Doc 10021

INTERNATIONAL CIVIL
AVIATION ORGANIZATION

FINAL REPORT OF THE INDEPENDENT EXPERT OPERATIONAL GOALS GROUP (IEOGG)

REPORT

MONTRÉAL 2014

Doc 10021

INTERNATIONAL CIVIL
AVIATION ORGANIZATION

FINAL REPORT OF THE INDEPENDENT EXPERT OPERATIONAL GOALS GROUP (IEOGG)

REPORT

MONTRÉAL 2014

Published in English only, by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 University Street, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

Doc 10021 ***Final Report of the Independent Expert Operational Goals Group (IEOGG)***
Order Number: 10021
ISBN 978-92-9249-615-9

FINAL REPORT OF THE INDEPENDENT EXPERT OPERATIONAL GOALS GROUP (IEOGG)

1. INTRODUCTION

1.1 Operational improvements, in conjunction with aircraft technology improvements, are key elements that contribute to the achievement of ICAO environmental goals and the sustainability of the aviation sector. ICAO therefore requires the thorough assessment and definition of potential environmental goals.

1.2 The high-level purpose of operational goals is to inform decision makers of achievable environmental benefits if the potential improvements are implemented. In addition, these goals will provide valuable input into the ICAO Committee on Aviation Environmental Protection (CAEP)'s environmental trend assessment process through its Modelling and Databases Group (MDG).

2. BACKGROUND

2.1 Past ICAO Independent Expert (IE) Reviews

2.1.1 The Independent Expert (IE) review process was originated back to during the CAEP/7 cycle (2004-2007), when the first IE group was established under CAEP WG3 to develop medium-term and long-term technology goals for NOx emissions. Various IE review groups and processes were established during the CAEP/8 cycle (2007-2010), including noise technology goals IE review under WG1, second NOx technology goals IE review under WG3, fuel burn technology goals IE review under WG3 and operational goals IE review process under WG2.

2.2 The CAEP/9 Cycle Independent Expert Operational Goals Group (IEOGG) Review

2.2.1 During the CAEP/8 cycle, the Independent Expert Operational Goals Group (IEOGG) was established through CAEP-Memo/72. IEOGG met in December 2008 and produced its report for the Modelling Task Force (MODTF, now called MDG) in February 2009. This short timescale was mainly due to the late IE process kick-off and was also dictated by the needs of the Group on International Aviation and Climate Change (GIACC). The IEOGG report was subsequently submitted to Steering Group in June 2009. The report was not published because of concerns from the CAEP Steering Group, which included the lack of time devoted to IEOGG discussion and information gathering. As a result of these issues, the Operational Goals Review was therefore conducted a second time under the CAEP/9 cycle (2010-2013).

2.3 Difference between Operational and Technology Reviews

2.3.1 As previously mentioned, various environmental goal setting processes under Independent Experts (IEs) have been established by the ICAO CAEP to cover aircraft ‗technology‘ goals for fuel burn, noise and NOx emissions (engines and airframes). However, significant differences between operational and technology reviews have to be taken into account:

- Operational performance improvements are in part achieved via multi-sector plans and agreements. The relative complexity of Operations arises in part from the range of public and private stakeholders actively involved in delivering operational performance improvements, including governments, regulators, international institutions, professionals and their associations, air navigation service providers (ANSPs), airport and aircraft operators, research institutes, airframe, engine and air traffic management (ATM) technology manufacturers and communication system providers. This wide range of operational goal interests and delivery mechanisms results in some key differences between CAEP technology goals and operational goals in the scope, the process and the type of experts required.

- When IE reviews of technology plans were analyzed to develop recommended technology goals for CAEP, active employees of the relatively limited ‗goal applicable‘ sector (i.e. manufacturers) were not eligible to serve as an IE because they were not considered to be independent. However, if the same approach is utilized for operational goals IE selection, the potential pool of ―independent” experts would be extremely limited due to the multiplicity of sectors involved in operational improvements. In addition, no single organization or sector is capable of delivering an operational goal individually. Having a balanced representation of all stakeholders in the IE group therefore would implicitly facilitate collective independence. While ensuring the independence of IEOGG consensus, operationally active experts have therefore been eligible as IEs for the operational goals analysis.

2.4 Remit and Terms of Reference

2.4.1 The CAEP/9 cycle work programme contains an operational goals task designed to conduct a more robust IE review. The primary tasks include:

- Using the IE process, carry out a robust air traffic operational review and make recommendations for operational goals for noise and fuel burn in the mid term (10 years) and the long term (20 years), (Task O.01.01);

- Develop an action plan and schedule to address issues raised by the 2009 CAEP Steering Group (SG) and to conduct a more robust IE process (Task O.01.02); and

- Provide overall facilitation of the IE Operational review including i) generate the guidance, information and material needed for the IE process; ii) hold a workshop and the IE Review; iii) facilitate the IE assessment and formulation of findings and report (Task O.01.03).

2.4.2 The CAEP/8 meeting (February 2010) also decided that the time-frame for all the IE goals (technology and operational) should be harmonized to the years 2020 and 2030.

2.4.3 The proposed terms of reference and CAEP Memo for recruitment were discussed and refined at the 2010 CAEP SG. The IEOGG objectives were set and approved as follows:

- Review and summarize available information on relevant areas of planned regional and global operational improvements and research on operational improvements;
- As a basis for goal setting, consider the worldwide potential "pool" for operational improvements (i.e. total inefficiency in today's system);
- Develop a base-case scenario against which to measure future benefit delivery – harmonizing to the extent possible with timelines used for related goals (e.g. other IE groups and/or GIACC);
- Based on the initial Operational Goals report submitted to CAEP/8 (CAEP/8-WP/12) and addressing the concerns raised by CAEP/8 SG in Salvador in 2009, develop challenging and aspirational Operational Environmental Goals for the medium-term (2020) and long-term (2030), for consideration by CAEP/9; if possible providing an interim report to MDG during 2011;
- Ensure that their proposed goals are sufficiently robust to allow fir their publication and for the subsequent trend assessment activities of MDG;
- Highlight any uncertainties or anticipated range of accuracy of the goals and likelihood of success;
- Identify weakness and gaps in available knowledge and information and advise ICAO where these should be addressed to inform future goal setting activities; and
- Establish a framework for the consistent periodic iteration of the operational goal setting activity in the future.

2.4.4 The full IEOGG Terms of Reference are included in Appendix C.

3. ADMINISTRATION AND SUPPORT

3.1 Support from the Operational Goals Planning Committee (OGPC)

3.1.1 The IEOGG process is designed to deliver operational goals for use by CAEP and CAEP working arrangements (primarily MDG) for the CAEP/9 meeting (February 2013). To support this review, the Operational Goals Planning Committee (OGPC) was established within WG2 to elaborate on the terms of reference and timeline of activities of IEOGG, develop initial plans and material, support the IE nomination process and organize an initiation workshop.

3.2 Part of the recommendations made by the CAEP/8 meeting was the close coordination with other IE groups, in particular the WG3 fuel burn reduction technologies goal process. In defining the proposed IEOGG plan and terms of reference, sharing of information between WG2-OGPC and the WG3 Fuel Burn Reduction Technology Goals team was therefore undertaken. This has helped to ensure consistency and to avoid the risk of overlap.

3.3 Recruitment Process and Membership

3.3.1 CAEP-Memo/79 was sent on 22 November 2010 to Members and Observers to call for nomination of the IEs. In March 2011, six experts had been nominated and in April 2011 one of the original nominations was withdrawn. Two new nominations were made and accepted after the Steering Group meeting in September 2011. In August 2012, the IATA member resigned and a replacement was identified in October 2012. The group of experts was set as described in Table 1. Full accounting of membership attendance is shown in Appendix D.

Table 1: CAEP/9 IEOGG Membership

IE Name	Nominating Body	Relevant Knowledge (selected elements only)
Michael Ball	U.S. (FAA)	Air Traffic performance, systems and operations.
Lee Merry Brown (Chairperson)	U.S. (FAA)	Air Traffic Operations and Airspace Design
Teresa Di Lallo	Italy (ENAV)	CNS/ATM performance metrics and Functional Airspace Blocks
Dirk Kugler	Germany (DLR)	CNS/ATM, Navigation Systems
Robert Goldman (replaced Grady Boyce)	IATA	Airline Operations
Richard Marchi	ACI	Airport operations and management. ICAO goal setting.
Mohamed Osman Alata Soliman	ACAC	Public relations, air transport and international affairs; and in, airport environmental management.
Anton Walsdorf	ICCAIA	Aircraft Systems Engineering, SESAR, NextGen, Security and Military

3.4 Conduct of the IEOGG Kick-off Workshop

3.4.1 Part of the action plan to facilitate the IE review, as outlined in Task O.01.02, was to hold a workshop and establish the IE Review group.

3.4.2 The objective of this two-day workshop was to inform the IEs of substantial inputs related to IEOGG activities, including the clarification on terms of reference, lessons learned by other IE processes, expectation from CAEP MDG, relevant information on various initiatives such as NextGen, SESAR, AIRE and ASPIRE, and other inputs from stakeholders.

3.4.3 WG2 and the IEOGG therefore thoroughly reviewed the terms of reference as supplied in CAEP-Memo/79. Presentations were made from key stakeholders and colleagues whose work is considered significant to the IEOGG task. In addition, the IEOGG elected a chair and took control of the remaining work program with WG2 providing support as needed. The workshop concluded with the election of Lee Brown from the U.S. as Chair of the IEOGG.

3.4.4 Although presentations were thorough, relevant, and reflected current experience in operational efficiency calculations, they also reflected the limitations of geographical representation. Presentations primarily considered performance and benefits modeling for the U.S. and Europe and the models and databases dealt mostly with fuel rather than noise.

4. SCOPE AND TECHNICAL CONSIDERATIONS

4.1 The Terms of Reference defines Operations to ―…encompasses the direct facilitation of the utilisation of civil aircraft in any phase of the Gate-to-Gate regime, both in the air and on the ground." The IEOGG has further refined this definition to broadly include changes from an initiative that involves how, when or where an airframe is utilized. This definition includes three classes of operational changes: Air Traffic Management (ATM) Operations, Airport Operations, and Aircraft Operations.

- ATM Operations include those initiatives that directly impact the path (in all dimensions) and how airspace is used. Examples would include Performance-Based Navigation Routing, Optimized Profiles, Flexible Airspace, and Functional Airspace Blocks. Collaborative decision making techniques would also be considered in this category.

- Airport Operations include those initiatives in and around the airfield. Examples include Improved Surface Management, Minimum Engine Taxi, and Enhanced Ground-Movement Information Sharing.

- Aircraft Operations include initiatives specific to the aircraft but not associated with technologies. Scheduling and operating procedures could also be considered in this category. Examples include Aircraft Type, Auxiliary Power Unit Use, and Relaxation of Take-off Speed Limitations.

4.2 Future activities that do not directly affect gate-to-gate operations were not included in the IEOGG analyses. However, the IEOGG has attempted to put the potential impact of these actions in the context of other in-scope activities (e.g. trade-offs between noise and emissions impacts). The IEOGG notes that congestion management techniques (e.g. slot restrictions, or minimum aircraft size requirements) and land use restrictions may influence and produce operational effects.

4.3 The Terms of Reference identifies the IEOGG environmental scope to develop goals for fuel consumption (an efficiency metric) and operational noise mitigation. The analysis approaches for fuel consumption and noise are described in separate sections of this report.

4.4 The IEOGG‘s scope includes a baseline of 2010, with two target goal years 2020 (mid-term) and 2030 (long-term). At the inaugural workshop, the IEOGG was asked to consider adding an additional year, 2040, to coincide with the MDG modelling timeframes planned for CAEP/10. This report includes 2020, 230, and 2040 goals. The longer-range goals, i.e. 2040 do not have the same rigor as the 2020 and 2030 goals.

5. TECHNICAL COORDINATION

5.1 The IEOGG had one coordination teleconference with the Chair of the Modelling and Database Group (MDG). Subsequently, the IEOGG received 2006 global operations data and a draft 2036 global operations forecast.

5.2 Richard Marchi (IEOGG member and FESG member) provided the IEOGG with the FESG traffic and passenger forecasts from May 2012 for the route groups. The IEOGG used these two data sets to construct its required traffic forecasts for 2020, 2030, 2040.

5.3 At its February 2012 meeting, the IEOGG received a briefing of the Aviation System Block Upgrades (ASBUs) from Steve Bradford from the U.S. FAA. The briefing acquainted the group with the ASBUs, and the IEOGG will be using this material in its deliberations. The IEOGG has received the most recent draft/version of the ASBU document.

5.4 The IEOGG also received a briefing from ICCAIA at its February 2012 meeting. The briefing included several proposals for operational improvement in both emissions and noise. The IEOGG used the information in its deliberations.

5.5 On Day 1 of the June 2012 meeting, the IEOGG met with David Knorr, Senior U.S. FAA Representative in Paris. Mr. Knorr is a primary author on many performance assessment studies that the IEOGG has used in its deliberations. The IEOGG discussed several studies with Mr. Knorr for understanding of assumptions and interpretation of results.

5.6 At the CAEP SG3 meeting held in July 2012, several participants volunteered additional data and support. Information received and utilized by the IEOGG in its August meeting included a preview of recent performance assessment reports from Australia, delay and diversion data from Brazil, CARATS project material from Japan, PBN project data in UAE from ARAC, Hudson Bay ADS-B project data from Canada, and noise contour data from MDG and WG1.

5.7 A special teleconference was held in July 2012 with Tim Rees, Airservices Australia, to discuss recent performance assessment studies.

5.8 At the August 2012 meeting, the IEOGG held a coordination teleconference was held with Dennis Huff, the Noise IE Chairperson. Assumptions on feasibility of steeper approaches were discussed at this meeting.

6. REVIEW OF RELEVANT RESEARCH, STUDIES AND DEMONSTRATION PROJECTS

6.1 The IEOGG informed its deliberations using the results of several studies, research papers and demonstration projects. This work generally either describes a ―theoretically available” benefit pool or describes benefits that can be achieved using a certain technology or operational process. It is also the case that the results typically apply to a specific geographic region, e.g. North Atlantic and to a specific phase of flight, e.g. terminal area/descent. As discussed later, the IEOGG analysis was generally organized along these lines. In this section the relevant work reviewed by the IEOGG is listed. The application of specific results to the IEOGG analysis is discussed later in this report.

6.2 While the work of the IEOGG took a ―bottom-up” approach, earlier ―top-down” studies were considered to provide context and validation. These include, the CAEP/8 IEOGG report (CAEP/8 2010), the CANSO goals (CANSO 2008) and the IATA sponsored NLR study (Brok and Hoogerbrugge, 2000). As identified in the IEOGG Terms of Reference, the IEOGG used the CAEP/8 IEOGG Report as a starting point for its deliberations. The IEOGG used resource documents and studies that were referenced by the CAEP/8 IEOGG.

6.3 Several broad studies and demonstration projects provided the IEOGG with input and information across multiple dimensions. These include the U.S./Europe ATM performance study (Performance Review Commission and the Air Traffic Organization, Strategy and Performance Business Unit, 2009, Gulding et al 2009), the AIRE project (Aguiar 2020, Forsberg 2009, Bourgin, and Renou, 2010, Delain et al 2010, Lachance 2011, Maier 2011, RETA-CDA Consortium, 2010) and the ASPIRE project (ASPIRE 2009, ASPIRE 2010).

6.4 As discussed later in this report, the IEOGG analysis of operational fuel and atmospheric emissions goals is broken down by phase of flights: taxi-out, climb, cruise, descent and taxi-in.

6.5 The U.S./Europe ATM performance study provided a starting point in estimating benefit pools for taxi-in and taxi-out. Specific references on virtual queuing, which has the potential to substabtially reduce taxi-out emissions in the U.S. include Bhadra et al 2011, Brinton et al 2011, Deonandan and Balakrishnan 2010 and Simaiakis et al 2011.

6.6 Estimates for the climb pool employed Robinson and Kamgarpour 2009 and Performance Review Commission 2008. Additional insights were provided by Mitchell and Ekstrang 2011, which also explored noise/emissions tradeoffs.

6.7 Basic estimates of the enroute benefit pool used the U.S./Europe ATM performance study, Lovegren and Hansman 2011, Fujisaki 2012, and Palopo and Windhorst 2009. The AIRE and ASPIRE project also provided specific validation and insights. Additional insight was provided by Malwitz et al 2007.

6.8 References used to estimate the descent benefit pool include CAEP/7 2007, Dinges 2007, Knorr et al 2011, Robinson and Kamgarpour 2009, Shresta et al 2009. Insights into mechanisms to achieve these benefits were provided in Shresta et al 2011, Swenson et al 2011, Churchill and Hall 2012.

6.9 Ryerson et al 2011 provides insights on the relationship between various flight characteristics and fuel usage, which were useful in validating certain ideas and estimates.

6.10 References used in estimating the noise goals include: Airservices Australia 2007, Clarke 2000, Clarke et al 2004, Dinges 2007, Graham et al, 2009, ICAO 2007, Lissek 2011, Mitchell and Ekstrand 2011, Reynolds et al 2007

6.11 The SESAR and NextGen program plans have been used for determining the timing and feasibility of any specific operational enhancements, technologies, or procedures in Europe and the United States. The Aviation System Block Upgrade draft materials have been used to estimate similar capability availability for other parts of the world.

7. LIMITATIONS AND ASSUMPTIONS

7.1 This section includes a list of issues and concepts that could constitute limitations on the IEOGG analysis approach. The IEOGG has made assumptions and simplifications concerning these areas in order to support its conduct of the analyses.

7.1.1 Fuel Efficiency: As recognized by the CAEP/8 IEOGG the relationship between operational efficiency and fuel efficiency/CO2/NOx is complex. The challenges faced during the CAEP/8 processes have not yet been resolved. Thus, the IEOGG approach to emissions reduction is to assume emissions are linearly related to fuel usage so that an X% reduction in fuel usage corresponds to an X% reduction in emissions. The IEOGG believes that this approach is consistent with its broad goal-setting mission, while recognizing that in the specific case of NOx emissions, there are some specific measures that can be taken to reduce NOx that do not correspond to similar reductions in fuel usage.

7.1.2 Operational Goals May Require Technology Investments: The IEOGG goals represent savings that can be achieved by new operational practices. However, in many cases these require new technology investments on the part of both ANSP‘s and flight operators, such as those associated with NextGen and SESAR. Very specifically, it is important to note that achieving the goals require substantial reduction in taxi-in and taxi-out emissions through efficient queuing and through the eventual use of electric taxi systems.

7.1.3 Goals May Require Policy Changes: The goals, at least in part, may require changes in policies and practices, not only of ANSP‘s but also of flight operators and national states. For example, achieving certain cruise benefits may require flight operators to give higher priority to the use of fuel efficient speeds. Flight operators may also have to avoid practices that lead to excess airport congestion. Also, some cruise benefits may require that national states provide additional access to special use airspace, e.g. airspace currently reserved for military purposes.

7.1.4 Goal Interpretation: The emissions/fuel efficiency goals refer to improvement in the operational efficiency on a per-flight basis. To illustrate, the IEOGG 2040 goal could be interpreted as follows: on the average, an equivalent flight, e.g. a B737-800 from KATL to KORD, should use 9% less fuel in 2040 than the same flight would use in 2010. Specifically, these goals do not account for growth in the overall number of flights and the characteristics of a ―average” flight, which likely will become longer and use a larger aircraft. This is discussed in more detail later in the report.

7.1.5 Business Case of Stakeholders: the economic impact of implied operational changes on the various stakeholders has not been taken into account. Certain means to improve the benefit or mitigate the negative environmental impact of the air transport management system could compromise the operational business case of stakeholders, even leading to a loss of the ―livelihood of a stakeholder”. Such potential outcomes would certainly make the implementation of such operational changes a public policy challenge.

7.1.6 New-Air-Transport-Concepts: the current assumptions are based on current air travel technologies of commercial transport aircraft, e.g. fixed wing aircraft, where in the long-term new air transport solutions/concepts, e.g. lighter than air, autonomous traffic/UAV, etc. could provide even more significant reduction of environmental impact.

7.1.7 Governances: the potential evolution in air transportation business models and systems, e.g. in regional/leisure aircraft, military aviation or new security requirements, has not been taken into account. These could further impose constraints on the ATM system. Today, the current ATM system is mainly driven and designed by state authorities and under civil/economical boundary conditions. New methods for providing ATM services, e.g. privatization of ANSP services, could have a substantial impact the issues addressed in this report.

7.1.8 Inter-―Transport-Modes”-Effects: the underlying forecasts have not taken into account the potential shift in long-term transportation needs, through changes in social requirements or demands imposed through living environments, e.g. Mega-Cities. Further, the potential reduction in passenger or freight transport demand by the development into a more information driven society has not been taken into account.

7.1.9 Climate Change: Constraints imposed by emerging climate changes were not taken into account.

7.1.10 Policies Constraints: Constraints imposed by local, regional or global policies facilitating or hampering traffic growth/efficiency in operation were not taken into account.

7.1.11 Noise Impacts: The IEOGG focus is on operational measures having the potential to reduce noise through ATM operational changes of the type that are being contemplated in SESAR and NextGen. The IEOGG did not consider actions to reduce noise impacts through non-operational measures, such as land use measures, aircraft operating restrictions, curfews, up-gauging or other measures outside of the ATC arena. The IEOGG also did not consider measures that could be considered ―operational” by managing the performance of the aircraft, such as: noise abatement departure procedures, flap management, measures affecting aircraft dispatch weight (such as loading less fuel or lightening aircraft by reduction in service equipment weight, etc.), all of which have the potential to improve aircraft climb performance and, thus, potentially reduce departure noise.

7.1.12 Definition of Operational Change: The IEOGG goals represent reductions achievable by operational changes. At times the definition of an operational change versus a technology change can be a bit arbitrary. New engine technologies certainly belong in the technology arena and thus were not considered by the IEOGG. Similarly, the use of alternative fuels is being considered elsewhere and was not considered in scope. On the other hand, many operational changes require advanced avionics, e.g. ADSB; such operational changes were included in the scope of the IEOGG even though they require adoption of new technology. The use of electric taxi systems is, perhaps, the one case that most represents a ―judgment call” on the part of the IEOGG. This could clearly be classified as a technology improvement or an operational improvement. For several reasons the IEOGG included the impact of electric taxi systems within its domain. This should be taken into account when using the IEOGG goals in further analysis.

8. OPERATIONAL FUEL AND ATMOSPHERIC EMISSION GOAL DEVELOPMENT

8.1 Analysis Approach for Operational Fuel and Atmospheric Emission Goal Development

8.1.1 The IEOGG approach was devised to take advantage of a variety of recent research, demonstration projects and studies that estimate both potential benefit pools and also benefits that could be achieved using certain technologies and procedures. This work generally applies to specific operations or phases of flights. Therefore the IEOGG broke down benefits pools by phases of flight as follows: taxi-out, climb, cruise, descent and taxi-in. In some cases, as discussed below there were further refinements to each component.

8.1.2 Recognizing that both the benefit pool as well as the feasibility of operational improvement in the time horizon of interest varies by geographic region, the IEOGG broke down benefit calculations as follows. Conceptually, the surface and terminal area benefits (taxi-in, taxi-out, climb, descent) were associated with an airport and the cruise benefits with a city-pair flow. However, data and time limitations did not support a comprehensive analysis of this type. Rather, cruise benefits were associated with each of the 23 ICAO flow categories and the surface and terminal area benefits were associated with one of the six ICAO regions. That is to say, a specific goal or benefit pool was determined for the cruise phase for the ―average” flight for each flow category and a specific goal or benefit pool was determined for the terminal area and surface movements for an ―average” flight at an ―average” airport within each region. In a few cases, some limited airport level analysis was done for the U.S. and Europe.

8.1.3 The IEOGG analysis starts by establishing a maximum available benefit pool for each category of interest. This can be expressed as a maximum fraction of the 2010 emissions that could be eliminated by any operational measures within the maximum time horizon of interest (until 2040). For example, a value of .20 for descent for the Asia Pacific (AP) region indicates that the greatest reduction in the descent phase emissions that could be achieved using operational means for airports in the Asia Pacific region by 2040 is 20% of 2010 emissions. This maximum reflects the best possible and most comprehensive use of all foreseeable operational enhancements. In fact, there are many research reports available that the IEOGG was able to use in establishing such maximum values. However, as discussed in

Section 6, much of this work is specific to a region with only a small select set of regions being analysed. Thus, determining values for many regions required IEOGG estimation and judgment.

8.1.4 Once the maximum benefit pools were established the IEOGG reviewed planned and emerging operational improvements, including the plans of major programs such as NextGen and SESAR. Using this work as well as its judgment, the IEOGG estimates the portion of the maximum benefit to be set as a goal in each of the years of interest: 2020, 2030, 2040. Using the example from the previous paragraph, the IEOGG might indicate that 1/5 of the maximum AP descent pool could be achieved by 2020, 3/5 by 2030 and 4/5 by 2040. Thus, the 2020 goal would be a 4% reduction, the 2030 a 12% reduction and the 2040 a 16% reduction. The IEOGG took many factors into account in establishing these values, including the current maturity of technology and the likelihood that such technologies and procedures could be implemented in the region of interest. Again available research was used to related operational improvements to potential benefits.

8.1.5 It is important to note that the IEOGG benefit pool is defined relative to the scope of operational changes considered. For example, the benefit pool does not include potential improvements that could be achieved by the use of new engine technologies or alternative fuels. On the other hand, it does include benefits achievable by electric taxi systems and, of course, many other (more obvious) operational changes.

8.1.6 It is most common when estimating unknown or future parameter values to give upper and lower confidence limits around the actual estimate. In this report, the IEOGG provides an estimate and a lower confidence limit. The rationale for this approach is as follows. First, the goals produced are aspirational in nature and as such the IEOGG tended to push its goals toward the upper side of its interval of uncertainty. In several instances, however, the IEOGG sees scenarios in which the goals or benefit pools could be underestimated. However, there was insufficient information available to make any reasonable attempt at calculating an upper limit for a confidence range and so this was not done.

8.1.7 The final step in the process took the individual goals and aggregates them to a world-wide level. This requires appropriate traffic information so that weighted averages could be computed. Draft traffic forecasts were obtained from the CAEP MDG group. These were combined with the FESG route group forecasts. These had to be interpolated and/or extrapolated to get values for the years of interest. In order to combine fuel usage or goals by phase-of-flight one must have information regarding the length of the flight and aircraft type or at least aircraft size. To do this, per flight fuel usage and goals were computed at the route group level. The FESG route group forecasts contain information on both length of flight and also a distribution of flight lengths by aircraft size. Each flight length was mapped to an aircraft type as indicated in Table 2. Using data obtained by the application of the U.S. FAA‘s NASPAC model to actual flight plan data, fuel usage by length of flight and a distribution of fuel usage by phase of flight could be obtained. These calculations also required assumptions regarding taxi-in and taxi-out times. Region-specific average taxi-times were obtained from a variety of sources and input into the model.

Table 2: Mapping from Aircraft Size to Representative Aircraft Model

Number of Seats	**Representative Aircraft**
< 20	EMB-135
20-50	
51-100	B737-800
101-150	

151-210	B757-200
211-300	B767-300ER
301-400	A330-300
401-500	B747-400
501-600	
601-650	

8.1.8 While this process is certainly subject to approximation errors, the IEOGG believes the errors to be relatively minor given that the fuel-usage values are only required to determine the manner in which goals are averaged over route groups and phases of flight. In particular, the IEOGG recognizes that the representative aircraft used in Table 2 might not be the most appropriate, especially for future-looking analysis. It should be noted that the choice of aircraft types was limited by the availability of NASPAC aircraft models.

8.1.9 The steps just described yield goals that indicate, on a per-flight basis, percentage goals for reducing emissions relative to 2010 emission levels.

8.1.10 The IEOGG, and also the larger ATM community, recognize that even maintaining per-flight 2010 emission levels requires an improvement in ATM technology and operations relative to current practices. This is so because as traffic grows, congestion levels will increase throughout the global air transportation system. Further, as congestion increases, ATM efficiency decreases (and fuel burn increases). In fact, a simple analysis of current emission and efficiency levels indicates that the highest per-flight fuel burn and lowest per-flight efficiency occurs in terminal areas around highly congested airports and along highly congested air corridors. To reflect the improvements required, and also significance of the IEOGG goals, the IEOGG also expressed its goals relative to a static ATM scenario in which current ATM technology and procedures are held constant in the future. This is accomplished by estimating the decrease in world-wide system efficiency for 2020, 2030 and 2040. The models underlying these estimates are described in Appendix B.

8.2 Benefit Pool

8.2.1 The operational fuel and atmospheric goals express the degree to which fuel usage and emissions can be reduced by eliminating fuel-usage-inefficient operational practices. Thus, the associated benefit pool is the level of fuel-usage inefficiency.

- The IEOGG estimates the 2010 worldwide operational fuel and atmospheric emissions benefit pool to be 12.75%. This corresponds to a worldwide system efficiency level of 87.25%.

- The lower limit of the IEOGG confidence range for the benefit pool is 10.25%, which corresponds to an efficiency level of 89.75%.

8.3 Comparison to Prior Estimates

8.3.1 The size of this benefit pool is larger than the size estimated by the prior IEOGG and earlier CANSO estimates. It should be noted that IEOGG CAEP/9 took a bottom up approach that was informed by the work of IEOGG CAEP/8 and the CANSO analysis. However, IEOGG CAEP/9 computed new values based on an examination of a variety of specific research studies. Thus, the differences could result from many factors, however, some obvious reasons include:

- The IEOGG estimated the benefit pool for those regions with limited data availability, e.g. the Middle East, China and India, South America and Africa, to be larger than the pool estimated earlier. This difference was based on access to some additional data and also anecdotal evidence obtained in discussions with local experts.

- The IEOGG considers all taxi-in and taxi-out emissions to be part of the benefit pool. This is based on the potential for electric taxi systems to eliminate the majority of these emissions. It should be noted however that the IEOGG goals do not assume a total elimination of these emissions.

- The IEOGG analysis took into account recent research that estimated inefficiencies in typical cruise speed and altitude values. Consideration of this work expanded the cruise benefit pool. Since the majority of worldwide aviation fuel usage occurs during cruise, reduction in fuel usage during cruise can have a substantial impact on overall fuel consumption.

8.4 Worldwide Goals

8.4.1 The IEOGG worldwide operational fuel usage and atmospheric emissions goals are:

2020: 3.25% 2030: 6.75% 2040: 9.00%

8.4.2 The corresponding lower limits of the IEOGG confidence range are:

2020: 2.25% 2030: 4.5% 2040: 5.75%

8.5 Worldwide Goals Relative to a Static ATM System

8.5.1 The goals expressed above indicate a reduction in fuel usage/emissions relative to 2010 levels. As the previous IEOGG observed under a static ATM system, congestion levels would increase and this increased congestion would lead to less efficient operations. For example, there would be more congestion in the terminal areas and more surface congestion at airports. This would lead to more excess fuel usage on a per flight basis and an overall degradation of the worldwide system efficiency level. The IEOGG estimates that overall system efficiency would degrade by 2% by 2020 and an additional 2% in each of the succeeding decades so that the 2010 87.5% efficiency level expressed above would degrade to 81.5% by 2040. Thus the goals expressed above represent even greater emissions reductions relative to a static ATM system.

8.5.2 The IEOGG worldwide operational fuel usage and atmospheric emissions goals expressed as reductions in overall fuel usage and atmospheric emissions relative to a static ATM system are:

2020: 5.25% 2030: 10.75% 2040: 15%

8.5.3 Figure 1 expresses the degradation in efficiency level relative to a static ATM system and the impact of achieving the goal relative to such degradation.

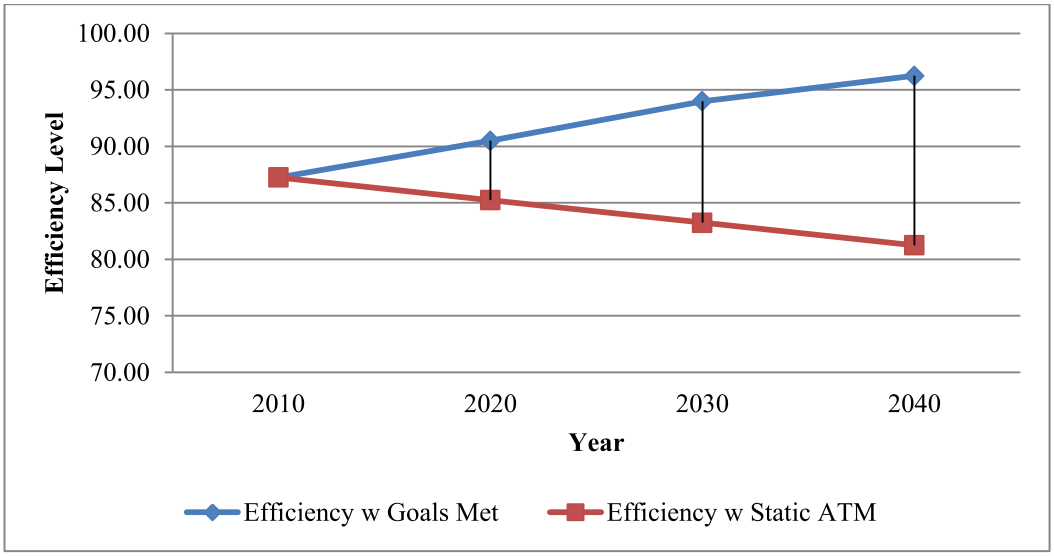

Figure 1: Goals Relative to Static ATM System

8.6 Worldwide Goals by Phase of Flight

8.6.1 The IEOGG analysis produced a benefit pool and goals for each phase of flight: taxi-out, climb, cruise, descent and taxi-in. The phase-of-flight specific goals are given below in Tables 3-5.

8.6.2 The IEOGG worldwide operational fuel usage and atmospheric emissions pools by phase of flight are:

Table 3: Worldwide Operational Fuel Usage and Atmospheric Emissions Pools by Phase of Flight

	TAXI-OUT	CLIMB	CRUISE	DESCENT	TAXI-IN
2010 Pool	100.00%	1.50%	6.25%	19.75%	100.00%
LCL	76.75%	1.25%	4.25%	15.25%	76.75%

(LCL = lower confidence limit)

Table 4: Efficiency Levels for Worldwide Operational Fuel Usage and Atmospheric Emissions Pools by Phase of Flight

	TAXI-OUT	CLIMB	CRUISE	DESCENT	TAXI-IN
2010 POOL	0.00%	98.50%	93.75%	80.25%	0.00%
LCL	23.25%	98.75%	95.75%	84.75%	23.25%

(LCL = lower confidence limit)

Table 5: Worldwide Operational Fuel Usage and Atmospheric Emissions Goals by Phase of Flight

	TAXI-OUT	CLIMB	CRUISE	DESCENT	TAXI-IN
2020 GOAL	33.50%	0.50%	1.50%	4.75%	27.25%
LCL	22.25%	0.25%	0.75%	3.25%	18.75%
2030 GOAL	62.25%	0.75%	3.50%	12.00%	50.50%
LCL	39.00%	0.50%	1.75%	7.50%	30.75%
2040 GOAL	81.25%	1.00%	4.75%	14.75%	66.50%
LCL	49.75%	0.75%	2.50%	9.00%	40.75%

(LCL = lower confidence limit)

8.7 Mechanisms Required to Achieve Goals

8.7.1 The stated goals are aspirational: the IEOGG believes that they are feasible but at the same time in order to achieve them the international aviation community must make strong and concerted efforts. To be achieved, a variety of performance enhancing mechanisms must be implemented over time. The specific mechanisms underlying the goals by phase-of-flight are given below.

- Taxi-Out: minimum engine taxi and better surface management, especially reduction in physical taxi-out queues in the near-term; electric taxi in the longer term.

- Climb: dynamic airspace configuration; denser terminal area operations, including performance-based navigation (RNAV/RNP routes); better traffic flow management, especially coordination between surface and airspace; time-based metering; trajectory-based operations.

- Cruise/speed and altitude optimization: ADS-B and datalink; better traffic flow management, especially relative to reducing overall congestion; performance-based navigation; increased carrier priority/attention to fuel-optimal speed control.

- Cruise/2-D trajectory optimization: ADS-B and datalink; better traffic flow management; improved weather information and prediction, including wind forecasts; trajectory-based operations; better access to special use airspace.

- Descent: optimized profile descents; speed control in enroute to reduce congestion in terminal in near term; time-based metering in intermediate term; performance-based trajectories and full trajectory-based operations in longer term; dynamic airspace configuration; denser terminal area operations, including performance-based navigation (RNAV/RNP routes); better traffic flow management, especially coordination between surface and airspace; ADS-B.

- Taxi-in: minimum engine taxi and better surface management in near term; in North America, some move toward common use gates in mid-term; electric taxi in longer term.

8.8 Rationale for Goals

8.8.1 Taxi-Out/In

8.8.1.1 A max value (benefit pool) of 1.0 has been set for both taxi-out and taxi-in. This indicates the possibility of a total elimination of emissions based on the potential use of electric taxi systems.

8.8.1.2 Prior to the broad availability of electric taxi systems, there are several steps that can and are being taken to reduce taxi-out/in emissions. In the U.S. departure priority is generally established by physical queues within an airport‘s taxi-way system. Recent research and demonstration projects have shown the effectiveness of various forms of ―virtual queuing” systems (see Bhadra et al 2011, Brinton et al 2011, Simaiakis, 2011). These can be used to delay push-back and/or to allow aircraft to maintain departure priority while parked away from the gate. Such methods reduce taxi-out times and emissions. In Europe the problem of taxi-out queues are less severe. This is reflected in the analysis in Gulding et al

2009 and related references. Nonetheless, there is room for some improvement in Europe through better surface management and the European airport CDM activities can reduce taxi-out times and emissions, although the extent of the reduction will be less than in the U.S. In addition to these activities it is possible to reduce emissions through the use of minimum-engine taxi. This has the potential to cut emissions in half (or more). The IEOGG recognizes, however, that this technique is already being used to a certain extent so this limits the potential for further reductions. The taxi-out/in goals for the U.S. and Europe for 2020 and 2030 are based on these arguments. The goals for other regions are based on IEOGG judgment on the potential similarity to the cases where data is available and also available statistics on average taxi times. Specifically, airports and environments in other regions of the world are matched to similar environments in the U.S. and Europe in order to achieve global estimates.

8.8.1.3 By 2040, the IEOGG believes electric taxi systems can have substantial penetration. However, universal penetration and use under all circumstances could not be achieved by 2040. Further, even with routine use of electric taxi system, complete elimination of emissions would never be achieved as there will always be some overhead in starting up and shutting down engines and the use of conventional jet power for taxi for safety and other reasons in many circumstances.

8.8.1.4 The IEOGG recognizes that there may be efficiency and/or capacity losses with the use of electric taxi systems. However, since such systems have been demonstrated to work, it is certainly possible to implement them broadly in the future and, therefore, the IEOGG believes setting goals based upon them is reasonable.

8.8.2 **Climb**

8.8.2.1 Fuel and emissions can be saved during climb by removing constraints on the vertical and horizontal profiles flights can take during the climb phase. For example, the use of level-offs increases the time required to get to top of climb and wastes fuel. The use of RNAV and RNP routes as well as dynamic airspace configuration can reduce the constraints on available departure paths and thus can improve fuel efficiency during the ascent phase. The maximum benefits were based on Roach and Robinson 2010 and Performance Review Commission 2008.

8.8.3 **Descent**

8.8.3.1 Inefficiencies in the terminal area arise from at least two sources. First, in order to organize traffic and deal with uneven flow patterns, particularly during high demand periods, various types of maneuvers, e.g. holding patterns, ―tromboning”, etc. are used. These add extra time and distance to the flight‘s trajectory. Second, for similar reasons, typical descent profiles include smooth descent portions followed by level-offs. Several recent studies have shown that substantial fuel savings can be achieved through the use of continuous idle-thrust descent procedures. The descent max value is based on several studies of inefficiencies in the terminal area and the use of various optimized descent profiles including Knorr et al 2011, Robinson and Kamgarpour, 2009.

8.8.3.2 The IEOGG recognizes that achieving the impressive benefit pool discussed above may be difficult especially in the near term due to traffic and airspace constraints in the terminal area. However, work is progressing on approaches that may be able to achieve part of the benefit pool by 2020. Multiple groups are working on the use of speed control in the enroute to transfer costly (with respect to fuel consumption) delay in the terminal area to less costly (or near-costless) delay in the enroute (see Knorr et al 2011, Moertl 2011). Longer term, the use of time-based metering and eventually a complete implementation of trajectory-based-operations coupled with RNAV and RNP routes and dynamic airspace configuration (Churchill and Hall 2012) should allow a greater portion of the benefit pool to be achieved.

8.8.4 **Cruise**

8.8.4.1 The cruise phase of flight, on average, consumes the greatest amount of fuel and thus savings here can potentially have the greatest impact. At the same time, the benefit pool generally (on a per cent basis) is less than for other phases. The IEOGG divided the cruise benefit pool into two categories based on available research. The first pool includes those savings that can be achieved through better optimization of trajectories in the X-Y plane. Two types of research are available. The first consider the deviation of trajectories from the great-circle path. The second considers the potential savings that could be achieved if flight operators had more freedom in choosing wind-optimal trajectories. Various factors influence the degree of these inefficiencies including the presence of special use airspace, jet route structure, airspace congestion as well as others. It is also the case that in order to get the full benefit of wind optimal routes that improved wind forecasts will be required. The cruise max value is based on various studies including Fujisaki 2012, Knorr et al 2011, Palopo and Windhorst 2009.

8.8.4.2 The second cruise pool includes savings that can be achieved through better optimization of flight speed and altitude. That is, given a fixed trajectory in the X-Y plane, there would be an optimal trajectory altitude and speed profile. Various factors, most notably airspace structure and traffic congestion, constrain the ability of a flight operator to achieve the most fuel efficient profile. It is also the case, that some aircraft may not be equipped to find the optimal profile, or for various reasons do not bother to seek it. Of course, there are also (perhaps many) situations where a flight operator desires to use a profile that does not minimize fuel usage, e.g. in order to meet an arrival time goal or to avoid airspace charges. The IEOGG used a recent reference (Lovegren and Hansman 2011) that established bounds on the available benefits of this type for domestic flights in the U.S.

8.8.4.3 Emerging technologies and procedures, including RNAV routes, dynamic airspace configuration, e.g. Lee et al 2011, and the use of ADS-B to reduce separation standards for Oceanic and other airspace, e.g. Ohsfeldt et al 2011 and various AIRE reports, can help achieve some of the potential benefits associated with deviation from great circle or wind optimal routing and also better speed and altitude optimization. Dynamic airspace configuration and political changes may provide access to currently off-limits special use airspace. The IEOGG uses judgment and available information on the penetration to these technologies in estimating the goals for 2020, 2030 and 2040.

8.9 Geographic Breakdown of Goals

8.9.1 The process used by the IEOGG to develop the goals involved associating taxi-out, climb, descent, and taxi-in goal with each of the six CAEP regions. Cruise goals were associated with each of the 23 CAEP flow categories. By associating regions with the end points of each flow, an overall goal was obtained for each flow. This process allows a natural geographic breakdown of the goals to be provided: i) an overall goal for each flow category, ii) taxi-out, climb, descent and taxi-in goals for each region and iii) cruise goals for each flow category. The cruise goal was further subdivided into a) better speed/altitude optimization (SPD/ALT) and b) better horizontal optimization (HORIZ) – this can be interpreted as either better adherence to great circle routes or better access to wind-optimal routes, whichever is most appropriate for the city-pair in question. This geographic breakdown of the goals is given in Tables 6-9.

Table 6: Overall Goals by Flow Category

Flow Name	**2020 Goal**	**2030 Goal**	**2040 Goal**
Domestic Africa	3.13%	6.59%	9.95%
Domestic Asia/Pacific	4.01%	8.70%	11.53%
Domestic Europe	4.35%	8.28%	11.30%
Domestic Latin America	3.33%	7.46%	10.38%
Domestic Middle East	4.00%	8.98%	11.71%
Domestic North America	4.73%	8.98%	11.41%
Europe – Africa	2.38%	5.26%	7.55%
Europe - Asia/Pacific	2.27%	4.94%	6.26%
Europe - Middle East	1.67%	4.46%	6.86%
Intra Africa	2.50%	5.24%	8.09%
Intra Asia/Pacific	2.82%	6.12%	7.82%
Intra Europe	3.41%	6.63%	9.23%
Intra Latin America	2.96%	6.83%	9.39%
Intra Middle East	3.50%	7.88%	10.26%
Intra North America	4.73%	9.27%	12.05%
Mid Atlantic	2.30%	4.90%	6.08%
Middle East - Asia/Pacific	2.46%	5.35%	6.72%
N America - Cen America/Caribbean	3.19%	6.73%	9.01%
North America - South America	2.24%	5.31%	7.15%
North Atlantic	2.33%	4.93%	6.11%
Other International Routes	2.63%	6.18%	8.42%
South Atlantic	2.12%	4.64%	5.78%
Transpacific	2.10%	4.61%	5.76%

Table 7: Taxi-Out and Climb Goals by Region

Region	2020 Taxi Out Goal	2030 Taxi Out Goal	2040 Taxi Out Goal	2020 Climb Goal	2030 Climb Goal	2040 Climb Goal
North America	42.00%	74.00%	92.00%	0.75%	1.20%	1.35%
Europe	38.00%	71.00%	90.00%	0.30%	0.60%	1.05%
Asia Pacific	30.00%	60.00%	80.00%	0.30%	0.60%	1.05%
Middle East	25.00%	55.00%	75.00%	0.30%	0.60%	1.05%
Africa	20.00%	40.00%	60.00%	0.00%	0.05%	0.10%
Latin America	20.00%	40.00%	60.00%	0.30%	0.60%	1.05%

Table 8: Descent and Taxi-In Goals by Region

	2020	2030	2040	2020	2030	2040
Region	Descent Goal	Descent Goal	Descent Goal	Taxi In Goal	Taxi In Goal	Taxi In Goal
North America	7.00%	14.00%	16.00%	35.00%	60.00%	80.00%
Europe	5.00%	14.00%	16.00%	35.00%	50.00%	70.00%
Asia Pacific	4.00%	12.00%	16.00%	20.00%	50.00%	65.00%
Middle East	6.25%	17.50%	20.00%	20.00%	50.00%	65.00%
Africa	0.00%	1.00%	3.00%	20.00%	40.00%	50.00%
Latin America	1.00%	4.00%	8.00%	20.00%	40.00%	50.00%

Table 9: Cruise Goals by Flow Category

	2020		2030		2040	
Flow Name	SPD/ALT	HORIZ	SPD/ALT	HORIZ	SPD/ALT	HORIZ
Domestic Africa	0.35%	0.35%	0.88%	0.88%	1.75%	1.75%
Domestic Asia/Pacific	1.05%	0.75%	2.10%	1.50%	2.63%	1.88%
Domestic Europe	0.18%	0.70%	1.05%	1.40%	2.10%	2.10%
Domestic Latin America	0.70%	0.70%	2.10%	2.10%	2.63%	2.63%
Domestic Middle East	1.05%	0.75%	2.10%	1.50%	2.63%	1.88%
Domestic North America	0.18%	1.00%	1.75%	1.50%	2.80%	2.00%
Europe - Africa	0.70%	0.70%	1.75%	1.75%	2.63%	2.63%
Europe - Asia/Pacific	1.05%	0.75%	2.28%	1.63%	2.80%	2.00%
Europe - Middle East	0.18%	0.70%	1.05%	1.75%	2.10%	2.80%
Intra Africa	0.35%	0.35%	0.88%	0.88%	1.75%	1.75%
Intra Asia/Pacific	1.05%	0.75%	2.10%	1.50%	2.63%	1.88%
Intra Europe	0.18%	0.70%	1.05%	1.40%	2.10%	2.10%
Intra Latin America	0.70%	0.70%	2.10%	2.10%	2.63%	2.63%
Intra Middle East	1.05%	0.75%	2.10%	1.50%	2.63%	1.88%
Intra North America	0.18%	1.00%	1.75%	1.50%	2.80%	2.00%
Mid Atlantic	1.05%	0.75%	2.28%	1.63%	2.80%	2.00%
Middle East - Asia/Pacific	1.05%	0.75%	2.10%	1.50%	2.63%	1.88%
N Amer - Cen Amer/Caribbean	0.70%	0.70%	1.93%	1.93%	2.63%	2.63%
N America - S America	0.70%	0.70%	1.93%	1.93%	2.63%	2.63%
North Atlantic	1.05%	0.75%	2.28%	1.63%	2.80%	2.00%
Other International Routes	0.70%	0.70%	1.93%	1.93%	2.63%	2.63%
South Atlantic	1.05%	0.75%	2.28%	1.63%	2.80%	2.00%
Transpacific	1.05%	0.60%	2.28%	1.30%	2.80%	1.60%

8.10 Interpretation and Insights from Fuel and Emissions Goals

8.10.1 Reference Point for Goals

8.10.1.1 The IEOGG was tasked with expressing goals for emissions reductions on a per flight basis. Further modelling, e.g. by the Modelling and Data Group (MDG), should combine these goals with traffic growth forecasts and technology goals to understand their impact on total aviation system emissions.

8.10.1.2 It is important to further dissect the exact meaning of a per-flight goal. As new ATM procedures and technologies are put in place, virtually all flights will experience a reduction in emissions. However, depending on aircraft type, flight length, origin and destination airport and other factors the amount of savings will differ. For example, the potential savings are much greater for taxi-out, descent and taxi-in than for cruise; therefore, a trans-Atlantic flight whose fuel usage is overwhelmingly dominated by cruise will experience much less savings on a percentage basis than a shorter haul flight using the same aircraft type.

8.10.1.3 To illustrate, the IEOGG 2040 goal could be interpreted as follows:

> On the average, an equivalent flight, e.g. a B737-800 from KATL to KORD, should use 9% less fuel in 2040 than the same flight would use in 2010.

8.10.1.4 When considering this interpretation, it is important to also note that the characteristics of a typical flight are changing. This issue is discussed in the next section.

8.10.2 Changes in the Characteristics of a "Typical Flight"

8.10.2.1 In the process of producing its goals, the IEOGG considered forecasts of traffic patterns and growth. Note from Figures 2 and 3 that both average aircraft size and average flight length are expected to grow between now and 2040. The net effect is that if the IEOGG goals are met then an equivalent flight will use less fuel (9% less by 2040). However, the fuel used by the average flight will grow since the average flight will be longer and will use a larger aircraft. Specifically, the fuel used by an average flight will increase from 7600 KG to 8600 KG even in the presence improved fuel efficiency associated with achieving the stated goals. Of course, that average flight will be carrying more passengers and traveling a longer distance.

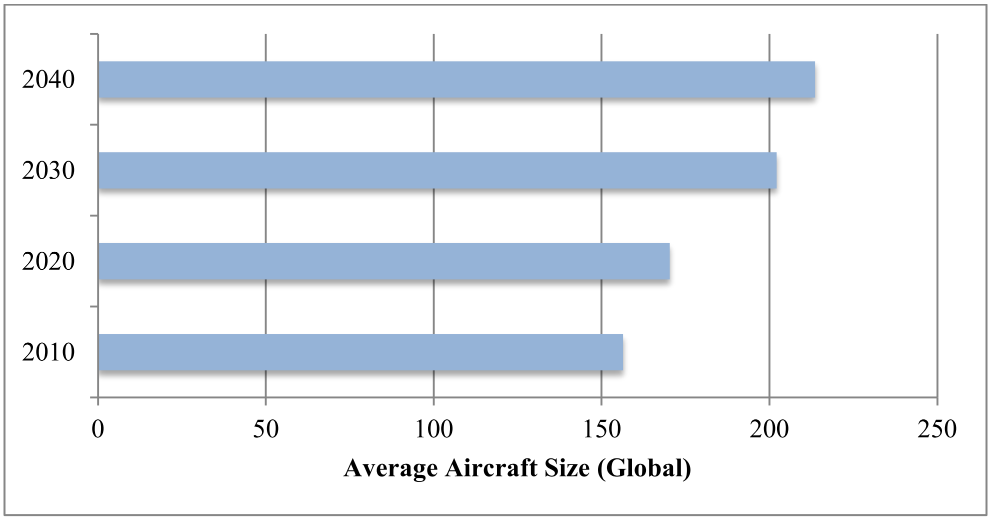

Figure 2: Growth in Average Aircraft Size

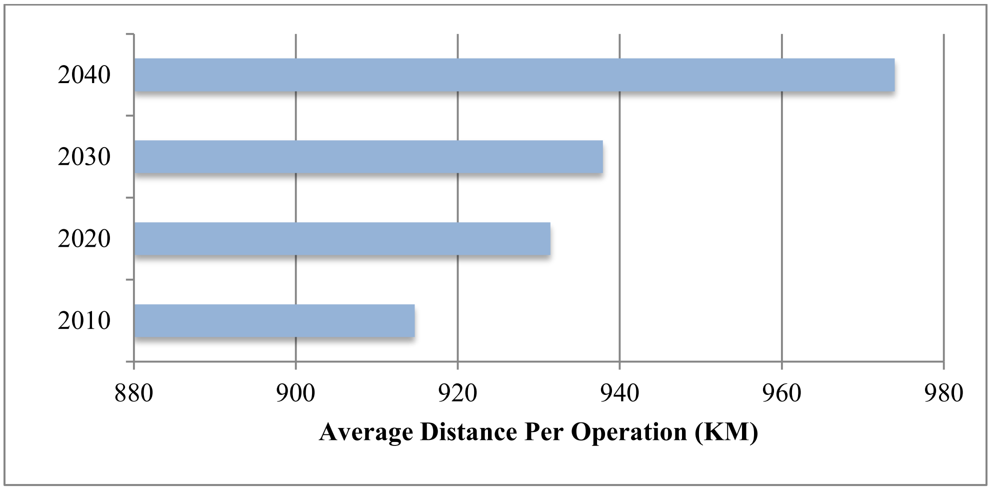

Figure 3: Growth in Average Distance per Flight

8.10.3 Fuel Usage by Phase-of-Flight and Impact on Goals

8.10.3.1 The IEOGG analytic approach broke down fuel usage and its goal calculation by phase-of-flight. Similarly, operational and technology improvements (and investments) usually apply to certain phases and not others. Thus, it is important to understand this breakdown and where improvements can have the most impact. The IEOGG estimated the world-wide average breakdown of fuel usage by phase-of-flight in 2010 to be:

Taxi-out: 4.8% Climb: 21.2% Cruise: 68.8% Descent: 2.9% Taxi-in: 2.3%

8.10.3.2 This breakdown clearly indicates the dominance of the cruise phase in fuel usage and also the very significant part played by climb. Thus, one might conclude that the role of potential benefits in taxi-out, descent and taxi-in is minimal. However, such a conclusion would be incorrect. Specifically, while cruise very much dominates long-haul oceanic flights, cruise plays a much smaller role in short haul domestic fights. Probably more importantly it should be noted that the benefit pools for taxi-out, descent and taxi-in are much larger than the pools for cruise and climb. Thus, as illustrated in Figure 4 the phases of flight that dominate the fuel savings underlying the goal are: taxi-out, cruise and taxi-in. To understand the underlying logic note that while taxi-out only represents about 4.8% of fuel consumption, as much as 80% of this fuel usage could be eliminated by 2040 through electric taxi and other mechanisms. On the other hand, while climb represents about 21.2% of fuel usage, the IEOGG judges that only 1% of this fuel usage can be eliminated by 2040.

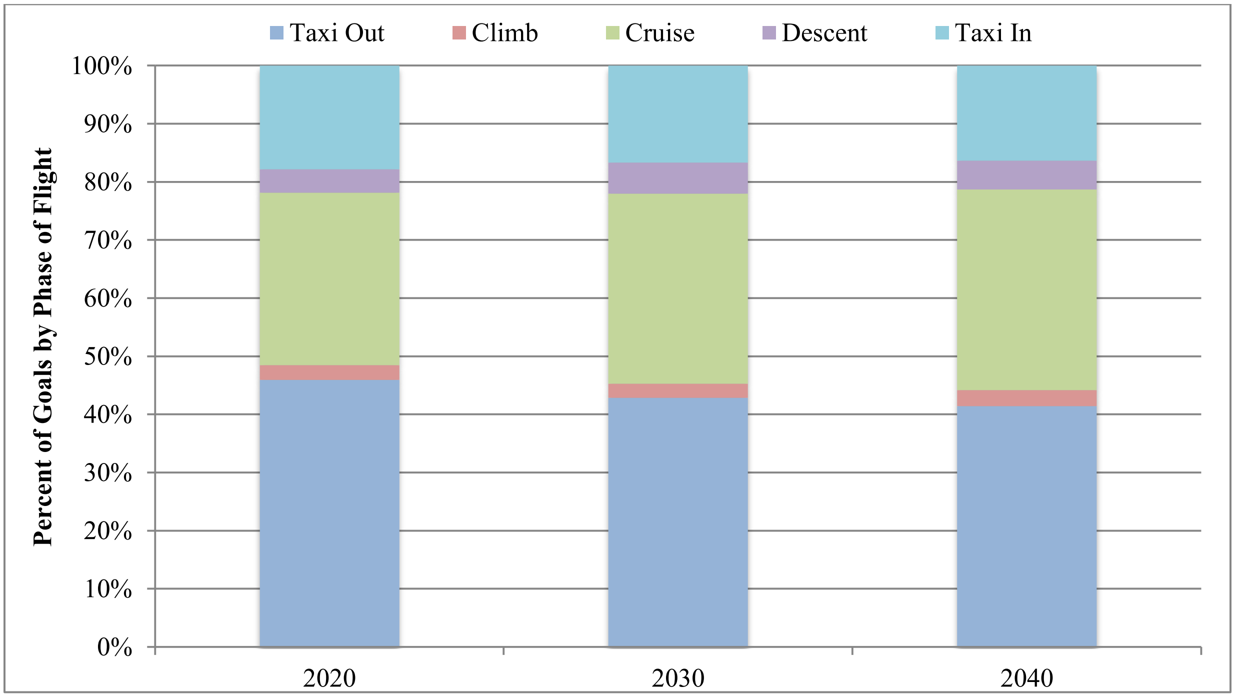

Figure 4: Distribution of Goals by Phase of Flight

8.10.4 Distribution of Fuel Usage by Flow Category

8.10.4.1 Just as it is instructive to understand how the various phases flight influence goals, it is also useful to understand how the various geographic regions and flows categories influence the goals. Figure 5 provides the distribution of fuel usage by flow category and year. Note that in 2010 the combination of Domestic and Intra North America and Domestic and Intra Europe tend to dominate. However, by 2040 Domestic and Intra Asia Pacific dominate. Note also the growth in the relative position of trans-Atlantic and trans-Pacific traffic. These trends indicate that in order to influence worldwide emissions in the long term, initiatives similar to NextGen and SESAR will be necessary for regions outside of the US and Europe.

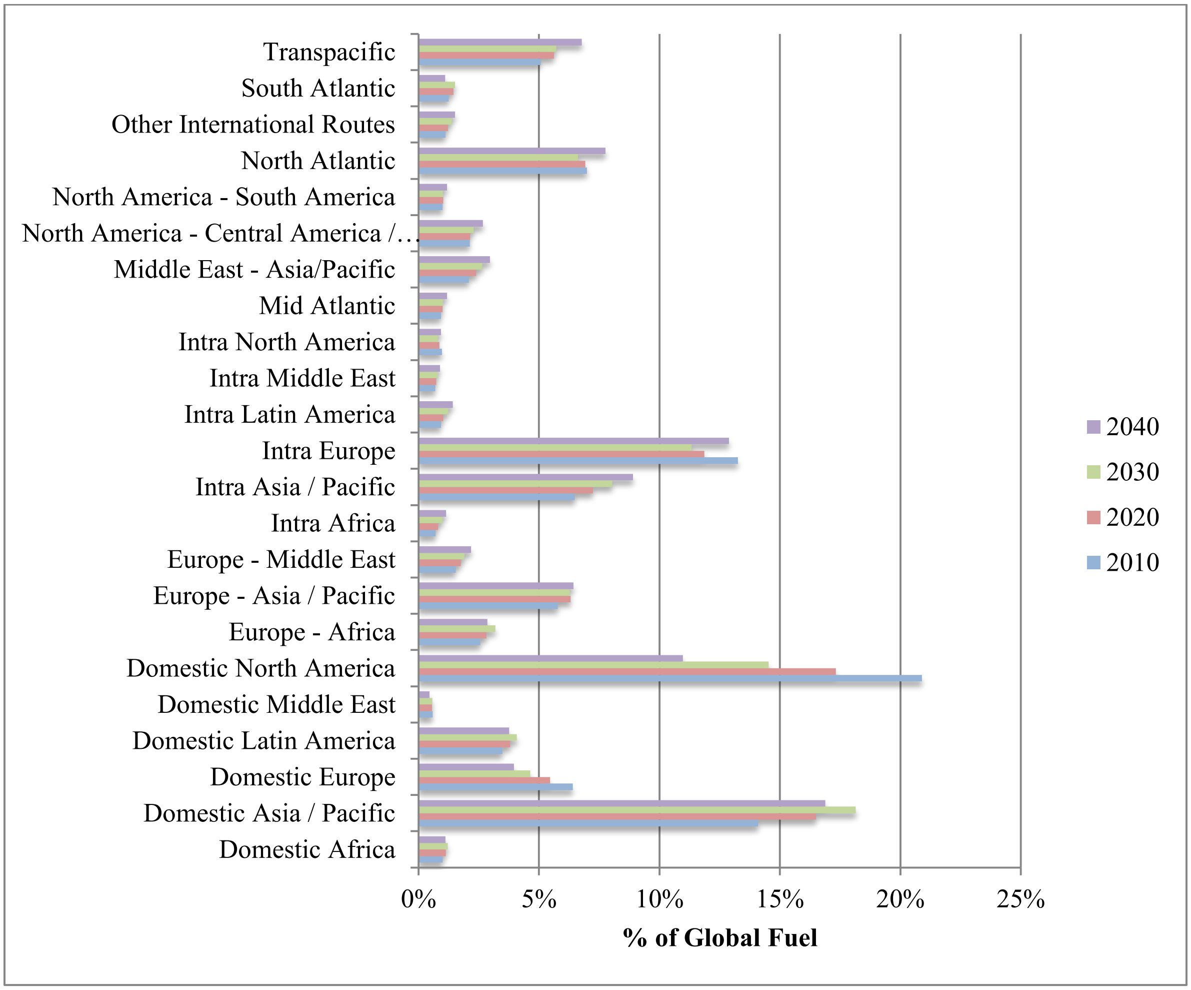

Figure 5: Fuel Usage by Flow Category

9. OPERATIONAL NOISE GOAL DEVELOPMENT

9.1 Analysis Approach for Noise Goal Development

9.1.1 As noted in the first Independent Expert Report for Operational Goals, CAEP/8-WP/12, definition of a quantitative operational noise goal is a complex exercise. Ideally, the noise impacts of any operational enhancement would be assessed using a series of cumulative model runs that are consistent with the basic CAEP modeling methodology. Population impacts and contour areas would be generated from a base-case estimate using ground tracks, vertical profiles, fleet mix and traffic levels that are consistent with other CAEP noise analyses. A second set of contours would be generated, using the same fleet and traffic level but substituting revised flight profiles or ground tracks consistent with the operational enhancements under consideration. This comparison would be done for current and future years that are consistent with other CAEP noise analysis and would indicate the population and area reductions attributable to the changed profiles and/or ground tracks compared with the base case as well as the populations affected in the future if the operational enhancements were to be employed as traffic grows according to the CAEP forecast.

9.1.2 However, such an analysis was not feasible within the scope of the IEOGG terms of reference and resources. Thus, as with approach for the fuel and atmospheric emission goal development, the IEOGG noise goal analysis approach leveraged research and studies that estimated or calculated the benefits that could be achieved using certain technologies and procedures. Unlike the circumstances surrounding the fuel goal, relevant applicable operational noise research/studies are sparse and inconclusive. Due to issues with the scalability of noise impacts, it is difficult to apply the same quantitative methodology used for fuel burn goals to determination of noise goals. The current population exposure metric has limited descriptive and predictive value for gauging public reaction to aircraft noise, the calculation of noise population exposure is locally dependent, and aggregation of a noise population exposure metric at a global level is very complex.

9.1.3 With these caveats noted, the IEOGG has focused primarily on two major factors associated with operational enhancements that could potentially impact noise:

- Placement and profile of an aircraft's flight track, which can reduce, increase, disperse or concentrate noise exposure
- Aircraft operating parameters, such as thrust and configuration, that could minimize noise output from engines.

9.2 Interpretation of Flight Track Placement Studies

9.2.1 ATC procedure changes that modify ground tracks have been shown to reduce populations impacted by noise by varying amounts, depending on the intensity of the noise impact at individual airports and the specific distributions of populations around airports and the availability of geographic features, like rural or industrial areas, rivers or oceans, over which flights can be relocated. Performance Based Navigation technologies, RNAV or RNP, can be used to enable such track placement. The advanced navigation capabilities can reduce track dispersion that usually accompanies conventional ground-based navigation, thus more precisely placing flight tracks.

9.2.2 Flight track changes to reduce noise impacts are most commonly done on departures, where there is often more flexibility to re-route aircraft traffic than on arrivals. However, there are possibilities to modify arrival tracks prior to ILS capture or through the use of shorter than normal final approach segments. Finally, preferential runway assignment programs can minimize the flights of noise sensitive areas by using tracks overflying low populations when traffic demand permits, particularly in late night hours.

9.2.3 In one dramatic example, departures from Boston-Logan International Airport (KBOS) runway 22R were re-routed over the waters of Boston harbor in 1980. The U.S. FAA environmental impact statement for the project estimated that on a typical summer day when that runway is used for all departures, the population impacted at DNL 65 would be reduced from 115,800 to either 29,300 or 27,300, depending on which alternative was selected.

9.2.4 The location of flight tracks to reduce noise impacts for either normal operations or for night time noise abatement procedures is fairly widespread, both for arrivals and departures with well-known examples at Washington (KDCA), Brisbane (YBBN), Los Angeles (KLAX) and numerous other locations. However noted in some of the available studies, the difficulty of estimating benefits was, in part, due to the fact that the studies combined CDO with flight track changes. This created a difficulty of separating the benefit of CDO from the benefit caused by flight tracks designed to reduce noise at Louisville (KSDF), Frankfort (EDDF) and Portland (KPDX).

9.2.5 Another common noise reduction technique is the use of preferential runway use programs to minimize overflight of populated areas to the extent possible. The Boeing compilation of worldwide airport noise restrictions lists 651 airports, of which 517 have some sort of noise abatement procedure and 366 have preferential runway use procedures.

9.2.6 Given the variability of geography and population distributions around airports and the fact that many airports have already taken advantage of flight track optimization to control noise, the IEOGG does not feel it is possible to quantify the operational benefits of flight track changes without an extensive examination of several hundred of the most noise sensitive airports to assess the potential for track relocations.

9.3 Interpretation of Continuous Descent Operations (CDOs) Studies

9.3.1 The IEOGG identified two studies (Clarke 2004, Dinges 2007) that expressed the benefits of CDOs in terms that were comparable to the CAEP noise modeling, total populations and areas within various Day/Night Average Sound Level (DNL) contours on an annual average. Several other studies the IEOGG reviewed combined analysis of CDOs with ground track changes, which did not permit separation of the two effects. Most of the studies expressed the noise benefit in terms of the reduction in single event (SEL) or peak (LAmax) noise levels at some specified distance from the airport. The IEOGG found one study (Clarke 2000) that calculated the populations and areas exposed to peak noise levels, which do not easily correlate with DNL. The IEOGG approach was to use the reductions reported in in these studies as the basis for estimating a goal for CDOs.

9.3.2 A study of the benefits of CDO at KSDF (Clarke 2004) used a combination of measured and modeled results. The measured results involved a relatively small number of flights and were used to validate modeling that indicated population reductions of 4.3% and 2.3% at the DNL 50 and 55 contours, respectively using INM version 6.0. The report also reported a reduction of 7% in the area of the DNL 50. Finally it reported reductions in the LAmax levels of approximately 7dBA (62.9dBA with CDO versus 69.9dBA without CDO) at a point 14 nm from the airport where the INM modeling conducted for the study indicated contours of 55 – 60 DNL would occur. The authors stated: ―Additionally, the distances where these reductions were measured also suggest that much of the benefit will accrue in communities that are further from airports than those typically considered, that is, beyond the 65 DNL noise contour."

9.3.3 A similar study by ATAC Corporation (Dinges 2007) used the U.S. FAA AEDT to model CDO and baseline approaches to LAX. The study reported modeled reduction in the area of contour values of 45, 50, 55, 60, 65, 70, 75 and 80 DNL for West flow arrivals. It also estimated the area reductions for CDO flight participation rates of 0.75, 1.75, 3.0, 4.25 and 5.0 arrivals per 15 minute time interval. The reduction in the area of DNL contours were greatest at the lower DNL values, ranging from – 20% at DNL 45, -10% at DNL 50, -7.4% at DNL 55, -5% at DNL 60 and -2.6% at DNL 65. As expected, the reduction in contour areas was greater with increasing participation rates, falling off markedly below about 3 CDO flights per 15 minute interval. The author cautions that the reductions at the very lowest DNL levels might not be perceived because the single event aircraft noise levels might be obscured by ambient noise.

9.3.4 To confirm the general trend reported in the previous studies the IEOGG reviewed the noise analysis of the Seattle/Tacoma (KSEA) ―Greener Skies" Draft Environmental Assessment, August, 2012, Chapter 6, Figure 6.1. This project involved the use of PBN to reduce the length of the downwind leg of approaches to KSEA for suitably equipped aircraft and to reduce the dispersion of ground tracks. The modeling also included OPD‘s for capable aircraft. A comparison of populations exposed to various DNL‘s during south flow shows substantial numbers of people removed from contours below DNL 60 and a small number added to contours above DNL 60.

9.3.5 Since the purpose of the U.S. FAA environmental assessment was to evaluate the environmental implications of a federal action in conformance with the U.S. National Environmental Policy Act, the KSEA Greener Skies study considered existing and alternative air traffic procedures, each of which included several elements with potential to reduce noise: CDO, concentration of flight track dispersion through the use of PBN and changing ground tracks by shortening the downwind leg. As noted, it is not possible to identify the effects due solely to CDO separately from those due to ground track relocation or decreased dispersion from this study. However, the concentration of benefits at the lower DNL levels is in general conformance with the results reported in other studies. The KSEA Greener Skies procedures also resulted in significant reductions in distance flown with corresponding benefits to fuel burn and emissions, and the new procedures were recommended for adoption. The noise analysis was performed using the U.S. FAA's Noise Integrated Routing System (NIRS) Version 6.1, which estimates populations affected by various DNL, but does not produce contours or contour areas.

9.3.6 Another study of interest was found in ―The Parametric Aircraft Noise Analysis Module - Status Overview and Recent Applications", by the German research agency DRL which conducted a model analysis of a CDO procedure with late gear extension for approaches to Portland International Airport (KPDX), runway 28L. The analysis calculated the reduction in peak single event noise levels (LAmax) from the CDO procedures at the locations of three KPDX noise monitoring stations. The results indicated that noise levels were reduced 3.3 dBA (5.8 EPNdB) at the P 05 measurement point located 28,000 feet from the runway threshold, where the overflight noise levels were about 60 dBA. For comparison, a review of the KPDX Noise Exposure Map shows the DNL 65 contour located at approximately 8,000 feet from the threshold of runway 28L. (FAR Part 150 Noise Exposure Map Update, Port of Portland, July 2010, PDX NEM Chapters 1 to 3 (2 MB). This generally confirms the results of the studies that indicate benefits of CDO well outside to DNL 65 contour.

9.3.7 The U.S. FAA environmental assessment of procedures at KSEA and the DLR modeling of results at KPDX tend to confirm the results in previous CDO studies showing the benefit from tends to occur at greater distances from the runway, well outside the DNL 65 contour.

9.3.8 The reductions in populations affected by CDO will vary depending on the population distribution around the airport, in general, and under the particular approach being considered for CDO. However the reduction in contour area is independent of population distribution and, thus, should be achievable at other airports where convention step down arrival procedures are used. It is conceivable that the population distribution within each of the DNL 50 and 55 contours at any particular airport might be skewed toward the louder or quieter edge of the contour. In this unlikely event, a 10% reduction in contour area would not necessarily result in a 10% reduction in population within that contour. However, given the large number of airports modeled for CAEP analysis, the IEOGG think it is reasonable to assume that global populations affected will be reduced in proportion to the area reduction seen in these studies.

9.3.9 Some of the reports the IEOGG reviewed identified nearby airspace constraints as an impediment to implementing CDO procedures. Given the long time span over which the IEOGG goals will be implemented, the IEOGG feel that redesign of such airspace is feasible and should not impede the long term implementation of CDO procedures.

9.3.10 Although the IEOGG only found two studies that expressed the noise benefit of CDO in terms that are directly comparable to the metrics used by CAEP (populations exposed to, and areas of various DNL contours (Clarke 2004 and Dinges), the IEOGG feel that reductions in populations impacted and contour areas on the order of 7 DNL and in areas of 7 - 10% are reasonable at the 50 – 55 DNL contours. It is the IEOGG view that the benefits of CDO can be phased in for all regions of the world.

9.3.11 In the KSDF flight tests, as with flight tests in other early studies, pilots experienced some practical difficulty in avoiding thrust spikes while conducting the CDO descent. The IEOGG feel that better performance will become achievable in the future using improved PBN procedures and FMS to better control descent profiles and thrust. Although the populations affected by CDO will vary with population distribution at different airports, the reductions in the area of the contours experiencing noise reduction will be similar for all locations. Given the large number of airports modeled in CAEP analyses, the IEOGG feel that the population distributions within the contours benefitting from CDO will, on average, reflect the reduction in area of the DNL 50 and 55 contours reported in the cited studies. Therefore the IEOGG recommend that CAEP adopt a CDO goal of a 10% reduction in both populations and areas within the DNL 50 and 55 contours through the increased use of CDO by 2040. Because the ability to conduce precise CDOs will improve with advances in equipage, the IEOGG recommend that the goal be prorated at the intermediate years according to the implementation schedule used in the IEOGG fuel burn and emissions goals.

9.3.12 While CDO offers noise reduction by minimizing the thrust application associated with step down approaches, steeper glide paths are have the potential to reduce approach noise by increasing the distance between the aircraft and the population on the ground. However, there is significant concern in the pilot community over the difficulty of managing the higher energies that will accompany significantly higher glide angles. Technical pilots (from Air Berlin, Delta and the Air Lines Pilots Association) in discussions with IEOGG members expressed very strong reservations about the ability to conduct approaches much steeper than 3 degrees.

9.3.13 A study by DLR of steeper descents conducted for Frankfurt was flight tested using a B-737-700. It examined the noise reductions achieved by increasing glide angles to as much as 5.5 degrees. The evaluation was conducted during the initial approach segment of approximately five miles in length, after which the airplane transitioned to a standard 3 degree glide slope for the final approach.

9.3.14 Given the concerns of the pilot community with flying a steep approach all the way to the runway, there is considerable doubt as to whether the benefits of approaches much above 3.2 degrees for current design turbojet aircraft will be operationally feasible. In those cases where steeper approaches may be feasible, they will probably have to be part of a two segment approach where the airplane transitions to a standard 3 degree glide path, as in this study, at distances of about 13,000 km (approximately eight miles). As with CDO, the benefit of steep approaches will be outside the normal threshold of significance (usually DNL 65) and will probably only affect the 50 or possibly the 55 DNL contour. Because the IEOGG did not find any research that quantified the benefit of steep approaches in terms of reductions in populations affected at various DNL contours or reduction in contour area, and because of the feasibility concerns with steeper approaches, the IEOGG did not include this technique in its estimation of operational noise goals.

9.4 Operational Noise Goals

9.4.1 The CAEP/9 IEOGG is in concurrence with the findings of the previous CAEP/8 IEOGG. Operational enhancements offer limited noise reduction. Aircraft/engine technology offers the primary opportunities for reducing aircraft noise. Of expected operational enhancements over the next three decades, moving aircraft ground tracks, enabled by increased use of PBN technologies, to less populated areas provides the highest potential noise benefit. It should be noted that changing flight tracks for noise reduction has the potential to increase flight distance, thus reducing fuel efficiency. The emergence of quieter aircraft technologies may provide opportunities to reduce negative fuel burn impacts of noise abatement procedures.

9.4.2 The IEOGG offers two goals:

- Reduce population exposed to significant aircraft noise around appropriate airports at suitable DNL levels by 2040, through strategic placement of ground tracks using advanced PBN technologies;

- Reduce aircraft noise 55DNL contour area, and associated exposed population, by 10% by 2040, through operational improvements such as continuous descent operations.

9.4.3 The IEOGG notes that increased aircraft performance (along with engine technology) may reduce noise impacts and design of higher climb procedures could take advantage of this capability. As stated earlier, relevant studies of the benefits of this capability were not available to the IEOGG.

9.4.4 The IEOGG also notes that other operational enhancements have more limited noise benefits than track movement. As detailed earlier in the paper, steeper approaches have significant safety concerns and operational limits. Benefits associated with concentration of routes are limited without moving away from populated areas.

9.4.5 The IEOGG further makes the following recommendations concerning future work in support of noise impacts from operational improvements:

- The ability of this IEOGG to develop quantitative goals for future noise reductions through operational means was severely hampered by the lack of relevant studies. Many of the reports that are available are studies of combinations of noise abatement techniques intended to address particular noise impacts at individual airports. They often include alternatives which blend different operational techniques, such as CDO, late flap deployment and ground track changes. There is an urgent need to conduct research that assesses the noise reduction benefits of individual operational actions in a way that permits parametric analysis of the benefit of each operational technique, isolated for all others.

- In the case of assessing CDO for CAEP purposes, a study should be conducted that uses MAGENTA to perform analysis of the populations impacted and areas at DNL 50, 55, 60, and 65 of all CAEP-modeled airports modeled using baseline flight tracks with both existing and CDO profiles.

- In the case of estimating the benefit of ground track changes, a study should be conducted that assesses the potential at all airports (or the nosiest airports) modeled by CAEP to relocate flight tracks away from populated areas. This would be a major undertaking, but could be done using individual airport population distributions and aerial photography.

9.4.6 The IEOGG is also concerned that, over a multi-decade period CAEP has relied on cumulative noise metrics to assess noise impacts, IE: the populations and area affected by given DNL contours. Despite dramatic decreases in the populations affected by DNL contours throughout the years, public opposition to aircraft noise and airport development has not abated. Respected noise researchers have raised concerns over the continued relevance of cumulative noise metrics to describe public annoyance with and reaction to airplane noise. Currently there is research underway in the FAA PARTNER program to reassess the basic relationships between community reactions to airplane noise. The IEOGG urges CAEP to support these, and other, studies into the underlying factors affecting community reaction to airplane noise in order to support the development of new metrics that more closely correlate airplane noise exposure with community reaction and opposition to airport development.

10. OTHER QUALITATIVE INSIGHTS

10.1 There are a broad set of changes in the manner in which air transportation services are provided that would have a substantial impact on fuel usage and emissions. At a very macro level, the same set of passengers could be served by say 20% fewer flights, using 20% larger aircraft. Such a shift could lead to a large reduction in fuel usage and emissions. This very simplistic view masks a wealth of challenges and details. Replacing smaller aircraft with larger ones could involve reduction in service frequency to certain city-pair markets, the elimination of service between some city-pairs, a reduction in the competition among carriers (and potentially higher fares), to name a few. Further, implementing such a change involves a major public policy challenge. The most obvious way to influence a shift toward fewer flights with larger aircraft would be through the imposition of slot controls or a reduction in slot levels at existing slot-controlled airports. It is noteworthy that many airports in Europe operate under a slot control regime whereas only a very small number do so in the U.S. The IEOGG does not take a position on the merits of policies aimed at reducing airspace demand but only points out that such policies could have a very substantial positive environmental impact. It seems clear that future debates on slot controls and related public policy options should include environmental impact within the tradeoff space considered.

10.2 There are many other flight operator business practices that have adverse environmental impact. For example, it is very often the case that the most fuel-efficient airspeeds are not used. A typical flight operator applies a complex cost model to determine the best speed. Factors such as on-time performance, crew timing constraints and the like may influence a flight operator to use non-fuel-optimal speeds. It is also the case that a flight operator may not use the most fuel efficient aircraft option to serve a city-pair market. Again, many factors might influence such a choice, including fleet limitations, fleet schedule optimization, etc. Public policy initiatives could be aimed at influencing flight operators to adopt more fuel-efficient options. Any such initiatives should recognize the complexity of the flight operator decision space and avoid the possibility of yielding unintended consequences or even inducing a counter-productive change in flight operator behavior.

11. BIBLIOGRAPHY

Aguiar, A.,G. Pelletier and J. Geraldes, L. Renou, 2010, NATCLM Project: North Atlantic ―Cruise Climb” ―Lateral Deviation” and ―Mach Number” Flight Trials Demonstration, SESAR/AIRE Report, April 2010.

Airservices Australia, 2008, RNP Project: Brisbane Green, Stage One Report. March, 2008.

Alcabin, M., R. Schwab, C. Soncrant, K-O. Tong, and S. Cheng, 2009, Measuring Vertical Flight Path Efficiency in the National Airspace System, AIAA ATIO Conference, September, 2009.

ASPIRE, 2009, 2009 ASPIRE Annual Report.

ASPIRE, 2010, 2010 ASPIRE Annual Report.

Bertsch, Lothar, Sebastien Gueriny, Gertjan Looyez, and Michael Pott-Pollenske. The Parametric Aircraft Noise Analysis Module - status overview and recent applications, German Aerospace Center (DLR), Published in: 17th AIAA/CEAS Aeroacoustics Conference(32nd AIAA Aeroacoustics Conference) 5-8 June 2011, Portland, Oregon.

Bhadra, D., D. Knorr and B. Levy, 2011, Benefits of Virtual Queuing at Congested Airports Using ASDE-X: A Case Study of JFK Airport, in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany, June, 2011.

Bourgin, A. And L. Renou, 2010, Performance of Flight Trials and Demonstrations Validating Solutions for the Reduction of CO2 Emissions: Terminal Operations Final Report (D2), Sesar Report, February, 2010.

Brinton, C., C. Provan, S. Lent, T. Prevost and S. Passmore, 2011, Collaborative Departure Queue Management An Example of Airport Collaborative Decision Making in the United States, in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany, June, 2011.

Brok, P.H.H. and L. Hoogerbrugge, 2000, Operational measures to improve aircraft fuel efficiency and reduce emissions, NLR Report NLR-CR-2000-332, November, 2000.

CAEP/7, 2007, Review of Continuous Descent Approach (CDA)

Implementation and Associated Benefits, ICAO Working Paper 26, February, 2007.

CAEP/8, 2010, Independent Expert Report for Operational Goals, ICAO Working Paper 12, 2010.

CANSO, 2008, ATM Global Environment Efficiency Goals for 2050, December, 2008.

CANSO and Boeing, 2012, Accelerating Air Traffic Management Efficiency: A Call to Industry.

Churchill, A. and W. Hall, 2012, Using Dynamic Airspace Configuration in The Terminal Area to Enable Optimal Profile Descents, ICRAT, 2012.

Clarke, J.P., Systems Analysis of Noise Abatement Procedures Enabled by Advanced Flight Guidance Technology, J of Aircraft, 37, pp. 266-273, 2000.

Clarke, J.P., N. Ho, L. Ren, J. Brown, K. Elmer, K. Tong and J. Wat, 2004, Continuous Descent Approach: Design and Flight Test for Louisville International Airport, J of Aircraft, 41, 1054-1066.

Delain, O., L. Renou and R. Onghena, 2010, Performance of flight trials and demonstrations validating solutions for the reduction of CO2 emissions: Ground Movements, Final Report (D2), Sesar Report, January, 2010.

Deonandan, I. and H. Balakrishnan, 2010, Evaluation of Strategies for Reducing Taxi-out Emissions at Airports, AIAA ATIO Conference, 2010

Dinges, E., 2007, Determining the Environmental Benefits of Implementing Continuous Descent Approach Procedures, in 7th USA/Europe Air Traffic Management R&D Seminar, Barcelona, June, 2007.

FAA, Draft Environmental Assessment for Proposed Arrival Procedures to Seattle-Tacoma International Airport Chapter 6, Environmental Consequences, August 2012.

FAA, Final Environmental Impact Statement – Departure Procedures, Runway 22 Right, Logan International Airport, March 1980.

FAA, Final Environmental Impact Statement – New York/New Jersey/Philadelphia Metropolitan Area Airspace Redesign, July 2007.

Forsberg, C., 2009, MINT, Phase 2 Report, SESAR Report, December, 2009.

Fujisaki, N. 2012, private communications on recent Metron Aviation Study on wind optimal routing.

GCC, 2012, UAE PBN Implementation Plan.

Graham, M., S. Augustine, C. Ermatinger, J. DeFilici, T. Thompson, M. Marcolini, J, Creedon, 2009, Evaluating the Environmental Performance of the U.S. Next Generation Air Transportation System Quantitative Estimation of Noise, Air Quality, and Fuel-Efficiency Performance, in 8th USA/Europe Air Traffic Management R&D Seminar, Napa, CA, June 2009.

Gulding, J., D. Knorr, M. Rose, J. Bonn, P. Enaud, and H. Hegendoerfer, 2009, US/ Europe comparison of ATM-related operational performance: An initial harmonized assessment by phase of flight, in 8th USA/Europe Air Traffic Management R&D Seminar, Napa, CA, June 2009.

ICAO, 2007, Review of Noise Abatement Procedure Research & Development and Implementation Results Discussion of Survey Results, ICAO Report, 2007.

Knorr, D., X. Chen, M. Rose, J. Gulding, P. Enaud, Phillippe and H. Hegendoerfer, 2011, —Estimating ATM Efficiency Pools in the Descent Phase of Flight: Potential Saving in both Time and Fuel," in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany June 2011.

Kuenz A and C.Edinger, 2010, Green Approaches without Trade-Off: Final Results from the Fagi-Project, 29th Digital Avionics Systems Conference, October, 2010

Lachance, L., 2011, Atlantic Interoperability Initiative to Reduce Emissions -- Performance of Flight Trials Validating Solutions tor the Reduction Of CO2 Emissions, Lot 3: The Engage Corridor

Lee, P., C. Brasil, J. Homola, A. Kessell, H. Lee, M. Mainini and T. Prevot, Benefits and Feasibility of the Flexible Airspace Management Concept: A Human-in-the-loop Evaluation of Roles, Procedures, and Tools", in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany, June, 2011.

Lissek, G, 2011, ERAT LHR D8-1 Airport noise contours and CO2 emissions results for London Heathrow, ERAT Report, September, 2011.

Lovegren J. and R. J. Hansman, 2011, Estimation of Potential Aircraft Fuel Burn Reduction in Cruise Via Speed and Altitude Optimization Strategies, Report No. ICAT-2011-03, MIT, February, 2011.

Maier, T., 2011, Atlantic Interoperability Initiative to Reduce Emissions -- Performance of Flight Trials Validating Solutions for the Reduction of CO2 Emissions, Lot 4: A380 Transatlantic Green Flights.

Malwitz, A., T. Yoder, S. Balasubramanian, G. Fleming and I. Waitz, 2007, Assessment of the impact of reduced vertical separation on aircraft-related fuel burn and emissions for the domestic United States MIT, PARTNER, REPORT N0. PARTNER-COE-2007-002.

Mitchell D. and H. Ekstrand, 2011, A CO2 versus noise trade-off study for the evaluation of current air traffic departure procedures: A case study at Gothenburg Landvetter Airport, Sweden, in Proceedings of First SESAR Innovation Days, 29th November - 1st December 2011

Moertl, P., 2011, Airline Based En Route Sequencing and Spacing Field Test Results: Observations and Lessons Learned for Extended Metering, in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany, June, 2011.

Ngo, T. and P. Moran, 2011, Tracking Emissions Tracking Emission Reductions with Demonstrations and Operations, in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany, June, 2011.

Noise contours around Brussels Airport for the year 2011

Ohsfeldt, M., T. Supamusdisukul, and T. Ngo, 2011, Capturing AIRE Demonstration Benefits: Modeled versus Perceived", in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany, June, 2011.

Palopo, K. and R. Windhorst, 2009, Wind-Optimal Routing in the National Airspace System, 9th AIAA ATIO Conference, September, 2009.

Performance Review Commission, 2008, Technical Note: Vertical Flight Efficiency, Final Report.

Performance Review Commission and the Air Traffic Organization, 2009, Strategy and Performance Business Unit, 2009, U.S./Europe Comparison of ATM-related Operational Performance, Final Report.

Performance Review Commission and the Air Traffic Organization, 2010, 2010 U.S./Europe Comparison of ATM-Related Operational Performance, Final Report, March 2012.

Post, J., 2010, FAA NextGen Benefits Estimates: Dec 2010 Update, presentation to ICAO CAEP Independent Experts Operational Goals Group, May, 2011.

RETA-CDA Consortium, 2010, RETA-CDA: Reduction of Emissions in Terminal Areas using Continuous Descent Approaches, SESAR/AIRE Report, March, 2010.

Reynolds, T., L. Ren and J.P. Clarke, 2007, Advanced Noise Abatement Approach Activities at a Regional UK Airport, Air Traffic Control Quarterly, 15, 275-298.

Roach K. and J. Robinson, 2010, A Terminal Area Analysis of Continuous Ascent Departure Fuel Use at Dallas/Fort Worth International Airport, AIAA ATIO 2010

Robinson, J. and M. Kamgarpour, 2009, Benefits of Continuous Descent Operations in High-Density Terminal Airspace Under Scheduling Constraints, AIAA ATIO Conference, September, 2009.

Ryerson, M., M. Hansen and J. Bonn, —Fuel Consumption and Operational Performance" in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany June 2011.

Schultz, T.J. —Synthesis of social surveys on noise annoyance", J Acoust. Soc. Am, vol. 64, pp 377-405.

Simaiakis, I., H. Khadilkar, H. Balakrishnan, T. G. Reynolds, R. J. Hansman, B. Reilly and S. Urlass, 2011,—Demonstration of Reduced Airport Congestion Through Pushback Rate Control", in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany June 2011.

Shresta, S., B. Hogan, P. Railsback, M. Yankey, J. DeArmon, and K. Levin, 2011, Comparison of Strategies for Continuing Time-Based Metering During Inclement Weather, in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany June 2011.

Shresta, S., D. Neskovic, and S. Williams, 2009, Analysis of Continuous Descent Benefits and Impacts during Daytime Operations, in 8th USA/Europe Air Traffic Management R&D Seminar, Napa, CA, June 2009.

Swenson, H., J. Thipphavong, A. Sadovsky, L. Chen, C. Sullivan and L. Martin, 2011, Design and Evaluation of the Terminal Area Precision Scheduling and Spacing System, in 9th USA/Europe Air Traffic Management R&D Seminar, Berlin, Germany June 2011

Toebben, Helmut H., Vilmar Mollwitz, Lothar Bertsch, Bernd Kor, Dirk Kügler. Flight Testing Of Noise Abating RNP Procedures and Steep Approaches. DLR German Aerospace Center, Institute of Flight Guidance, Institute of Aerodynamics and Flow Technology.

Transportation Research Board, 2008, ACRP Synthesis 9 -- Effects of Aircraft Noise: Research

— END —

ISBN 978-92-9249-615-9

9 789292 496159