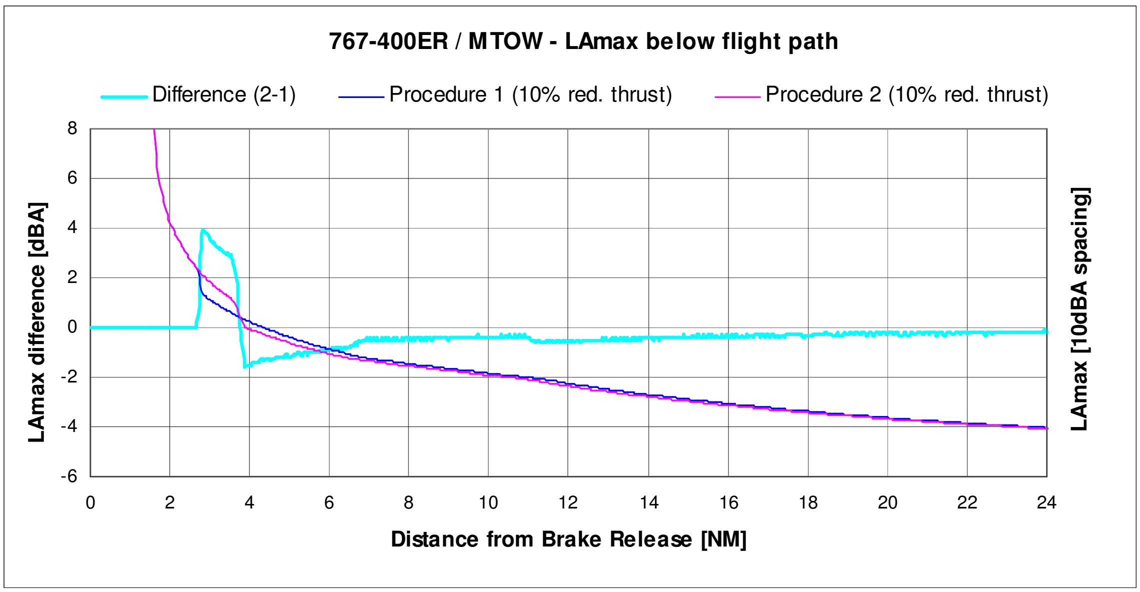


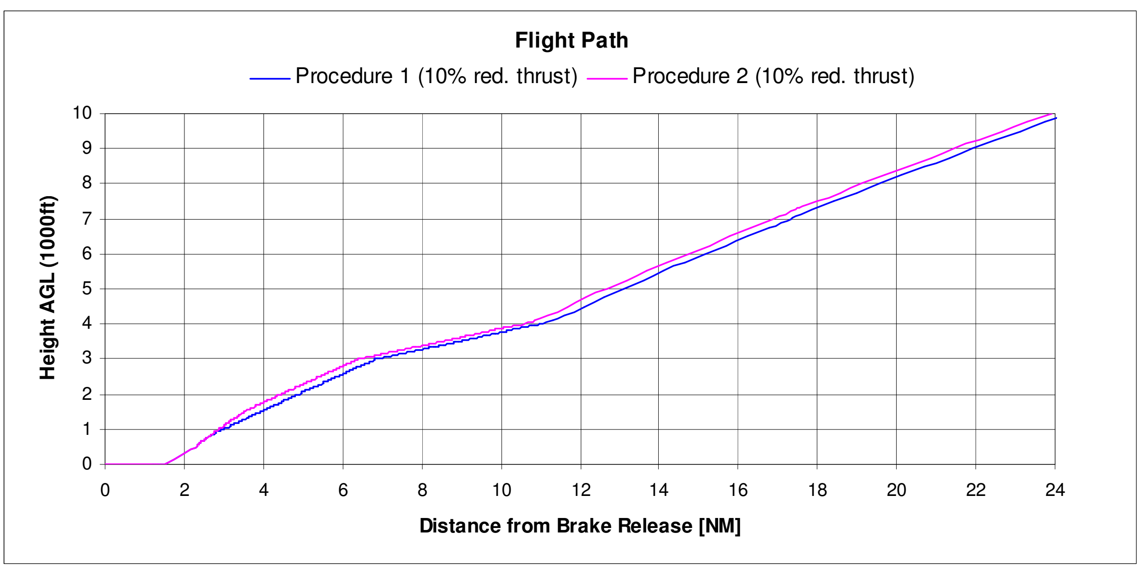
767-400ER/CF6-80C2B8F

- **10% Reduced Thrust**
- **MTOW = 440,000lbs**



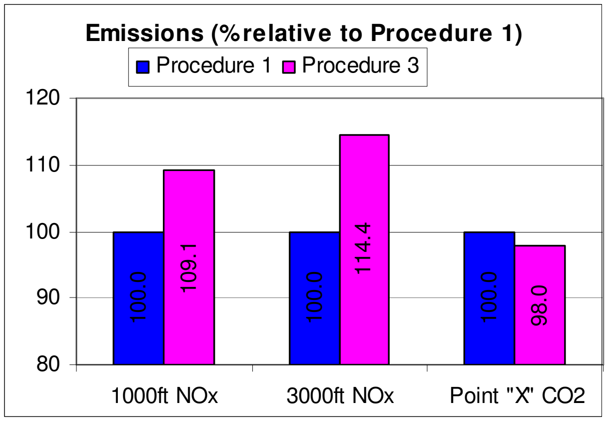
Comparison of Procedure 1 to Procedure 2



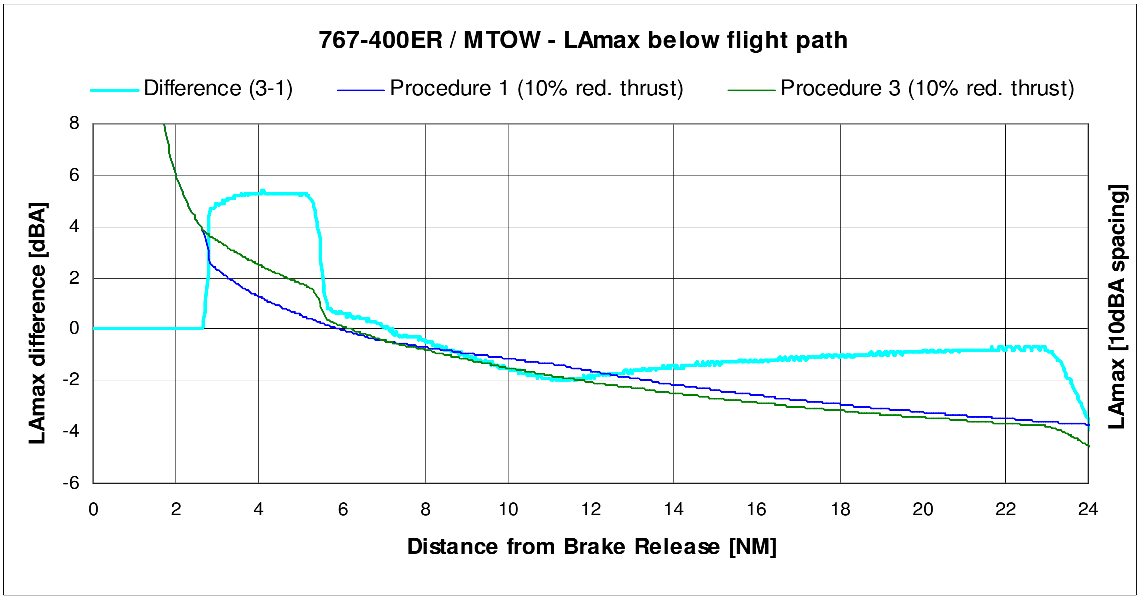


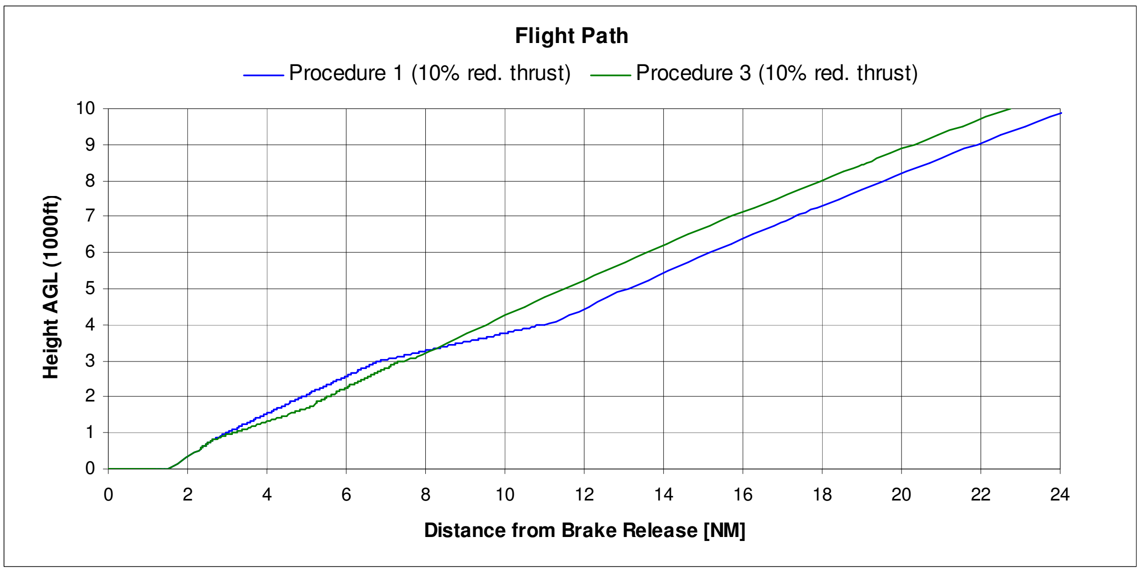
767-400ER/CF6-80C2B8F

- **10% Reduced Thrust**
- **MTOW = 440,000lbs**



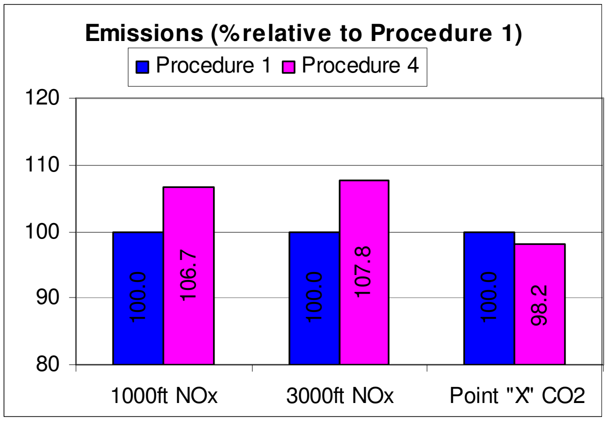
Comparison of Procedure 1 to Procedure 3



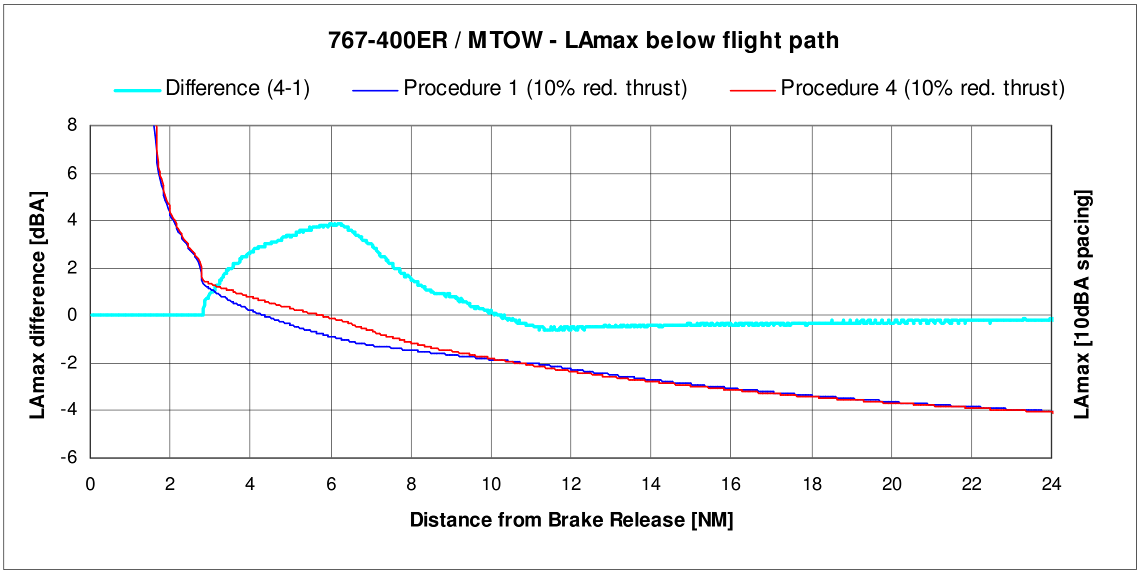


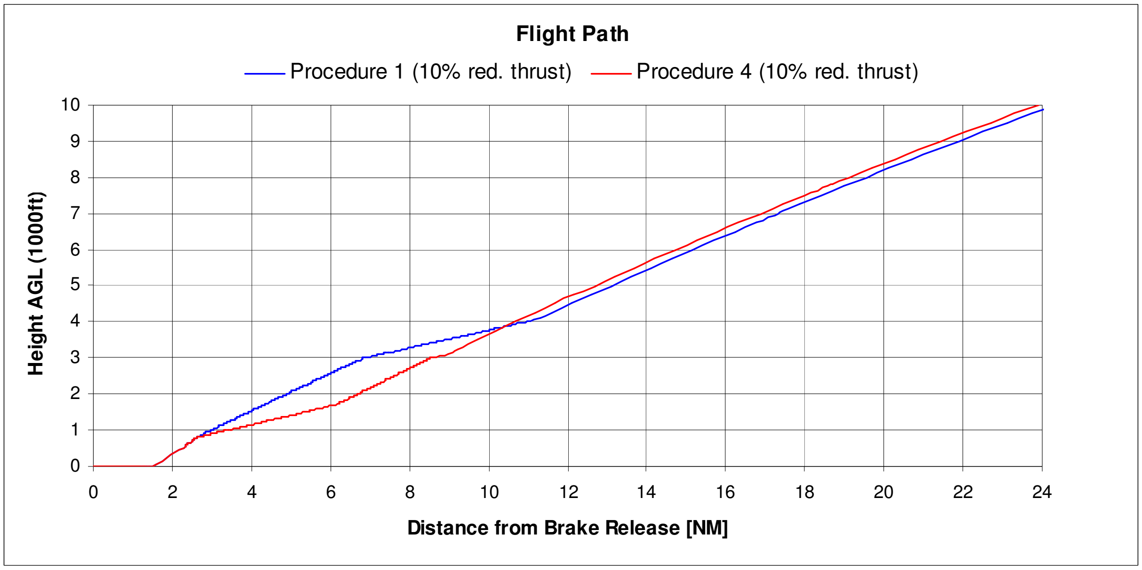
767-400ER/CF6-80C2B8F

- **10% Reduced Thrust**
- **MTOW = 440,000lbs**



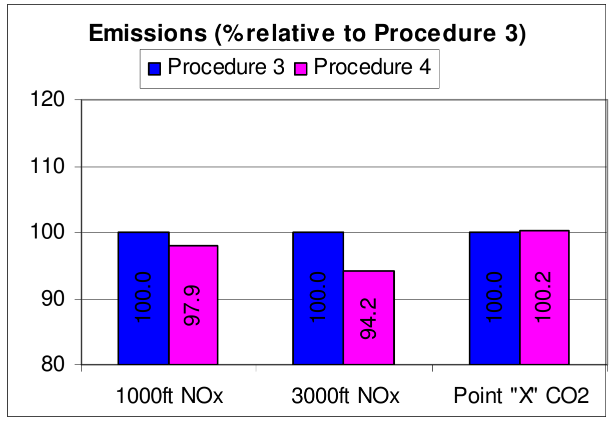
Comparison of Procedure 1 to Procedure 4



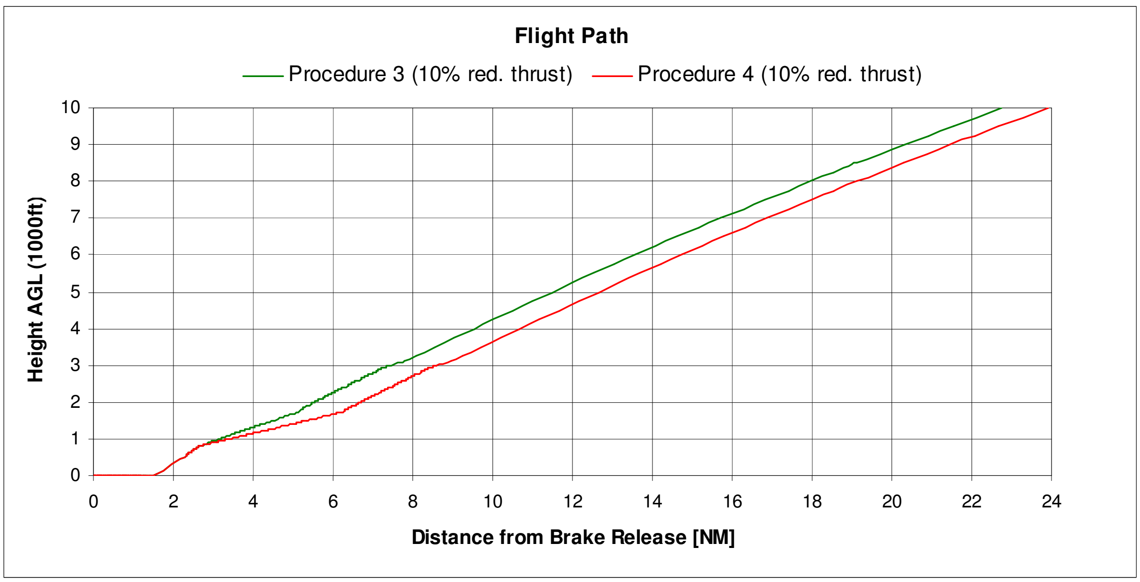


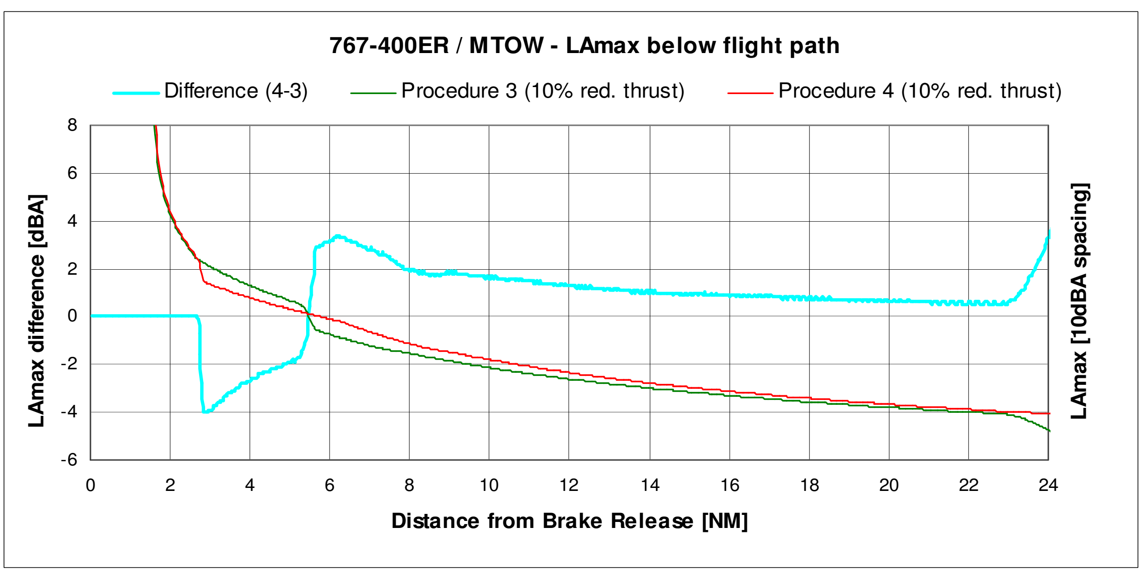
767-400ER/CF6-80C2B8F

- **10% Reduced Thrust**
- **MTOW = 440,000lbs**



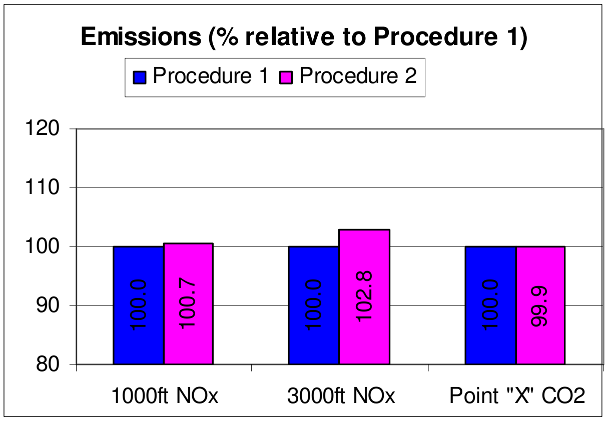
Comparison of Procedure 3 to Procedure 4



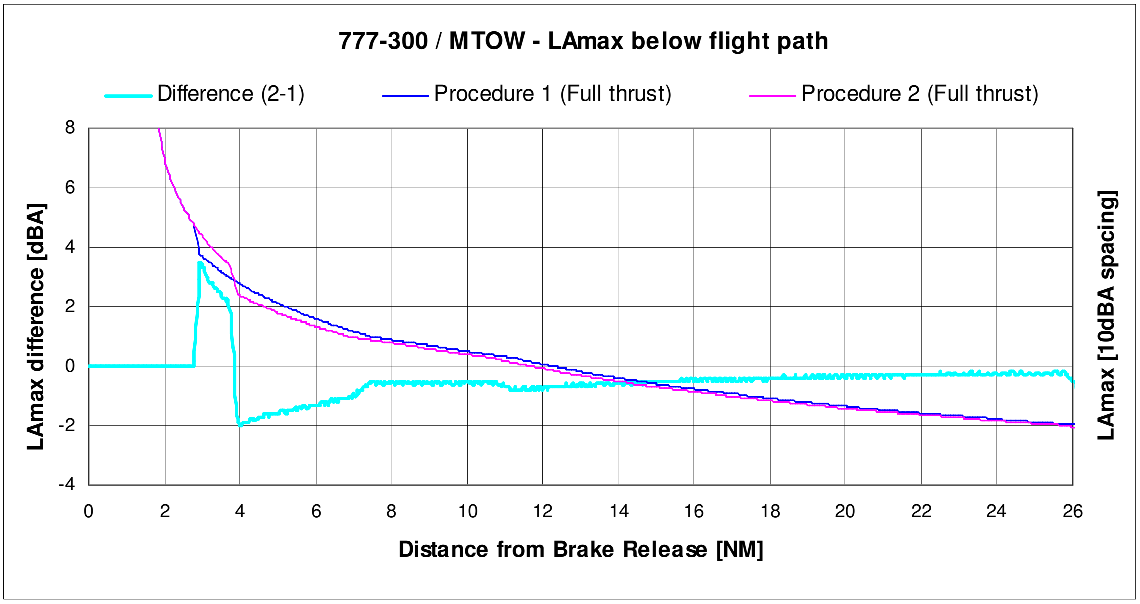


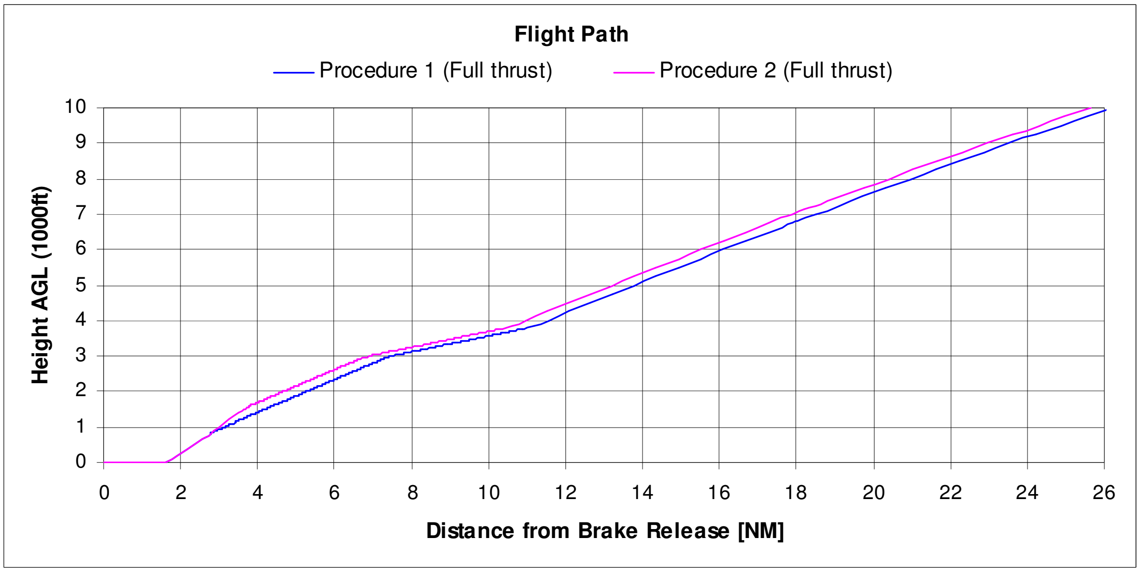
777-300/Trent 892

- **Full Power Thrust**
- **MTOW = 660,000lbs**



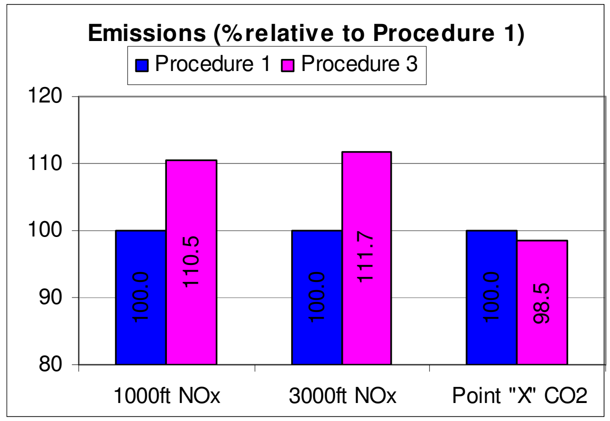
Comparison of Procedure 1 to Procedure 2



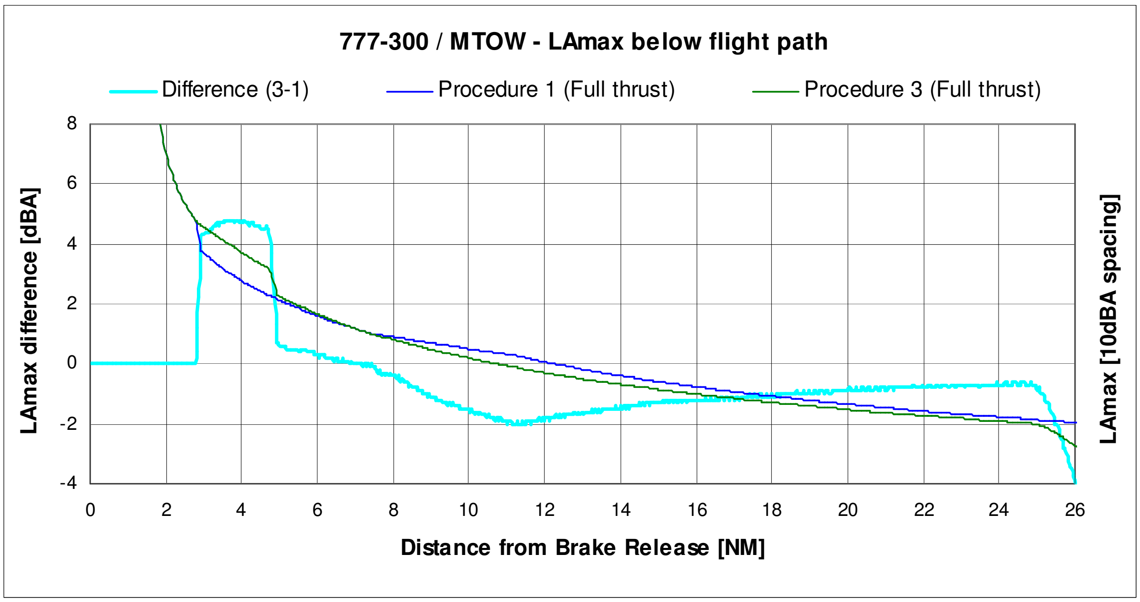


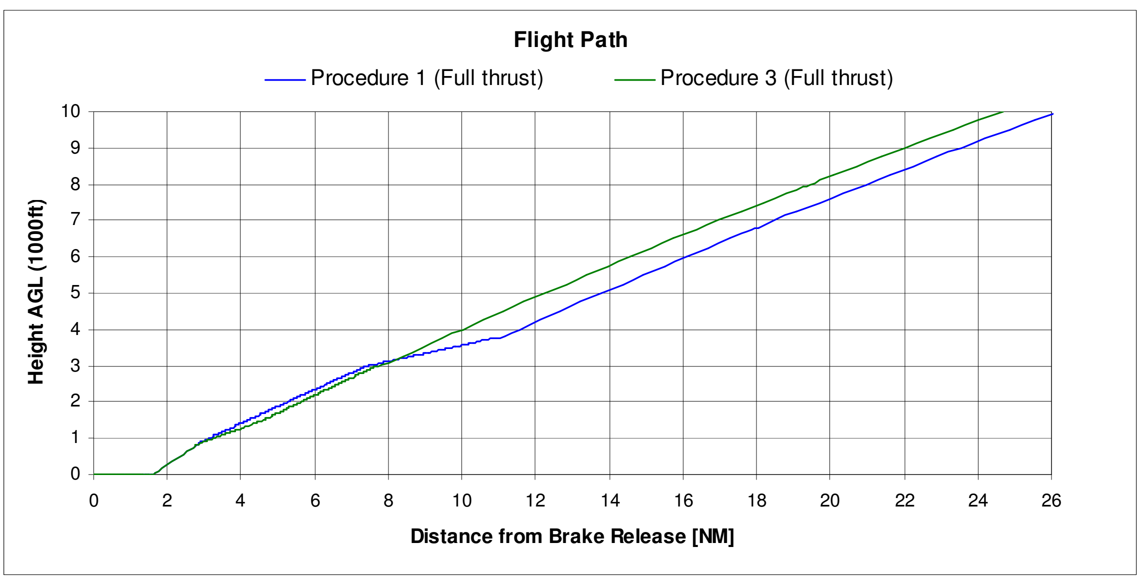
777-300/Trent 892

- **Full Power Thrust**
- **MTOW = 660,000lbs**



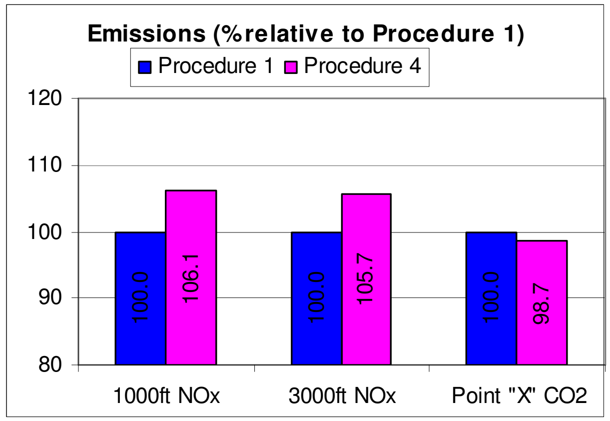
Comparison of Procedure 1 to Procedure 3



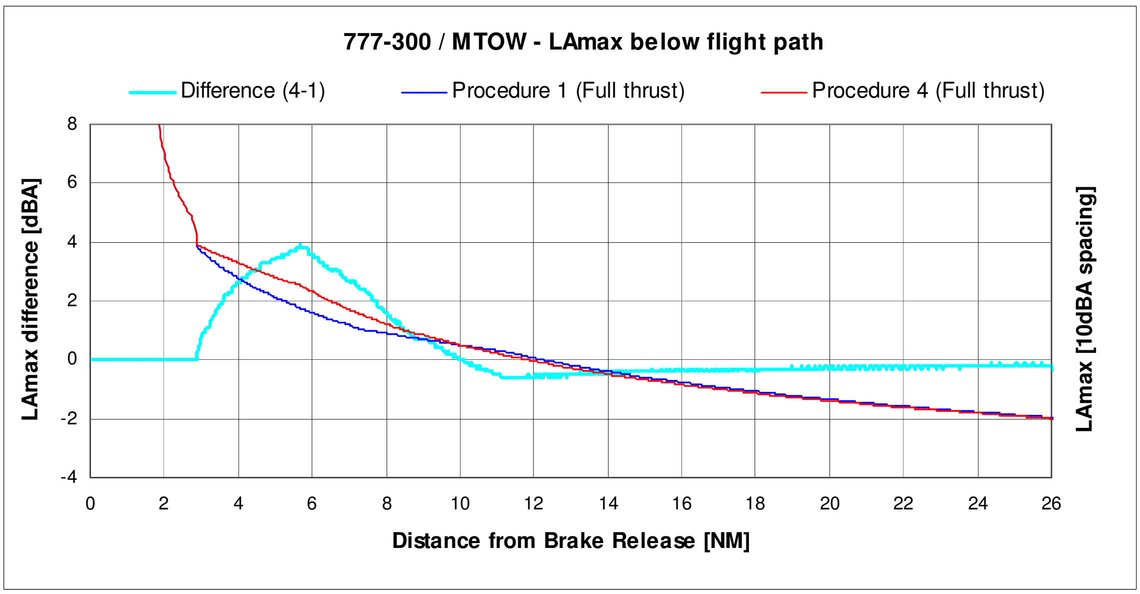


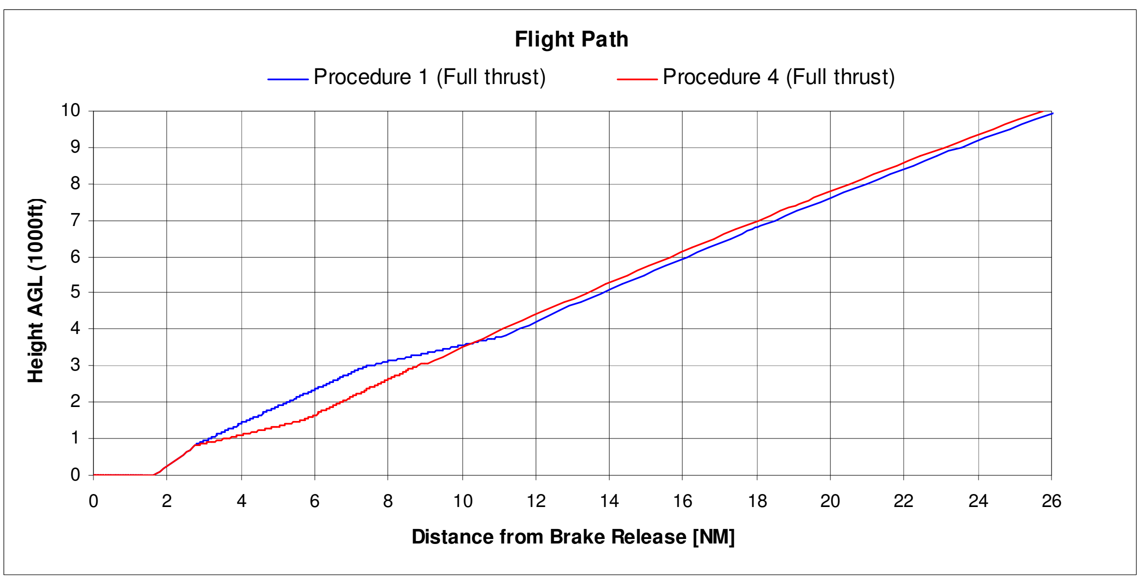
777-300/Trent 892

- **Full Power Thrust**
- **MTOW = 660,000lbs**



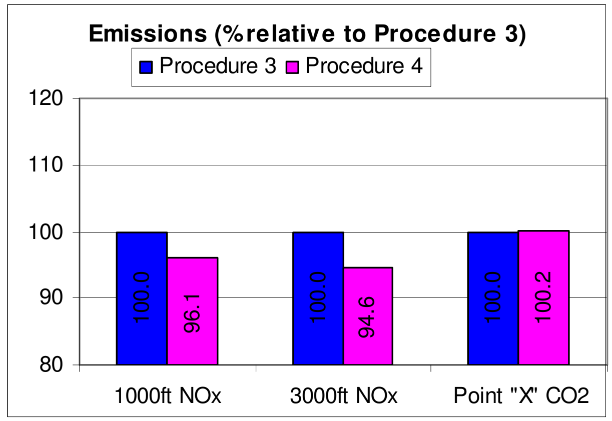
Comparison of Procedure 1 to Procedure 4



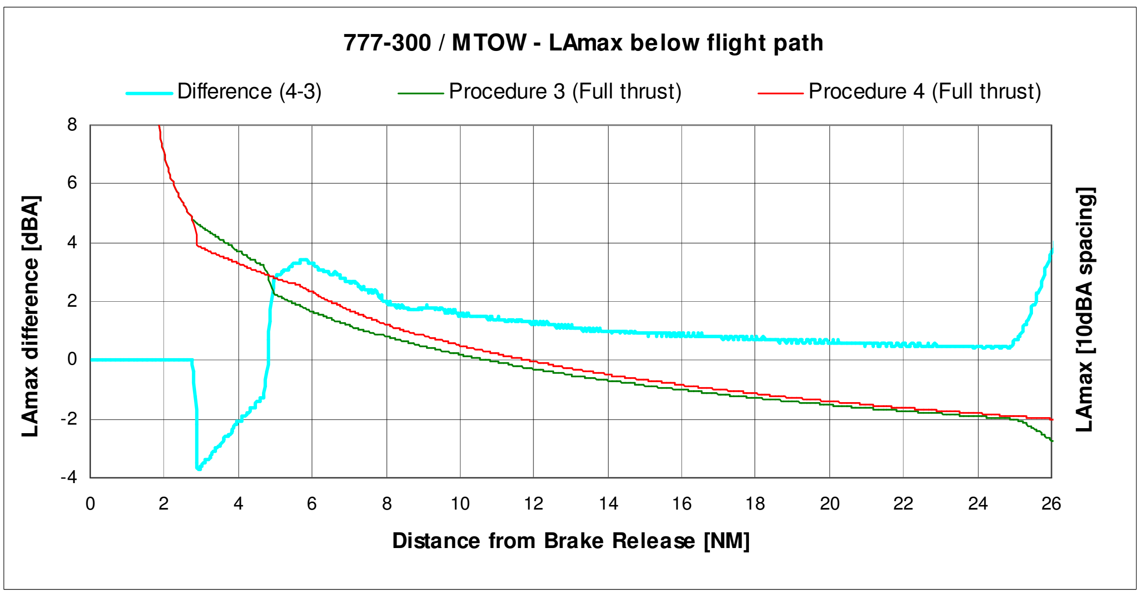


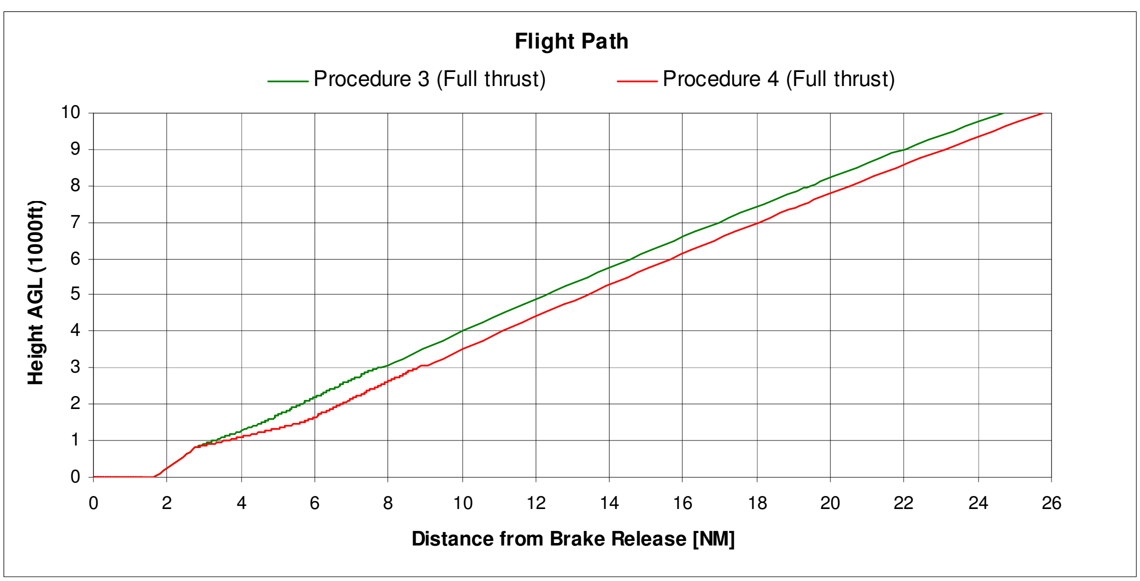
777-300/Trent 892

- **Full Power Thrust**
- **MTOW = 660,000lbs**



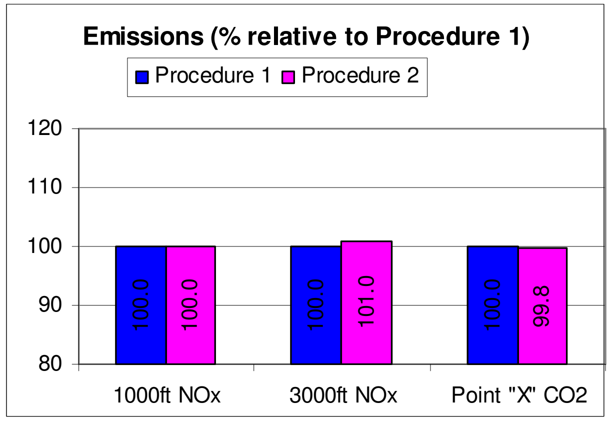
Comparison of Procedure 3 to Procedure 4



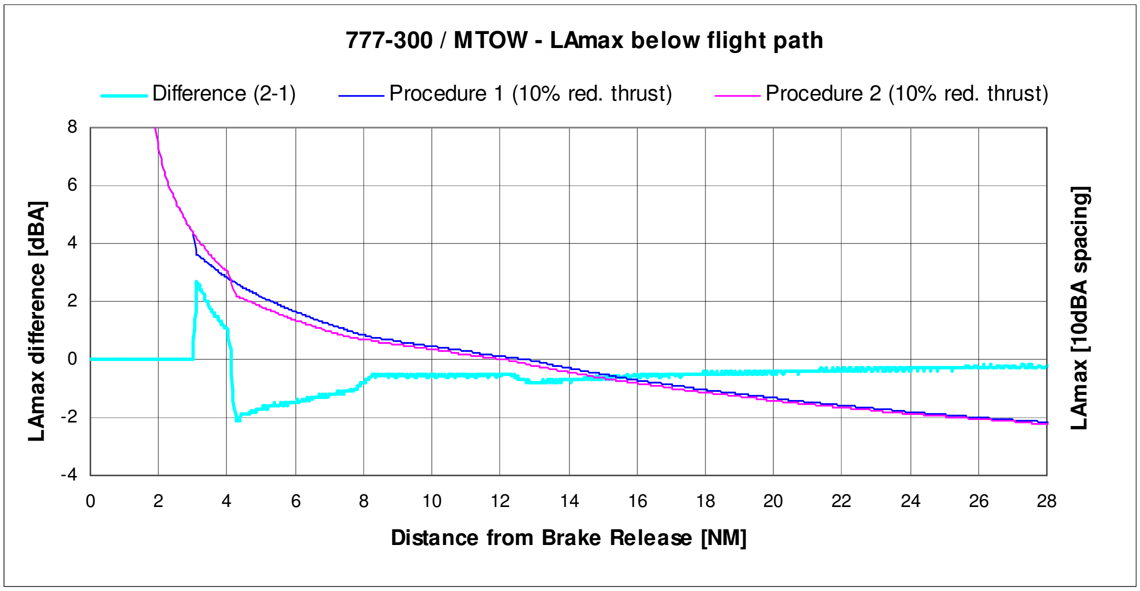


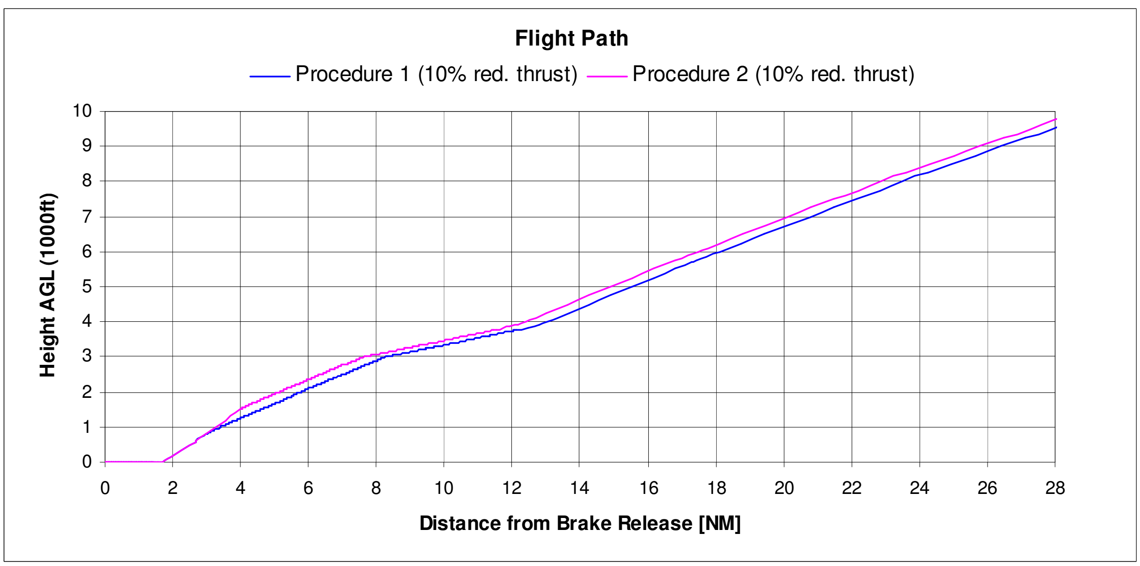
777-300/Trent 892

- **10% Reduced Thrust**
- **MTOW = 629,100lbs**



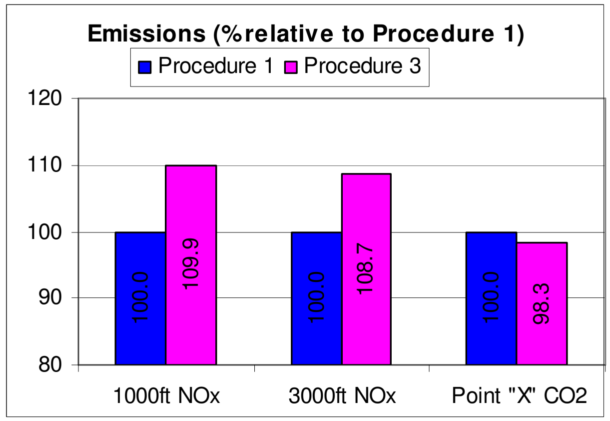
Comparison of Procedure 1 to Procedure 2



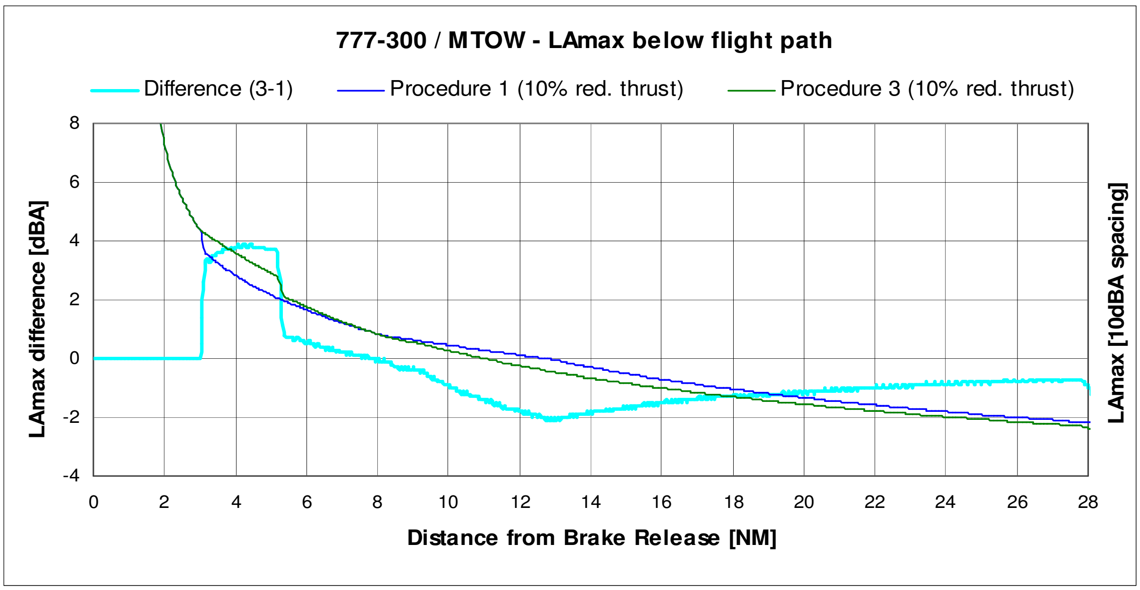


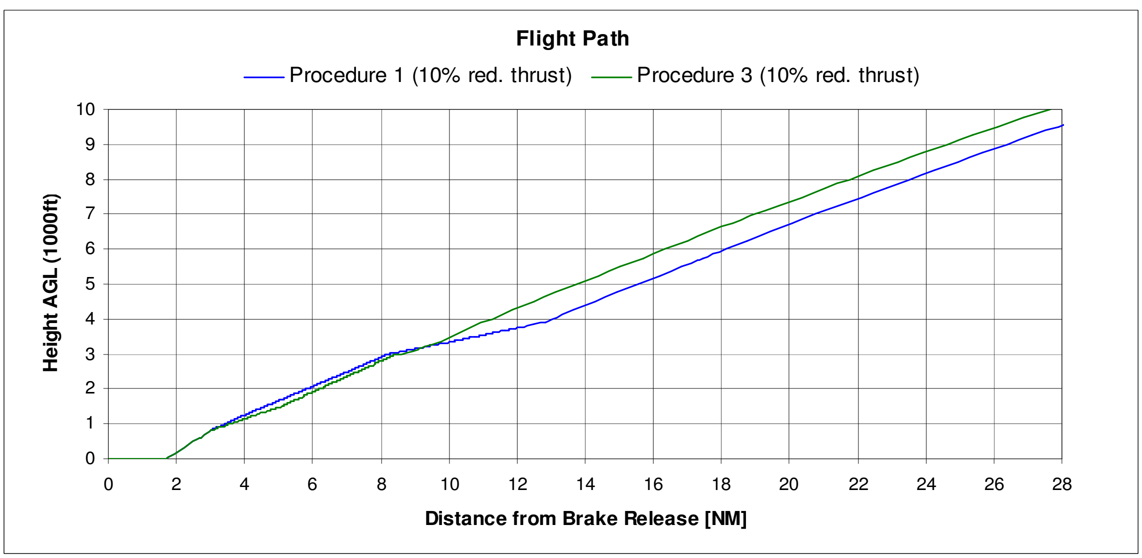
777-300/Trent 892

- **10% Reduced Thrust**
- **MTOW = 629,100lbs**



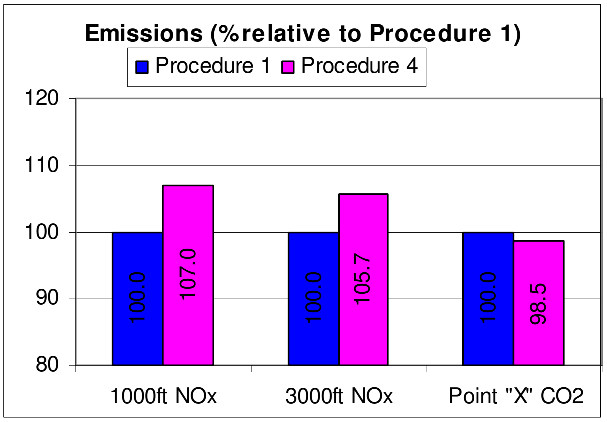
Comparison of Procedure 1 to Procedure 3



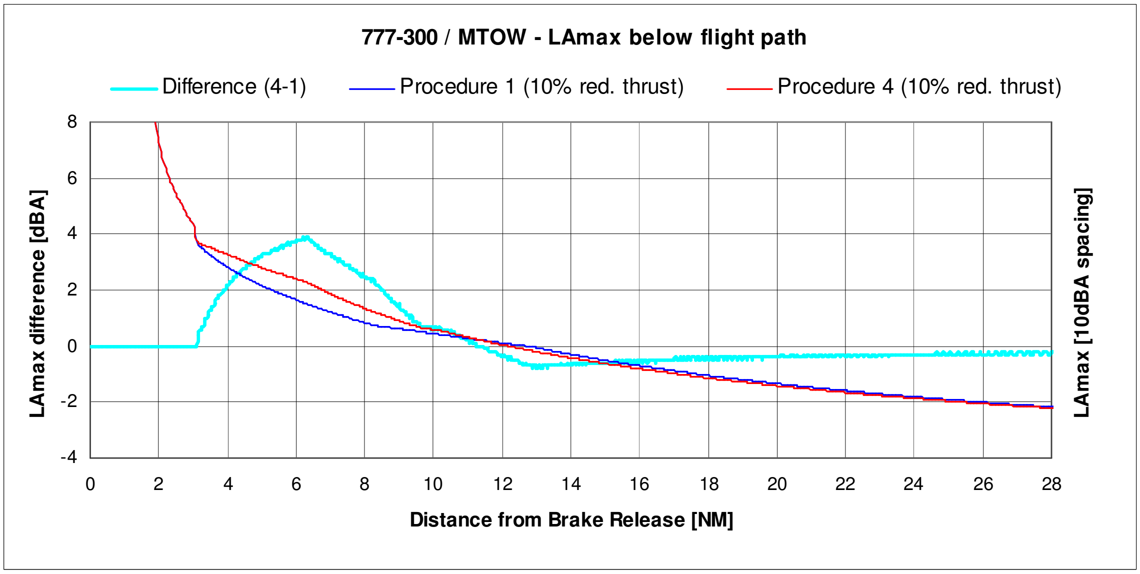


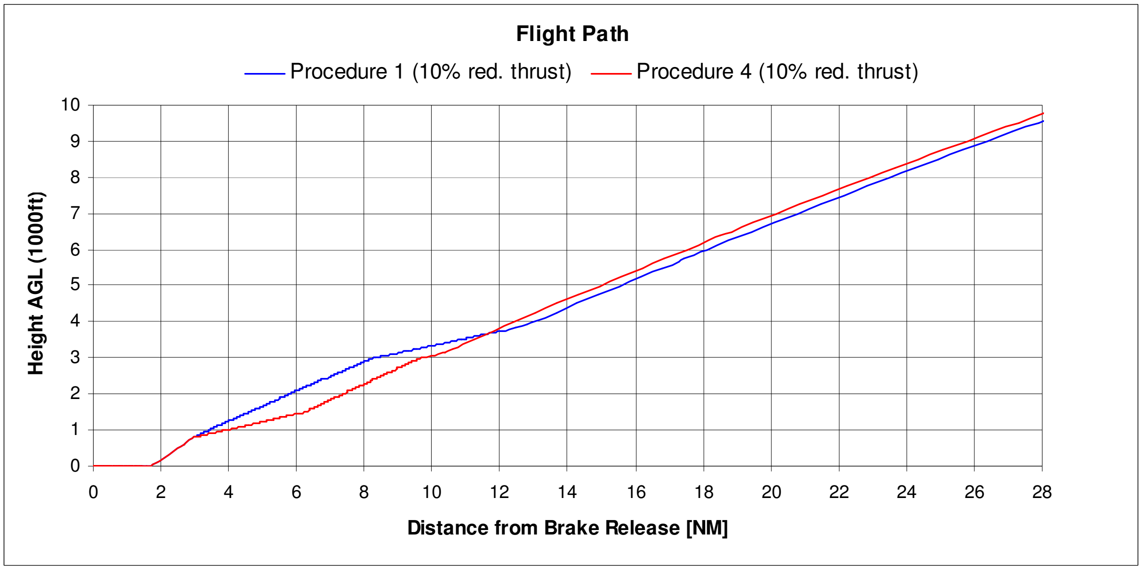
777-300/Trent 892

- **10% Reduced Thrust**
- **MTOW = 629,100lbs**



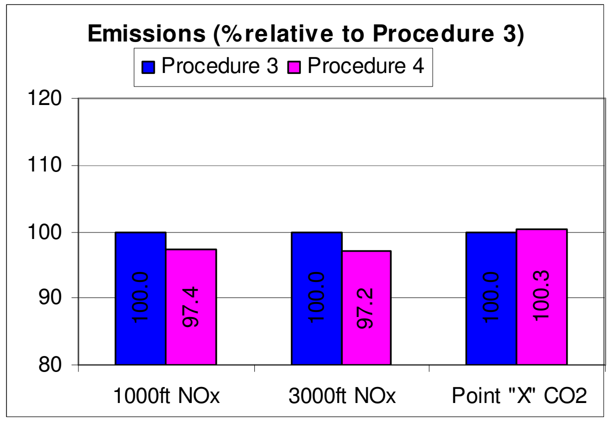
Comparison of Procedure 1 to Procedure 4



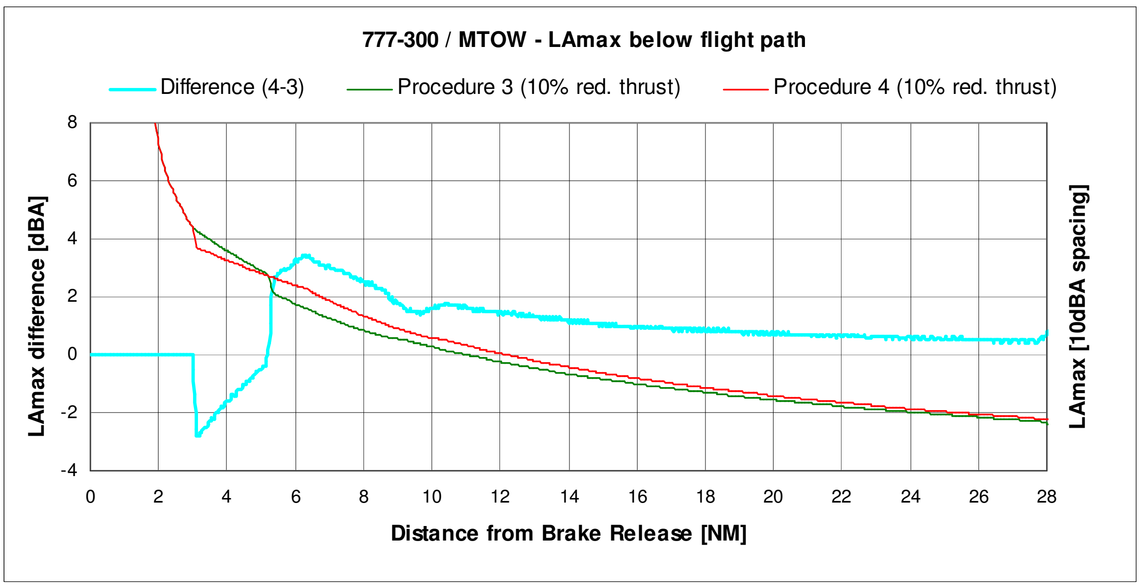


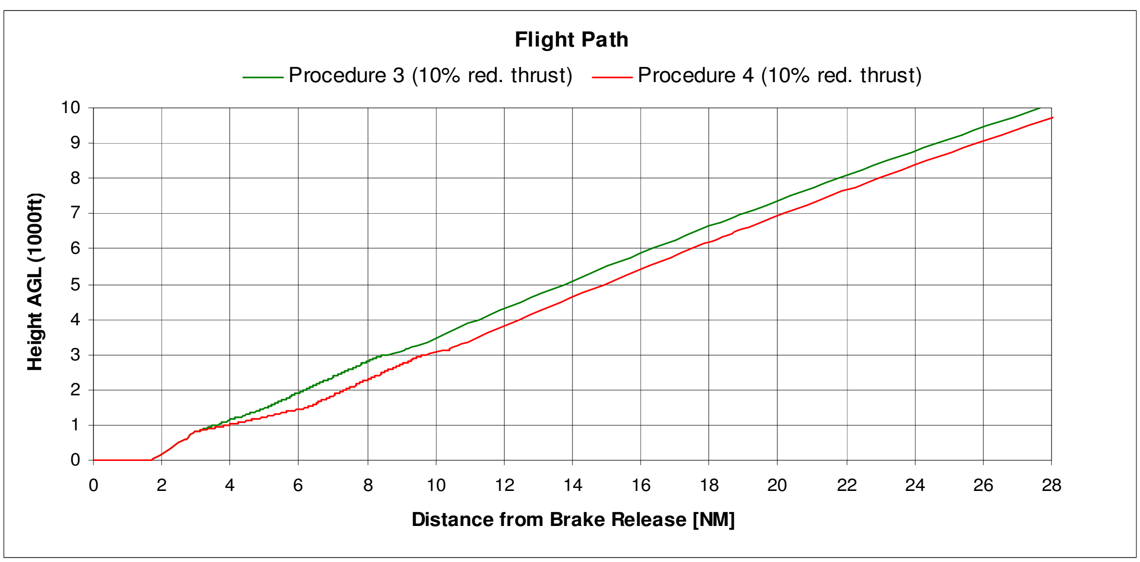
777-300/Trent 892

- **10% Reduced Thrust**
- **MTOW = 629,100lbs**



Comparison of Procedure 3 to Procedure 4





APPENDIX C: RESULTS BOMBARDIER

Aircraft Studied:

CRJ900ER, CF34-8C5

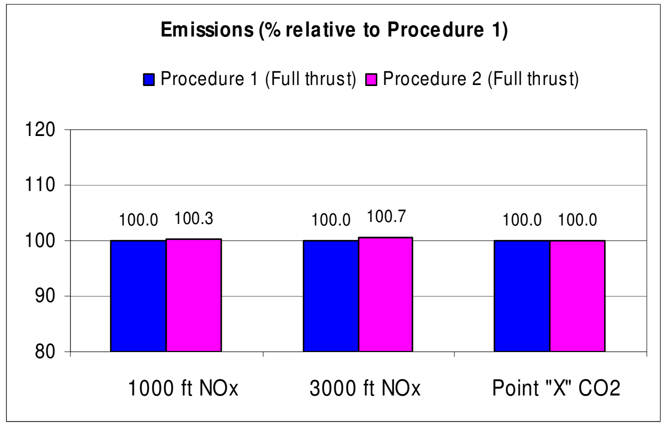
- Take-off in Flaps 8 configuration
- Initial climb at V_2+10 KIAS
- Common climb schedule from 10,000 ft AGL to Adjusted Top of Climb
- Adjusted Top of Climb: 35,000 ft AGL cruise altitude
- Thrust/weight cases:
    - Full thrust:
        - TOGA
        - MTOW=82,500 lbs
    - Reduced thrust:
        - 10% reduced thrust
        - TOW=74,034 lbs

Atmospheric Conditions:

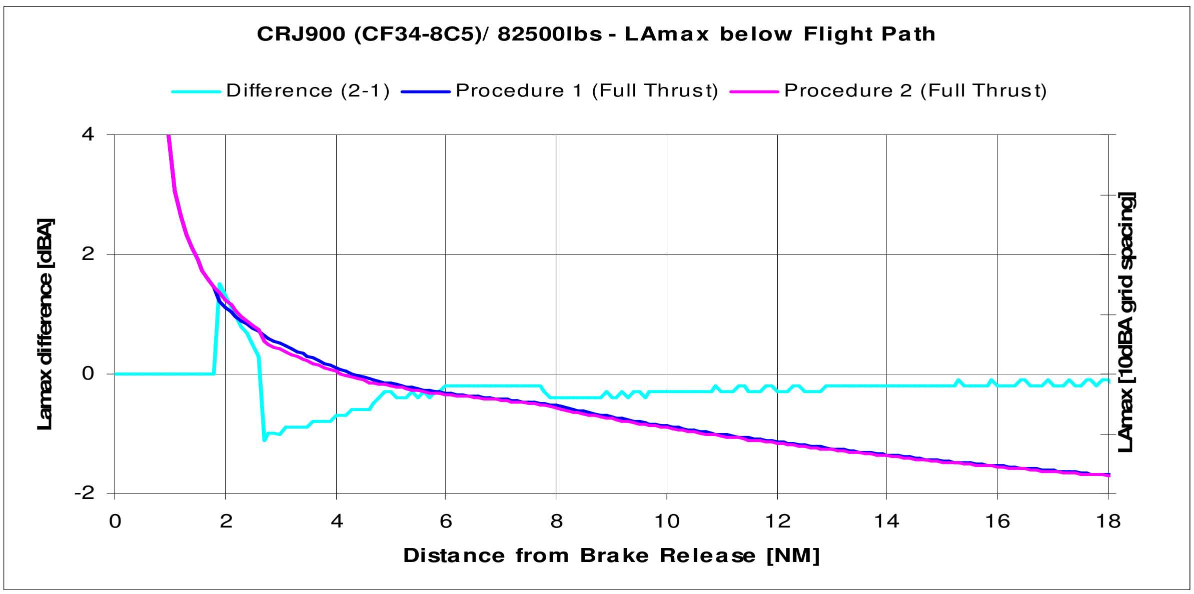
Temperature:	ISA
Relative Humidity:	70%
Wind:	zero
Elevation:	sea level

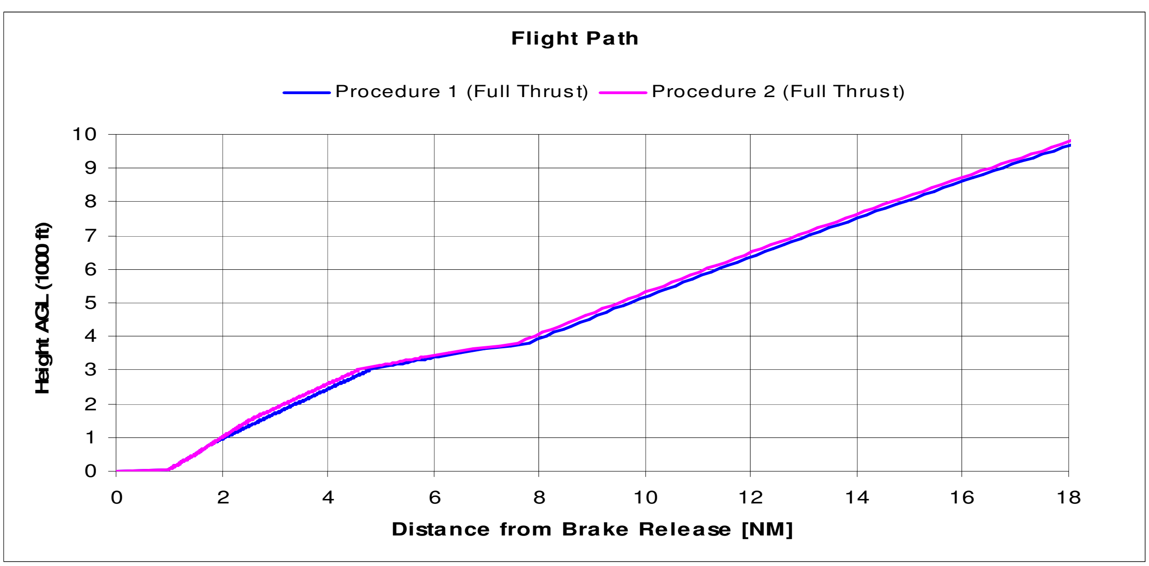
CRJ900ER, CF34-8C5

- **Full Thrust**
  - **TOGA**
  - **MTOW = 82,500 lbs**



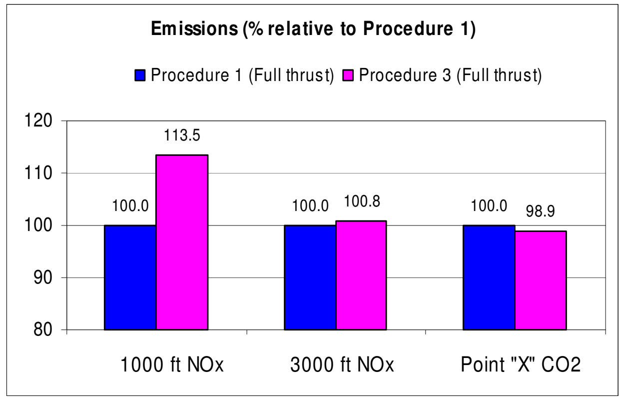
Comparison of Procedures 1 and 2



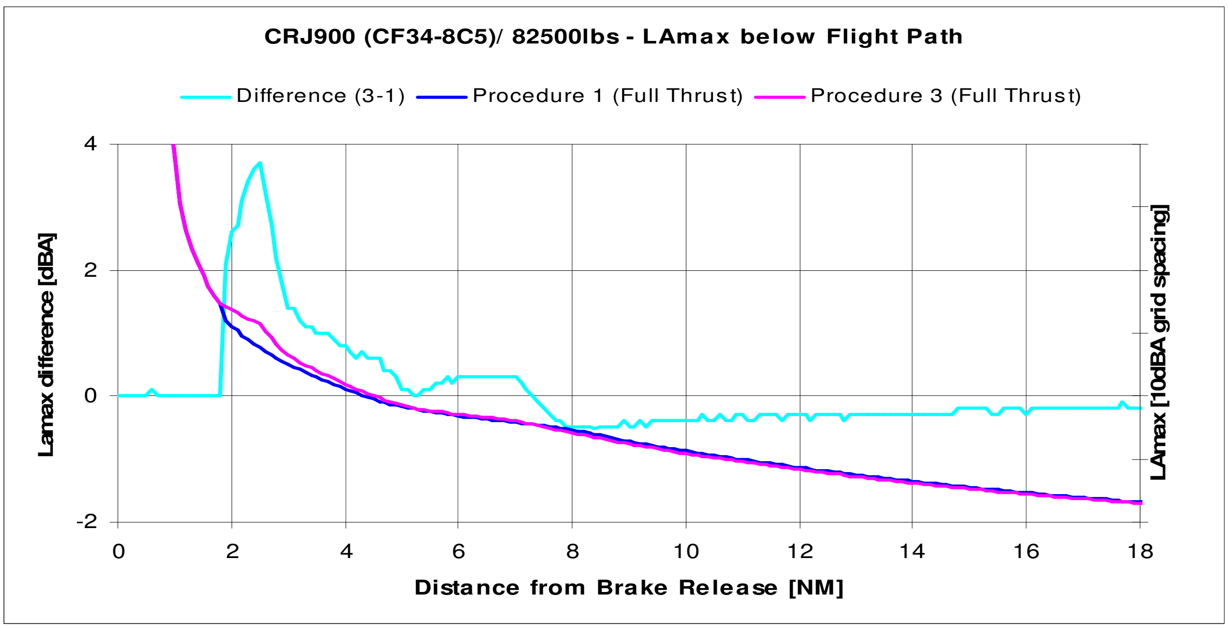


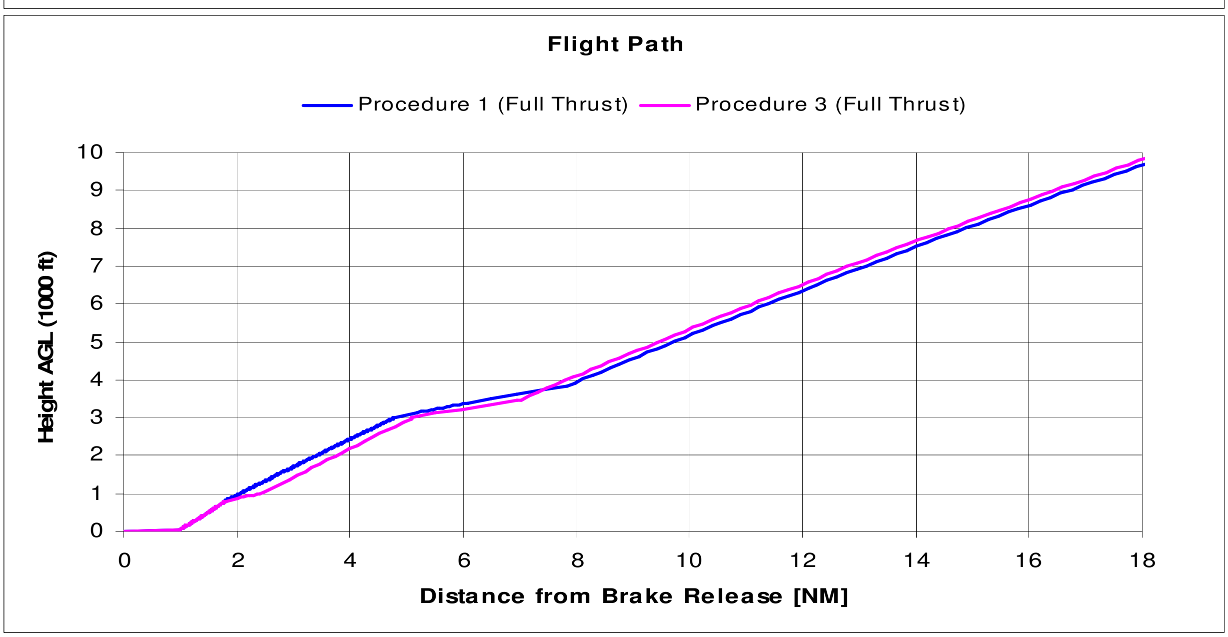
CRJ900ER, CF34-8C5

- **Full Thrust**
  - **TOGA**
  - **MTOW = 82,500 lbs**



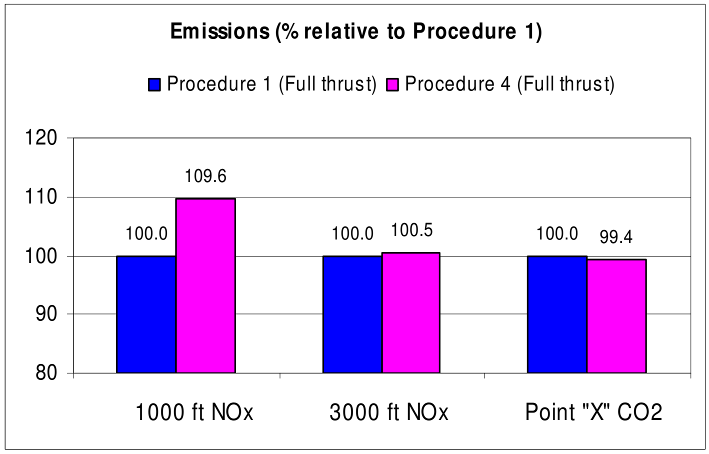
Comparison of Procedures 1 and 3



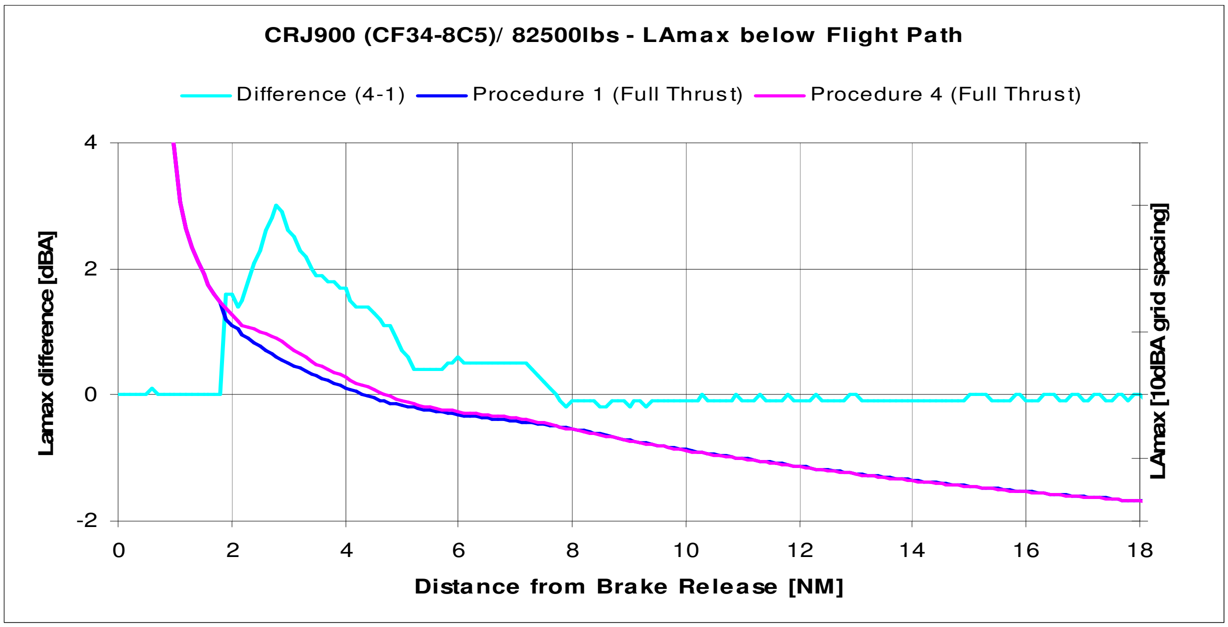


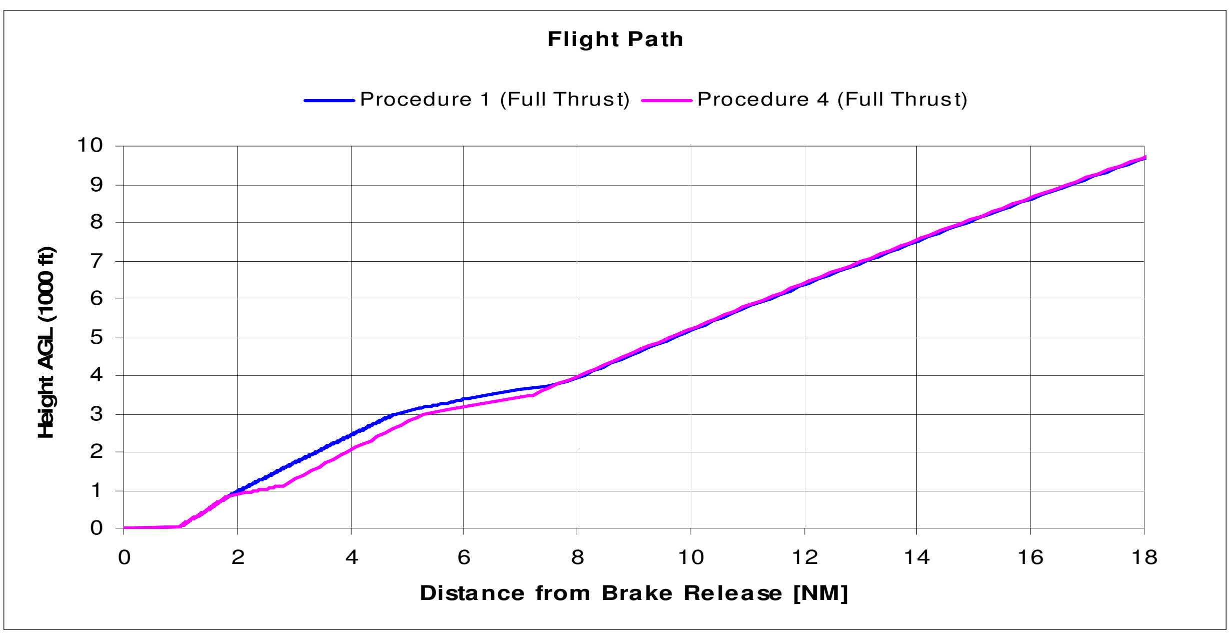
CRJ900ER, CF34-8C5

- **Full Thrust**
  - **TOGA**
  - **MTOW = 82,500 lbs**



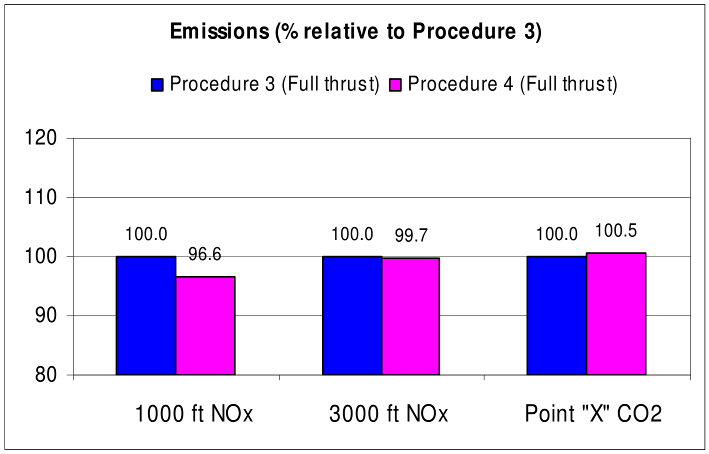
Comparison of Procedures 1 and 4



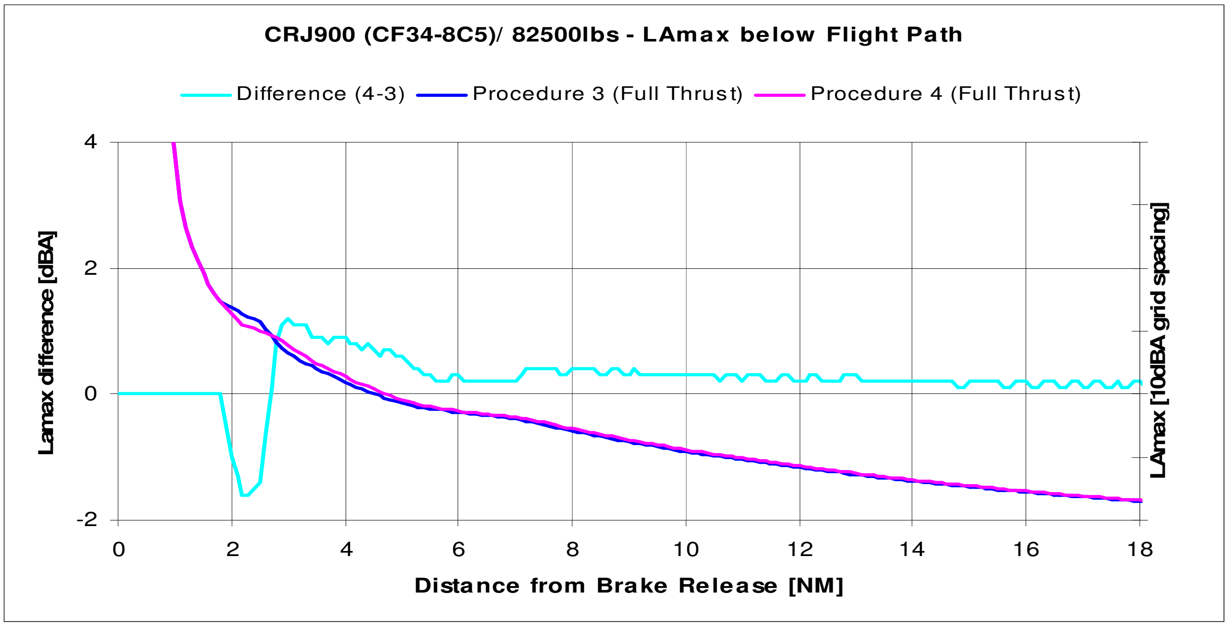


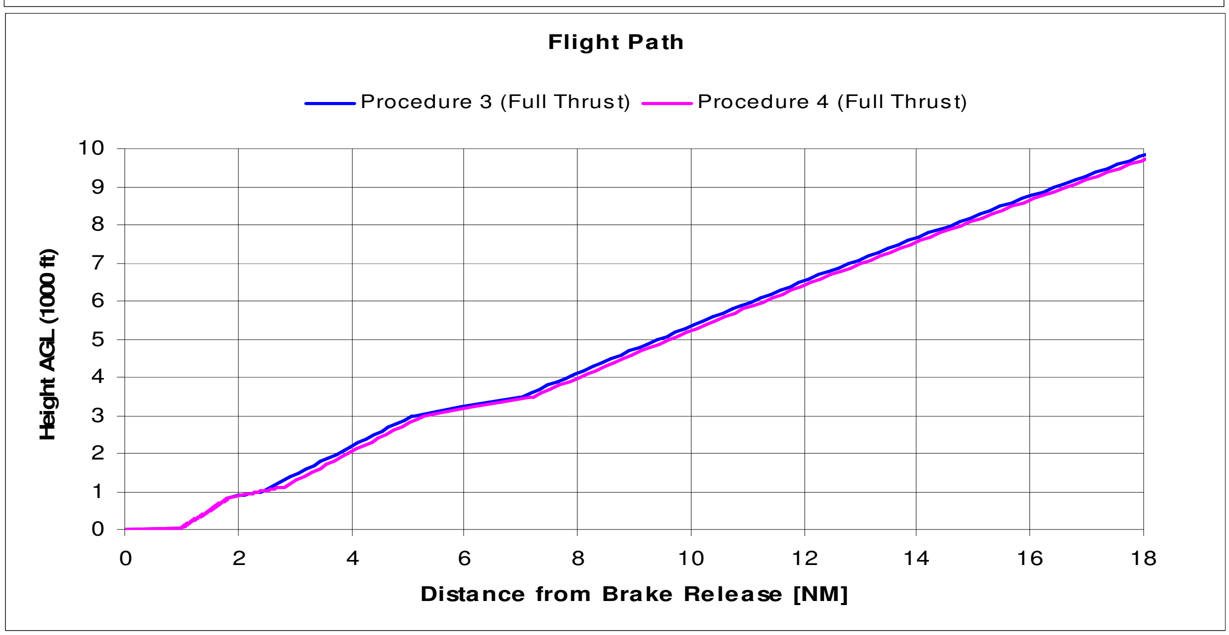
CRJ900ER, CF34-8C5

- **Full Thrust**
  - **TOGA**
  - **MTOW = 82,500 lbs**



Comparison of Procedures 3 and 4

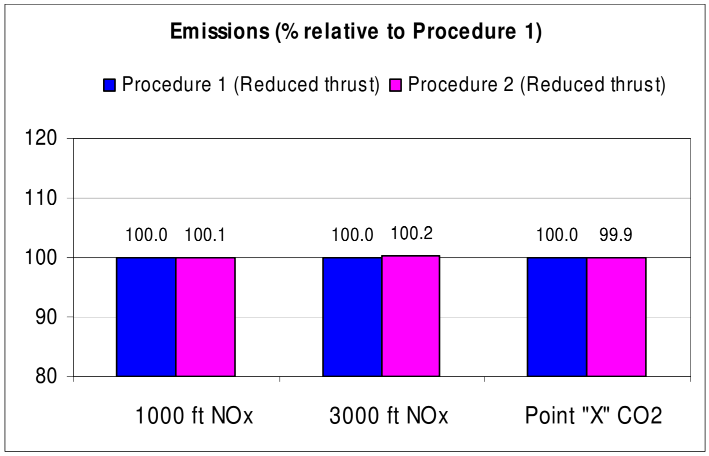


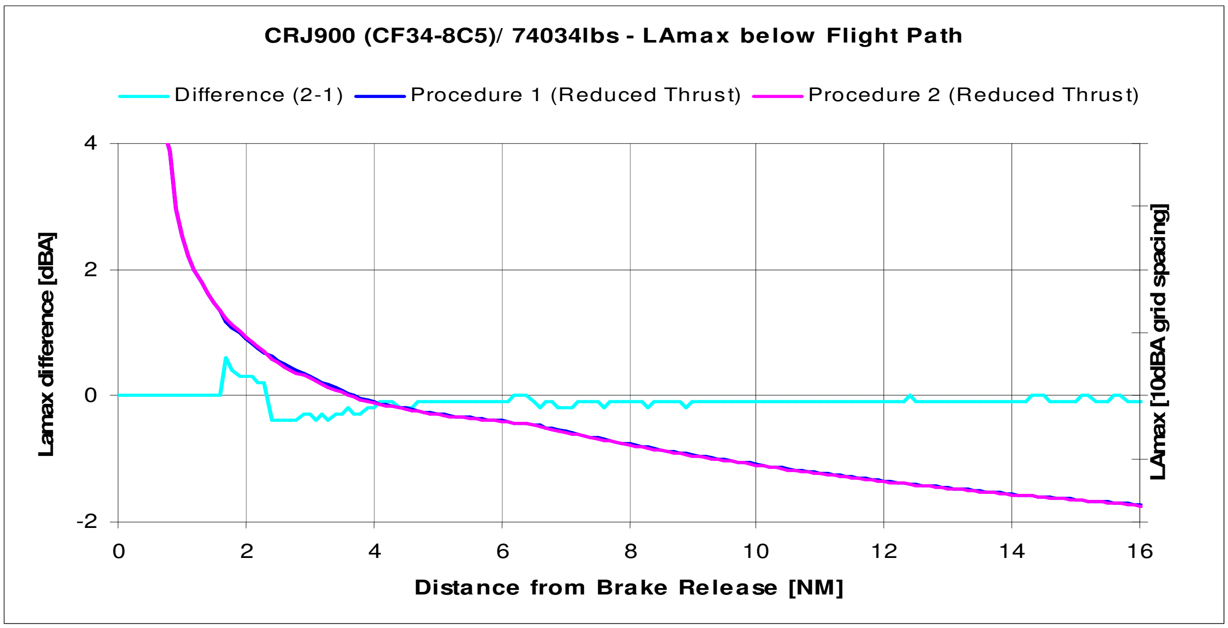


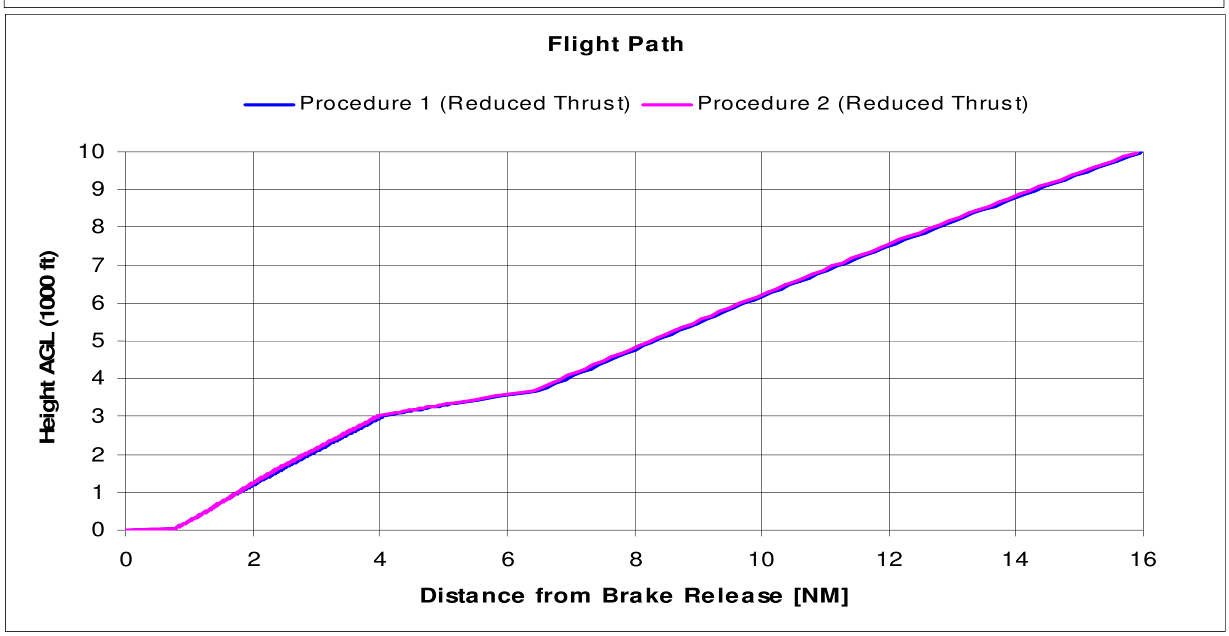
CRJ900ER, CF34-8C5

- **Reduced Thrust**
  - **10% Reduced Thrust**
  - **TOW = 74034 lbs**

Comparison of Procedures 1 and 2

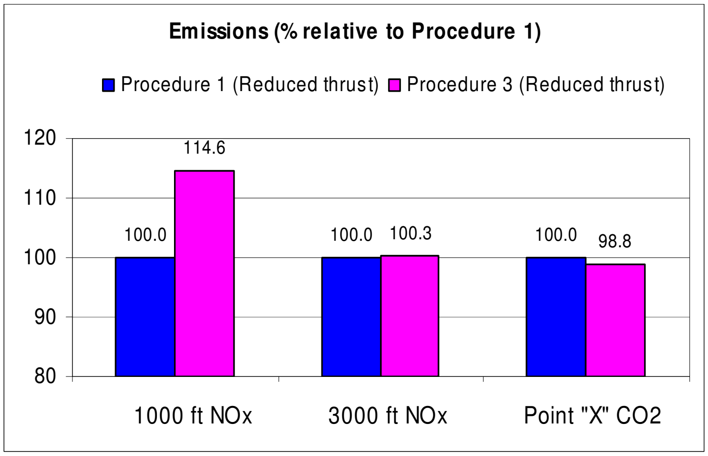




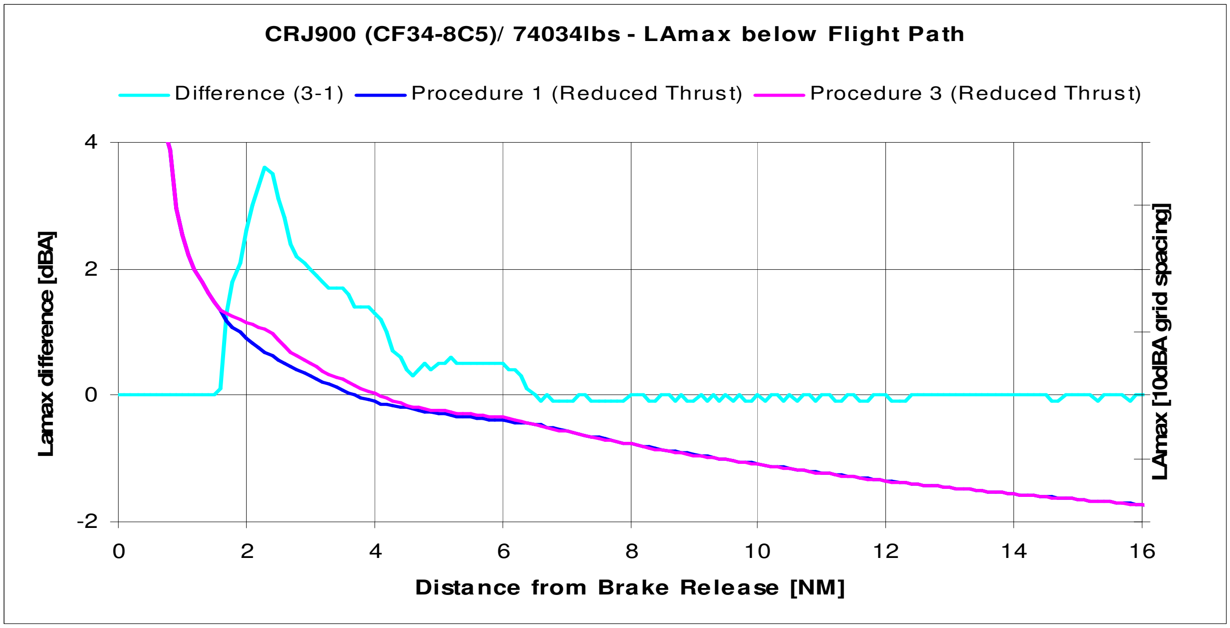


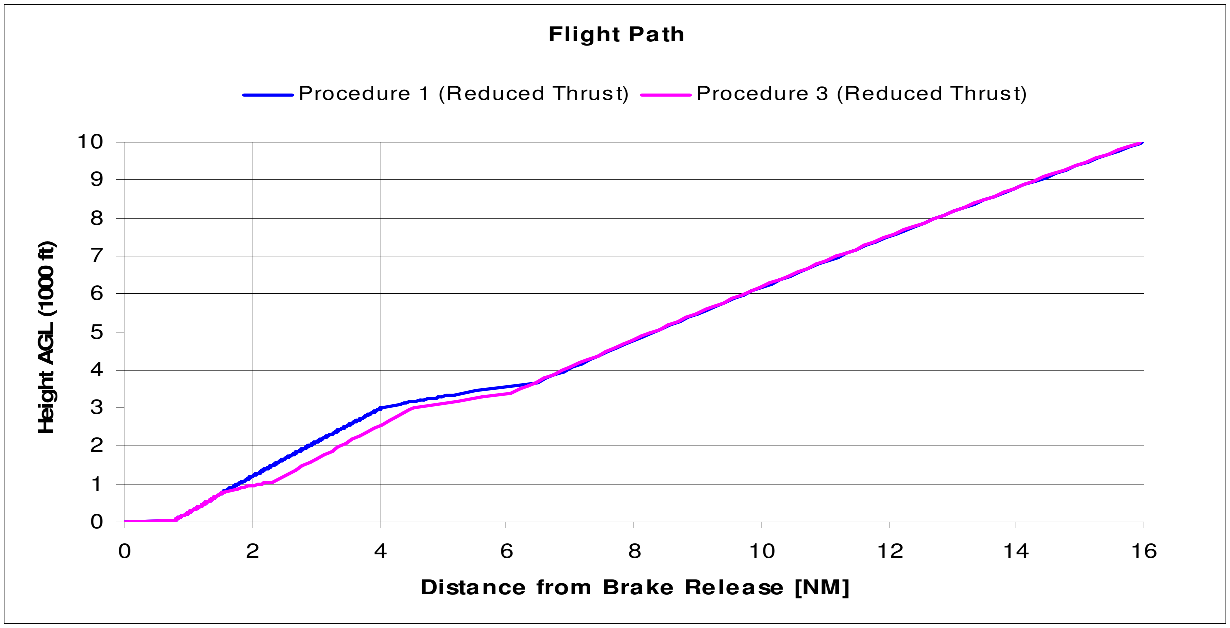
CRJ900ER, CF34-8C5

- **Reduced Thrust**
  - **10% Reduced Thrust**
  - **TOW = 74034 lbs**



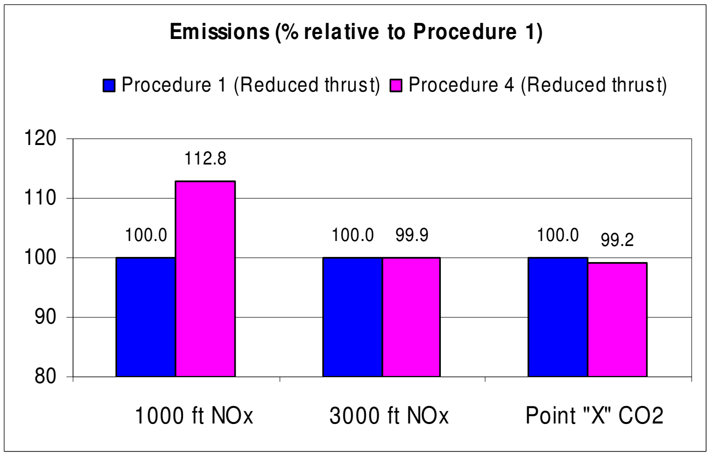
Comparison of Procedures 1 and 3



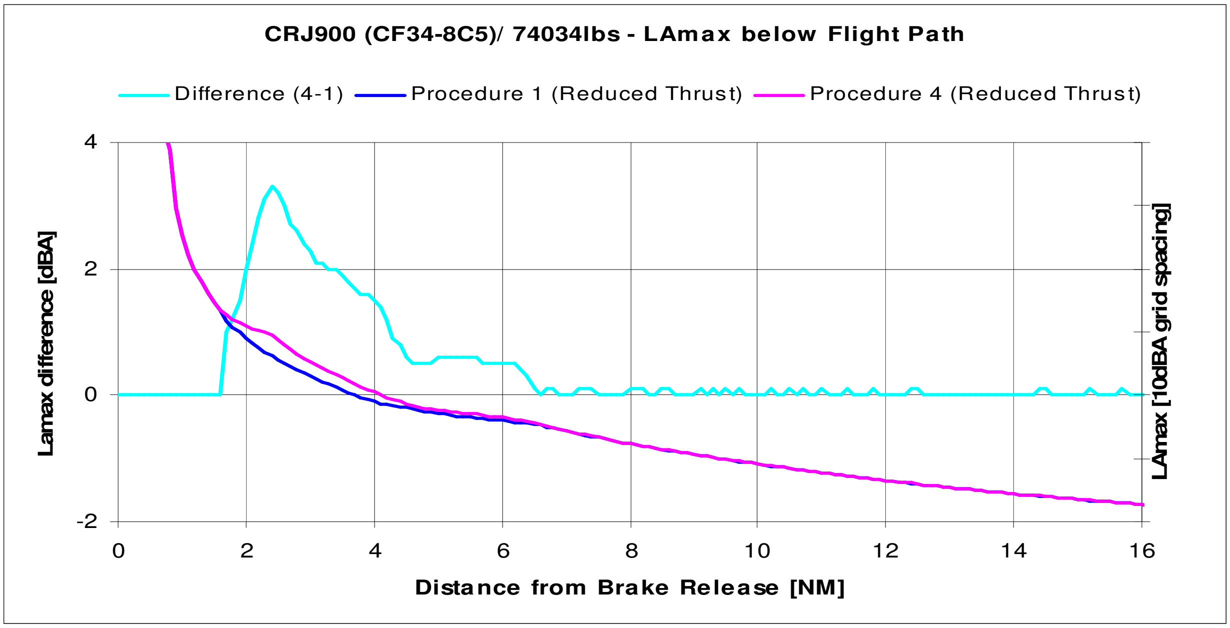


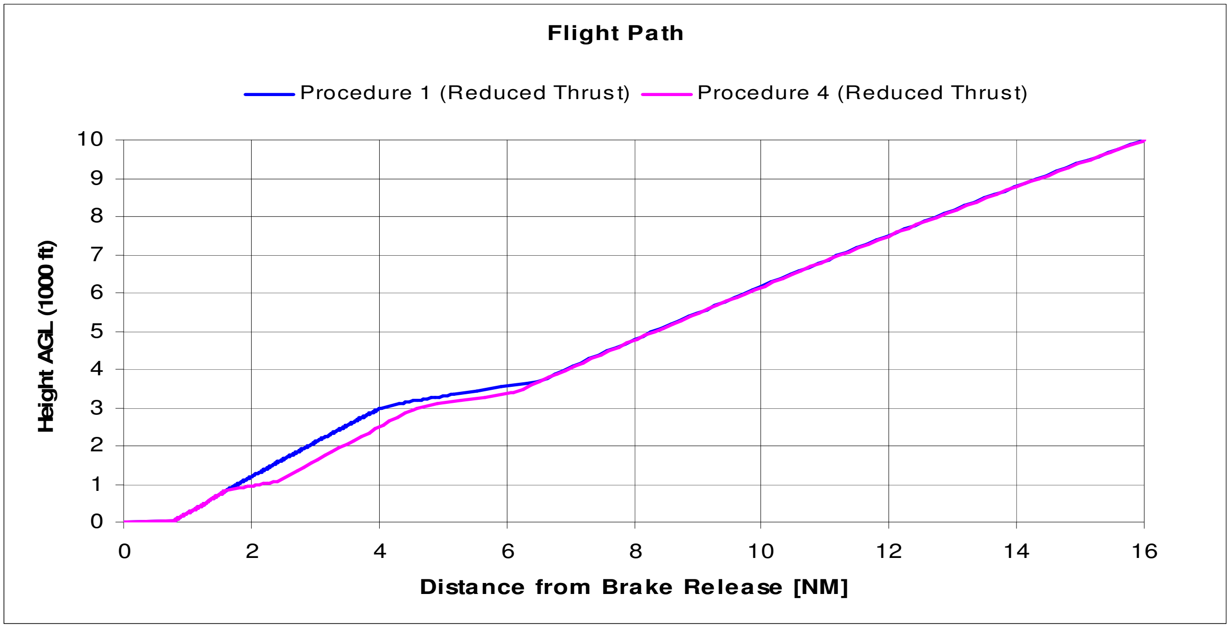
CRJ900ER, CF34-8C5

- **Reduced Thrust**
  - **10% Reduced Thrust**
  - **TOW = 74034 lbs**



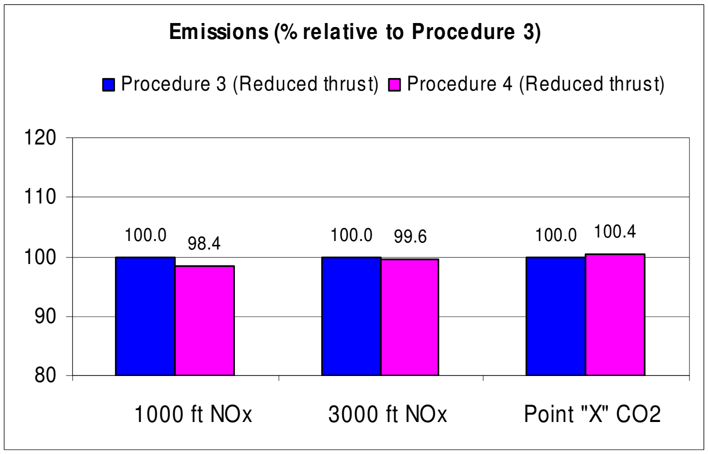
Comparison of Procedures 1 and 4





CRJ900ER, CF34-8C5

- **Reduced Thrust**
  - **10% Reduced Thrust**
  - **TOW = 74034 lbs**



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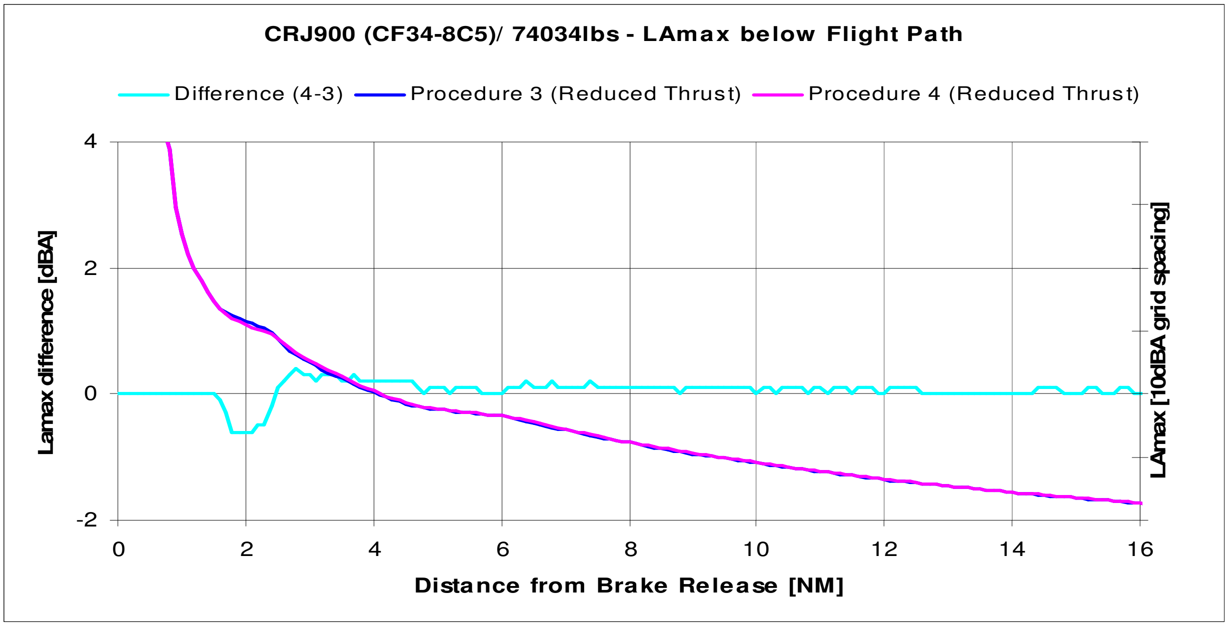
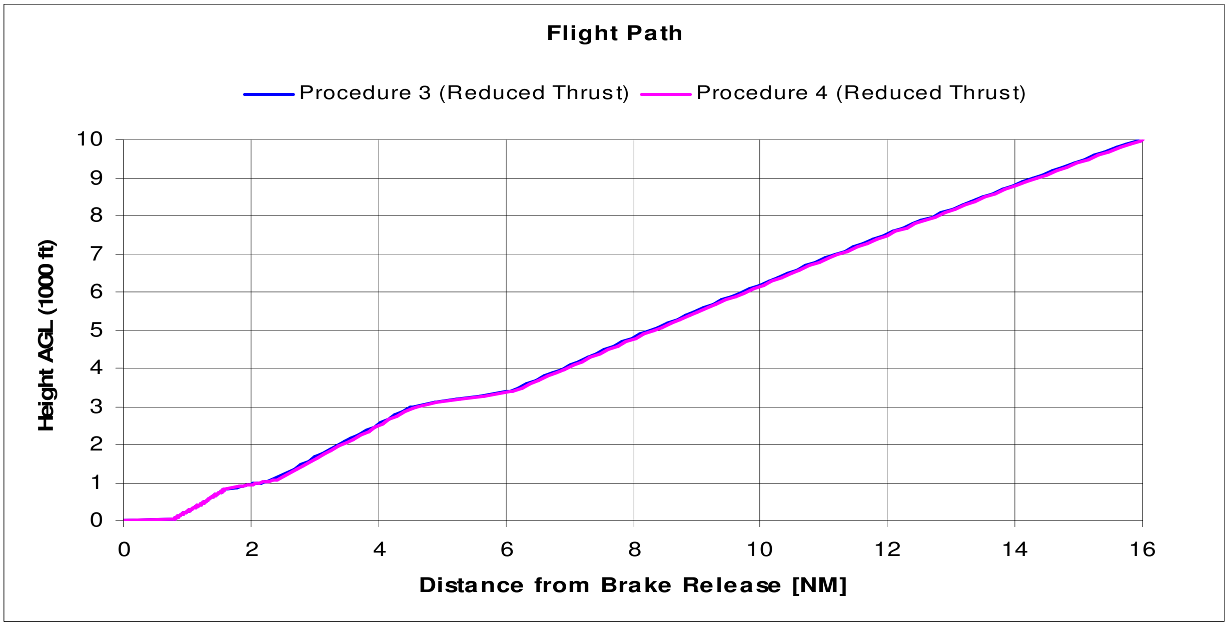




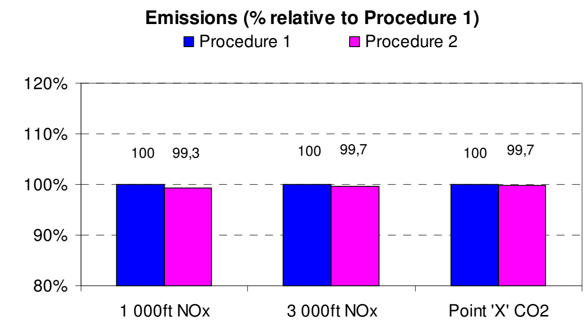
APPENDIX D: RESULTS DASSAULT

Aircraft Studied

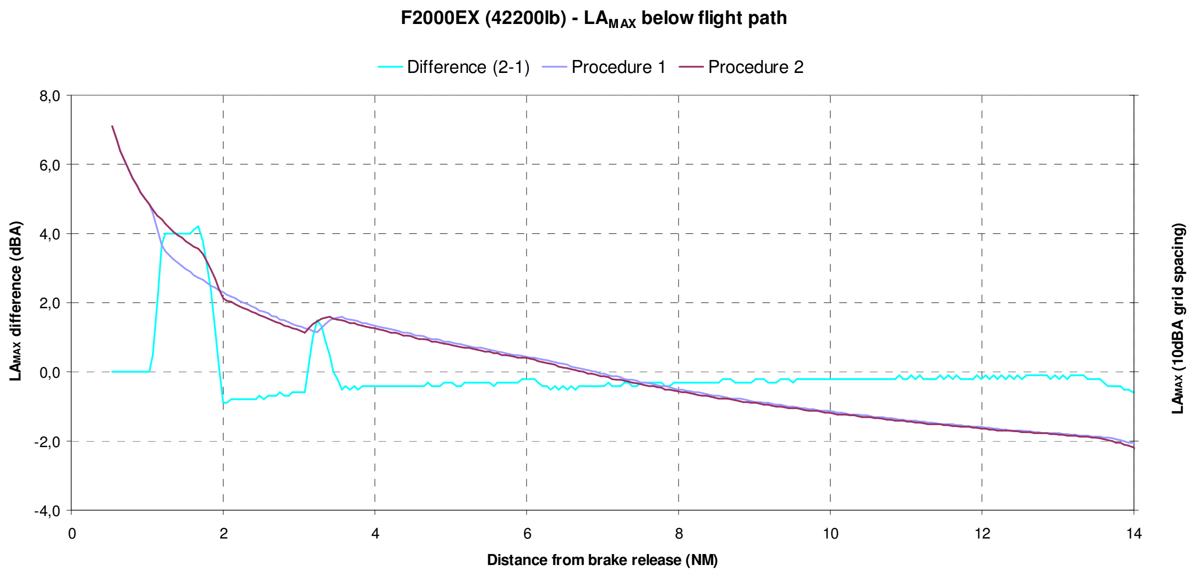
FALCON 2000EX, PW308C
- Takeoff in SF2
- Climb at V2 + 15 kt IAS
- Full thrust (MTO)
- MTOW (42200lb)
- Cutback to MTO - 13%

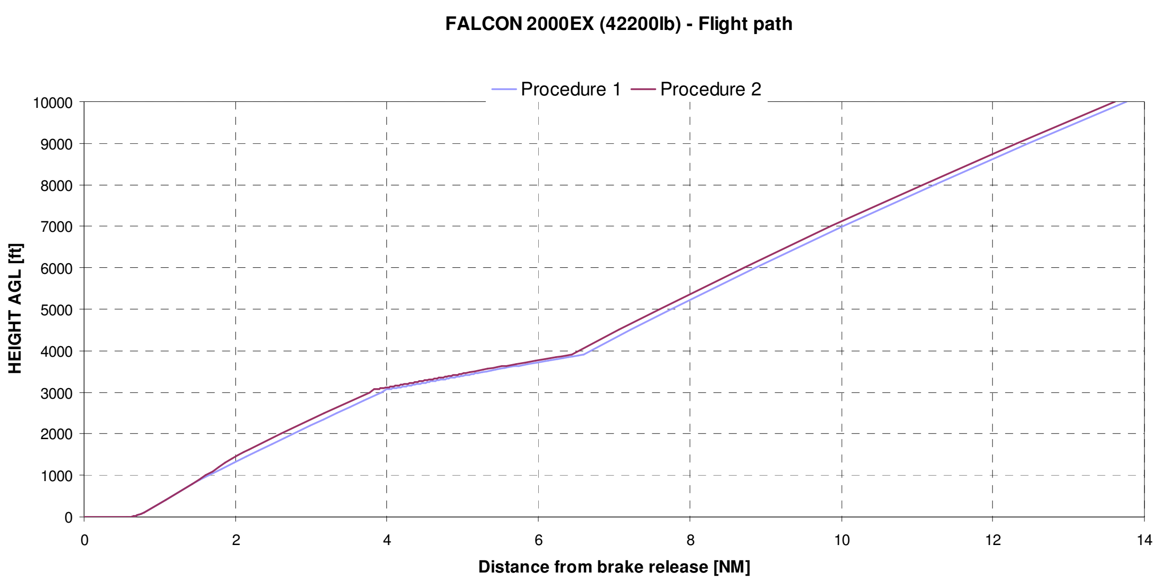
FALCON 2000EX, PW308C

- **Full thrust (MTO)**
  - **TOW = 42200lb**



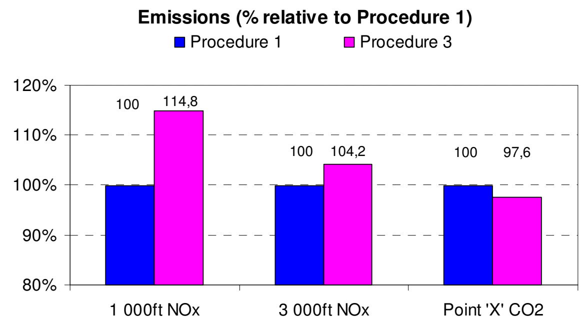
Comparison of Procedures 1 and 2



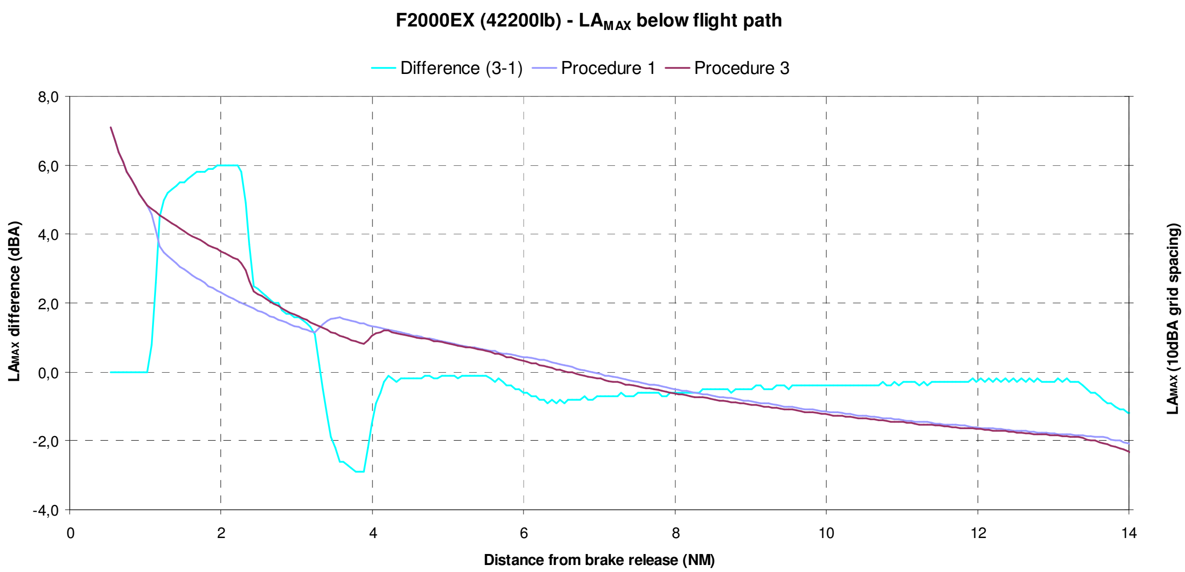


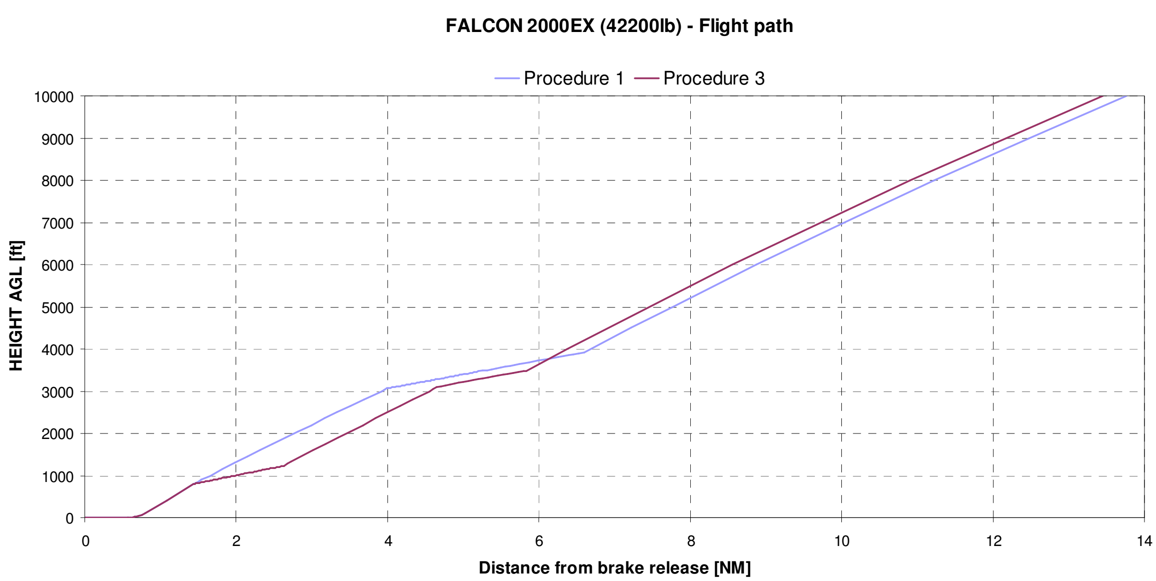
FALCON 2000EX, PW308C

- **Full thrust (MTO)**
  - **TOW = 42200lb**



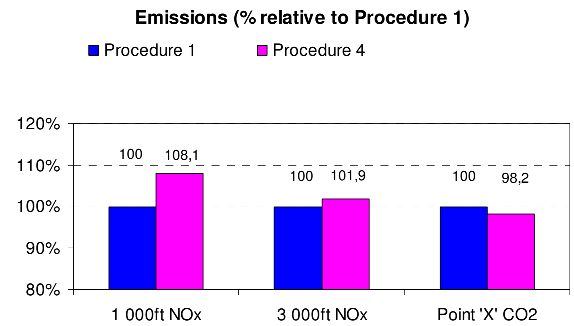
Comparison of Procedures 1 and 3



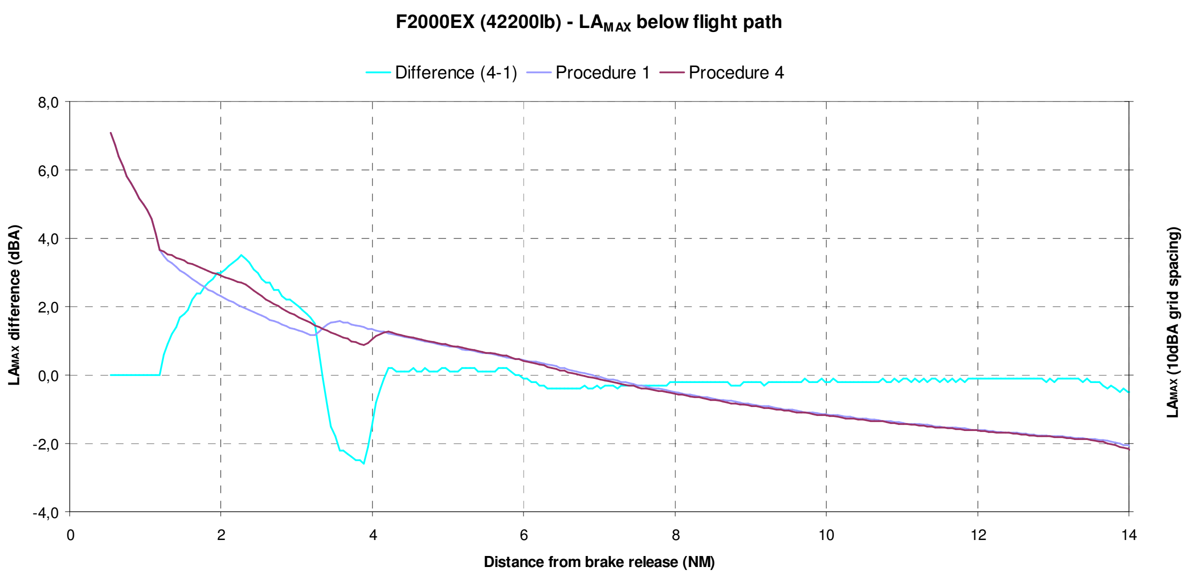


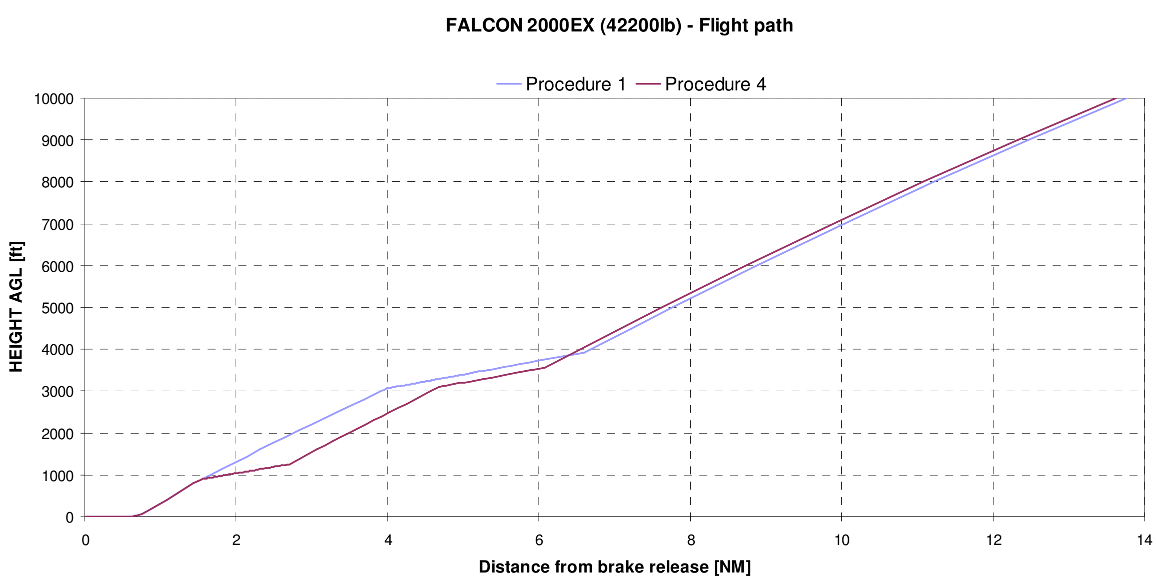
FALCON 2000EX, PW308C

- **Full thrust (MTO)**
  - **TOW = 42200lb**



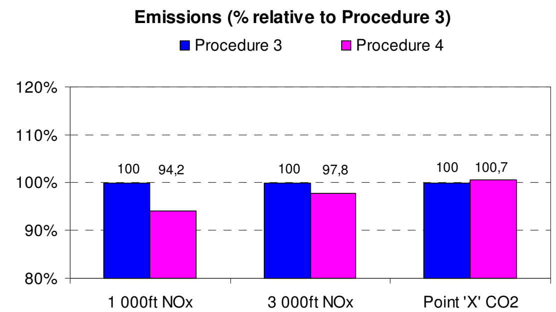
Comparison of Procedures 1 and 4



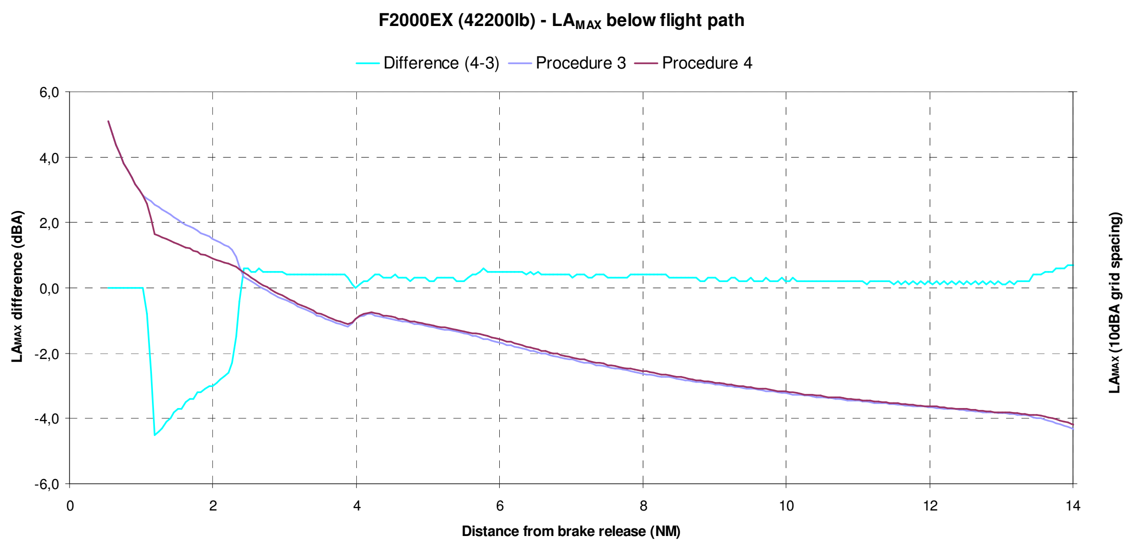


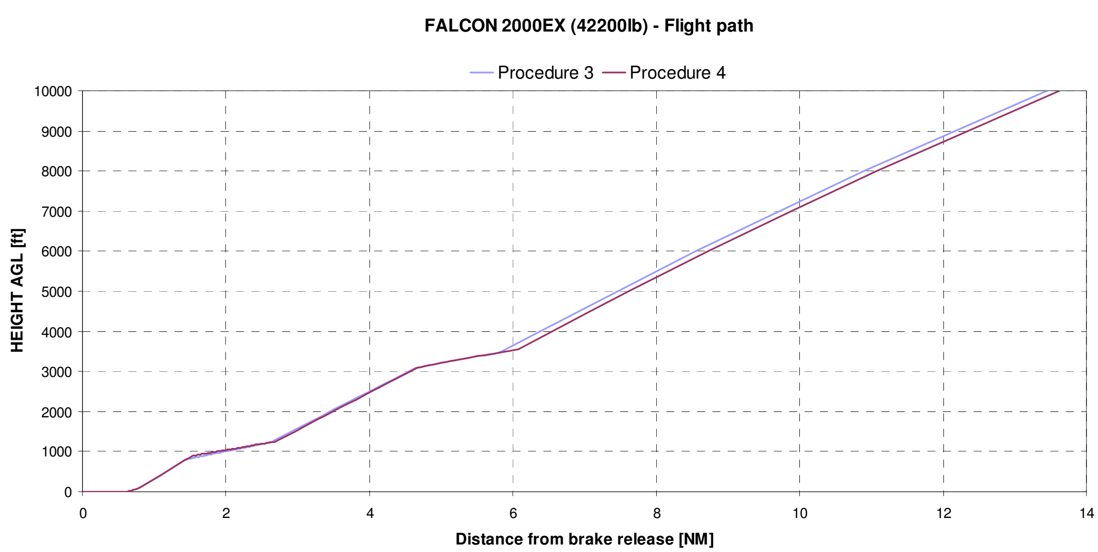
FALCON 2000EX, PW308C

- **Full thrust (MTO)**
  - **TOW = 42200lb**



Comparison of Procedures 3 and 4





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Agenda Item 4: Future work

4.1 INTRODUCTION

4.1.1 It was noted that, in defining the new work programme, special attention needed to be given to the resources available to develop the work, the priority and relevance of the tasks and a clear definition of the end product envisaged.

4.1.2 It was expected that tasks proposed be focussed on a specific end result. An example of an end product would be the development of guidance/information material for an ICAO publication.

4.2 PREPARATION OF THE WORK PROGRAMME

4.2.1 A general proposed work programme had been compiled by the Secretariat taking into account initial input from WG rapporteurs. Also presented was a list of items proposed by ICAO and CAEP Members and Observers. Once approved by CAEP, these proposals would form the work programme leading to CAEP/8 to be submitted to the Council for consideration as part of the CAEP/7 Report. The proposals had been separated as follows:

a) Modelling and Database Development — tasks proposed by WG2 pertaining to the development of models and databases in support of CAEP/8 (and beyond) activities. These tasks were intended to improve the economics and technical analytical ability of CAEP;

b) Noise — tasks proposed by WG1 and WG2 (and others) related to noise technology, certification of aircraft, land-use planning and management, noise abatement operational procedures and noise modelling. All of these activities were aimed at reducing the effects of noise;

c) Emissions — tasks proposed by WG2 and WG3 (and others) related to emissions technology, aircraft engine certification, operational measures, and emissions modelling. All of these activities were aimed at reducing the effects of emissions;

d) Forecasting and Economic Analysis Support Group (FESG) — tasks proposed by FESG consisting of coordination with other CAEP Working Groups, particularly Working Group 2, regarding modelling assumptions, databases and methodologies. As the work of the FESG depended on the overall CAEP work programme, some tasks might be added as appropriate if the need arose;

e) Proposals from ICAO — tasks proposed by ICAO including items from the Secretariat and the Council; and

f) Proposals from Member States and Observers — new tasks proposed in the field of noise, emissions, modelling, forecasting and market-based measures.

4.2.2 Ensuring that the necessary resources and collaborative support were available to continue to improve the modelling tools used by CAEP for the purpose of assessments was paramount.

The future work for model and database development, which represents work items received from WG2 and WG3 in collaboration with the FESG, was shown in the first group (para. 4.2.1 a) above). This also contained a list of some models and databases currently used in CAEP and others were projected for potential use.

4.2.3 CAEP needed to develop a process that would better enable enhancement of these modelling activities to improve its ability to deal with aviation environmental issues in several areas and to respond to Assembly requests. The general guidelines for future work on models and databases were to:

a) further develop and maintain the models and databases endorsed by ICAO and used to assess the environmental impact of aviation and the impact of environmental policy on aviation; and

b) explore further development of the models and the possibility of better integrating the ICAO-agreed models and/or databases used, or expected to be used, in environmental analysis;

4.2.4 **Work Programme arising from the ICAO Assembly**

4.2.4.1 Many work items in the CAEP work programme had their origins in Assembly Resolutions. Some of them were requests of a permanent nature and required continuous action from CAEP. The following work items emanating from the Thirty-fifth Session of the ICAO Assembly, in Resolution A35-5, were in this category:

a) a request to the Council to regularly assess the present and future impact of aircraft noise and aircraft engine emissions and to continue to develop tools for this purpose;

b) to assess continuously the evolution of the impact of aircraft noise, ensuring that the guidance on the balanced approach in Doc 9829 is current and responsive to the requirements of States, and to promote the use of the balanced approach, for example, through workshops;

c) to ensure that the guidance on land-use in the Airport Planning Manual (Doc 9184) is current and responsive to the requirements of States and to consider what steps might be taken to promote land-use management, particularly in those parts of the world where the opportunity may exist to avoid aircraft noise problems in the future;

d) to continue to cooperate closely with the IPCC and other organizations involved in the definition of aviation's contribution to environmental problems in the atmosphere, and with organizations involved in policy-making in this field, notably with the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC);

e) to continue to study policy options to limit or reduce the environmental impact of aircraft engine emissions and to develop concrete proposals and provide advice as soon as possible, to the Conference of the Parties of the UNFCCC, placing special emphasis on the use of technical solutions while continuing the consideration of market-based measures, and taking into account potential implications for developing as well as developed countries;

f) to continue to assist the UNFCCC's Subsidiary Body for Scientific and Technological Advice with regard to methodological issues;

g) to continue to develop the necessary tools to assess the benefits associated with ATM improvements, and to promote the use of the operational measures outlined in ICAO guidance (Circ 303) as a means of limiting or reducing the environmental impact of aircraft engine emissions; and

h) to maintain the initiative in developing policy guidance on environmental impacts that may be related to civil aviation, and not leave such initiatives to other organizations.

4.2.4.2 Other items requested by the Assembly had a more temporary nature and were as follows:

a) to study the effectiveness of, and to develop further guidance on, emissions levies related to local air quality, by the next regular session of the Assembly in 2007; and

b) to focus on two emissions trading approaches. Under one approach, ICAO would support the development of a voluntary trading system that interested Contracting States and international organizations might propose. Under the other approach, ICAO would provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process. Under both approaches, the Council should ensure the guidelines for an open emissions trading system address the structural and legal basis for aviation's participation in an open emissions trading system, including key elements such as reporting, monitoring and compliance.

These items had, however, been completed and were no longer reflected in the new work programme.

4.3 MODEL EVALUATION

4.3.1 Two observers noted that models were powerful tools intended to provide information and data aimed to help CAEP in decision-making. To ensure that the information and data provided were reliable and unbiased, the models evaluation process needed to be rigorous, robust, transparent and well-documented. CAEP had undertaken thorough and rigorous analyses of models used in CAEP decisions in the past, but previous discussions at this meeting concerning the evaluation of models to be used in the CAEP/8 work had highlighted a number of questions remaining concerning the model evaluation process.

4.3.2 To resolve this issue it was suggested that Task MOD.01 should be amended to:

a) identify the elements of a robust, rigorous, transparent, and well-documented process for evaluation of models to be used in CAEP decision-making;

b) while initiating a), but recognizing the tight timeframes for CAEP/8 analysis, the evaluation process for models to be used in CAEP/8 decision-making would need to proceed based on, but not necessarily limited to, the following elements:

1) completion of additional sample problems (including consideration of technology response and economics);

2) evaluation of model results via comparison with available "gold standard" data and experience;

3) completion of model sensitivity tests; and

4) full documentation of the above efforts.

The model evaluation process for CAEP/8 might need to be refined based as a result of the work noted in a) above.

4.3.3 This proposal was generally supported in its intent, but one Member considered that the wording need to be adjusted to leave enough flexibility. Additional analyses might be required for some models, but this was a normal part of the evaluation procedure. The meeting nevertheless agreed to the integration of the proposed intent into the wording of the work programme item MOD.01.

4.4 REQUIREMENTS OF AIRPORTS ON LOCAL AIR QUALITY MODELS

4.4.1 An Observer referred to the guidance material on Airport Air Quality currently being developed (see para. 1.9 of the report on Agenda Item 1) to assist States and interested organisations to implement best practices for airport air quality assessments. The observer supported the continued development of this guidance and suggested some key elements for inclusion in the on-going work as follows:

a) The Inventory section currently did not include some so-called “emerging issues”, e.g. engine start-up to idle emissions which should be included since they were a substantial source of hydrocarbons.

   In the current version of the Aircraft Emissions section in the Guidance Material three methods are described – Simple, Advanced and Sophisticated. The Simple method would give results with considerable uncertainty and low accuracy and was intended to give a very rough, first estimate of the order of magnitude of the aircraft emissions at an airport. At the other end of the scale, the Sophisticated method, as currently drafted, would require a high level of detailed information such as possibly proprietary data obtained from engine manufacturers. Generally this would mean that a multi-stakeholder approach would be needed and, because of the considerable effort required, the method was not likely to be used routinely.

b) The “Advanced” method of estimating emissions was expected to be the most widely used by airports. In the current draft, the method relied on the ICAO certification LTO cycle and the Guidance Material noted that in many cases the calculated pollutants will be overestimated, mainly because the LTO cycle was never intended for developing emission inventories. To be truly useful, the Advanced method needed to include means of considering aircraft performance.

c) Given the differences in airport operations, it was necessary to have all emission factors changeable in the models to accommodate local circumstances. In order to assess the peak emission loads it should be possible to model hour-by-hour emission variations (with variations for roads, aircraft and other sources). Since airports are often only one of many sources that affected local air quality around airports, models should also be able to take account of important sources external to the airport, in particular, road traffic emissions.

d) Another important need was for dispersion studies that model the concentrations of various pollutants.

4.4.2 In response to a query, the observer clarified that the intention was that the models should be checked to determine whether they had the capabilities desired. The Co-Rapporteur of WG2 considered that the proposal was very detailed and it would be preferable to allow WG2 latitude to review the implications and report to the next Steering Group meeting instead of expanding the work programme at this moment. The meeting agreed with this approach.

4.5 GUIDANCE ON COMPUTING, ASSESSING AND REPORTING AVIATION EMISSIONS

4.5.1 A member drew attention to the increasing community focus on the impacts of aviation on global climate and local air quality and the public perception that aviation emissions were increasing rapidly and that little was being done to control them. It was therefore important that the aviation sector be able to accurately quantify changes in the level of emissions over time and to demonstrate the efficiency gains that were being achieved by the introduction of control measures (e.g., ATM efficiencies). There was a need for computation, assessment and reporting at the local, national and global level. Pressures were growing to trade off noise in order to reduce emissions. Guidance on ways to compute, assess and report these trade-offs would assist decision makers and the public to understand the issues and to gain an appreciation of the outcome of choosing between competing options. In view of this situation, it was proposed to include development of an ICAO Guidance document on computing, assessing and reporting on aviation emissions at the national and global levels in the CAEP/8 Work Programme.

4.5.2 There was general agreement with this proposal, which, it was suggested, was a refocusing of current work rather than being entirely new. It was also mentioned that IPCC had developed such guidelines and the SAE and others were doing similar work in this area. Care would be needed not to duplicate work.

4.6 ENVIRONMENTAL IMPACT ASSESSMENT APPLIED TO ATM

4.6.1 A member noted that a lot of work had been done to improve the performance of the air traffic management (ATM) system so as to increase safety, capacity and cost-efficiency. Many current activities were expected to accelerate the definition and development of future ATM concepts and technologies, with due regard to coordinated implementation of air and ground integrated systems, leading to faster achievement of operational benefits.

4.6.2 However, the development of air traffic was becoming a complex task due to environmental constraints; such constraints limited airport operations and may provoke vigorous opposition to the expansion of air traffic capacity, preventing the full exploitation of the airport infrastructures (both air and land sides). Moreover there was a risk that the implementation of strategic ATM development plans, linked to ever increasing traffic demand, would erode environmental improvements that had already been achieved.

4.6.3 The importance of trade-off considerations between noise and emissions was already well understood by CAEP. However, air traffic management might affect noise pollution by affecting when, how and where aircraft fly, for example, by facilitating noise abatement techniques such as CDA. If these measures were not fully assessed, however, they might lead to increased fuel use. An environmental assessment applied to ATM projects could quantify the net impact on the environment in terms of the costs of fuel use, greenhouse gas emissions, air quality impacts and noise as the key impacts. It should also consider (as far as possible) other sustainability related impacts to ensure that the optimum overall solution for society was reached.

4.6.4 Major infrastructure developments which could have significant effects on the environment were commonly made subject to systematic environmental assessment. If this transparent approach were applied to key aviation decisions it would help to secure their acceptance, optimise environmental performance and most importantly, prevent non-optimal solutions being imposed under the banner of environmental improvement.

4.6.5 Such a systematic environmental impact assessment should be carried out in the case of plans and programmes regarding the ATM system. It was appropriate to introduce the concept of environmental assessment in the application of CNS/ATM plans and programmes leading to improvements in efficiency and capacity of the ATM system, in order to:

a) quantify and weigh the effective benefits resulting from their implementation with a view to achieving maximum environmental benefit;

b) better evaluate the appropriateness of technical and operational solutions; and

c) protect already achieved environmental improvements, so that they are not eroded by incompatible ATM plans.

4.6.6 The first step in this process would be to define the concept of environment assessment for ATM purposes, with the aim of identifying a common understanding in the aviation field. The second step would be to develop the necessary methodologies/tools to carry out the environmental assessment and the pertinent analysis.

4.6.7 The meeting agreed with the principles of the proposal, although it was cautioned that it would be necessary to be clear about ICAO's role. It was eventually for States to carry out such assessments locally and ICAO should therefore only offer guidance. It was agreed that language would be included clarifying this task within the WG2 work programme. With regard to the modelling aspect, the meeting agreed that it would be necessary to evaluate methodologies and models.

4.7 THE NEED FOR INCREASED NOISE STRINGENCY

4.7.1 An Observer introduced papers calling for increased noise stringency in Annex 16, Volume I. While supporting the implementation of all the elements of the Balanced Approach to Aircraft Noise Management, it was suggested that the reduction of noise at source was the key factor of this issue. It was consequently proposed that, in the next three years, CAEP should develop a new and substantial increase in the noise stringency which would set ambitious and realistic maximum noise levels for new aircraft certificated in the second decade of this century. It was also emphasised that the cumulative approach to specifying noise stringency introduced at CAEP/5 did not ensure noise reduction in all communities affected by aviation operations. Therefore is was considered necessary that any new provisions should include a minimum requirement at each of the three reference noise measurement points.

4.7.2 It was further stressed that the reduction of noise at source was the one element of the Balanced Approach which was entirely within the realm of CAEP and it was the element guaranteed to deliver improvements in the noise climate. It was noted that international civil aviation was forecast to grow at annual rates of between 4 and 5%, which would mean a doubling of traffic over a period of 14 to 17 years. CAEP was therefore urged to develop increased certification stringency at a rate to offset the anticipated growth in air transport, as a minimum.

4.7.3 The cumulative increase in stringency of 10 dB introduced with Chapter 4 was being met by virtually all aircraft in production when the chapter was developed in 2001. Therefore, aircraft newly certificated after the applicability date of 2006 were not required to perform better than the majority of aircraft already in production in 2001. A substantial reduction in the noise impact around airports was not therefore to be expected from the Chapter 4 standard. CAEP/8 was expected to be held in 2010 and, if any new stringency were agreed at that time, there would probably be an implementation lead-time of 4 or 5 years. Therefore 2014 would be the earliest likely introduction date of a new stringency. If the development of a new noise stringency level was delayed to CAEP/9 or 10, it could be a decade or more (i.e., 2017, or 2020) before new production aircraft were required to be better than the aircraft already in production in 2001.

4.7.4 It was reiterated that noise remained the basis for the most frequent objection to the operation, expansion and construction of airports around the world and thus hindered the ability of aviation to grow to meet future demand. Several specific examples to demonstrate the global nature of the problem were provided.

4.7.5 Several members disagreed with this proposal. They believed that the approach to noise mitigation should be through the balanced approach and should not concentrate on one element. Moreover, it was suggested that the scale of the problem had not been adequately demonstrated; specifically it was considered that complaints from the public were not a good basis for establishing the need for increased stringency. As an example one member mentioned that noise complaints in his State had risen at a time when there had been a significant reduction in noise around airports. It was suggested that action at present might be premature and there may be many disbenefits due to trade-offs if Standards were to be developed prematurely.

4.7.6 Other members supported the suggestion. They believed the issue of stringency should be pursued in its own right, notwithstanding its place as one of the elements of the balanced approach. It was, moreover, suggested that a case could be made for reviewing stringency (for NO_x as well as noise) as a routine part of CAEP's work. While in some States the noise situation might be improving, in many parts of the world it was not, and the problem should be approached globally.

4.7.7 The meeting returned to this subject in its later discussions (see para. 4.9 below).

4.8 PHASE-OUT OF MARGINALLY COMPLIANT CHAPTER 3 AIRCRAFT

4.8.1 An observer reminded the meeting that CAEP/5 had evaluated the phase out of marginally compliant Chapter 3 aircraft and had concluded that such a phase out was not technologically feasible or economically reasonable at that time. In the ensuing years, the normal fleet replacement process, often prompted by economic considerations caused by high fuel prices, had seen the early retirement of many such aircraft. However, early retirements had not fully resolved the noise problems caused by these aircraft. At many airports around the world, marginally compliant Chapter 3 aircraft contributed disproportionately to the total noise impact on neighbouring communities and were the primary cause of political opposition to increasing airport capacity. At some airports these aircraft accounted for approximately 5% of movements but 30% to 50% of noise complaints. It was therefore requested that consideration of a phase out of marginally compliant Chapter 3 aircraft be included in the work programme for CAEP/8.

4.8.2 It was questioned whether this was a global problem and one member described how it had been dealt with at a major airport in his State by applying the balanced approach. The source of the statistics quoted was questioned and it was explained that it was not based on a study. The meeting also agreed that it was not clear how "marginally compliant" would be defined. The Secretary reminded the meeting that the ICAO Assembly had agreed that global phase-outs should be avoided and CAEP could not ignore this high-level policy statement. If any action were necessary, it would need to be taken locally as part of the balanced approach.

4.9 THE CASE FOR FURTHER CAEP WORK ON NO_X STRINGENCY

4.9.1 Several members and an observer recalled that CAEP/6 in 2004 had decided to approach the question of NO_x stringency in two-stages. The first was to agree a modest increase in stringency for certain turbojet and turbofan engines (which would formally become applicable with effect from 1 January 2008). The second stage was to consider, as appropriate, more stringent standards for aircraft engine emissions, especially NO_x, in light of the technological review process and the CAEP principles of technical feasibility, economic reasonableness, environmental benefit and interdependencies, aiming to complete the process for review at CAEP/8 (in 2010). It was suggested that there was now needed to be agreement on what had to be included in the work programme in order to enable CAEP to complete the process for review at CAEP/8.

4.9.2 The meeting was reminded that the analysis conducted for CAEP by FESG had found that global NO_x emissions from aircraft in 2020 would be about 150% above 2002 levels, only a 3-4% reduction from the reference case, despite the new standard.

4.9.3 It was pointed out that data provided by the manufacturers' organization clearly illustrated that - despite the difficulties - NO_x emissions technology had continued to improve. Any decision made at CAEP/8 in 2010 to increase further the stringency of the NOx requirement would probably have a formal date of applicability some years later, at which point newly certificated engines would have a still larger margin relative to the standard agreed at CAEP/6.

4.9.4 The group of independent experts commissioned to assess the prospects for NO_x emissions reductions from technology developments that might be possible in the medium and long term (10 and 20 years respectively) had characterized the possible emissions reductions by their median Dp/F_{00} values at PR30 as being reductions of 46 and 60% below CAEP/6. These figures were an indication of the extent to which technology, if appropriately funded, could further mitigate aviation NO_x emissions, and provided an agreed range of emissions performance inputs for evaluating the benefits from such developments over time. However, these were only goals and there were no guarantees that they would be achieved, and even if achieved, they may not be achieved over a sufficient range.

4.9.5 It was the view of an observer and some members that there was a need for including work on a possible further increase in stringency of the ICAO NO_x provisions because:

a) several European States were facing difficulties in meeting NO_2 air quality standards at and around airports. NO_2 limit values would become mandatory in 2010;

b) the growth in aircraft size, plus higher overall engine pressure ratios, combined with the ICAO NO_x standard allowance for higher pressure ratio engines, was offsetting gains made by previous technology improvements and standards;

c) the predicted improvements in NO_x performance reflected in the long-term technology goals appeared insufficient to offset the effects of traffic growth and fleet changes;

d) with the reduction of road transport emissions over time, the contribution of aircraft was emissions increasing in relative terms;

e) there was increasing concern about the effects of climate change and the contribution of aircraft emissions to that change; and

f) the foregoing factors affect the ability of some airports to increase capacity.

4.9.6 Another observer presented a paper reiterating many of these concerns. The paper stressed the need for timely action, no later than CAEP/8, in view of the delayed implementation date normally built into ICAO stringency standards and the growth in traffic that would occur in the interim. Attention was also specifically drawn to the fact that NOx emissions from other sources at airports, especially from ground vehicles, were being reduced so that emissions from aircraft engines were becoming relatively much larger contributors to deteriorating air quality.

4.9.7 Two observers were of the contrary view that this was not time to revise the ICAO noise or emissions certification standards. Given that the CAEP/5 noise standard only went into effect in 2006 and the new CAEP/6 NOx standard would not go into effect until 2008, they believed that it was premature to revisit these standards. If CAEP did, nevertheless, decide to include on the CAEP/8 work programme a review of either the noise or any of the emission certification standards, it was suggested that the relevant work programme item(s) should follow a two-step process. First, the relevant CAEP working groups should fully explore whether a new stringency standard was truly warranted. Then, should the CAEP Steering Group agree that consideration of a change in stringency was warranted, it should direct that the working groups proceed to the second step of looking at what a new stringency standard might be. In addition, it was specifically suggested that CAEP should ensure that the work programme would continue to include a range of measures, and that progress on implementation of these measures and their environmental benefits should be documented. Specific suggestions in this regard were presented.

4.9.8 Discussions of these proposals included a continuation of the discussion described in paragraph 4.6 above. A suggestion was that an exercise to determine mid- and long-term technical goals for noise should be undertaken for noise as it had been for NO_x. The co-rapporteur of WG1 cautioned that such an exercise would be much more complex for noise than it had been for NO_x in view of the much larger number of different technologies involved. However, it was pointed out that the work would no doubt be assigned to a group of independent experts, as in the case of NO_x together and not WG1.

4.9.9 There was general agreement that further work on assessing the need for increased stringency should go forward, perhaps on both noise and NO_x together, taking account of interdependencies. Some difficulty was experienced, however, in specifying exactly how the task should be specified. After further discussion, it was agreed:

a) using the independent expert process, to examine and make recommendations for noise, NO_x and fuel burn with respect to aircraft technology and air traffic operational goals in the mid term (10 years) and long term (20 years);

b) to analyse the technological response to a range of NO_x stringency options up to CAEP/6 levels minus 20% at OPR=30, for applicability no sooner than 2012; and

c) provide a report to CAEP/8 on the results of a review and analysis of certification noise levels for transport category jet aircraft to understand the current state-of-the-art of aircraft noise technology.

4.10 TRANSLATION OF ANNEX 16 INTO THE ARABIC LANGUAGE

4.10.1 The meeting noted an invitation from a member to agree that both volumes of Annex 16 should be translated into the Arabic language, bearing in mind the global nature of noise and emissions problems and the fact that Arabic was one of ICAO's official languages. The Secretary informed the meeting that it was the Organization's intention to translate the Annex into Arabic as soon as possible, but this document was one of among many awaiting translation and the Organization's language services were facing a large demand on their resources.

4.11 APU NO_X EMISSIONS

4.11.1 A Member suggested that there were several reasons for addressing auxiliary power unit (APU) NO_x emissions in the future work programme of CAEP:

a) several States were facing difficulties complying with NO_2 air quality standards around airports – for Europe, a NO_2 Standard would become mandatory from 2010;

b) aircraft size growth at a number of airports was increasing APU NO_x emissions because of larger APUs and longer operating times associated with larger aircraft;

c) with the reduction of road traffic emissions over time, the aircraft contribution was increasing in relative terms;

d) the predicted improvements in main engine NO_x performance evident in the proposed long-term technology goals were expected to be insufficient to offset the effects of growth in movements and fleet change; and

e) failure to deliver all possible gains in aircraft NO_x emissions performance, and thus maintain the ongoing driver for industry innovation and inclusion of latest technology in the fleet, was likely to affect the ability of some airports to increase capacity.

4.11.2 Consequently, the Member believed that development of a test and measurement methodology, which could eventually lead to a certification regime for APU NO_x, should be included in the CAEP/8 work programme for delivery at CAEP/8, together with an examination of the potential for setting a NO_x emission standard for APUs at CAEP/9 or earlier. Additionally, it was considered that ICAO should seek the examination, harmonisation and consequent public release of APU NO_x emissions data by CAEP/9 as a work item in the CAEP/8 work programme. This work item was needed to permit transparent assessment of APUs.

4.11.3 It was agreed that some study of this issue was desirable, although it was cautioned that considerable resources might be required. It was reiterated that there was no intention of developing standards for CAEP/8, although it could not be ruled out that this might eventually occur.

4.12 DEMONSTRATION AND ASSESSMENT OF THE US/CANADA ENVIRONMENTAL ANALYSIS TOOL SUITE

4.12.1 A member drew attention to past modelling tools that supported the CAEP work programme which had separately computed either noise or emissions estimates. These estimates were then separately considered as part of an economic evaluation process. To inform stringency considerations, the economic impact assessment process also only considered a single environmental indicator (e.g., NO_x emitted or noise generated). However, as the CAEP terms of reference recognized, aviation policies, technologies, and operations that affect noise and emissions were interrelated. Therefore, a need existed for a new set of tools to inform policy decisions. These new tools had to be capable of considering the interdependencies among aviation policies, technologies, operations, industry costs, consumer costs, and the human health and welfare impacts of noise, local air quality, and climate change. The US Federal Aviation Administration's Office of Environment and Energy (FAA/AEE), in collaboration with Transport Canada, was working with an international team of researchers to develop a comprehensive suite of software tools that would allow for better assessment of the environmental effects of aviation. The main goal of the effort was to develop a capability to assess the interdependencies among aviation-related noise and emissions effects, and to provide comprehensive cost-benefit analyses of aviation environmental impacts. To further the development of the tool suite, the team was conducting a set of sample problems (SP) and capability demonstration (CD) analyses and assessments to advance the breadth and robustness of the tool suite, and to determine the ability of the tools to capture air transportation system response to various policy scenarios.

4.12.2 The paper presented a summary of the SP and CD analyses and assessments undertaken to date, as well as those that were ongoing as part of the continued development of the tool suite. The results of these activities demonstrated the ability to conduct the broad range of analyses that were expected to be necessary to support future CAEP work programmes. The results also provided valuable input to the model evaluation process.

4.12.3 The meeting was requested to:

a) take note of the capability demonstration problems being pursued by the US, which are an integral component of the ongoing development of the US/Canada environmental tool suite;

b) ensure that sample problems exercise the range of analyses anticipated to be required as part of the CAEP/8 work programme; and

c) agree with the need to continue development of these capabilities and endorse the development of, and participation in, additional broadly-based sample problems and capability demonstrations for changes to all models, or new uses of existing models to be used in carrying out the CAEP/8 work programme and agree that these results should be considered as part of the model evaluation process.

4.12.4 There was general agreement with the proposals. However, it was noted that the proposals implied a process beyond that previously agreed for assessing models. The proposer agreed, but advised the meeting that sample problems tested so far had led to identifying areas for improvement, so they were essential. Also that presumably if a policy option could not be addressed by a model within a sample problem it would be difficult to actually analyze it for decision making.

4.13 REVISITING THE IMPORTANCE OF LOCAL MICRO-CLIMATE CONDITIONS IN LOCAL AIR QUALITY

4.13.1 A member pointed out that although the inventory of air pollutants was one of the most important requisites for diagnosing air quality in the vicinity of airports, experience had shown that local weather conditions played a fundamental role in pollutant dispersion, especially in lower latitudes. The existence of favorable meteorological conditions might eventually exempt airports from the need to prepare comprehensive and expensive inventories of air pollutants. CAEP was therefore invited to consider the introduction of local meteorological factors when setting up requirements for the inventory.

4.13.2 It was questioned whether meteorological factors were already included in dispersion modeling. The meeting was informed that work on dispersion modeling was ongoing and that information from States such as this would be welcomed as part of that work.

4.14 TRANSITION TO A MORE COMPREHENSIVE APPROACH FOR ASSESSING AND ADDRESSING AVIATION ENVIRONMENTAL IMPACTS

4.14.1 Introduction

4.14.1.1 A member noted that CAEP's work was guided by four elements: technological feasibility, economic reasonableness, environmental benefit, and the consideration of interdependencies. To date, analytical tools used by CAEP to assess environmental benefit generally had developed inventories for individual environmental effects (e.g. NO_x emissions or noise generated). These noise or emissions estimates had then been individually compared to costs as part of a cost-effectiveness analysis to help CAEP assess economic reasonableness.

4.14.1.2 However, aviation-related noise and emissions were interrelated and had complex health and welfare impacts. Furthermore, determination of benefits-costs was generally preferred over cost-effectiveness as the basis for making environmental policy decisions. Ultimately, sound environmental policy should be based on establishing a clear understanding of the state of the problem and identifying the benefit of reducing future environmental impacts based on establishing the value of such reductions in addressing the stated problem.

4.14.1.3 For CAEP to fully assess interdependencies and analyses of the human health and welfare impacts, CAEP would need to do three things. First, it would need to employ tools that were capable of looking not only at one aviation environmental parameter in isolation, but also at the effect that changing one aviation-related environmental parameter has on other aviation environmental parameters. Second, CAEP would need to frame the impacts of these parameters on common terms, so that it can understand the implications of the interdependencies and make policy decisions taking those implications into account. Third, CAEP should establish the benefit of environmental mitigation as part of a comprehensive assessment.

4.14.1.4 The United States Federal Aviation Administration's Office of Environment and Energy (FAA/AEE), in collaboration with Transport Canada, was working with an international research team to develop a comprehensive suite of software tools that would permit better assessment of aviation's environmental impacts including human health and welfare impacts. The new tools being developed and proposed by the United States and Canada, as well as tools under consideration by others for CAEP applications, would facilitate new, more comprehensive methods of estimating interdependencies and the environmental benefits, and to analyze proposed approaches to mitigating aviation environmental impacts. These tools would also allow CAEP to focus on and compare the environmental impacts of various aviation environmental parameters to facilitate CAEP decision-making under its Terms of Reference.

4.14.1.5 The member consequently presented a proposal for a more comprehensive approach for future environmental analyses, made possible by the new tools. The approach was based on isolating aviation's contribution to environmental impacts, establishing the benefit of environmental mitigation by estimating the human health and welfare impacts attributable to aviation, evaluating potential near- and long-term solutions, adopting near term solutions and establishing long-term goals, adopting a balanced set of mitigation strategies to achieve the goals, and periodically assessing progress toward achieving the CAEP goals. He recommended that CAEP endorse a transition in its work to this more comprehensive approach.

4.14.2 **Discussions and conclusions**

4.14.2.1 Some members and observers welcomed this approach and the rationality that it would introduce into CAEP's work. Other members, while applauding the efforts invested in the model development involved, were less certain. In particular, some members were not in favour of involving health and welfare impacts and, furthermore in attempting to monetize them. A member suggested that cost/benefit analyses had been tried by some entities without success in the past in this context but had always had to be abandoned. There might be pressure in some parts of the world to perform cost/benefit analyses, but by no means all over the world. While the work being done in the States was supported, it was suggested that CAEP should restrict itself to exploring its possibility rather than making a transition to the approach for the time being.

4.14.2.2 The member making the original proposal welcomed the support he had received from some members. He noted that the ICAO Assembly had already clearly stated that ICAO should examine the environmental impacts of aviation. Moreover, the use of cost/benefit analyses was recommended by other international bodies, such as OECO. He reminded the meeting of the need to develop a common currency which could be used to assess interdependencies. Notwithstanding the outcome of the this discussion, he welcomed open collaboration in further development of the analytical tools involved.

4.14.2.3 Following the discussion, the meeting:

a) acknowledged the growing complexity associated with assessing noise and emissions effects of aviation, especially when considering impacts and their influence on benefits-costs, as well as the case for CAEP to get a better understanding of these impacts and the benefits of environmental mitigation based on establishing the value of such reductions in addressing the stated problem ;

b) endorsed the consideration of a transition to a more comprehensive approach to assessing actions proposed for consideration by CAEP/8;

c) specified that traditional cost-effectiveness analyses of policy scenarios requiring economic analysis be provided for CAEP/8, but that environmental impacts and cost-benefit information and analyses also be provided in the form of a sample problem which may enable CAEP/8 to put the new information into context, and to further consider how to integrate environmental impacts and interdependencies information into its decision-making; and

d) note that the tool suite under development by the United States and Canada is intended to have the capability to enable implementation of this more comprehensive approach in a manner that is consistent with the interdependencies framework established for the CAEP/8 work programme.

4.15 DEVELOPMENT OF RESEARCH TOOLS AND OTHER DEVELOPMENTS

4.15.1 A member briefly introduced a number of information papers describing progress being made in developing environmental research tools and other developments. These are summarized as follows:

a) Environmental Design Space

The United States Federal Aviation Administration Office of Environment and Energy (FAA/AEE), in collaboration with Transport Canada, was developing a comprehensive suite of software tools that would permit a thorough assessment of the environmental effects of aviation. The main goal of the effort was to develop a new, critically needed capability to assess the interdependencies among aviation-related noise, emissions, and associated environmental impact and cost valuations, including cost-benefit analyses. The Environmental Design Space (EDS) tool had been formally introduced to the sixth meeting of the CAEP in February 2004. Since that time the Steering Group, WG1, WG2, WG3, FESG and this meeting had been kept informed of EDS research and design developments.

b) Aviation Environmental Design Tool

The Aviation Environmental Design Tool (AEDT) was formally introduced to the CAEP Steering Group at its November 2004 meeting. Since that time the Steering Group, FESG and WG2 had been kept informed of AEDT research and design developments.

c) Aviation Environmental Portfolio Management Tool

The Aviation Environmental Portfolio Management Tool (APMT) was also formally introduced to the CAEP Steering Group at its November 2004 meeting. Since that time the Steering Group, FESG, WG2 and this meeting had been kept informed of APMT research and design developments.

d) Workshop on the Impacts of Aviation on Climate Change

The Canada-United States-sponsored Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence and the United States. Next

Generation Air Transportation System (NextGen) Joint Planning and Development Office Environmental Integrated Product Team (JPDO/EIPT) had sponsored a workshop on the Impacts of Aviation on Climate Change. The workshop brought together international science experts to assess and document the current state of knowledge of climate impacts of aviation and to recommend short- and long-term research priorities to address underlying scientific uncertainties and gaps. The goal was to focus the scientific community on the aviation-climate change research needed to enable the NextGen growth goals, and to guide Canadian and United States research efforts to support future CAEP work. More details on the findings and recommendations of the workshop were provided to the meeting.

e) PARTNER Centre of Excellence Research Activities and International Collaboration

Members of the United States and Canada provided a summary of research conducted by PARTNER Center of Excellence. The Center, jointly sponsored by Canada and the United States, seeks to enhance the understanding of aerospace environmental issues and foster breakthrough technical, operational, and workforce capabilities, enabling a quieter and cleaner aviation sector. The consortium conducts basic research and engineering development to reduce uncertainties associated with aviation's environmental impact and prototype solutions to mitigate these impacts. Information was provided on PARTNER's efforts to expand its international collaborative research efforts and its student paper competition. The knowledge and capability gained from PARTNER will provide critical information to government, industry and community decision-makers for tackling environmental impacts, which may represent the single greatest challenge to the continued growth and prosperity of civil aviation.

f) The potential use of alternative fuels for aviation

Interest in alternative fuels for commercial aviation had grown in tandem with concerns about rising fuel costs, energy supply security and the environmental effects of aviation. At the moment, the largest single driver for industry adoption of alternative fuels was the high cost of petroleum. However, energy security and possible environmental benefits were also powerful drivers. The United States had determined that it was prudent to explore now the potential move toward alternative fuels. The Member from the United States informed CAEP that the United States, in coordination with potential international collaborators, had launched the Commercial Aviation Alternative Fuels Initiative (CAAFI) to develop a national roadmap for assessing, and possibly adopting, alternative aviation fuels. Alternative fuels efforts may offer opportunities to CAEP as it seeks balanced and robust strategies to mitigate aviation's environmental impact.

g) The United States Joint Planning and Development Office

The Member from the United States provided an information update on efforts by the United States' Joint Planning and Development Office (JPDO) to plan for the Next Generation Air Transportation System (NextGen). An Integrated National Plan outlined eight strategies aimed at transforming the existing United States air transportation system to meet a projected system capacity growth between 200 and 300 percent by the year 2025. Since environmental constraints could prove the limiting factor on system capacity growth, the NextGen Plan had adopted a specific strategy to develop environmental protection that would allow sustained aviation growth.

4.16 OMEGA (OPPORTUNITIES FOR MEETING THE ENVIRONMENTAL CHALLENGE OF GROWTH IN AVIATION) — A NEW UK KNOWLEDGE TRANSFER NETWORK

4.16.1 The member from the United Kingdom briefly drew attention of the meeting to a new United Kingdom Knowledge Transfer Network (KTN). OMEGA drew together nine United Kingdom universities and a range of stakeholder organizations that were addressing aspects of the evidence base relevant to the debate on aviation sustainability. OMEGA had been funded for two years by the United Kingdom government. It intended that OMEGA would work with international academia and stakeholders (e.g. PARTNER in the United States) as well as UK stakeholders. Through collaborative working on key open questions and with a long-term view, OMEGA intended to accelerate the delivery of solutions that would reduce aviation's environmental impacts. It was expected that that the network would address many issues of direct relevance to CAEP and the United Kingdom would report at regular intervals to CAEP on developments arising from OMEGA work.

4.17 WORKSHOP TO SEEK SCIENTIFIC INPUT ON AVIATION ENVIRONMENTAL HEALTH AND WELFARE IMPACTS

4.17.1 A member noted that advice on the scientific understanding of the environmental impact of aviation was crucial to CAEP. Recognizing the complexity, the breadth of the subjects related to the impact of aviation on the environment, the number of research organizations, programme and researchers involved, and the connections with the work being done under other bodies such as the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC) and the World Health Organizations, CAEP generally sought scientific advice through its Research and Science Focal Points (RFPs). The RFPs informed CAEP about the current scientific understanding of the environmental impact of aviation. The work of the RFPs had been extremely valuable in past CAEP cycles. However, considering the growing complexities and the need to inform the CAEP process in a timely manner, further improvements to the CAEP scientific input process were desirable in future.

4.17.2 He suggested that the best and most timely approach to seeking this advice would be to convene a workshop on the state of science that would provide information for the CAEP process. This should include noise, local air quality, and climate impact considerations. The workshop should also consider environmental impacts for assessing the state of knowledge in modelling and analysing health and welfare impacts.

4.17.3 He considered that the workshop should take place no later than the summer of 2007, and results should be presented to the first Steering Group meeting of the CAEP/8 cycle. This timing was crucial to providing information for the tool evaluation process agreed to by the Steering Group with any tool that might be considered for use as part of the CAEP/8 work programme and for CAEP analysis. It was suggested that the report might take the form of a summary of findings and recommendations by participants immediately for presentation to the Steering Group meeting.

4.17.4 **Discussions and Conclusions**

4.17.5 While welcoming the suggestion, the Secretary expressed reservations about the suggested timing, noting that apart from CAEP/7 itself, ICAO would also be holding the Colloquium on Emissions as well as the Assembly Session during this year, which would already stretch the resources. Some members agreed with this view.

4.17.6 Notwithstanding the potential timing difficulties, the meeting was generally in favour of the proposal. The member proposing the workshop indicated that his State would be willing to undertake most of the organizing of the meeting. Several members and observers nominated advisers to a small group who would suggest appropriate members of the scientific community to participate in the workshop and undertake the detailed organization of the event with the Secretariat, while taking into account the availability and required quality of the presenters would determine the timing of the workshop.

4.18 INDEPENDENT ASSESSMENT OF THE EFFECTIVENESS OF CAEP

4.18.1 A member noted that CAEP had guided aviation environmental improvements for nearly 25 years. Its working methods and results had been reviewed after CAEP/5, and it was timely to conduct a further assessment now, not least to ensure that its working practices, aims and outcomes remained appropriate to the issues it continued to address. It was proposed that such a review might be conducted through an external independent assessment of CAEP's working practices, as compared with those of other environmental bodies.

4.18.2 There was some support for this proposal, which would obviously need the Council's approval before any action could be taken. It was suggested that a refusal to consider it could be interpreted as a reluctance by the committee to have its workings scrutinized. While agreeing in principle, a member cautioned that the previous review had led to no action on its conclusion.

4.18.3 There was considerable discussion on who might be nominated to undertake an assessment. It was unlikely that any suitable person(s) could be found who understood aviation and the constraints under which CAEP and ICAO worked. These included the need to pay due attention at all times to ICAO's responsibilities for the safety and security of aviation and the fact that ICAO had no control over the implementation of its provisions, which was a Contracting State responsibility.

4.18.4 Other members did not agree that the difficulty in finding suitable people to conduct an assessment should be the reason to not consider it and examples were quoted of other bodies similar to ICAO, e.g. IMO, which had conducted such reviews.

4.18.5 The Secretary noted that CAEP had a good record of producing its deliverables in a timely manner. It had established a list of deliverables as a measure of efficiency and during this meeting, for example, CAEP delivered all of them. That its efforts had not always translated into State implementation of environmental improvements was largely out of ICAO's control. Working methods (e.g. the use of the internet and teleconferencing) had recently improved considerably, although suggestions for further improvement would always be welcome. It was also of note that ICAO had recently conducted a major re-examination of its working procedures and was moving towards a performance-based budget. Finally, it was cautioned that CAEP should be very careful to avoid any impression that it was encroaching upon the Council's responsibilities.

4.18.6 The member making the proposal noted that it had provoked an interesting debate, which had been the intention. He believed it would be useful as a follow-up if the Secretary could prepare a note on the lessons learned from the preparations for and the holding of CAEP/7. Furthermore, he invited all members and observers to provide him (or the Secretary) with comments on the strengths and weaknesses of CAEP's working procedures within the next three months. This initiative might not lead to a review, but the results should be of interest to all parties concerned.

4.19 **THE NEED TO PROVIDE FESG PROJECTIONS TO 2050**

4.19.1 A member noted that developing the inputs appropriate for use in air quality and climate impact models could be pursued through WG3, and quantifying the value of emissions reduction and estimating the benefit from long term goals would require the involvement of FESG. Benefits assessments required a forecast *projection* capability to 2050 as a basic requirement to produce indicative trends of, for example, future aviation emissions burdens that might be influenced by LTTG goal achievement, and for assessments of policy options to address climate change. FESG's current intention was to extend the forecasting horizon to 30 years to allow better assessment of stringency options. This was an insufficient timeframe to capture the benefits that long-term goal achievement, from technologies that cannot be assumed to enter service for 20-25 years, might produce. He therefore suggested that FESG should develop a means to provide appropriate projections of aviation activity to 2050 to allow quantification of the benefits from long-term technology goals for CAEP/8.

4.19.2 The FESG rapporteurs responded that this would be a very difficult task and in considering it there had been a number of issues raised about the complexity and lack of accuracy in the results. It would be possible with the clear understanding that it could not be a true forecast. It could possibly be based on the examination of possible future scenarios.

4.19.3 The proposal was consequently agreed and it was left to FESG to determine how best to undertake the task.

4.20 **ICAO DATABASES**

4.20.1.1 The Secretariat made a brief presentation on the databases available in the ICAO Secretariat which could be of value to CAEP.

4.21 **ENVIRONMENTAL MANAGEMENT SYSTEMS**

4.21.1 A member drew the meetings attention to the potential use of an environmental management systems (EMS) approach as a means to enhance dealing with the environmental impacts of international aviation in a more systematic and cost-effective manner. The discussion was presented in the context of activities already undertaken by ICAO as well as the efforts of member States and aviation organizations. Based on the benefits realized by aviation organizations, and recognized by ICAO, the member believed that use of performance-based EMS approaches in a harmonized manner with international guidelines for aviation organizations could prove of utility to Contracting States and aviation organizations.

4.21.2 The member stressed that he was not proposing that CAEP develop guidance material on this subject, which was already adequately covered in ISO 14000. He would like to see a collection of information on how the system was already being implemented by the aviation industry, which might provide guidance to CAEP on what action, if any, it might wish to take in the future.

4.21.3 The meeting generally supported the suggestion to collect information as a first step, noting that EMS had already been implemented by a number of States and organizations. The Secretary pointed out that EMS was already mentioned briefly in the Airport Planning Manual.

4.21.4 The meeting consequently agreed that WG2 should prepare a report for CAEP/8 providing information on the existing use of EMS by airports, airlines and air traffic services providers in order to provide a basis of understanding for the aviation sector. It further agreed that, based on this report, recommendations should be developed on how CAEP could promote the use of EMS in the aviation system.

4.22 **ICAO EMISSIONS PLAN**

4.22.1 The Secretariat informed the meeting that it reported to Council during its 179th Session on its proposal to the CAEP Steering Group, to form a think-tank force to engage in discussions of possible ways for aviation to address emissions, with a view to prepare a report for the consideration at CAEP/7.

4.22.2 Council was informed that CAEP members expressed concern with the short time period available between the Steering Group meeting and the CAEP/7 meeting, and with the risk of creating high expectations where no new solutions were envisaged in this short term. The Steering Group considered that there was no need for establishing the dialogue "think-tank" for the moment but agreed on the need for improved communication of the work already developed by ICAO. Some examples of such work would be updating the ICAO Action Plan on Emissions developed at CAEP/5.

4.22.3 Based on the conclusions from the Steering group, Secretariat proposed to Council that a possible work item could be the development of and ICAO Emissions Plan outlining aviation action to address emissions. This plan should be prepared based on previous work by ICAO and Assembly policies in this area, the CAEP/5 Action Plan on Emissions, recommendations emanating from CAEP/7, views and suggestions arising from a consultation with States and international organizations and take into account the results of the Colloquium on Aviation Emissions.

4.22.4 This initiative relates to the mandate emanating from the 35th Session of the Assembly for ICAO to take a leadership role in all civil aviation matters related to the environment. It is necessary that the solutions to aviation emissions be proposed and promoted by ICAO and not left to other fora to take the lead in this regard. CAEP has been developing the building blocks of an emissions policy focussing on the technological, operational and market-based areas, but it would be beneficial to put these building blocks together and to establish a more structured plan outlining aviation's action to address emissions. Although much progress was achieved in the last CAEP cycle, the absence of the right communication tool (a comprehensive plan) clearly showing how ICAO proposes to address the effects of aviation emissions may be viewed by the public and other international organizations as lack of progress, or worse, lack of commitment by the aviation sector to meaningfully address this issue. The discussion of aviation measures to address climate change must be associated with the overall discussion of measures to address the full range of environmental effects of aviation emissions due to the interdependency of such measures.

4.22.5 The CAEP/5 Action Plan focused mainly in conveying the work programme approved by CAEP. It was prepared by Secretariat in consultation with the rapporteurs. Although this procedure could be adopted for the description of the activities in the ICAO Emissions Plan, due to the importance of the subject and its more forward looking aspect, Secretariat suggests that a consultative group of members be established to support this initiative. A group similar to the "virtual group" used in the preparation of the CAEP working methods report. The ICAO Emissions Plan would be submitted to the Council prior to its consideration by the Assembly. It will also be used by ICAO in its communications with other UN Organizations.

4.22.6 The Action Plan on Emissions as developed by CAEP/5 and an initial draft proposal for the ICAO Emission Plan were made available to the meeting with a view to stimulate discussion during the CAEP/7 meeting.

4.22.7 The meeting discussed the proposal for the ICAO Emissions Plan, its possible contents and the establishment of the support group.

4.22.8 There was general support for the development of the ICAO Emissions Plan and the need for a good communication tool regarding ICAO activities in this area. A member expressed preference for a plan that would be limited to communicating the existing ICAO work and work plan, as he had concerns with CAEP's ability and the appropriateness of exploring areas where consensus was not yet reached. If the plan reflected only the ICAO work, he was confident that the Secretariat could develop it and send it for the approval of members. If there were new areas that could be part of the Emissions Plan, where further progress could be achieved, he was of the opinion that all CAEP members should be consulted. In this case, one possibility would be to hold a CAEP members only meeting to address any pending issues following the ICAO Emissions Colloquium, being held in May 2007, since it was expected that most CAEP members would be in Montreal for this event, thereby not incurring any additional travel costs.

4.22.9 A member expressed full support to the initiative of developing the Emissions Plan. In his view, there was a need for ICAO and the aviation community to clearly inform the public "where we are, what we are doing and where we are heading". He expressed willingness to be involved with the development of the plan.

4.22.10 Another member expressed the view that all the points raised were not inconsistent and that all agreed that there was a need for more efficiently communicating the achievements in aviation emissions. Many members expressed their support of the idea of developing the ICAO Emissions Plan using the CAEP/5 Action Plan as a starting point, and their willingness to provide assistance as necessary. It was agreed that in light of the first reviews of the draft Emissions Plan and further developments, the need for a CAEP members only meeting to further progress and adopt the Plan will be defined.

4.23 ICAO COLLOQUIUM ON AVIATION EMISSIONS AND ENVIRONMENTAL REPORT 2007

4.23.1 The Secretariat briefly reported on the Colloquium on Aviation Emissions, with exhibition, which ICAO was organizing from 14 to 16 May 2007 at ICAO Headquarters and was calling on the active participation of CAEP members and observers. ICAO is also developing its first Environmental Report. The Report could only materialize with the contributions of CAEP members, observers and others who were encouraged to provide articles in their domain of expertise.

4.23.2 ICAO was counting on CAEP Working Groups and their affiliated Task Groups and Research Focal Points to have their collective and individual work and achievements reflected.

Rapporteurs and other experts were encouraged to propose how they would like to participate in these two follow-up activities of CAEP/7.

4.24 REVIEW OF THE WORK PROGRAMME

4.24.1 It was considered important that the work programme be clearly and objectively defined whilst maintaining some degree of flexibility to incorporate new tasks that could arise after the CAEP/7 meeting, especially tasks arising from the Thirty-Sixth Session of the ICAO Assembly. These would be considered by the Council and CAEP in meetings following the Assembly, and added to the CAEP work programme. They might have to be given greater priority than other previously approved tasks.

4.24.2 The Secretary's consolidated list of work programme items, plus items arising from the discussions reported in paragraphs 4.3 through 4.23 of the report on this agenda item, were first reviewed by the respective working group rapporteurs and the rapporteurs of FESG. It was agreed that the tasks relating to models and databases would be presented in a separate list. Remaining tasks would be listed under the working groups which would undertake them. The meeting also reviewed the other lists, ensuring that there was consistency between them and that appropriate deliverables, support and target date information was included.

4.24.3 Proposed Work Items on Market-based Measures

4.24.3.1 CAEP members and observers presented various proposals for future work. The meeting paid particular attention to market-based measures and carried out a thorough review of a number of proposals for future work that originated from the Council and from CAEP members and observers. With the objective of reaching a consensus on the various proposals it had to review, the meeting based its decisions on resources available to conduct the requested work, on priority considerations, on the body that would be responsible for conducting/overseeing the work, and on the timeframe available. The meeting agreed that the tasks should preferably be decided based on the consensus of the group but that it would accept work to be conducted in certain areas when there was support of some members, as well as resources committed to do the work. For ease of consideration, the items were ranked into four categories, as reflected below. The tasks examined below are incorporated in the work programme of the various CAEP working groups or task forces, as reflected in the relevant Appendices. The Appendices indicate for each task the type of deliverable which is expected, the body responsible for overseeing the task, the resources committed for conducting the task and the target date.

4.24.3.2 In view of the specific nature of certain tasks and the lack of adequate expertise in the existing structure, the meeting agreed to establish a Market-Based Measures Task Force (MBMTF) that would be responsible for conducting the tasks identified under M.01 -through M.04 in Appendix A. This task force would report to the CAEP Steering Group. It would be headed under a co-rapporteurship arrangement, which would include one of the co-rapporteurs of the previous ETTF (Mr. Kalle Keldusild, from Sweden) and a new co-rapporteur (from Canada - to be designated). The membership of the task force would be established at a later stage, after members and organizations have had a chance of discussing the issue with their administration or headquarters.

Role of market-based measures in a management framework for local emissions

4.24.3.3 The initial proposal was to produce guidance material on an "emissions management framework that addresses the relative roles that technical, operational, mitigation and market-based measures play in aircraft local air quality emissions management, how they interrelate with each other, and on tracking progress on implementation of the various measures and on their environmental benefits". There was extensive discussion on this proposal, which led to a compromise solution by which the proposed task was reformulated into two different tasks. The meeting agreed on those two new tasks, and decided to entrust the responsibility of conducting the work to WG2. Consequently, the two tasks appear in Appendix D, under O.18 and O.19.

Emissions trading

4.24.3.4 Seven proposals had initially to be reviewed under this category. Five were endorsed by the meeting; and the other two were rejected, as explained hereafter.

4.24.3.5 A proposal to further develop the technical and legal details allowing to optimize the flexibility and cost efficiency of emissions trading models, based on the ETS guidance material, was met with general opposition from the meeting and the sponsor of the proposal withdrew it.

4.24.3.6 A proposal to review/update the ETS guidance to adapt it to the specificity of business aviation was not accepted by the meeting as such. Instead, it was considered more appropriate that the sponsor of the proposal describe its views and specific requests in a report that would be presented to the next CAEP Steering Group meeting. It was clarified that the meeting was only in agreement to revise the guidance on aspects of a technical nature not affecting the general scope of the guidance. The sponsor agreed with the proposed procedure.

4.24.3.7 The proposal to conduct an economic analysis of the financial impact of including international aviation in existing trading schemes was accepted and the responsibility for conducting this task was entrusted to FESG. It consequently appears in Appendix F, under F.05 1).

4.24.3.8 The proposal to undertake a literature review of cost-benefit analyses of existing trading systems was accepted and the responsibility for conducting this task was entrusted to FESG. It consequently appears in Appendix F, under F.05 2).

4.24.3.9 The other three proposals were accepted and the responsibility for conducting the tasks was entrusted to the newly created MBMTF (see 4.24.3.2 above). The description of the tasks and other related information is contained in Appendix A, under M.01, M.02 and M.03.

Emissions charges

4.24.3.10 A proposal to collect more information on the implementation and effectiveness of local emissions charges schemes was not accepted by the meeting, for the following reasons:

a) the work requested had already been conducted;

b) there were resources limitations

c) there would no added value, because of data limitations, and

d) there was general opposition from members and observers.

One member, however, estimated that there might be more information available within the three-year time span leading to CAEP/8 and that he was willing to lend resources to accomplish the task. The meeting conclusion on this issue was that there was limited value to conduct such study at this time, unless new experiences become available.

Alternative measures

4.24.3.11 Three proposals had to be reviewed under this category. One was accepted and two were not.

4.24.3.12 A proposal to explore alternative measures such as a funding mechanism for civil aviation mitigation projects was not retained as part of the future work programme at this stage. The meeting considered that such a project was too broad and exceeded the capabilities of CAEP. There was no clear definition of the proposal and the meeting considered that it was more appropriate for the sponsor of the project to undertake consultations with such international funding institutions as the World Bank and the Interamerican Development Bank, and also with the UNFCCC and report on the results of this undertaking to the next CAEP Steering Group meeting in a more structured way, which would enable the Committee to examine which action should be performed to further advance the project within CAEP's remit. The sponsor agreed with the proposed procedure and welcomed the interest and support expressed by two other members in exploring the possibilities that might arise from this option.

4.24.3.13 A proposal to consider aviation non-CO_2 offset projects was met with general opposition from the meeting, and was not included in the work programme.

4.24.3.14 The proposal related to emissions offset measures was accepted and the responsibility for conducting this task was entrusted to MBMTF. It consequently appears in Appendix A, under M.04

4.24.4 **Other Proposed Items**

Noise-related tasks

4.24.4.1 The meeting reviewed the noise-related tasks. Some specific comments were as follows:

a) Item N.12: it was noted that this was a new task. It was stressed that the TIG was a coordinating group and as such did not need to be large; membership was therefore best left to the rapporteur to decide. It was also noted that not much expertise was available to evaluate models and some independent expertise would be valuable;

b) Item N.24: this was a new task on the state-of-the-art of aircraft noise technology and members volunteered support to undertake it;

c) Items N.27, 28 and 29: it was suggested that there could be overlap between these items. It was left to the rapporteur to deal with these items in the most appropriate manner;

d) Item N.30: it was suggested that there was a problem with the timescale involved in this item. For modelling work, results were needed by the end of 2007. The rapporteur considered that this would be difficult, but every effort would be made to meet the deadline.

Emissions-related tasks

4.24.4.2 The meeting noted several new tasks, some of which were parallel to noise-related tasks.

Operations-related tasks

4.24.4.3 Some specific comments were as follows:

a) Item O.04: this item dealt with curfews and had originally been put on the work programme at the request of a State. Initial work had been completed and it was not clear what further work was required. It was agreed that the State involved would need to be consulted.

b) new tasks related to CNS/ATM (O.07) were noted and a member offered to take the lead on these items.

Modelling-related items

4.24.4.4 The meeting reviewed the proposals. Potential deadline problems for other groups to supply information for modelling were again noted. Modelling work would have to begin by March 2008 at the absolute latest which meant providing data to the modelling task group by the end of 2007. It was again stated that this might prove very difficult. It was noted that the list of tasks was accompanied by a list of models and databases, as well as a list of work item interdependencies.

FESG

4.24.4.5 The new task to extend forecasts to 30 years and consider developing a projection to 2050 were noted. It was also noted that FESG would need new expertise for items F.03 a), F. 04 a) and F.05.

4.24.5 **Proposed work items arising from ICAO**

4.24.5.1 Proposals for new work items had arisen from the discussions during the 179th session of the ICAO Council, as mentioned in 4.2.1 e) above. These items have been considered by the meeting and the following actions were agreed:

a) to consider aviation alternate fuels — task proposed by the Secretariat. This task is covered by WG3 in E.09;

b) to consider aviation environmental indicators — tasks proposed by the Secretariat. This task is covered by WG2 in O.10;

c) to consider an ICAO emissions plan — task proposed by the Secretariat. This task is covered in 4.22;

d) to consider an ICAO emissions management system — task proposed by the Secretariat. This task is covered by O.18 and O.19;

e) to collect more information on the implementation and effectiveness of local emissions charges schemes — task proposed by the Council. This task was not accepted by the meeting as explained in para. 4.24.3.10 above;

f) to develop the necessary studies to better understand the damage of aviation emissions to the environment — task proposed by the Council. This task is covered by E.02;

g) to further study operational measures that minimize the impact of aviation on the environment — task proposed by the Council. This task is covered by WG2 among various tasks included in Appendix D;

h) to continue to work on market-based measures by exploring other kinds of measures such as the creation of mechanisms that could provide resources for fleet renewal and make the best technology more widely available — task proposed by the Council. This task was not accepted by the meeting as explained in para 4.24.3.12 above;

i) to study the effect from the application of curfews on destination airports — task proposed by the Council. This task is covered by WG2 in O.04

j) to conduct an economic analysis of the financial impact of including international aviation in existing trading schemes — task proposed by the Council. This task is covered by F.05.

4.24.6 **Recommendation**

4.24.6.1 The meeting approved the revised lists of work programme items as shown in the Appendices at the end of the report on this agenda item:

Appendix A: tasks related to market-based measures (MBMTF)

Appendix B: tasks related to noise (WG1)

Appendix C: tasks related to emissions (WG3)

Appendix D: tasks related to operations (WG2)

Appendix E: tasks related to modelling and databases (MODTF)

Appendix F: tasks related to forecasting and economic studies (FESG)

It consequently developed the following recommendation:

Recommendation 4/1 — Future work programme
That the Council approve the future work programme for CAEP detailed in Appendices A, B, C, D, E and F to the report on this agenda item.

4.25 **CAEP STRUCTURE**

4.25.1 The meeting agreed with the following structure to undertake the work leading to CAEP/8:

a) Working Group 1 – Noise technical;

b) Working Group 2 – Operations;

c) Working Group 3 – Emissions technical;

d) Forecasting and Economic Analysis Support Group (FESG);

e) Market-based Measures Task Force (MBMTF); and

f) Modelling and Databases Task Force (MODTF).

Working groups 1, 2 and 3, as well as FESG were maintained from the CAEP/6 structure.

4.25.2 The meeting agreed that the following co-rapporteurs for WGs 1, 2 and 3 would continue in their roles as follows:

a) WG1 – Mr. James Skalecky (USA) and Mr.Willem Franken (EASA);

b) WG2 – Mr. Alec Simpson (Canada) and Mr. Roger Gardner (UK); and

c) WG3 – Dr. David Lister (UK) and Mr. Curtis Holsclaw (USA).

The meeting also agreed that Mr. Paul Hooper, ICAO Secretariat; and Ms. Sylvie Mallet (Canada) would be the new co-rapporteurs for the FESG.

4.25.3 New task forces and rapporteurs were agreed by the meeting, as follows:

a) the modelling and databases task force – Mr. Greg Fleming (US) and Mr. U. Ziegler (Switzerland) as co-rapporteurs; and

b) the market-based measures task force – Mr. Kalle Keldusild (Sweden) and a co-rapporteur to be nominated by Canada.

4.25.4 Mr. F. Coulouvrat, Mr. V. Sparrow and Mr. R.C. Miake-Le continued in their role as Research Focal Points. Mr. Y. Makino was added as a new Research Focal Point from Japan.

4.26 RESOURCES

4.26.1 The meeting was informed by A/D/ATB on the current status of the Organization's resources to address aviation environmental issues. He expressed his concerns with the fact that the growing importance of environmental aspects of aviation requested increasing resources from Secretariat and CAEP participants. He cautioned that within the current budgetary discussions in ICAO it would be unrealistic to expect further expansion of the resources dedicated to the environmental activities, unless this area was given some priority.

4.26.2 He requested the meeting to give specific attention to the resources being requested from States, International Organizations and Secretariat while formulating the new work programme. He was aware and supportive of the steps already taken by the Secretary in terms of identifying the availability of resources for each of the proposed tasks in the new CAEP work programme.

4.26.3 He further invited the members and observers to explore with their respective administrations the possibility of secondments to the Secretariat to support the Environmental Unit, and thanked France and United States for their current contributions.

4.26.4 He called upon CAEP members and observers to fully commit to the new CAEP work programme. Without this commitment, it would be impossible for the Organization to respond to the expectations being placed upon ICAO.

4.26.5 He thanked the meeting for the support leading to CAEP/7.

4.27 CALENDAR

4.27.1 The meeting agreed to hold the following Steering Group meetings prior to CAEP/8:

a) Zurich, Switzerland, 26 to 30 November 2007;

b) Seattle, USA, 22 to 26 September 2008; and

c) Salvador, Brazil, 22 to 26 June 2009.

4.27.2 The full calendar leading to CAEP/8 will be agreed by the next Steering Group.

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APPENDIX A

MARKET BASED MEASURES - MBMTF

WORK ITEMS

Project No. and Title	**Description**	**Deliverable**	**Support** (names/ organization)	**Target** (date)
M.01	Update the Report on Voluntary Emissions Trading for Aviation.	Update information in the VETs report	Australia Japan	CAEP/8
M.02	Scoping study of issues related to linking open emission trading systems involving international aviation.	Report	Argentina Brazil Canada Japan US, IBAC IATA	CAEP/8
M.03	Conduct a scoping study into the potential for the use of emissions trading for local air quality.	Report	Canada UK US	CAEP/8
M.04	Examine the potential for emissions offset measures as a further means of mitigating the effects of aviation emissions on local air quality and global climate change.	Report	Australia Canada	CAEP/8

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English only

APPENDIX B

NOISE TECHNICAL – WG1

WORK ITEMS

Project No. and Title	**Description**	**Deliverable**	**Support** (names/ organization)	**Target** (date)
N.01	Coordinate with WG3 Rapporteur on the WG1-WG3 Technology Interdependencies Group.			
N.02	Coordinate with WG3 Rapporteur on programme schedules for development of both noise and emissions SARPs for future supersonic aeroplanes.			
N.03	Coordinate with other working group Rapporteurs as necessary.			
N.04	Investigate any other technical issues brought to the attention of the WG and if appropriate propose to add these to the work program.	Report to SG, propose work item if appropriate	All WG1 members	As appropriate
N.05	Further develop and monitor the use of guidelines for providing helicopter data for LUP purposes.	Report to SG (propose work item if considered justified)	ICCAIA, France, FAA	Last SG before CAEP/8
N.07	Monitor, and report on, status of SST projects and expectations for their operation (nature, frequency etc.).	Report to CAEP	ICCAIA, RFPs, FAA, France	CAEP/8
N.06	Investigate adoption of current subsonic noise rules for supersonic standards and make recommendations as appropriate.	Progress report to SG or recommendation concerning Annex 16 SARPS	ICCAIA, FAA, EASA, France	Last SG before CAEP/8
N.08	Monitor, and report on, research to characterize, quantify and measure (including metric) sonic boom signatures, and their acceptability.	Technical report to CAEP	ICCAIA, RFPs, FAA, France Japan	CAEP/8
N.09	Assess the extent of knowledge on sonic boom and decide if it is appropriate to consider drafting standards for sonic boom.	Recommendation to add (or not add) task to ToR to draft standard	All WG1 members	Last SG before CAEP/8
N.10	Reassess Terms of Reference for work on supersonic task.	Proposal for revised terms of reference	All WG1 members	Last SG before CAEP/8
N.11	Provide advice on and assess as necessary any noise related technical questions that may arise from the inter-dependency work.	Technical advice to TIG and/or other working groups	EASA, ICCAIA, France, FAA, IATA, TC	As requested

N.12	Technology interdependencies: 1. Provide the necessary inputs to WG2 and MODTF to integrate technology responses and trade-offs into the CAEP benefit-cost modelling. 2. "Evaluate" the Environmental Design Space concept, the Technology Evaluator and other candidate systems as potential tools to aid assessment of technological responses and to identify technology trade-offs.	Input on technology response to MODTF Progress report	Italy IATA ICCAIA TIG US	End 2007 SG / 07
N.13	Consider how best to support development of models used to populate future fleets and the replacement of retired aircraft. In this context review adequacy and update, if necessary, "Best practice database" (bearing in mind purpose, selection criteria, validation and coordination with emissions database).	Advice on and provide data for future fleet composition forecasts	All WG1	Mid 2007
N.14	Monitor SAE work to update the atmospheric absorption procedure and assess the impact, including the effect on stringency, of its adoption in the Annex. Make any recommendation that may be appropriate.	Recommendation	ICCAIA, France, FAA, TC	Last SG before CAEP/8
N.15	Investigate improvements in guidance within the following sections of Annex 16, Vol. I, Appendix 2: 1. Section 2.3 on Flight Path Definitions, Measurement Instrumentation and Procedures, and TSPI Data Reduction and Analysis; 2. Section 4 on the Calculation of EPNL; 3. Sections 8 and 9 on the Adjustment of Aircraft Noise Data to Reference Conditions Using the Simplified and Integrated Methods; and 4. Section 6 Nomenclature: Symbols and Units.	SARPs	ICCAIA, FAA, EASA, France	Last SG before CAEP/8

N.16	1. Clarify the intent of the applicability language of Annex 16, in respect of the appropriate amendment level of Volume I and revision of ETM (including the acceptability of equivalent procedures) when applied to: a) Applications for TC approval to states other than the state of design (after approval by State of Design); b) Applications for amended TCs (type design change) to State of Design and states other than the State of Design; and c) Applications for STCs to State of Design and states other than the State of Design. 2. With regard to all the above consider the definition of "derived version" (particularly *Note 1* and the link with airworthiness regulations) [in the context of commonly used terms such as "major / minor modifications", the "changed product rule" "acoustical change", and "supplemental type certificates"]. 3. To ensure that applicability language is appropriate to all Chapters of the Annex.	Report concerning revised SARPs	FAA, EASA, France, ICCAIA	Last SG before CAEP/8
N.17	Review Aerospace Recommended Practice-ARP1846, Measurement of Far Field from Gas Turbine Engines During Static Operation, identify deficiencies, and means of resolution (e.g. WG1 or A-21).	Report on deficiencies and the need for further action	ICCAIA, FAA, EASA	Next WG1 meeting
N.18	Investigate reference take-off speed definition Part/CS 23 jet aircraft.	Annex 16 SARPs	TC, EASA, FAA, ICCAIA, France	First CAEP/8 SG
N.19	Identify any changes to Annex 16 that may be necessary to enable the certification of selectable/variable systems and to develop possible supplemental schemes to credit their enhanced performance in operation.	Annex 16 SARPs	ICCAIA, FAA, France, EASA, ACI, IATA	Last SG before CAEP/8
N.20	Develop further guidance material in case of new certification of an existing aircraft making use of demonstration procedures not used in the original certification or aircraft modification applications (including the use of engine de-rate).	ETM material	FAA, IATA, ICCAIA, France, TC	Last SG before CAEP/8

N.21	Continue developing the New environmental technical manual: 1. Complete integration of texts and other information from approved and available resources into drafts of New ETM Chapters consistent with WG1 Approved Table of Contents; 2. Develop new material and revisions to existing material as considered necessary by WG1 (including review and possible use of available Appendix H & J material developed for AC36-4); and 3. Liaise with ICAO Secretariat to expedite its publication.	Proposal for new ETM	ICCAIA, EASA, FAA, France	Items 1 & 2: Last SG before CAEP/8 Item 3: As soon as possible after CAEP/8
N.22	Develop acoustical change analysis guidance for small propeller driven aeroplanes under Chapter 10 that have gone through a modification such as a different blade count propeller, weight change and/or drag change.	ETM material	EASA, FAA, France	Last SG before CAEP/8
N.23	Develop guidance for applicants and authorities on deriving certificated noise levels by interpolation between already approved noise/mass values.	ETM material	TC, ICCAIA, IATA, France, FAA	First CAEP/8 SG (Oct. 2007?)
N.24	Provide a report to CAEP 8 on the results of a review and analysis of certification noise levels for transport category jet aircraft to understand the current state-of-the-art of aircraft noise technology.	Report	EASA IATA ICCAIA Italy UK US	CAEP8
N.25	Monitor the process for updating the ICAO noise certification database.	Propose improvements if appropriate	WG1, ICCAIA, IATA, France, EASA, FAA	First SG after CAEP/7
N.26	Update and extend the ICAO noise certification database.	Up to date Noise Database	EASA, France, ICCAIA	Each WG1 meeting
N.27	Monitor and report on the various national and international research programme goals and milestones.	1. Workshop 2. Technical report	ICCAIA, ACI, IATA	1. First CAEP/8 SG 2. CAEP/8
N.28	Taking into account the work of Item N.27 (monitor and report on research) and, in coordination with WG3, provide advice and information on mid and long-term noise reduction technology prospects and future trends.	Report to WG2	ICCAIA, ACI, IATA	End 2007
N.29	Using the independent expert process, to examine and make recommendations for noise, with respect to aircraft technology and air traffic operational goals in the mid term (10 years) and the long term (20 years).	1) Plan 2) Report	FAA ICCAIA Italy IATA UK	1. First SG 2. CAEP/8
N.30	To consider alignment with WG3 [ref: CAEP/7 WP/9] on using the TRL concept for defining of technological feasibility for short term standard setting and medium/long term noise technology goals.	Progress report	US ICCAIA IATA	First SG

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APPENDIX C

EMISSIONS TECHNICAL – WG3

WORK ITEMS

Project No. and Title	**Description**	**Deliverable**	**Support** (names/ organization)	**Target** (date)
E.01	**Intergroup Co-ordination** 1. Coordinate with WG1 Rapporteurs on the WG1-WG3 Technology Interdependencies Group. 2. Coordinate with WG1 Rapporteurs on programme schedules for development of both noise and emissions SARPs for future supersonic aeroplanes. 3. Coordinate with other working group Rapporteurs as necessary, **in particular on the new Goals Task [Item E.04]**. 4. Provide support to other UN Bodies as appropriate.	Ref. Item E.03.2 Ref. Item E.08.3 Ref. Item E.04.1 As appropriate		
E.02	**Research** Monitor & foster research to characterise further the air quality and global effects resulting from current and projected future aircraft exhaust emissions, including aviation's contribution relative to other sources. Report on the results of this research, evaluating and highlighting the aviation environmental impacts relative to impacts from other sources.	Report	RFP and SFP	SG 2008 & CAEP/8
E.03	**Technology Advances & Interdependencies** 1. Technology advances: Provide assessment of advances in aircraft and engine design technologies for subsonic and supersonic aircraft and the degree to which these technologies could influence gaseous emissions, smoke, particulate matter and fuel consumption; including the potential benefits and trade-offs amongst various emissions and noise, the likely timescales for introduction and appropriate inputs for assessment of the associated economic costs and environmental benefits. 2. Technology interdependencies:	Report	ICCAIA	SG 2009

	a) Provide the necessary inputs to MODTF to integrate technology responses and trade-offs into the CAEP benefit-cost modelling; and b) Evaluate the Environmental Design Space concept, the Technology Evaluator and other candidate systems as potential tools to aid assessment of technological responses and to identify technology trade-offs.	Inputs on Technology response Progress reports	 TIG; All WG3	End 2007 SG 2007
E.04	**Technology goals** 1. Using the independent expert process, examine and make recommendations for NOx and fuel burn with respect to aircraft technology and air traffic operational goals in the mid term (10 years) and the long term (20 years). For NOx: 2. Monitor/review progress on medium and long term NOx technology goals. 3. Development of the Review process and structure in light of comments. 4. Develop, with other CAEP Groups, the means to use the output of the LTTG review process for: a) Identifying any gaps in relevant emissions data bases; b) Informing CAEP deliberations of possible timing and options for changes to the CAEP NOx standards; c) Providing modelling parameters to assess the probable range of future NOx emissions; and d) Informing CAEP deliberations on the degree to which NOx technology improvements could influence progress towards achieving CAEP Environmental emission goals.	Report on NOx goals progress Lessons learnt to be shared with other Groups	WG1	SG 2009 mid 2007
E.05	**Particulate Matter** 1. Recognising the interim approximate nature of the FOA PM methodology: a) Evaluate and document sampling and measurement procedures for non-volatile particulate matter emissions, which, if appropriate, could be used in a certification methodology; b) Develop measurement and sampling	Progress reports	FAA, EASA, RFP SFPs, ICCAIA	SG 2008 & CAEP/8

	techniques for volatile particulate emissions; and c) Assess and document scientific PM measurements as a means of validating and improving FOA PM methodology for environmental assessment purposes, with the ultimate objective of replacing FOA with PM measurement data, as confidence in measurement methods reaches an acceptable level. 2. Further characterise LTO particulate matter emissions from aircraft engines covering the state of the art science, FOA methodology, SAE-E31 progress, etc. 3. Monitor the latest understanding of aviation PM impacts on both LAQ and climate change. 4. Assess the data required for environmental impact studies of aircraft particle emissions on the upper atmosphere and provide data (e.g. emissions factors), including uncertainties, for global emissions inventories of particles based upon ground-based and other measurement data.			
E.06	**Annex 16, Volume II** Maintain Annex 16, Volume II, taking account of updates to SAE-E31 documentation.	Changes to Annex 16, Volume II	All WG3	SG 2009
E.07	**Environmental Technical Manual (ETM)** ETM developments: Further develop the emissions Environmental Technical Manual.	ETM material	EASA, FAA, ICCAIA	SG 2009
E.08	**Methods & Standards** 1. NOx LTO stringency Analyse the technological response to a range of NOx stringency options up to CAEP6 minus 20% at OPR = 30 for application no sooner than 2012. 2. NOx Cruise climb methodology: Monitor the need for and, subject to SG approval, the possible further development of the LTO NOx vs. cruise climb NOx relationship for future engine technologies to quantify control of mission emissions of NOx. 3. Super sonic aircraft emissions: a) Promote new global impact assessments associated with a fleet of supersonic aircraft and report progress; and b) Review and revise, as appropriate, the	Report Statement of need for SG consideration Report - possible revisions to Annex 16, Vol. II	All WG3 All WG3 EASA, FAA, ICCAIA	SG 2008 CAEP/8

	existing methodology for supersonic aircraft engine emissions certification. 4. APU emissions: Explore improved characterisation of APU emissions through acquisition and reporting of data, including consideration of measurement and sampling issues and make appropriate recommendations.	 Report	 UK, ACI, ICCAIA	
E.09	**Fuel composition - emissions effects** 1. Review trends in aviation kerosene fuel supply composition. 2. Promote improved understanding of the potential use and emission effects of alternative fuels.	 Report Report	 ICCAIA	 SG 2009
E.10	**Air Quality Guidance** Provide support to WG2, as appropriate, to assist the further development of the Local Air Quality Guidance.	 Methodology and data as appropriate	 All WG3	
E.11	**Operational issues - emissions** Provide support to MODTF, as appropriate, to assist in development of models.	 Methodology and data as appropriate	 All WG3	

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APPENDIX D

OPERATIONS – WG2

WORK ITEMS

Project No. and Title	Description	Deliverable	Support (names/ organization)	Target (date)
O.01	Review and updating of the Balanced Approach guidance to account for policy developments in aspects of CAEP's work that necessitates updating of the guidance. Study the use and way of implementation of the Balanced Approach at the airport level and evaluate the extent to which the BA contributes to solving airport noise related problems at airports.	Amendments to guidance and report of the evaluation study	Australia, Canada, Brazil, Italy, Netherlands, IATA	Third SG
O.02	Make headway with the package of work on the Encroachment Analysis Methodology which is currently stalled pending availability of a major FAA/ NASA/TC Centre of Excellence report on the subject.	Amendments to BA guidance	US, Brazil, Canada, IATA	Third SG
O.03	Review and update the Airport Planning Manual, Part 2: Land Use and Environmental Control (Doc 9184) as required.	Amendments to guidance	Australia, Canada, Brazil, IATA	Third SG
O.04	Estimate the environmental impact of curfews on destination countries with a case study for a major airport.	Define proposal/report	India	SG meeting/ CAEP/8
O.05	Examine a case study on the management of "area-wide" aircraft noise.	Report to CAEP	Australia	Third SG
O.06	On emissions management systems: 1. Deliver a report providing information on the use of EMS among airports, airlines, and air navigation providers in order to give a base of understanding in the aviation sector. 2. Based on the report in O.06 1) as appropriate, make recommendations on how CAEP could promote the use of EMS within the aviation system.	 Report Recommendations on promotion of EMS	 US US	 CAEP/8
O.07	Examine the concept of environmental impact assessment applied to CNS/ATM and define the appropriate methodologies in order to quantify the benefits resulting from the implementation of CNS/ATM plans/ programmes and to identify appropriate ATM improvements.	Technical report	Italy, US, Australia, IATA, Eurocontrol, ICCAIA	Status report to second SG
O.08	Based on the independent expert process, examine and make recommendations for noise, NOx and fuel burn with respect to air traffic operational goals in the mid term (10 years) and the long term (20 years).	Report to CAEP	Italy, Australia, UK, US, Eurocontrol, IATA ICCAIA	Third SG

O.09	Examine development of ICAO guidance on computing, assessing and reporting on aviation emissions at national and global levels.	Report to CAEP and possible guidance material	Australia, Italy	Third SG
O.10	Consider the development of environmental indicators in conjunction with other CAEP WGs.	Possible ICAO guidance material	Secretariat, UK, IATA, ACI, Eurocontrol Italy, ICCAIA	Third SG
O.11	Assess the effect of takeoff thrust and deeper cutback on noise and emissions, fuel consumption (constant weight) and climb-out time. This is an extension of current task on NADP noise and emissions effects.	Technical report	UK, ICCAIA, IATA, IFALPA	Third SG
O.12	Assess and validate noise and emissions reductions accrued from the use of continuous descent arrival techniques (e.g. CDA). This item, considered as high priority item by TG3, would require definition of continuous descent techniques with other ICAO groups (OCP, OPSP) and is conditional on availability of assessment methods and supporting data.	Technical report	UK, US, Eurocontrol, IATA IFALPA, ICCAIA,	Third SG
O.13	Review of NAP R&D/implementation projects, including advanced noise abatement departure procedures. This item would provide an analysis of options including the evaluation of tradeoffs of environmental effects.	Technical report and possible recommended practice	UK, Italy, Eurocontrol, IATA, ICCAIA	Third SG
O.14	Assess benefits of steeper approach. This item should include review of present practice and review of implications for assessment methodologies. Operational and technological feasibility are also considered as part of the assessment.	Technical report	UK, IATA, IFALPA, Eurocontrol, ICCAIA	Third SG
O.15	Study the noise arising from departing and arriving aircraft at locations 9 to 12 km away from the airport, and if appropriate further away, and investigate whether operational means rather than a change to the certification scheme would be the best way to address problems in these wider areas.	Report to Steering Group	Australia, France, UK, Eurocontrol, IATA, ICCAIA	Second SG
O.16	Develop and update the Airport Air Quality Guidance to include Dispersion Modelling, measurement and revision of the inventory chapter taking account of emissions source characterisation and with external expertise as necessary on new aspects of the guidance material.	Second phase of guidance	US, UK, Italy, Switzerland, Brazil, Canada, ACI, ICCAIA, IATA	Third SG
O.17	Continued coordination with FESG on 'times-in-mode' in relation to modelling capabilities	Advice to FESG and MODTF	All TG4	First SG

O.18	Role of MBM in a management framework for local emissions Prepare a report that describes the various technical, operational, mitigation and market-based measures available to address aircraft emissions impacting local air quality, identifies the factors that might inform a decision to choose a particular measure or measures, and notes the potential interrelationships between the measures.	Report	Argentina Brazil Canada Japan US ICCAIA IATA	CAEP/8
O.19	Based on the information developed under O.18, develop draft text that could be used for the main page on the ICAO web site that describes the available measures and further directs the reader to the relevant ICAO guidance documents that have been adopted on the subject.	Web material		CAEP/8

WG2 Proposed Coordination Activities

WG2 Task Groups	**External Groups**	**Linkage**
TGs 2 & 3	ANC, OPSP, OCP, FPLSG	Coordination on Noise Abatement Procedures and ATM
TG3	WG1	Coordination on far-out approach noise problem in relation to noise certification scheme
TG4	WG3	Coordination in relation to development of air quality guidance
TGs 2 & 3	MTF	Coordination in relation to NAP and CNS/ATM benefits
TG4	FESG & MTF	Coordination in relation to time-in-mode
TG4	SAE	Coordination in relation Airport Air Quality Guidance

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APPENDIX E

MODELLING AND DATABASES – MODTF

WORK ITEMS

Project No. and Title	**Description**	**Deliverable**	**Support** (names/ organization)	**Target** (date)
MOD.01	Continue the candidate model evaluation process initiated in the previous work program, which calls for sensitivity tests, comparisons with "gold standard data, and sample problems per MOD.02. Refine the process as appropriate on the basis of relevant criteria, to better inform CAEP which tools are sufficiently robust, rigorous and transparent, and appropriate for which analysis (e.g. stringency, CNS/ATM, market-based measures), and why there might be differences in modelling results.	Report recommending specific models to support policy-making decisions in the CAEP/8 Work Programme, including a comprehensive description of the evaluation process	ICCAIA, IATA, ACI, Model Owners	Preliminary CAEP/8/ 2007/SG Final CAEP/8/ 2008/SG
MOD.02	In support of the model evaluation process, conduct modelling sample problems (including technology response and cost-benefit analysis) to identify gaps in existing tools, to identify potential approaches to displaying interdependencies and to adapt models as necessary. (Note: Results not to be used for actual policy analysis.)	Report on model capabilities and potential enhancements to existing tools. This report will inform MOD.01	ICCAIA, IATA, ACI, Model Owners	CAEP/8/ 2007/SG
MOD.03	To support CAEP environmental goals as stated in the current A35.5, conduct an updated trends assessment, for the baseline case (and forecasts), and various cases which consider technology and operational improvements. As directed by Steering Group, assess the contribution of CAEP policies toward achieving CAEP environmental goals.	Report on noise, emissions and GHG goals	ICCAIA, IATA, ACI, Model Owners	CAEP/8
MOD.04	Examine how CAEP will directly compare the results of the various modelling tools, including the direct comparison of all aviation environmental impacts and costs versus benefits. This will draw on, as necessary, appropriate technical and scientific expertise from inside and outside CAEP, including a workshop.	Report on assessing aviation environmental impacts and monetisation Report on workshop	ICCAIA, IATA, ACI FAA, ICCAIA, U.K., Italy	Preliminary 2007/SG Final CAEP/8/ 2007/SG
MOD.05	Provide support to CAEP Secretariat on presentation of CAEP/7 environmental trends assessment.	As required	MTF	September 2007

Project No. and Title	**Description**	**Deliverable**	**Support** (names/ organization)	**Target** (date)
MOD.06	Conduct policy option analyses as requested by CAEP. This effort requires coordinating work including a specific framework and set of assumptions required to support CAEP/8 analyses (WG1/2/3/FESG).	Report on policy option analyses	As required	CAEP/8/ 2007/SG (Framework) CAEP/8 (Results)
MOD.07	Consider transition to a more comprehensive approach to assess proposed actions. This includes providing cost-benefit information and analyses in the form of sample information.	Progress Report Final Report	U.S.	CAEP/8/SG CAEP/8
MOD.08	1. 2006 Airports Database	Database	FAA, EUROCONTROL, and ICAO	CAEP/8/ 2007/SG
	2. 2006 Movements Database	Database	FAA, EUROCONTROL and ICAO, Member States	March 2008
	3. 2006 Fleet Database	Database	FAA and EUROCONTROL, IATA, CH, WG1 and WG3	March 2008
	4. Population Database	Database	FAA, CAA and EUROCONTROL	March 2008
MOD.09	Develop a plan for coordinating Modelling Task Force (MODTF) activities including links and support required from WG1/2/3/FESG to conduct the CAEP/8 Work Programme.	Report on CAEP coordination for CAEP/8 Work Programme	ICCAIA, IATA, ACI	June 2007 (WG) CAEP/8/ 2007/SG
MOD.10	Define/assess environmental need for emissions reduction from technology.	Report		CAEP/8

Name	**Description/Application**	**Support** (names/organization)
MODELS		
ADMS	A model capable of computing local air quality.	U.K.
AEDT (EDMS, INM SAGE and MAGENTA)	An integrated suite of modules and databases, capable of computing aviation noise and emissions interdependencies on a local, regional, and global scope. AEDT is also linked to APMT (economics) and EDS (technology).	U.S. + Canada
AEM	A model for computing regional and global inventories of aviation emissions and fuel useage.	EUROCONTROL
AERO MS	Suite of models by which effects of locally, regionally and globally applied emission reduction measures can be evaluated in terms of their environmental impact and their consequences for the aviation sector. Measures can be technical or economic by nature. The system is used for the assessment of market-based measures.	Netherlands + FESG
AERO2K	A model for computing regional and global inventories of aviation emissions and fuel useage.	EC/UK
ALAQs	A model capable of computing local air quality.	EUROCONTROL
ANCON2	A model capable of computing local noise.	U.K.
APMT	An economic analysis model, which is linked to AEDT through common input/output.	U.S. + Canada
EDS	A technology-response model, which is linked to AEDT through common input/output.	U.S. + Canada
ENHANCE	A model capable of computing local noise.	EUROCONTROL
FAST	A model for computing regional and global inventories of aviation emissions and fuel useage.	U.K.(MMU)
FESG Noise and NOx Cost Model	Models developed and used by FESG to assess the compliance costs of stringency options.	FESG
JCAB	A model capable of computing local noise.	Japan
LASPORT	A model capable of computing local air quality.	Germany
SONDEO	A model capable of computing local and regional noise.	EC
DATABASES		
Forecast and retirement curves (FESG)	Projected number of aircraft per seat category based on MODTF Movements database.	ICAO Secretariat + FESG + aircraft manufacturers
Airports	Information on airport regional assignment, as well as environmental parameters.	FAA and EUROCONTROL
Fleet	Aeroplane serial number specific database including certificated mass, emissions and noise levels.	Campbell-Hill/ IATA + FESG + WG/1 + WG/3
Movements	Flight data for input in models for CAEP use and for generating updated fleet forecast.	FAA and EUROCONTROL
Population	Population data for assessing noise impacts.	FAA and EUROCONTROL
Linked noise and emissions certification database	Aircraft/engine combinations, with noise and emissions data, identified as suitable for new and replacement aircraft in a future fleet, based on Noise	WG1/WG3/ICCAIA+States

Name	**Description/Application**	**Support** (names/organization)
	and Emission certification databases and associated Best - Practice Noise and In - Production Emissions databases.	
ICAO aircraft noise database (NoiseDB)	Aircraft noise certification levels as approved by the aviation authorities.	French DGCA + WG1 + NAAs + ICCAIA
ICAO aircraft engine emissions databank	Engine emissions certification levels as approved by the aviation authorities.	UK (CAA)
ANP – Aircraft Noise and Performance	Database providing the required aircraft data for practical implementation of the recommended methodology for computerised noise modelling systems.	EUROCONTROL
Air claims information	Information on stored aircraft.	Commercial data source
International Official Airline Guide (IOAG)	Flight schedules of all scheduled air carriers (input to forecast model).	Commercial data source
ICAO traffic forecast (pax. + cargo)	Number of passengers and cargo traffic.	ICAO Secretariat + FESG

Work Item Interdependencies:

1. Updated 2006 forecast and retirement curves (FESG) [Dec 2007]
2. Linked noise and emissions certification database for new and replacement aircraft in the global fleet (including Russian products) (WG1/WG3) [Dec 2007]
3. Goals efficiency metric (WG/1/3/MTF) [Dec 2007]
4. Report on CAEP cost effectiveness modelling and assumptions, potentially including monetization (MODTF/FESG) [CAEP/8 SG1]
5. Report on technology responses to CAEP policy analysis requirements (WG1/WG3) [Dec 2007]
6. Report on operational initiatives, including navigational technologies and associated benefits for goals and policy analysis (WG2/TG3) [Dec 2007]
7. Report on future technology assumptions for goals analysis (WG 1/WG3) [Dec 2007]
8. Specific framework and assumptions required to support CAEP/8 policy analyses (WG1/2/3/FESG) [CAEP/8 SG1]

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APPENDIX F

FORECAST AND ECONOMIC ANALYSIS - FESG

WORK ITEMS

OVERVIEW

For the most part, FESG's future work programme is determined by CAEP based on the policy scenarios that CAEP decides to study in a particular CAEP round. FESG expects that this will largely be the case for FESG's CAEP/8 work programme. However, based on work undertaken in the CAEP/7 cycle and on discussions at the Brisbane, Australia Steering Group, FESG has identified two specific areas of future work for the CAEP/8 cycle, which FESG wishes to bring to the attention of CAEP. These areas are (1) coordination with other CAEP Working Groups, particularly Working Group 2, regarding modelling assumptions, databases and methodologies; and (2) in-depth evaluation of the Aviation Environmental Portfolio Management Tool (APMT) that is being offered by the United States for performance of economic analysis.

Project No. and Title	**Description**	**Deliverable**	**Support** (names/ organization)	**Target** (date)
F.01	1. Produce a new traffic and fleet forecast over a 30 year time horizon. 2. Consider developing an approach to do projections to 2050.	1. new forecast 2. 2050 projection	FESG	2008
F0.2	1. The draft coordination plan is presented in a separate paper to CAEP. The FESG believes it would be useful for the coordination tasks that CAEP agrees to be reflected in the FESG work programme. 2. The work programme for CAEP/7 included a specific task (Task N.7.g) calling for **Modelling task force** to coordinate with FESG in reviewing potential models for CAEP analysis, in particular for analysis of tradeoffs and interdependencies. While this coordination was undertaken through "Ad Hoc Coordination" groups in (Modeling task force) and FESG, it was recognized at the CAEP Steering Group meeting in Australia that the coordination needs for CAEP/8 modelling and analysis (including assumptions, databases, and methodologies) would be even greater. Accordingly, the Steering Group requested that the FESG and **Modelling task force** Rapporteurs put together a coordination plan for CAEP/8.	Coordination work plan	Modelling task force and FESG	CAEP/8

F.03	1. The United States has offered to the CAEP process a model currently under development, known as the "Aviation Environmental Portfolio Management Tool" (APMT), for economic assessment of aviation environmental policy options. An initial review of the expected capabilities of APMT has been undertaken by MODTF in coordination with FESG. However, it was recognized at the CAEP Steering Group meeting in Australia that APMT will need to undergo a more systematic review by FESG to "validate" the model for CAEP use if the model is to be accepted for CAEP/8. 2. At the Australia Steering Group meeting, the FESG Rapporteurs agreed to begin this APMT "validation" task after the Oct. 24-25, 2006 FESG meeting. Accordingly, through its Ad Hoc Coordination Group, FESG has developed a strawman plan for APMT review, which is set forth in IP 14 "Strawman Plan for CAEP Acceptance of APMT."[1] Furthermore, FESG has begun assembling a task group to undertake the APMT review, with initial work on the review occurring just before CAEP/7. The Strawman Plan for CAEP Acceptance of APMT identifies the task, proposed evaluation elements, and a timeline consistent with expected CAEP/8 needs. FESG notes that the strawman work plan is necessarily a "living document," which will be revised and refined as the APMT review process takes place to take account of what is learned during the process about the model and the CAEP/8 modelling needs. However, this plan provides a guidepost for FESG's work. 3. To the extent that CAEP decides that FESG should continue with the APMT review, this task should be placed on the FESG work programme for CAEP/8. In light of the timeframe that is estimated to be needed for the CAEP/8 analysis, FESG's strawman plan calls for the full evaluation of the model to be completed in the first quarter of 2008, if the development of the APMT model proceeds according to its planned production schedule.	Development of a process for CAEP review and acceptance of APMT (Strawman Plan)		Before CAEP/8

[1] Although the Steering Group used the term "validation" when it described this task at the Australia Steering Group ("FESG agreed to take up the validation"), the FESG suggests that "review for CAEP acceptance" is a more accurate reflection of the task.

F.04	1. In recent years, participation in FESG appears to have waned to some degree. FESG wishes to bring to CAEP's attention the importance of having sufficient numbers of economic experts to undertake the economic analysis expected for CAEP/8. 2. FESG traditionally has conducted cost-effectiveness analysis for CAEP (generally, comparison of costs of an array of policy scenarios with the environmental benefits, such as cost per tonne of emission reduction). In addition to this cost-effectiveness analysis capability, APMT is expected to provide the capability for cost-benefit analysis (generally, comparison of the costs of an array of policy scenarios with monetary value of the environmental benefits). It would be helpful if CAEP would not only encourage heightened participation in FESG, but also specifically participation by those with economic expertise in monetization of environmental benefits (and dis-benefits) and cost-benefit analysis.	Increased participation of economics experts in FESG		2007/SG
F.05	1. Conduct an economic analysis of the financial impact of including international aviation in existing trading schemes. 2. Undertake a literature review of cost-benefit analysis of existing trading systems with a special emphasis on how it has been applied to other sectors in order to draw some pertinent lessons learned for the aviation sector.	Report	Australia Brazil Canada IATA	CAEP/8 and beyond

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ISBN 92-9194-991-4

9/07, E/P1/1030

Order No. 9886
Printed in ICAO