

INTERNATIONAL CIVIL
AVIATION ORGANIZATION



**REPORT TO CAEP BY THE CAEP NOISE
TECHNOLOGY INDEPENDENT EXPERT
PANEL**

**AIRCRAFT NOISE TECHNOLOGY REVIEW
AND MEDIUM AND LONG TERM NOISE
REDUCTION GOALS**

REPORT

ICAO COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

**Report to CAEP by the CAEP Noise Technology
Independent Expert Panel**

(Revised March 2010)

**Aircraft Noise Technology Review
and
Medium and Long Term Noise Reduction Goals**

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1. Executive Summary

1.1 Introduction

In support of the work programme agreed upon at CAEP/7 for the Technology Task Group (TTG) of Working Group 1 (WG1), a panel of Independent Experts (IEP) was selected and tasked with leading a review of technologies being developed for reducing aircraft community noise in the mid term (10 years) and in the long term (20 years). A formal review was held on September 29 through October 1st, 2008, in Seattle, Washington. This review was preceded by a Noise Technology Workshop on September 26th, 2008, which was held in conjunction with, and at the conclusion of, the CAEP Steering Group meeting in Seattle. The Noise Technology Workshop consisted of policy overview presentations by the various stakeholders attending the CAEP Steering Group meeting, and included a high-level overview of the various aircraft noise reduction technology programs being conducted in Europe, the U.S., Japan, Canada, and Russia.

WG1, with approval of the Steering Group, selected the following members of the Noise Technology Independent Expert Panel:

Jean Beslon – France
Wajid Chishty – Canada
Philip Gliebe – USA
Dennis Huff – USA
Hirokazu Ishii – Japan
Yuri Khaletskiy – Russia
Brian J. Tester – UK

Mr. Gliebe was subsequently selected to chair the Panel, with assistance from Co-Chairs Dennis Huff and Brian Tester.

The Independent Experts Review consisted of detailed presentations on aircraft noise reduction, beginning with a summary of aircraft noise sources and the relative contributions of various engine and airframe-related sources to the total aircraft noise for typical aircraft designs currently in use. Presentations were given by various industry and government representatives on component noise reduction research programs, highlighting noise reduction concepts being pursued and the progress in noise reduction that has been either demonstrated or projected thus far. For the engine, component noise reduction technology status presentations were given for fan noise, jet noise, core noise, and nacelle/liner suppression. Airframe noise source reduction status was also presented, covering landing gear noise, flap and slat noise, and engine-airframe related noise sources. A presentation was also given on novel aircraft concepts, including the “Functionally Silent Aircraft.”

Other presentations included material on integration of the various components of engine and aircraft noise and their potential reductions to forecast the total aircraft system community noise impact, advanced experimental diagnostic techniques for measuring noise sources, and advanced computational techniques for predicting the behaviour of engine and airframe noise sources.

This executive summary reports the key findings and conclusions arrived at by the Independent Expert Panel (IEP) as a result of assessing the information presented at the Noise Technology Workshop and the Independent Expert Review Meetings. The

panel also developed a methodology for evaluating the potential benefits of various noise reduction technology concepts for various classes of aircraft. The panel key findings and conclusions were based on results generated using this methodology, as well as on panel member past experience, expertise and knowledge of the subject matter. The panel is grateful to members of ICCAIA who provided the presentation material and provided clarification answers to questions raised by the IEP. ICCAIA also graciously provided additional data on the performance of various noise reduction concepts so that the panel could better evaluate their impact on projected aircraft system noise.

The IEP presents herein their recommendations for potential aircraft noise reductions that can reasonably be expected in the mid term (10 years), and in the long term (20 years), relative to today's in-service aircraft.

1.2 Background

Civil aviation is an integral and essential part of modern society, provides goods and services, and facilitates industrial, commercial, and social developments globally. Civil aviation operations are projected to continue to grow in the foreseeable future, thus potentially increasing the airport surrounding community population to objectionable levels of aircraft takeoff and landing noise. The current fleet of commercial aircraft consists of older, noisier Chapter 3 aircraft and newer, quieter aircraft that meet Chapter 4 limits. Note that it is currently projected that as the older aircraft are retired and replaced by newer aircraft, the increase in traffic growth will probably negate the benefits of increasing the percentage of newer aircraft, and the noise exposure and noise contour areas containing objectionable noise levels will still increase as a function of time.

It is therefore important to continue development of quieter aircraft, so that the civil aviation industry can continue to grow to meet the demands while still maintaining or even reducing the population exposed to objectionable noise.

1.3 Remit

WG 1 had assigned the following work item 29 to the Technology Task Group (TTG):

Using the independent expert process, to examine and make recommendations for noise, with respect to aircraft technology and air traffic operational goals in the mid term (10 years) and the long term (20 years).

The Independent Expert Panel (IEP) was directed to carry out the following, per CAEP-Memo/70, Attachment A, dated 1/4/08 (IEP1.1):

“Based on the material reviewed by the IE Panel, the report should:

- “Summarize the status of technology developments for aircraft noise reduction that could be brought to market within 10 years from the date of review, as well as the 20-year prospects for noise reduction suggested by research progress, without disclosing commercially sensitive information;

- “Assess the possibility of success for each technology, based on experience from past research and development programs;
- “Comment on the environmental, efficiency, and other economic tradeoffs resulting from adopting the candidate noise reduction technologies;
- “Define a noise level baseline; and
- “Recommend mid term and long term technology goals for reducing aircraft noise relative to the defined baseline.”

There are three primary approaches to reducing aviation noise exposure:

1. Reducing the noise at the source;
2. Noise abatement operational procedures; and
3. Land use planning.

The remit of the Panel was to primarily address the first, reducing noise at the source. However, some information was provided to the Panel regarding noise abatement procedures, and so, insofar as possible, the Panel has made qualitative assessments of the additional benefits of noise abatement procedures.

1.4 Aircraft Category Selection and Considerations

There was considerable discussion as to what classes of aircraft the Panel should consider in carrying out the assessment, as described in the remit above, as the Panel was requested to select a baseline from which to evaluate potential noise reductions and mid- and long-term technology goals. At the request of the WG1 Technology Planning Committee, a study was carried out by MODTF to evaluate the most important categories of aircraft in the fleet today, from the standpoint of their impact on population exposure. A summary of the MODTF study was provided to the Panel and Planning Committee, documented in Reference IEP1.2, which showed that aircraft in seat classes from 101-150, 151-210, 211-300, and 301-400 seats accounted for 86% of the noise energy exposure at Takeoff, and 84% at Approach. These results are summarized in Table 1.3.1 below, taken from Reference IEP1.2.

Table 1.4.1: Noise energy contribution by seat class

Seat Class	Number of Seats	T/O Energy Contribution (%)	APP Energy Contribution (%)
1	<20	1.3%	1.5%
2	20-50	0.9%	3.1%
3	51-100	0.9%	2.2%
4	101-150	13.2%	20.2%
5	151-210	18.8%	17.2%
6	211-300	36.2%	31.1%
7	301-400	17.8%	15.6%
8	401-500	10.9%	9.0%

The Panel concluded that seat classes 3 through 7 were of most importance. Further discussions with the WG1 Planning Committee resulted in the following guidelines for focusing the Panel assessments:

- Business jets, seat class 1, were dropped from further consideration, based on the MODTF results summarized in Table 1.4.1, and at the recommendation of the WG1 Planning Committee.
- Regional jets with completely new designs are not likely to be introduced in the mid-term (2018). Rather, modest redesigns, with additional noise reduction features will most likely be introduced as they become mature. Regional jets are not likely to have bypass ratios greater than 10 in the mid-term time frame, but the noise reduction technology benefits are likely to be comparable to those for short-medium range twin aircraft. However, some noise reduction technologies applicable to small-medium range aircraft may not be applicable to regional jet engines because of the difficulty in incorporating them in small engine sizes.
- Long range 2-engine (twin) and 4-engine (quad) aircraft in the mid-term (2018) are likely to have the same acoustic performance as the current project aircraft already entered into the “Best Practices Database”, and these entries should be representative of what is achievable in the mid-term.

1.5 Selection of Reference Aircraft

The IE Panel settled on four classes of aircraft, based on the MODTF study results and WG1 guidelines, for the purpose of recommending noise reduction goals in the mid- and long-term. These were as follows:

1. Regional Jets (RJ)
2. Short-Medium Range Jets (SMR2)
3. Long Range Twin Jets (LR2)
4. Long Range Quad Jets (LR4)

A study was made of the current Best Practices database noise levels for each of the above aircraft categories. Noise levels relative to ICAO Annex 16 Chapter 4 were studied as a function of certified Maximum Takeoff Gross Mass. From these data analyses, it was observed that various models of aircraft designs certified over the years exhibited an increasing cumulative noise level as the aircraft grew in capacity (MTOM) to meet customer requirements. For some aircraft categories, deviations from the nominal trends were identified which could be related to either introduction of non-optimum noise reduction features for specific customer requirements, or more advanced design features not present in other aircraft in the same category. Taking into account these deviations from common design practice, the Panel arrived at the following reference cumulative levels relative to Chapter 4, for the four aircraft categories listed above:

Table 1.5.1 – Reference Aircraft Take-off Weight and Noise Levels

Aircraft Category	MTOM, tonnes	Cum Level re: Ch. 4,
Regional Jet	40	-4 EPNdB
Small-Med. Range Twin	78	-5 EPNdB
Long-Range Twin	230	-6 EPNdB
Long-Range Quad	440	-5 EPNdB

The IE Panel, based on the Best Practices Database from which the reference aircraft were derived, and based on the recommended maximum range of bypass ratios provided by ICCAIA for the mid- and long-term, developed the following average bypass ratio variations from reference to mid-term to long-term aircraft designs:

Table 1.5.2 – Potential Engine Bypass Ratio Variations

Aircraft Category	Reference BPR	Mid-Term BPR	Long-Term BPR
Regional Jet	5	7 ± 1	9 ± 1
Small-Med. Range Twin	5	9 ± 1	10 or 11 ± 1*
Long Range Twin	6	10 ± 1	11 ± 1
Long Range Quad	5	9 ± 1	11 ± 1

*BPR = 10 for low-wing aircraft, BPR = 11 for high wing aircraft

The Panel used their judgment in selecting the most likely Bypass Ratios (BPR) for each aircraft category, which did not necessarily reflect the maximum BPR values provided by ICCAIA. The Panel considered the likelihood of achieving the maximum bypass ratios provided by ICCAIA, taking into account the impact of design trade-offs involving higher pressure ratio core technology, nacelle diameter increases and attendant weight and drag issues, and operational complexities associated with larger fan operating line shifts between take-off and high altitude cruise.

1.6 Pilot Studies

The Panel also requested that the WG1 industry members provide some sample aircraft noise estimates for a couple of bypass ratio scenarios and for a couple of Advanced Noise Reduction Technology package installations, to supplement the information provided in the IE Review. This information, referred to as “pilot studies,” provided by two aircraft manufacturers for a “Short-Medium Range Twin” virtual platform aircraft, gave the Panel critical information needed to assess the separate effects of Advanced Noise Reduction Technologies and Increased Bypass Ratio, as well as assess the likely uncertainty in the noise reduction benefits due to Advanced Noise Reduction Design Feature package variations, Bypass Ratio variations, and manufacturer implementation variations. In addition, the IE Panel carried out an independent “pilot study” of the impact of increasing bypass ratio for a sample short-medium range twin aircraft, using a proprietary empirical correlation method. Results from this study confirmed the impact of increasing bypass ratio for the two pilot studies provided by the aircraft manufacturers, and provided a process for establishing trend lines as a function of bypass ratio.

The results from the above pilot studies, review of past NASA advanced engine studies from the NASA AST Program, and analysis of CAEP Best Practices Noise Database information, were used to develop estimates of the impact of BPR on aircraft noise for each category, using the BPR increases indicated in the above table.

1.7 Conclusions & Recommendations

The following summarizes the conclusions and recommendations arrived at by the IEP, relative to the above CAEP-requested remit for the Panel.

1.7.1 Mid Term – Year 2018

The Panel concluded that there are two major approaches to reducing aircraft noise that can contribute to both mid term and long term noise reduction goals. These are: (1) Advanced Noise Reduction Technology (NRT) Design Features for the various components of both the propulsion system and the airframe, and (2) Advances in propulsions system design which provide Increased Bypass Ratio (BPR) and therefore lower exhaust velocities.

The Panel therefore focused on these two approaches. It was concluded that, for current aircraft propulsion systems, jet exhaust mixing noise is a dominant contributor to the total propulsion system and aircraft noise at takeoff, and that the most effective approach to reducing jet mixing noise is to increase bypass ratio. The panel therefore requested and received input from the Working Group 1 (WG1) planning committee an estimate of the range of bypass ratios that are likely to be developed (or at least considered) for the mid term and the long term, for several classes of aircraft. In addition, the Panel developed a set of trend lines which provided guidance on the amount of noise reduction that can be achieved for these various classes of aircraft, and used these trend lines to infer how much noise reduction might be possible based on bypass ratio improvements alone, and then with advanced noise reduction design features included.

Figure 1.7.1 illustrates the effects of Bypass Ratio (BPR) and the addition of Noise Reduction Technology (NRT) packages, for several case studies for the small-medium range twin (SMR2) category of aircraft. Results are shown in terms of cumulative noise level as a function of BPR. Similar BPR trends were derived for the individual certification points (Approach, Flyover and Lateral) as well. From these results and analyses of data from other aircraft classes, the Panel arrived at the Noise vs. BPR projection/trend lines shown in figure 1.7.1. Note that Pilot Study 3 excludes any NRT evaluations.

Following an assessment of the various Advanced Noise Reduction Technology (NRT) Design Features currently under development, as reported in the Review, it was concluded that NRT can provide small but not insignificant reductions in total aircraft system noise at takeoff, and that the increasing Bypass Ratio (BPR) provide a substantial improvement in takeoff noise. For approach noise, the Increased BPR benefits are not as great as at takeoff, but the NRT features have a more substantial benefit at approach than at takeoff. Estimated NRT benefits on cumulative noise level re: Chapter 4 limits are also shown in figure 1.7.1 for several of the pilot/case studies.

From the above-described information, the following aircraft noise reduction technology goals are recommended for the Mid-Term (year 2018), relative to current Best Practice Database reference aircraft average noise levels (see section 1.5), for consideration by CAEP.

**Table 1.7.1 - Mid-Term Goals – Year 2018 EPNL Noise Reductions
(Relative to Current Reference Aircraft)
(BPR + NRT = Total)**

Aircraft Category	Approach	Flyover	Lateral	Cumulative (TRL 6)	Cumulative (TRL 8)
Regional Jet	0.5+1.5=2.0	2.0+1.5=3.5	3.5+1.0=4.5	6.0+4.0=10.0	9.0
Small-Med. Range Twin	1.5+2.0=3.5	4.0+2.0=6.0	6.5+1.5=8.0	12.0+5.5=17.5	16.0
Long Range Twin	1.5+2.0=3.5	3.5+2.0=5.5	5.5+1.5=7.0	10.5+5.5=16.0	14.5
Long Range Quad	1.5+2.0=3.5	4.0+2.0=6.0	6.5+1.5=8.0	12.0+5.5=17.5	16.0

The goals at each condition plus the first column of cumulative figures listed in Table 1.7.1 are based upon NRT benefits at TRL6. Note that these are goals, not recommended rule limits. They are based on noise reduction benefits at a Technology Readiness Level of TRL6. Noise reduction technology realization factors, economic system trade-offs, etc., may preclude achieving these goals.

To estimate the corresponding cumulative figures at TRL8, a realization factor of 0.9 (90%) was applied to the TRL6 projected noise reduction benefits (relative to the selected 2008 baseline aircraft for each category) to bring the goal to TRL8. The selection of 90% realization factor was the best estimate the IEP could make based on information available and Panel member experience.

It is recommended that an in-depth analysis of realization factor be conducted as a work item for CAEP/9.

Short/Medium Range Twin Noise Reduction, Cumulative showing IEP deduced Mid & Long term BPR & NRT (TRL6) trends*

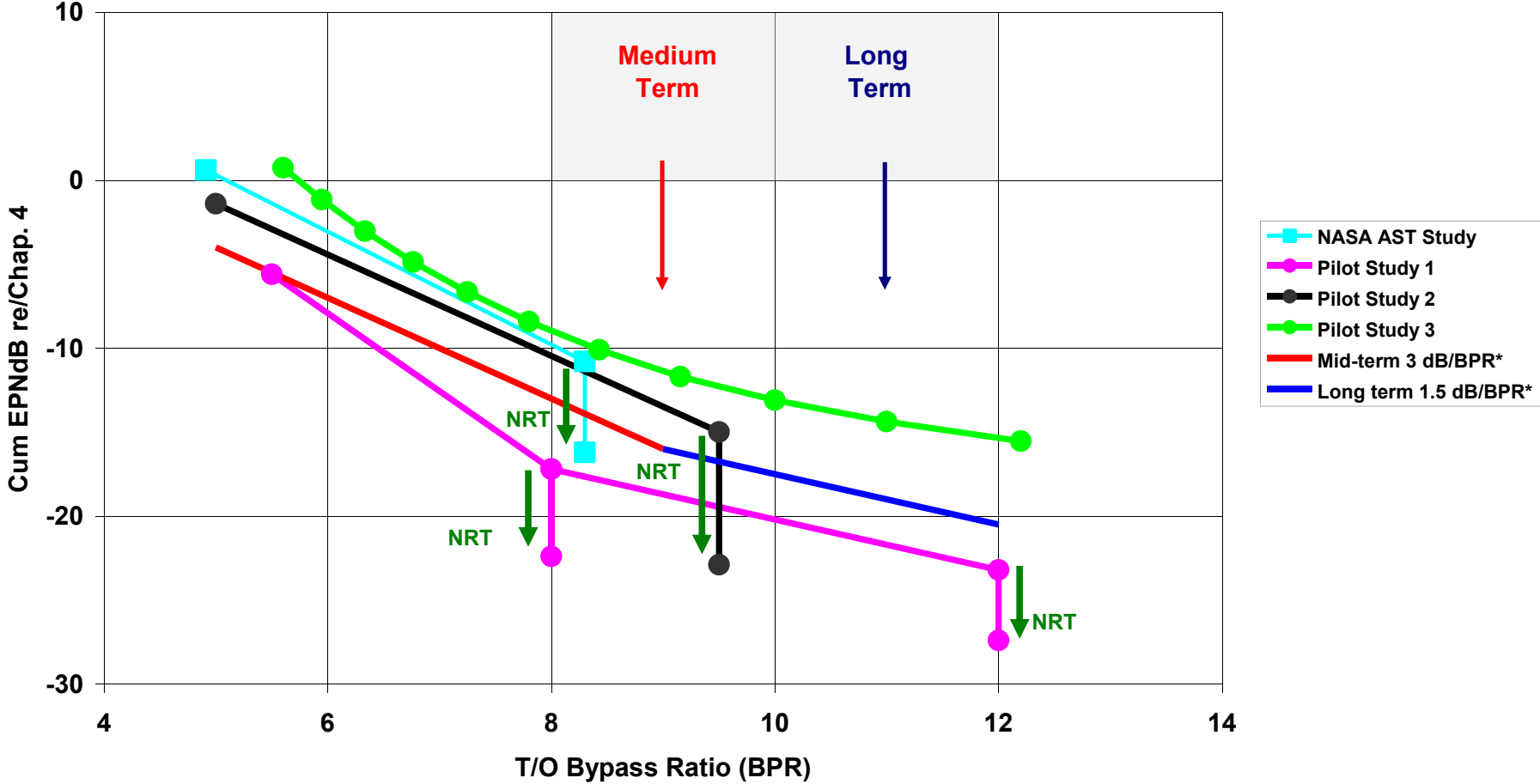


Figure 1.7.1: Short/Medium Range Twin cumulative margin noise trend with BPR (Note Pilot 3 does not include NRT)

1.7.2 Long Term – Year 2028

In addition to advances in conventional aircraft configurations that might occur, novel concepts such as the Blended-Wing-Body (BWB) aircraft, Open-Rotor Fan Propulsion, and the Functionally Silent Aircraft were reviewed by the Panel, to the extent that quantitative information was available. It was concluded that the Blended Wing-Body (BWB) aircraft concepts and the Functionally Silent Aircraft concept were at too low a Technology Readiness Level to become viable products by 2028, and so the Panel conclusions and recommendations are based on conventional Wing-and-Tube aircraft architecture. The Panel concluded that propulsion systems could potentially achieve larger bypass ratios than has been considered for the mid-term, based on input from the WG1 Planning Committee and individual ICCAIA member representatives.

From the above-described information, for the Long Term (year 2028), the following aircraft noise reduction technology goals, relative to current Best Practice Database reference aircraft noise levels, are recommended for consideration by CAEP:

**Table 1.7.2 - Long-term Goals – Year 2028 EPNL Noise Reductions
(Relative to Current Reference Aircraft)
(BPR+NRT=Total)**

Aircraft Category	Approach	Flyover	Lateral	Cumulative (TRL 6)	Cumulative (TRL 8)
Regional Jet	1.5+2.0=3.5	4.0+2.0=6.0	6.5+1.5=8.0	12.0+5.5=17.5	16.0
Small-Med. Range Twin	2.0+2.5=4.5	4.5+2.5=7.0	7.0+2.0=9.0	13.5+7.0=20.5	18.5
Long Range Twin	2.0+2.5=4.5	3.5+2.5=6.0	6.5+2.0=8.5	12.0+7.0=19.0	17.0
Long Range Quad	2.0+2.5=4.5	4.5+2.5=7.0	7.0+2.0=9.0	13.5+7.0=20.5	18.5

The cumulative noise goals listed in Table 1.7.2 are at TRL6 and at TRL8, where the latter has been estimated from the former by assuming a 90% realization factor, as for the Mid-term.

1.7.3 Noise Reduction Benefit Goal Uncertainty

A statistical analysis of several advanced aircraft system noise benefit studies was carried out by the Panel, utilizing the above-mentioned pilot study results and results from the recently published NASA Advanced Subsonic Transport System Noise Reduction Benefits Study. The analysis considered both the variation in BPR benefits and NRT benefits, due to variations in aircraft class/size, prediction methodologies, types of technology concepts considered, and differences in manufacturer design selection. The resulting uncertainties were derived as standard deviations from average characteristics, and have been summarized in Table 1.7.3 below.

Table 1.7.3 - Estimated Cumulative EPNL Noise Reduction Goal Uncertainty Bands (One Standard Deviation)
(±BPR / ±NRT / ±Total)

Aircraft Category	Mid-Term	Long-Term
Regional Jet	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3
Small-Med. Range Twin	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3
Long Range Twin	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3
Long Range Quad	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3

The above noise reduction goal uncertainties are to be applied to the nominal (but aggressive) goals given in Tables 1.7.1 and 1.7.2, for Mid-Term and Long-Term goals, respectively. Note that, within the limited database and study results available, the uncertainty bands are the same for all the vehicle classes considered.

The projections in this report are based on best available information on the potential benefits of noise reduction technologies and expected future vehicle configurations. Specific noise reduction technologies have been used in the IEP evaluation that can be realistically be implemented in the mid and long term timeframes. However, the marketplace will determine which technologies are actually selected for a particular vehicle. So while the results in this report show what can be done, what actually happens over the next ten and twenty years will depend on factors well beyond the scope of this study. This is why there will continue to be significant variations in noise levels for aircraft within a vehicle class that may either fall short or exceed the projections.

The above noise reduction goals assume propulsion systems with ducted fans. However, based on the information provided at the IE Review concerning Open Rotor Propulsion systems and their potential fuel burn advantage, the IE Panel recommends that a follow-on review of Open Rotor technology be carried out when sufficient information and data are available, to evaluate the trade-offs between noise and fuel burn.

It should also be noted that the Panel focused on two- and four-engine aircraft with wing-mounted, under-the-wing engine installation “wing-and-tube” configurations. The pilot studies carried out by the aircraft manufacturers and the Panel, as well as the NASA AST studies, all assumed this type of aircraft architecture.

1.7.4 Final Noise Reduction Goal Recommendations Summary

From the Noise Reduction Benefit goals summarized in Tables 1.7.1, 1.7.2 and 1.7.3, the resulting noise Reduction Goals referenced to ICAO Annex 16, Chapter 4 were evaluated. This evaluation included incorporating the reference aircraft noise levels relative to Chapter 4 from Table 1.5.1, and selecting a representative maximum Take-off mass for each category, listed in Table 1.5.1.

It was recommended by the ICCAIA members of the WG1 N29 Planning Committee that the Panel apply a “realization factor” to the recommended Noise Goal levels, to recognize the likelihood that some of the projected noise reduction concept benefits would erode as they are designed into a production aircraft system, and to recognize that there is an erosion in aircraft noise performance as it progresses from a TRL6

design definition to final aircraft certification. The ICCAIA recommendation was to add 5 EPNdB to the Panel TRL6 Noise Goal Levels to account for these effects. This correction represents the possible loss in noise benefits due to design compromises made as the design definition matures to a certifiable configuration, and due to certification flight test variability and uncertainty.

After several discussions with the WG1 N29 Planning Committee members, the Panel felt collectively felt that it was still unclear as to what parts of the above-described realization factor causes have already been taken into account in their goal assessments and the uncertainty analysis that had been carried out. However, the Panel recognizes that a realization factor should be applied to the noise reduction benefits associated with both the Bypass Ratio benefits and the Noise Reduction Technology benefits that result from design implementation from TRL6 demonstration to final manufactured product certification.

Therefore the Panel chose to apply a % realization factor to the cumulative noise benefit for each aircraft category. The factor chosen was 90%, i.e., 90% of the cumulative noise benefit demonstrated at TRL6 is estimated to be realized at aircraft certification. This factor was based on very little quantitative data, and the Panel used what little information it had available, plus several Panel members' past experience in choosing the above value of realization factor. The Panel therefore recommends that an in-depth study of "Realization Factor" be the subject of a future CAEP work project, as a step toward improving the goal forecasting process established in the present Panel Review effort. This study could include quantifying the effects of aircraft category, certification point (not just cumulative level), and Bypass ratio.

The Panel therefore offers the following Noise Goal levels, in cumulative noise level EPNL, relative to Chapter 4, with the understanding that they are based on TRL8 Noise Reduction Technology Benefits. It is important that CAEP realize that they are based on a somewhat arbitrary estimate of the realization factor employed to project benefits from TRL6 to TRL8. The Goal Levels given below in Table 1.7.4 have an uncertainty in their estimates, as described in section 1.7.3 above. Therefore an uncertainty band around the goal was estimated using the standard deviation values in Table 1.7.3, multiplied by a factor of 1.282 to yield an 80% confidence interval. Thus the band represents the range within which there is 80% probability that the goal can/may be achieved.

Finally, it is known that an aircraft initially certified will potentially be certified and offered in either higher or lower maximum take-off weights (or MTOM) during the life cycle of the aircraft design. The average MTOM variation is typically on the order of $\pm 25\%$ of the initial certification MTOM. Further, from studies of the existing Best Practices Noise Database, the N24 Task Group of WG1 carried out a multivariate regression study of certified noise levels as a function of various aircraft and engine parameters listed in the Database. The N24 study found that, on the average, cumulative noise levels varied as $\sim 67 \times \log_{10}(\text{MTOM})$. The N24 task group recommended that the IEP use this sensitivity of noise on MTOM to graphically show how an aircraft goal noise level might vary over its likely MTOM range of $\pm 25\%$.

Table 1.7.4 below gives the Panel recommendations for TRL8 Cumulative Noise Goal Levels relative to Chapter 4 Limits.

**Table 1.7.4 – Mid-Term and Long-Term Noise Goal Recommendations
Cumulative EPNL re: Chapter 4 Limits at TRL8**

Aircraft Category	Mid-Term (2018)	Long-Term (2028)
Regional Jet	13.0±4.6	20.0±5.5
Small-Med. Range Twin	21.0±4.6	23.5±5.5
Long-Range Twin	20.5±4.6	23.0±5.5
Long-Range Quad	21.0±4.6	23.5±5.5

These goals, their uncertainty bands, and their expected variation with changes from initial certification MTOM, are illustrated in figures 1.7.2 and 1.7.3, for Mid-Term and Long-Term, respectively.

It should be noted that the summary goals in figures 1.7.2 and 1.7.3, although shown for specific Maximum Takeoff Mass (MTOM) values (see Table 1.5.1), are meant to illustrate the goals given in Table 1.7.4 for example aircraft weights in each representative aircraft family. Table 1.7.4 is applicable to other new design aircraft MTOM's in the representative aircraft families listed in Table 1.7.4.

The Bypass Ratio Trends for the SMR2 aircraft in figure 1.7.1 have been repeated below as figure 1.7.4, but with the TRL6 goal levels of Tables 1.7.1 and 1.7.2 included. It can be seen that the goals are consistent with the various TRL6 Pilot Study results.

1.7.5 Noise Abatement Operational Procedures Goal Benefits

The potential benefits of advanced Noise Abatement Operational Procedures were evaluated by the Panel, based on information provided at the Independent Experts Review. The Panel assessed that the landing or approach condition was the most likely candidate for application of advance Noise Abatement Procedures (NAP's).

*It seems possible to provide an additional 3 EPNdB reduction
in aircraft noise level at Approach.*

This would offset the somewhat smaller noise reductions forecast for Approach noise resulting from increasing BPR and adding NRT packages.

Medium Term (2018) Cumulative Noise Goals

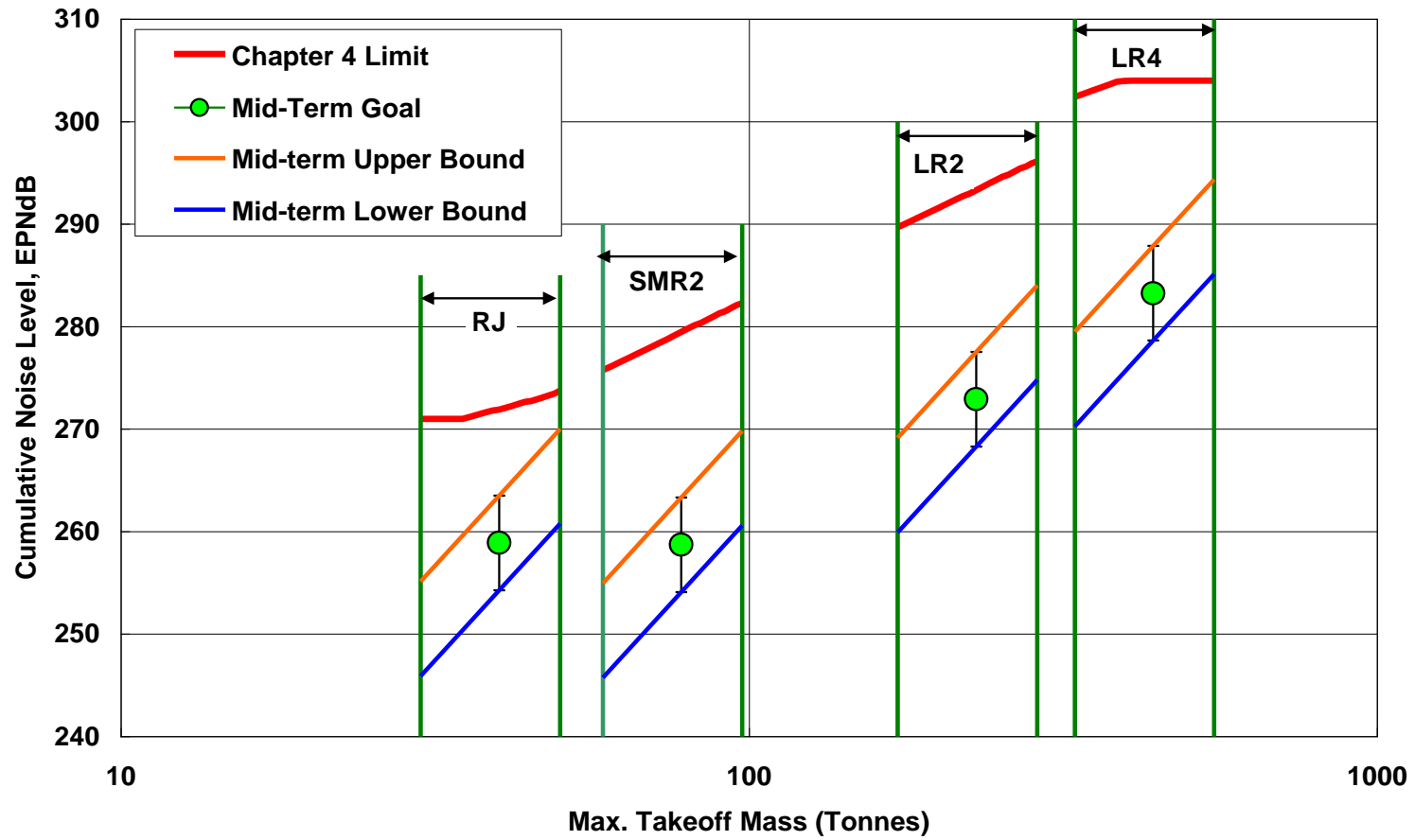


Figure 1.7.2 – Mid-Term Aircraft TRL8 Noise Goal Summary

Long Term (2028) Cumulative Noise Goals

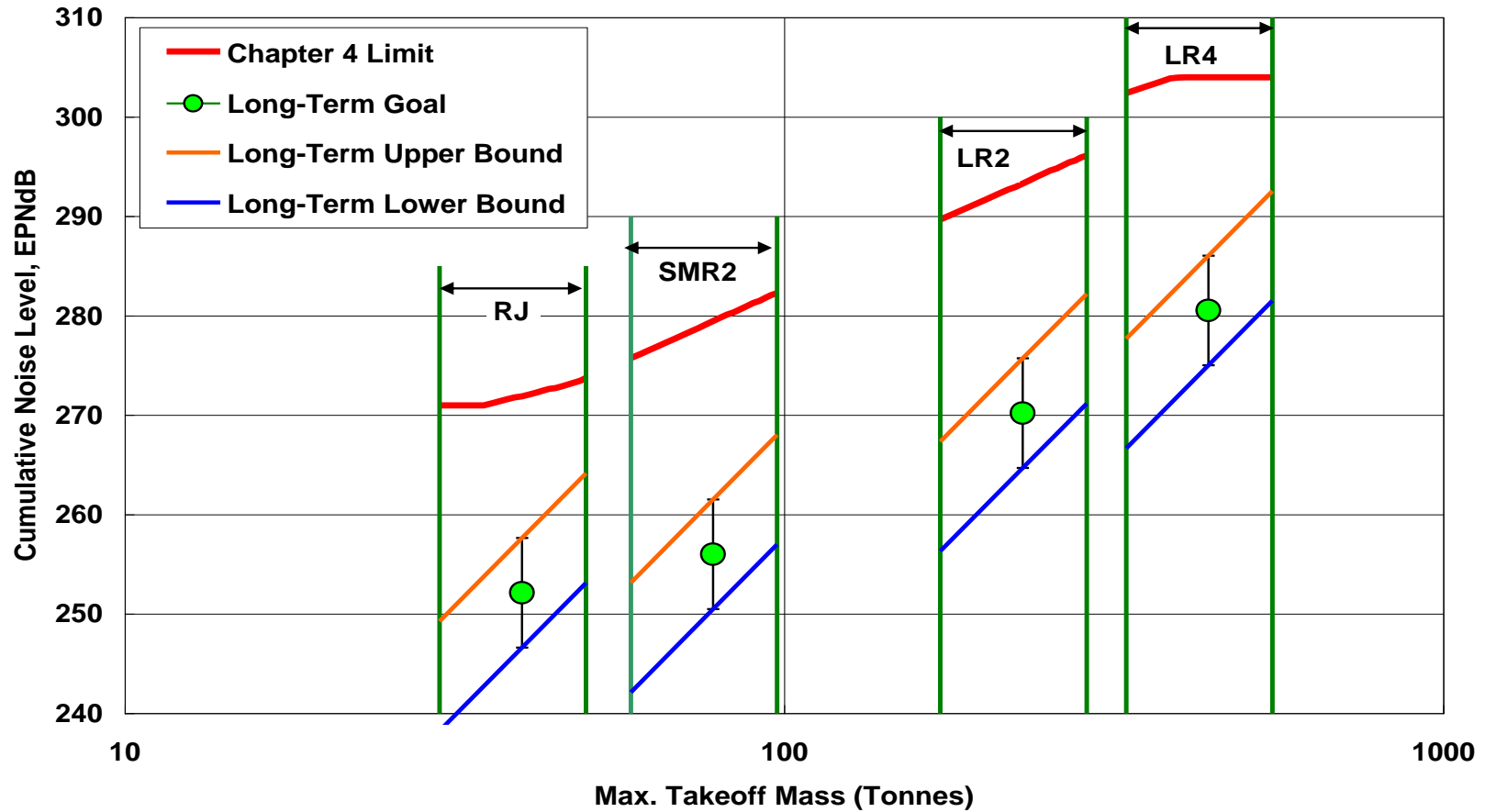


Figure 1.7.3 – Long-Term Aircraft TRL8 Noise Goal Summary

Short/Medium Range Twin Noise Reduction, Cumulative
 showing IEP deduced Mid & Long term BPR & NRT (TRL6) trends*

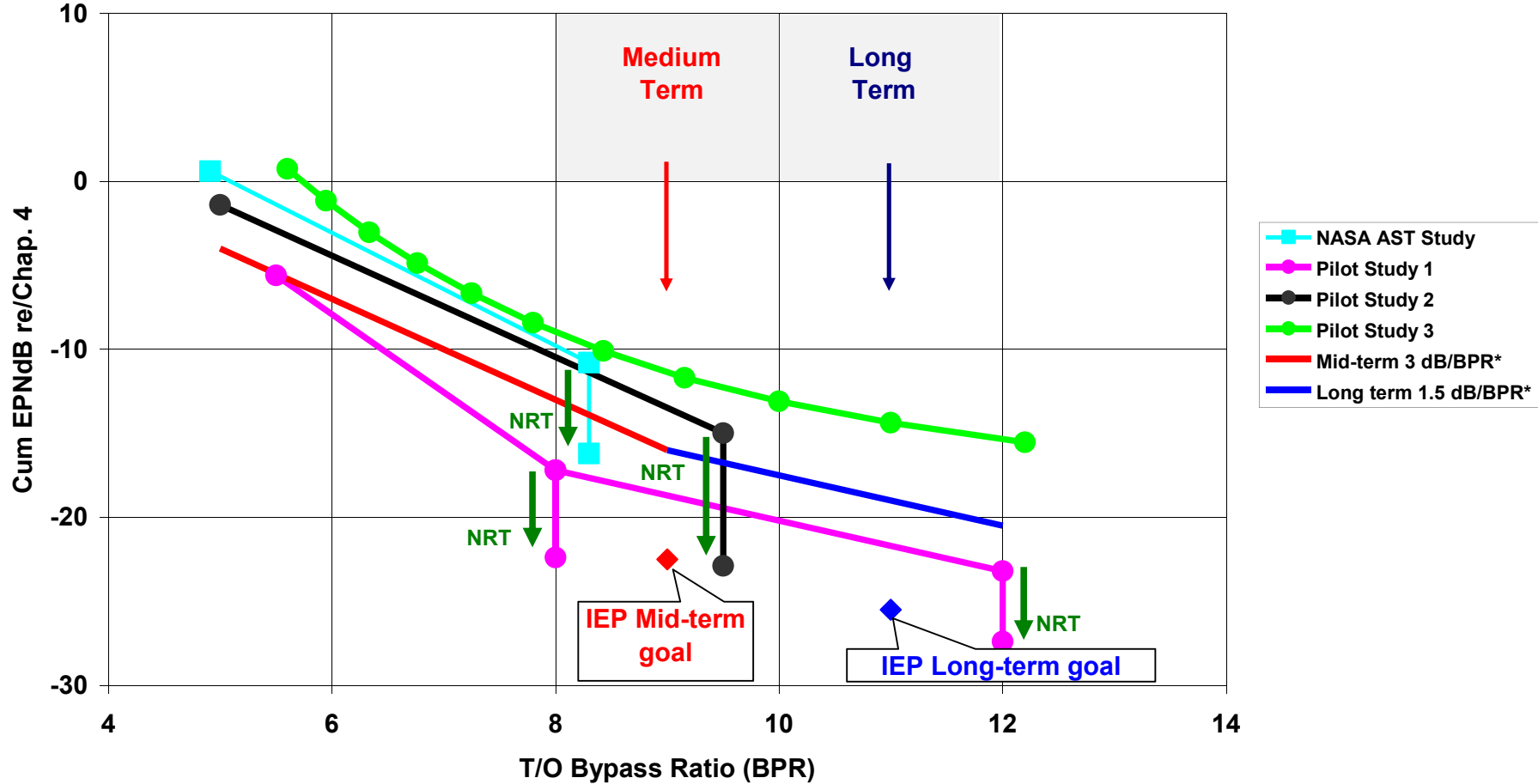


Figure 1.7.4: Short/Medium Range Twin cumulative margin noise trend with BPR (Note Pilot 3 does not include NRT)

2. Introduction

2.1 Background

The Technology Task Group (TTG) of CAEP Working Group 1 nominated a Panel of Independent Experts (IE's) who were subsequently appointed by the CAEP Steering Group. The Panel of Independent Experts (IEP) was charged with conducting a review of aircraft noise reduction technologies for reducing aircraft noise certification levels and community noise exposure, and using the review results and evaluations of same to establish medium term (10 year) and long term (20 year) technology goals for future aircraft noise reduction.

Technology goal-setting is a means to provide to CAEP members and stakeholders a forward view on what technology might be able to deliver in terms of noise mitigation over the goal-setting period set against foreseen (or quantified) environmental need. Technology goals are not guaranteed to be achieved, and they should not be regarded as alternatives to CAEP standard stringency, given the fundamental difference in nature between the two.

Engine and aircraft manufacturers have already produced successive reductions in aircraft noise in the past two decades that have allowed certification standards to be tightened (e.g., the ICAO Annex 16 Chapter 4 standard). Reductions in operational noise levels have been demanded largely by the airport operators, local community action organizations, and airline operators, in response to increasing environmental concerns, both locally and globally.

An important element of the Review process laid down by the TTG was the use of a panel of Independent Experts (IE's) with balanced backgrounds and perspectives, assisted by industry members, to provide an independent assessment of the prospects for reducing aircraft noise in the mid term and long term, based on the current technology research and development programs presented in the review. The IE's were selected from France, the UK, the US, Russia, Canada and Japan, and represent backgrounds in government research organizations, academia and industry.

2.2 Remit

This is the report of the 'Noise Technology Independent Experts Panel (IEP)' to the Committee on Aviation Environmental Protection (CAEP).

WG 1 had assigned the following work item 29 to TTG:

Using the independent expert process, to examine and make recommendations for noise, with respect to aircraft technology and air traffic operational goals in the mid term (10 years) and the long term (20 years).

2.3 Conduct of the IE Review

A review was held in Seattle from 29 September to 1 October 2008 in Seattle, referred to as the 'CAEP Noise Technology Independent Experts Review', which was organized by the TTG/WG 1. That review, *which will be referred to in this report as the 'Review'*, consisted of a number of presentations by members of WG1 supported by representatives of FAA, ICCAIA, and IATA. It was preceded by a half-day

workshop on 26 September 2008, mainly to introduce the CAEP Steering Group and the independent experts to the Review by providing a general introduction to noise-reduction research and goals worldwide.

2.4 Terms of Reference

The terms of reference provided by TTG/WG1 for this report were as follows:

1. Summarize the status of technology developments for aircraft noise reduction that could be brought to market within 10 years from the date of Review, as well as the 20-year prospects for noise reduction suggested by research progress, without disclosing commercially sensitive information.
2. Assess the possibility of success for each technology, based on experience from past research and development programs.
3. Comment on the environmental, efficiency, and other economic tradeoffs resulting from adopting the candidate noise reduction technologies.
4. Define a noise level baseline.
5. Recommend mid term and long term technology goals for reducing aircraft noise relative to the defined baseline.

2.5 Additional Guidance

Additional suggestions and guidance were provided by WG1 on issues to consider when carrying out the IEP evaluations and establishing recommendations:

Which technologies will deliver in the Medium / Long term (2018 / 2028)

- Medium-term (TRL5-6 now, TRL 8 within 10 years)
- Long-term (TRL3-4 now, TRL 8 within 20 years)
- Including performance benefits due to new aircraft technology

With what benefit?

- Average noise reduction over all three certification conditions
- Relative to chapter 4 limits
- Noting particular difficulties at any one condition

What trade-offs?

- Historical trade-offs / environmental interdependencies only
- No assessment of impact of more radical trade-offs associated with novel configurations (e.g. open rotors)

Applicable to what aircraft class

- Business jets
- Short/medium range aircraft
- Long-range aircraft

An expression of uncertainty with the goals may be appropriate

3. Scope of report

3.1 IEP Report Preparation Preliminary Work

The remit, terms of reference and additional guidance for the Independent Expert Panel report to CAEP are given in sections 2.2, 2.4 and 2.5, respectively.

Key outcomes of this Review are viewed to be the estimated Medium and Long term technology goals – aircraft noise reduction targets judged to be achievable within 10 and 20 years, respectively. It should be emphasized that they are not guarantees of future noise performance, nor are they alternatives to CAEP standard stringency.

The Independent Expert Panel Technology Review was based on evidence presented in the Review and the combined judgment of the IE's. The industry had been asked to assess critically their own technology and research programs and to present the information to the IEP in as open a manner as possible, given the commercial and proprietary restrictions that might apply. In order to respect sensitivities, technology conclusions have been reported largely without attribution to specific manufacturers.

3.2 Goal Metrics

The Review presented aircraft component noise reduction estimates for various technology concepts under development in various metric formats. The Review had to interpret these estimates in terms of the possible impacts on the noise certification metric Effective Perceived Noise Level (EPNL), not only for the component for which the given technology applied, but also how this component impact on component EPNL affects the total aircraft system EPNL. This required a considerable amount of discussion, dialogue and requests for additional information and data from the Review presentation contributors after the formal review was held. The IEP is grateful to the presentation members, especially to ICCAIA, for their willingness and cooperation in providing this valuable information after the formal review had been completed.

3.3 Component Technology Classification

The assessment of the status of technologies presented in the review was based on the CAEP-agreed Technology Readiness Level (TRL) scale. It was agreed that those technologies that, in the opinion of the presenters and the IEP, had reached a TRL of 5 to 6 or higher were applicable to Medium term goal maturity, while those at a TRL of 3 to 4 or less were applicable to the long-term goal assessment.

3.4 Noise Reduction Technology Primary Focus

There are three primary approaches to reducing aviation noise exposure:

1. Reducing the noise at the source;
2. Noise abatement operational procedures; and
3. Land use planning.

The remit of the IEP was to primarily address the first, reducing noise at the source. However, some information was provided to the IEP regarding noise abatement procedures, and so, insofar as possible, the IEP has made qualitative assessments of the additional benefits of noise abatement procedures.

4. Policy overview

Several Presentations were given at the September 2008 Aviation Noise Technology Workshop which informed the IEP regarding Aviation Noise Policy. Civil aviation is an integral and essential part of modern society, is a wealth-generating industry, and a facilitator of industrial, commercial, and social developments globally. On the other hand, civil aviation makes a relatively small but significant and increasing contribution to global environmental problems, affecting global climate change, local air quality, and noise.

In reference ANTW02, results of a CAEP Global analysis showed that the global impacted population experiencing 65 LDN or greater in aircraft community noise exposure decreased from about 3.1 million in the year 2000 to about 2 million in the year 2005, but that the exposed population is expected to climb in succeeding years, such that by the year 2018, the exposed population will return to the 3 million level. Further, it is forecasted that by the year 2028, the exposed population will increase to about 3.4 million. Reference ANTW02 noted regulatory options/instruments to promote adoption of noise reduction technology such as

1. Standards, which promote the incorporation of noise reduction technologies in aircraft design,
2. Phase-out of less environmentally-friendly aircraft technologies, and
3. Restrict/Modify Operations (e.g., curfews, noise-abatement procedures during take-off and/or landing), and
4. Market-based options such as charges, taxes, and trading schemes.

The UK Department of Transport perspective on Aviation Noise Policy was related in reference ANTW03. Results were shown indicating a diminishing population exposure vs. time for both Leq and Contour Area, even though the number of airport operations has steadily increased as a function of time over the years. However, the trends of exposure have levelled off in the past 3 to 5 years, and the steadily increasing air traffic suggests that the exposure will increase with time again in the near future. In addition, more recent data trend curves showing the subjective “mean annoyance” in per cent vs. 16-hour Leq levels indicates a lower tolerance to aircraft noise than was previously the case. This is attributed to greater public awareness of the impacts of environmental intrusions of all kinds, not just to annoyance, but to other factors such as stress, learning ability, physiological effects, and life expectancy. The public wants to see a clear rate of progress in reducing aircraft noise exposure, and the regulators and policy makers need strong assurance of commitment and delivery of this progress in lieu of setting standards which force technology into the products.

The airport operator perspective on aviation noise policy, provided by ACI, was presented in reference ANTW04. The presentation emphasized the strong relationship between aircraft noise exposure and surrounding community acceptance, airport expansion, economic growth, and impact of land use planning around the airport and airspace. Response to public complaints directly influences the adoption of operational restrictions and constraints. The key to future air traffic growth and expansion is the progress in aircraft noise reduction which outpaces the increase in

traffic. A trade-off cited was that 0.1 dB annual reduction in aircraft noise via technology is equivalent to allowing a 2.3% increase in air traffic growth without increasing the community impacted population. The airport perspective notes that the current Chapter 4 noise standards do not specify stringency increases at all three certification points, but allow flexibility in the noise reduction relative to Chapter 3 at each point, so long as the cumulative reduction meets or exceeds 10 dB relative to Chapter 3. This, in the airport operators' view, doesn't enforce sizeable reductions at the sideline or full power condition, which skews public perception of noise reduction progress in a negative way. It was further noted that several new aircraft certifications in the past couple of years have demonstrated noise levels which are significantly lower than the new Chapter 4 standard. The ACI therefore encourages consideration of more stringent standards sooner, e.g., every 6 years, and further encourages defining lower limits for all three certification conditions rather than just cumulative reductions.

The airline operator perspective on Aviation Noise Policy was presented in reference ANTW06. The airline operator perspective emphasized the role Aviation Noise Policy impacts fleet planning decisions. Aircraft purchases represent significant financial investment decisions, involving not only environmental standards compliance, but life cycle operating cost, fleet mix tailored to anticipated route traffic, and timing for acquisition, replacement and retirement. Airlines usually require new aircraft purchases to have comfortable margin to existing standards, so that compliance is assured over the useful service life of the aircraft, even when stringency is increased at some future date during that life span. In certain cases, aircraft selections are made with noise as a primary selection criterion for special route situations where local airport limits are in place, e.g., Orange County Airport. Where airports have noise quotas, aircraft noise improvements permit traffic growth over time as quieter aircraft are deployed. Finally, the airline operator perspective is that noise reduction technology features must balance the benefits of lower noise with potential penalties in manufacturing cost, airline operating cost, fuel consumption and maintenance cost, i.e., there are trade-offs to consider when adopting more stringent noise standards.

The aircraft manufacturer perspective on Aviation Noise Policy, presented in reference ANTW05, emphasized the recognition that noise reduction goals are separate and distinct from standards. Goals reflect projections of both the benefits and the time it takes to develop noise reduction concepts. Historically it has been observed that initial concept benefit estimates deteriorate as the technology matures to the state of product readiness, and that the development time typically takes much longer than initially anticipated. This observation was quantified through the use of the parameter Technology Readiness Level (TRL), which numerically quantifies the state of a concept from idea (TRL 1) to concept demonstration in a realistic environment (TRL 5 or 6) to in-service demonstration on aircraft (TRL 9). Industry, through ICCAIA, has provided reasonable estimates of the long-term trends for aircraft noise reduction (slide 17 of ANTW07), considered to be generic trend lines for the purpose of forecasting potential future global noise exposure as a function of time. Two scenarios were proposed, a "worst case" scenario of 0.1 EPNdB noise reduction per year, and a "best case" scenario of 0.3 EPNdB noise reduction per year, for each of the certification points. This trend is shown in figure 4.1.

It is a major objective of the IEP to evaluate these trend scenarios, including the trends shown in figure 4.1, and provide an assessment of the most probable trend that can be expected in the next 10 years and in the next 20 years. Historically, the aviation noise reduction policy of CAEP and the manufacturers has been based on the so-called “3-legged stool” philosophy that noise reduction concepts introduced into new aircraft must be:

1. Environmentally beneficial,
2. Technically feasible, and
3. Economically viable.

The IEP, in the process of assessing the most likely noise reduction trends for forecasting fleet average noise reductions as a function of time, must therefore evaluate:

1. The state of readiness of the noise reduction technologies being developed (i.e., what is their TRL);
2. When will they be ready for TRL9;
3. How much of the currently-assessed noise benefit will be retained as it reaches product maturity, and
4. What are the likely trade-offs that will be required to bring the concepts into a production state, and on what classes of aircraft.

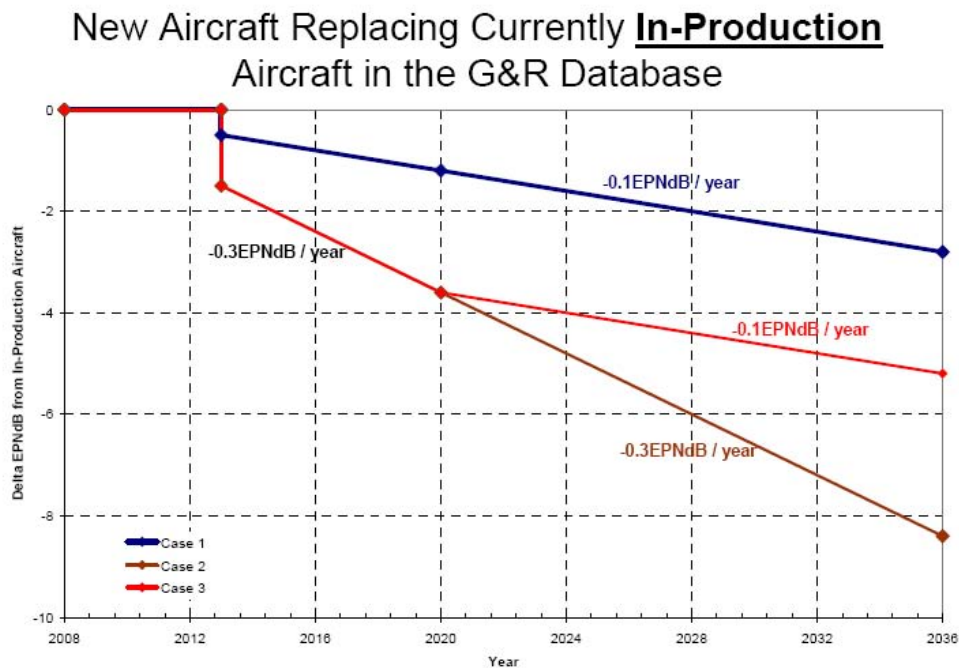


Fig. 4.1: Estimated aircraft noise reduction as a function of time for three scenarios of EPNL reduction per year

5. Research & Technology Assessment

5.1 Noise Reduction Technologies – Medium Term

5.1.1 Fan

5.1.1.1 Fan Source Noise Reduction Technologies

The presentation on fan noise technology, reference IER2008-04, listed several on-going programs for developing fan noise reduction technologies. In the Medium term, i.e., where the technology being pursued is at roughly TRL 5 to 6 or higher, the application of swept rotor designs, swept and/or leaned stator designs, and increasing engine bypass ratio are the primary technologies that can be expected to reach maturation in the next 10 years. These technologies, their projected benefits, estimated TRL values, and their anticipated key integration issues, are summarized in Table 5.1.1.1 below.

Table 5.1.1.1 – Fan Noise Reduction Medium Term Technologies

Technology	Noise Reduction Potential	Current TRL	Key Integration Issues
Rotor Sweep	Inlet Tones: 2-4 dB at T/O; Exhaust Tones: 2 dB	5 to 9	Fan aero and mechanical performance; fan stability and stall margin; cost and complexity
Stator Sweep and Lean	Inlet Tones: 2 - 4 dB at APP Exhaust tones: 3 - 5 dB Fan Broadband: 1 to 3 dB	5 to 9	Fan aero performance; cost and complexity
UHBR; Rotor Speed Optimization	Fan tones: 2 to 4 dB Fan BB: 1 to 3 dB	6 to 7	Nacelle and engine weight and installation drag; fan operability

From the summary benefits presented, it was estimated that these technologies would provide 2 to 4 dB reductions in fan tone noise and 1 to 3 dB reductions in fan broadband noise. An exception was the effect of stator sweep and lean on fan exhaust tones, which was estimated to be 3 to 5 dB reduction.

5.1.1.2 Nacelle and Liner Technologies

The zero splice inlet liners are the most mature (TRL 7-9) and have been successfully implemented to provide 1 to 4 dB inlet fan noise reduction depending on the fan speed (higher benefit for higher fan speeds). It was noted that even though the acoustic benefits for this technology have been known for many years, manufacturing technologies needed to be developed before it was possible to implement zero splice liners. Even though there is higher cost and maintenance, this technology has been implemented into the nacelle for the A380 and is expected also in the A350, B747-8 and B787 aircraft in the near future.

Scarf inlets can also provide fan noise reduction for inlet radiated sound by as much as 3 dB, but there are differing views on the aerodynamic performance impact. There is general agreement that this technology cannot be retrofitted into an existing nacelle. Several test programs have successfully shown this technology to be matured to TRL 6. However, the aerodynamic performance results are mixed. Some tests show acceptable performance data, while others imply that the trade off between takeoff and cruise conditions needs further work, particularly for wing mounted engines. The availability of this technology in the Medium term depends on the specific application.

Nose lip liners increase the treatment area at a more effective location on the engine inlet to reduce inlet radiated turbomachinery noise (fan and LPC). Noise reduction benefits range from 1 to 3 dB. The main issue with this technology is the integration with anti-icing devices for safety, as well as trade-offs with increased weight and possible aerodynamic penalties from surface roughness. The IEP consulted with icing experts who indicated that there are methods for integrating anti-icing devices in this region. The TRL for this technology varies from 4 to 6. There was no information available on what is being done to address these issues and therefore it is not clear if lip liners will be feasible for the Medium term.

Aft cowl liners were presented at the Review as a long term technology. As discussed in the long term section for Nacelle & Liners of this report, the IEP believes that some form of this technology can be ready in the Medium term, as evident by short extensions of acoustic treatment currently used on the CF6-80C2 engine.

Table 5.1.1.2 – Fan Noise Reduction Medium Term Liner Suppression Technologies

Technology	Noise Reduction Potential	Current TRL	Key Integration Issues
Zero Splice Inlet Liners	Inlet noise: 1-4 dB at Flyover (in service on A380)	7 to 9	Manufacturing & repair technologies need to be developed
Scarf Inlets	Inlet noise: ~3 dB	4 to 6	Aero performance trade-offs at cruise vs. T/O
Nose Lip Liners	Inlet noise: 1-3 dB	4 to 6	Integration with anti-icing systems
Aft cowl Liners	Aft noise: 1-3 dB PWL	3-4	Large-scale validation data required

Taking all these estimates into account as well as the reported progress in developing these technologies, it is the Independent Expert Panel (IEP) view that, collectively, these technologies can provide approximately 2.5 to 4.5 dB reduction in fan component EPNL in the next 10 years, or approximately 2.5 EPNdB reduction in fan component EPNL, plus or minus 1.0 EPNdB. The total aircraft system impact will of course depend on the propulsion system cycle, the aircraft performance and the component contributions of other noise sources.

5.1.2 Jet

The only jet noise technology presented in the Review that could be brought to market in the medium term for turbofan engines with bypass ratio (BPR) in the range 7-9 - the largest in service today - is the chevron or serration device that can be applied to the bypass and/or core jet nozzles. A component noise reduction benefit of less than 0.5 EPNdB at Departure [average of certification Lateral (sideline) and Flyover (takeoff)] was quoted. Even this reduction may be optimistic, and will certainly become smaller with increasing BPR as newer generations of engines are developed.

It appears, from the material presented, that the only way to reduce jet noise for the large BPR turbofan is to significantly increase the BPR. From the historical perspective, the maximum BPR that can be achieved with a conventional un-geared or direct-drive single rotation fan engine, without incurring unacceptable performance losses due to nacelle weight and drag, has changed with time, partly due to improvements in the core engine performance. The currently envisioned maximum BPR for a new propulsion system design during the next five to ten years is a proprietary issue, but the IEP believes this will be greater than 10. Assuming a rule-of-thumb quoted by one industrial representative of 3 dB aircraft noise reduction (cumulative) per unit BPR, largely at Departure, then a new propulsion system with a BPR of say, ~ 12, would yield 9 dB cumulative EPNL reduction, largely at Departure relative to today's highest BPR. As the primary driver for this design would be fuel burn, this development is regarded as highly likely, although the actual achievable maximum BPR must remain a matter for conjecture at this stage, considering aircraft integration and applicability to aircraft class (size and mission) issues, among other things.

A geared turbofan would allow the BPR to be increased even further, to BPR = 15 and beyond. There are serious enabling technology issues that need to be overcome, however for such high bypass ratios to become a reality:

- nacelle weight and drag,
- engine-out drag and consequent effect on tail surface control size,
- landing gear length for nacelle ground clearance,
- core size limitations and auxiliary bleed requirements,
- fan stall and stability control during extreme shifts in operating line from sea level to cruise,

Incorporating a very high BPR cycle, in the range of 15 and beyond, would reduce jet mixing noise to extremely low levels and reduce total propulsion system noise at departure significantly, provided the other component sources do not increase significantly. However our current understanding is that this technology is not likely to be applied to long range aircraft that are currently powered by engines with BPR in the range of 7 to 9.

For aircraft powered by engines with BPR in the range of 4 to 6, the chevron or serration device can be applied to the bypass and/or core jet nozzles with a benefit of 1-3 EPNdB jet noise reduction. It should be emphasised that no other medium term technologies were identified in the IE Review for jet noise reduction at BPR values in

the range 10-15 and beyond. A table summarizing the currently active technology concepts for reducing jet exhaust noise are listed in the table below, taken from reference IER2008-05.

Table 5.1.2.1 – Jet Noise Reduction Medium Term Technologies Summary

Technology	Noise Reduction Potential	Current TRL	Key Integration Issues
Fixed Geometry Chevrons	1 – 3 EPNdB at Takeoff and Lateral	6 to 9	SFC impact, Nacelle/pylon integration to minimize fuel burn penalty
Variable Geometry Chevrons	0.5 – 1.0 EPNdB at Takeoff and Lateral	6	Reliability, Maintainability, Design maturation for production.
High BPR Cycle (>10) GTF-type	Depends on Cycle	6 to 7	Nacelle and engine weight and installation drag; fan operability
Advanced Long-Duct Forced Mixer	~ 1-2 EPNdB at Lateral and Takeoff Re: unmixed flows	6 to 9	Applicable to long - cowl, mixed-flow nacelles with BPR ~ 4- 6 On regional & corporate jets

Taking all these estimates into account as well as the reported progress in developing these technologies, it is the Independent Expert Panel (IEP) view that, collectively, these technologies can provide approximately 1.0 to 3.0 dB reduction in jet component EPNL in the next 10 years, or approximately 2.0 EPNdB reduction in jet component EPNL, plus or minus 1.0 EPNdB, for propulsion systems with BPR in the neighbourhood of 8 or less. For significantly larger bypass ratios, say 12 to 13 or higher, it is estimated that jet component reductions due to lowering jet exhaust velocity (increasing BPR), on the order of 3 to 4 EPNdB may be possible at the flyover and lateral conditions. The total aircraft system impact will of course depend on the propulsion system cycle, the aircraft performance and the component contributions of other noise sources

5.1.3 Airframe

Since engine noise has been significantly reduced for decades, airframe noise has become comparable to engine noise during approach for current production airplanes with high bypass ratio engines. The major sources of airframe noise mentioned in the Review are the landing gear, high lift devices and noise due to aerodynamic interaction among them.

5.1.3.1 Landing Gear

From the materials presented in the Review, it was made clear that fairing and caps on landing gears are the only technology which will be brought to market in the Medium term. They are based on concept of covering the landing gear components and minimizing the exposure to, and creation of, turbulence generated by the flow. The potential benefit of fairing and caps of landing gears was quoted to be up to 3 dB for a component directly adaptable to existing designs. Fairings and caps have not been implemented on aircraft in production, probably because these are judged unnecessary for aircraft currently certified under Chapter 4, and they are heavy and costly.

Under the Quiet Technology Demonstrator 2 (QTD 2) program, the flight tests using B777-300ER showed gear deployment caused 3 dB increase of noise in wide range of 1/3 octave band spectra. However, the results of flight tests with a ‘toboggan’ type main gear fairing showed no reduction as has been seen in scale-model wind tunnel tests. This may be due to the complexity of flow around gears in actual flight. More effort is necessary to understand the mechanism of noise generation from gears in order to achieve noise reduction by full-scale aircraft in flight.

Nevertheless, even if at TRL3/4, a Low Noise Design landing gear looks to be, in the opinion of the IEP, a good candidate for noise reduction in the Medium term. This technology is planned, according to the Review, to reach TRL6 by 2013, and TRL8 by 2015, which suggests availability by 2018.

Moreover, a full scale experiment has been carried out with this concept, in a wind tunnel, at large scale, as part of a EU research programme, justifying TRL 5 (according to the TRL 5 definition). The landing gear design is very specific for an aircraft and cannot be tested on a flying test bed like an engine or nacelle, and so initial testing has to be done in a wind tunnel.

This technology includes an optimization of landing gear door position and shaping, a filling of forging voids, streamlining of bluff shapes for legs and stays. Some of this has already partly been introduced in some new aircraft.

The IEP considers that a potential EPNL reduction of up to 5 dB at component level may be expected by 2018. Fairings and caps benefits are not additive, but give credibility to the goal. This is applicable basically for conventional aircraft with under the wing installed engines, provided that the aeroacoustical aspects of the landing gear are taken into account from the very beginning of the project. Fuselage-mounted short landing gears – not mentioned during the review – might give better results but require aircraft architecture change.

These technologies, their projected benefits, estimated TRL steps and their anticipated integration issues are summarized in table 5.1.3.1 below, based on slides 17/18/19 presented in Airframe noise, reference IER 2008-08.

Table 5.1.3.1 – Landing Gear Noise Reduction Medium Term Technologies

Technology	Potential EPNL gain at component Level	TRL 2008	TRL 6 Goal	TRL 8 Goal	Main implementation issues
Fairing and Caps	Up to 3db	6			Weight, Heat dissipation, Access for Maintenance
Low noise Design	Up to 5 db	3 to 4	2013	2015	Structural And system integration

5.1.3.2 High Lift Devices

None of the proposed technologies related to slat and flap noise reduction have reached TRL 6 in 2008, but, as for the landing gear, the time schedule presented for the development of the slat/slat track/flap side treatments show that these technologies may reach TRL 8 in line with the medium term objective.

These technologies, their projected benefits, estimated TRL steps and their anticipated implementation issues are summarized in table 5.1.3.2 below, based on “Airframe noise”, reference IER2008-08, slides 17 to19, updated on 12 December 2008 by the presenter.

These technologies have to be adapted, each time, depending on the size of the aircraft, often “to a specific project application directly after component validation in a relevant environment”. They include slat track/wing leading edge treatment, porous material for slat trailing edge, flap edge, but also extension to other aircraft classes of devices similar to the droop nose device in service in the A380.

Taking all these factors into account, as well as the reported progress in developing these technologies, it is the IEP view that collectively can provide 3 to 4 dB noise reduction at the airframe level in the Medium term.

The total aircraft system impact will of course depend on the engine noise which has also to be reduced in parallel. If that is not done engine noise will dominate and the effect of the airframe noise reduction on the total aircraft noise will be very small.

Table 5.1.3.2 – High Lift Devices Noise Reduction Medium Term Technologies

Technology	Potential EPNL gain at component level	TRL 2008	TRL 6 goal	TRL 8 goal	Main Implementation issues
Slat and Slat track Treatment	Up to 3dB	3 to 4	2014	2016	Potential impact on L/D Retraction
Flap side edge Treatment	Up to 3 dB	4 to 5	2014	2016	Potential Impact on L/D
NB Gains are dependent on the configuration					

5.1.4 Core

The technology assessment presented in this section takes into account only mid-term technologies that are expected to mature in the next 10 years and is based on the presentations made to the IEP at the CAEP-WG1 Workshop and Review. These technologies are summarized in Table 5.1.4.1. No attempt has been made to include and assess other promising technologies, which although not presented at the WG1 Review, are however, available in open literature. The IEP is of the opinion that the core noise reduction technologies are mostly interdependent and thus their benefits are not additive. The IEP is also of the opinion that the enabling technologies presently available to experimentally diagnose and numerically model core noise are not mature enough to reasonably predict either the source contribution to the overall core noise or to predict the potential benefits of the promising technologies.

Presently, for many engines, the contribution of core noise to the total aircraft noise at the certification points is significantly lower than other noise sources like fan, jet and airframe, and therefore core noise mitigation often remains a low priority when it comes to the allocation of limited research funding. However, for smaller engines on corporate and regional jets the turbine noise is an important noise source. In addition, with the introduction of higher bypass ratio engines and other advanced technologies for fan/jet/airframe noise reduction, the core noise contribution is expected to be more significant in the future.

The contributing source components to core noise are turbine, combustor, bleed valve and compressor. The turbine and combustor are the dominant sources both at departure and approach, generating both tonal as well as broadband noise at these certification points. The compressor and bleed valves contribute mostly at approach.

In the case of turbine, the noise reduction concepts developed to reduce fan noise have potential application, i.e., application of hot-stream and long-cowl common nozzle liners, optimizing blade/vane counts and optimizing gap arrangement to reduce the noise generated due to potential field and wake interactions. Some of these technologies are already in use on in-service aircraft, providing an estimated tone noise reduction of 9~12 dB. For the mid term target of 2018, additional benefit of 2 to 4 dB in tone noise and 3 to 4 dB in broadband noise may be achieved by aerodynamic and geometric blade optimization via swept rotor design and swept and/or leaned stator designs. In the absence of any available test or prediction data specific to this turbine technology, the level of expected noise reduction is only an estimate.

Hot section liners are being developed to help reduce core noise. Composite liners capable of ~1250 deg. F were reported to be available, but they fall short of temperatures needed for the hot section of the core. These liners can however, be used further downstream after bypass air is mixed with the core stream. The TRL of these liners was reported to be 4 to 5. Liners in this region of an engine can reduce the aft-radiated core noise by about 2 dB for each unit treatment length per nozzle radius (assuming full annular treatment). For many smaller engines, however, the cost and weight constraints may not allow the use of turbine liners.

Table 5.1.4.1 – Core Noise Reduction Mid Term Technologies

Noise source	Reduction technology		Current TRL	Reduction potential	
Turbine	Hot stream acoustic liners		9*	2~4 dB	
	Long-cowl nacelle common nozzle		9	3 dB	
	Aerofoil counts (conventional and reverse)		9	4 dB	
	Optimized aerodynamics	Optimized gap arrangement (reduce potential field and wake interactions)		9	3~4 dB
		Aerofoil geometric optimization (via sweep, lean)		4~5	3dB
Combustor	Cavity acoustic plugs		4~5	4~9 dB at some frequencies 1~2 dB at others	

In the case of combustor noise, the only mid-term promising technologies that will be ready for application by 2018 are the tail-cone resonators, which comprise of micro-perforated liners and cavity septum rolled into folding cavity acoustic plugs. These can be tailored for specific frequency ranges to reduce a narrow range of the noise spectra by 4~9 dB at flyover and 3~4 dB at approach. How this impacts the overall engine noise depends on the relative levels of combustion noise to other sources such as jet noise. In addition, the application of optimized vane/blade ratio and curved and leaned turbine blades may not only provide turbine noise reduction, but can also aid in reducing downstream propagation of combustor noise by providing higher acoustic impedance at combustor exit.

Bleed valve exit screens are presently in use to mitigate bleed valve noise. They have been demonstrated to be very effective in reducing bleed valve noise to up to a 10 EPNdB component reduction, and sometimes a several EPNdB reduction on total aircraft noise. Another bleed valve noise reduction technology is the application of reduction teeth. This methodology can be put to use by 2018 and according to the

* The TRL is lower for small engines, since these liners are not widely used on such engines

information provided at the WG1 Review, can yield up to yield 5 ~ 7 dB reductions in screech tones.

Figure 5.1.4.1, taken from Reference IER2008-06 (slide 6), shows examples of the impact on total aircraft noise if turbine noise is not reduced but all other noise – airframe and engine - sources are reduced by 0.5dB per year for the next 20 years. As may be noted the impact on total aircraft noise is different for 6-stage and for 3-stage turbines. The figure highlights the noise reduction benefits of including hot-stream liners.

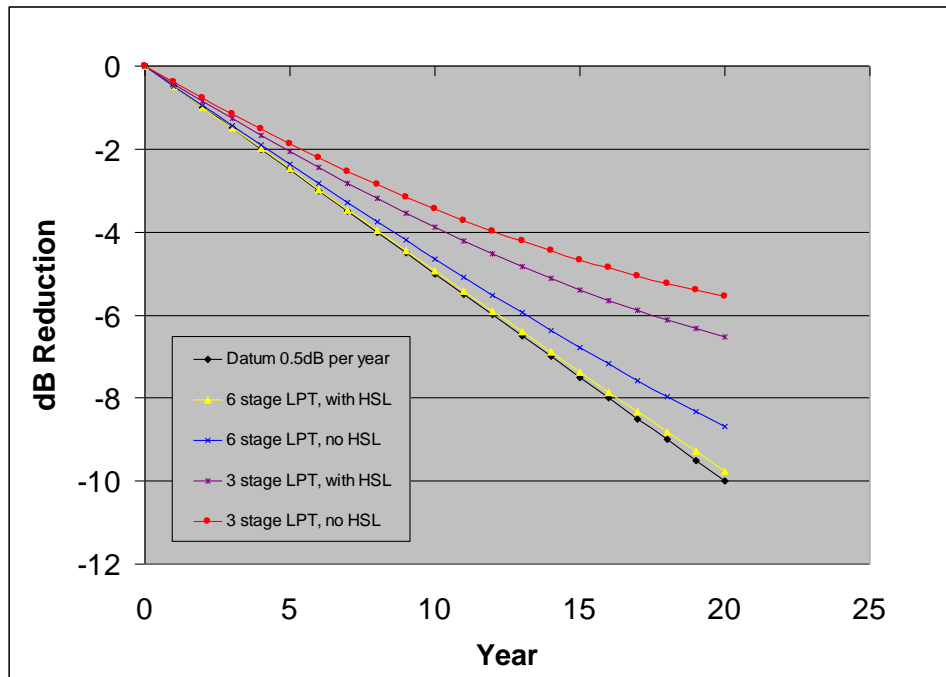


Fig. 5.1.4.1: Impact of turbine on long-term aircraft noise reduction goals. Ref. IER2008-06 (slide 6)

The figure also highlights that aircraft having engines with 6-stage turbines and equipped with hot stream liner (HSL) can follow an aircraft noise reduction trend of 0.5dB/year, without the use of any additional turbine noise reduction technologies. Application of additional technologies like aerodynamic/geometric optimized blade and vane design may further be exploited in terms of reduced weight, and reduced fuel burn.

Figure 5.1.4.2 shows SPL spectra of three classes of turbines. Class 3 represents turbines designed in the 1970's when turbine noise was not recognized as a significant contributor. Class 2 represents 1990's technology, and Class 1 represents turbines with newer technologies like acoustically optimized turbine designs. As shown, the Class 1 turbines may not even need liner treatment. Such turbines may not be aerodynamically optimized and may have more stages or more blade and vane counts to minimize noise. This reduction in noise then has to be balanced potentially by increased weight and reduced aerodynamic performance. Although hot-stream acoustic liners also incur extra cost and weight, some of the increase in cost and weight may be offset by allowing a differently-optimized turbine.

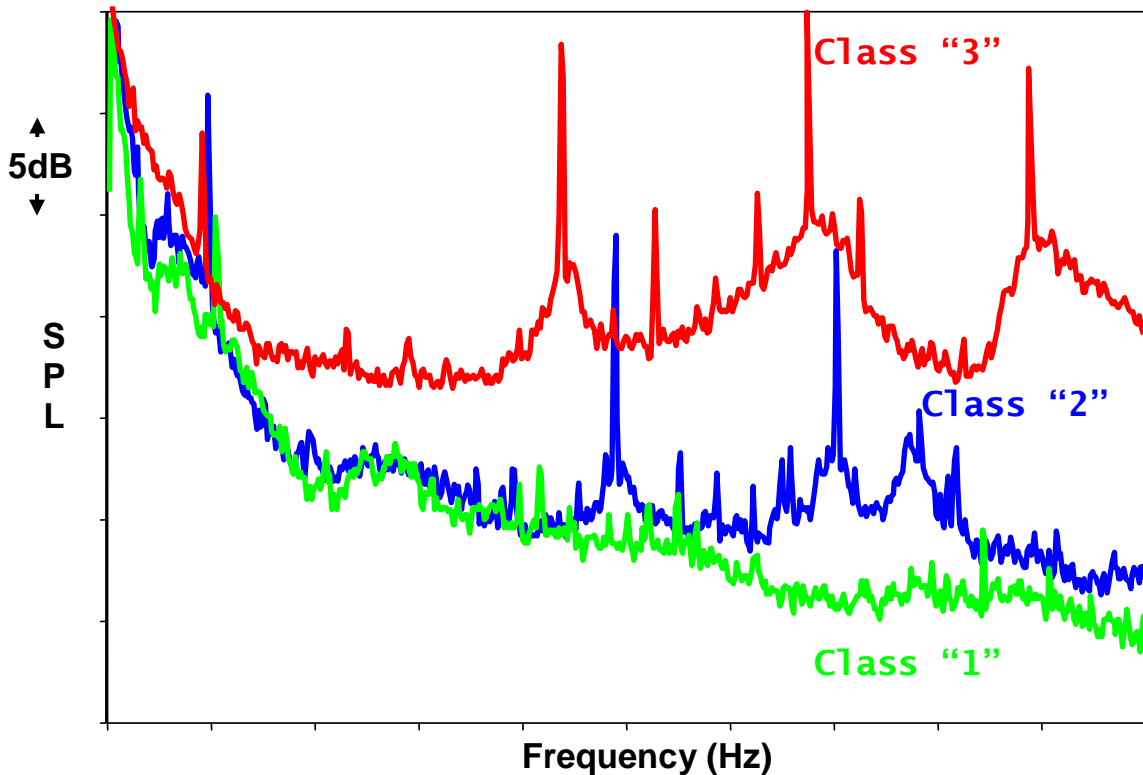


Fig. 5.1.4.2: Comparison of turbine noise reduction benefits for different classes of turbine. Ref. IER2008

It may be concluded that engines with higher number of turbine stages, designed and optimized for performance (lower stage loading) also provide noise benefits, even without aerodynamic or geometric blade/vane design optimization. But they do bring weight penalties, which may be unacceptable. The real benefit of turbine technologies such as aerodynamic or geometric blade/vane design optimization may therefore be on highly-loaded turbine designs.

Taking into account the noise reduction estimates shown in Table 5.1.4.1 as well as the reported progress in developing these technologies and other considerations highlight in this section, it is the IEP view that, collectively, the technologies can provide approximately 1.0 to 2.0 dB reduction in core component EPNL in the next 10 years.

5.1.5 Nacelle & Liners

The nacelle and liner technologies include methods for absorbing, cancelling or redirecting sound sources originating within an engine. A summary was given at the Review on promising Medium term technologies that included zero splice inlet liners, scarf inlets, nose lip liners, high temperature liners, combustor Helmholtz resonators, and Herschel-Quinke (HQ) tubes. The IEP evaluated each technology and agreed with the recommended time frame for technology maturation, except for HQ tubes which were moved to the Long term time frame. Apart from some generic aspects briefly covered in this section, nacelle and liner technologies are discussed under the appropriate component headings (i.e. fan and core)

Acoustic liners have well established benefits for nacelle applications. Single and double degree of freedom (DOF) liners are in production today and typically provide 3 to 6 dB fan noise reduction. There does not appear to be a strong case for higher DOF liners (greater than two) due to manufacturing cost, complexity, weight, and diminishing acoustic benefits. The selection of the liner is strongly dependent on the source and it is possible to design a single DOF liner that can be just as effective as a double DOF liner. There was a general impression at the Review that liners for cooler sections of the engine have matured and strategies for additional noise reduction should deal with more effective placement of the liners, e.g. nose lip liners, and the detailed design, e.g. zero-splice liners. *Apart from that, for a given liner area, there are no liner technologies available in the Medium term that will significantly reduce turbomachinery noise beyond current levels.*

There has been concern in the past about the scalability of liners tested in wind tunnels due to smaller size and the uncertainty to match target impedances. Discussion at the Review indicated that this is not a problem as long as the scale factor does not exceed 5 and if there are no additional self noise sources from the liner.

In summary, it is the opinion of the IEP that the technologies that will be ready for Medium term applications will be zero splice liners, scarf inlets (depending on application), possibly inlet nose lip liners, high temperature exhaust liners, tailcone resonators, and some form of aft cowl liners.

5.2 Noise Reduction Technologies – Long Term

5.2.1 Fan

5.2.1.1 Fan Source Noise Reduction Technologies

For the long term, several technologies for reducing fan noise were presented in reference IER2008-04 that are considered to be at TRL 3 to 4. These include: Variable-area fan nozzle, “Soft vane” for reducing rotor-stator interactions, Over-the-rotor treatment for reducing fan rotor noise, active stator control, active rotor tone control, and the “Zero-hub fan” for reducing fan inflow Mach number (and hence noise). The Long Term Technologies characteristics, benefits, and issues are summarized in Table 5.2.1.1 below.

Table 5.2.1.1 – Fan Noise Reduction Long Term Technologies Summary

Technology	Noise Reduction Potential	Current TRL	Key Integration Issues
Variable Area Nozzle	Tone & Broadband: 2 dB	4 to 5	Complexity, weight and Cost
“Soft” Vanes	Tones & Broadband: 1.5 dB	3	Maintenance & perhaps drag
Over-the-Rotor Treatment	Tones & Broadband: 3 dB	3	Fan performance impact
Active Stator	Inlet 1BPF: 8 dB Inlet 2BPF: 5 dB	3	Actuator integration; structural integrity; weight & cost
Active Blade Tone Control	Inlet 1BPF: 24 dB Inlet 2BPF: 9 dB	3	Complexity; weight & cost; TSFC impact
Zero Hub Fan	Inlet Tone and Broadband: 0.5 dB re: Swept Rotor	4	Structural Integrity

The “Soft Vane” concept and the Over-the-Rotor Treatment technologies listed Key Integration Issues, but, in the view of the IEP, overlooked some important ones. The “Soft Vane” concept (see slide 22 of IER2008-04) shows a very complex, and therefore possibly high-cost construction of the vane. Also, no mention is made of whether the concept can be incorporated into fan exit guide vanes which are also structural (fan frame struts), which also contain engine air and fluid piping. The Over-the-Rotor Treatment concept key integration issues are listed as performance impact, but the issue of fan blade containment and structural complexity and integrity were not mentioned. The IEP views these additional key integration issues as important, and therefore the estimated time to develop these technologies may be longer than currently envisioned.

For the Active control concepts, large reductions in tone noise, on the order of 5 to 24 dB for blade-passing frequency (BPF) and second harmonic tones, were quoted. Most

all of these long-term technologies involve much more complex component and system designs, thus introducing significant uncertainty in the resulting impact on manufacturability, performance, cost, maintenance, and reliability. The IEP view is that these technologies are interactive, in that their benefits are not additive. For example, if a fan BPF tone has been significantly reduced through cut-off design, σ stator sweep and lean, σ rotor sweep, or other means, then active control concepts may not produce nearly the tone reductions demonstrated on rig tests where the BPF tone is very high. The IEP view is that these long-term technologies may provide about 1 to 3 dB reduction in fan component EPNL over and above the Medium term technologies in the next 20 years.

It should be noted that some of the IEP members felt that the active control technologies described had a low likelihood of ever reaching maturity. The IEP also feels that some of the long-term technologies will probably prove unfeasible as further investigations on more realistic configurations are developed, but that perhaps other approaches or technologies will come to light that may prove to be more successful than those currently being pursued.

5.2.1.2 Nacelle and Liner technologies

Herschel-Quinke (HQ) tubes have been investigated as a way to increase fan noise attenuation when integrated into the liners. Results from engine tests have shown that they work well in isolation, but did not give the expected additional attenuation when added to the liners. A static engine test result showed 3 dB reduction when the HQ tubes were tested alone and 4 dB reduction when integrated with a liner. It is unlikely that this technology will be implemented in the Medium term unless significant noise reduction can be achieved beyond traditional liners and therefore is considered a Long-Term Technology.

Optimized zone liners were shown to be added as rings to the inner and outer walls of the aft bypass duct to reduce fan noise. The impedance is optimized for each ring to improve sound absorption and requires knowledge of the source distribution. Computational methods for duct sound propagation have been used to show that accounting for the curvature and the changes in impedance for each zone can increase the effectiveness of the liners according to the predictions. This idea is not new, but needs to be validated with experimental data. The reported benefit of 5 dB reduction of peak SPL spectra is significant and efforts should be accelerated if it can be shown to work in TRL 5 and 6 tests.

Aft cowl duct liners are a way to increase the treatment area for aft radiated noise beyond current practice. Estimated noise reduction ranges from 1 to 3 dB (PWL) based on predictions. It was recognized that some engines such as the CF6-80C2 already use short extensions of acoustic treatment beyond the fan cowl, although this was done primarily for manufacturing reasons. As suggested with the optimized zone liners, this technology should be accelerated if it can be shown to work in TRL 5 and 6 tests.

Acoustic splitters are also an old idea being revisited with today's technologies. Initially, multiple splitter rings were added to the inlet during research programs in the 1970's. The performance losses were found to be too high. Recent investigations have concentrated on aft radiated fan noise since it tends to dominate for lower speed

fans associated with higher bypass ratio engines. Splitters can be located in the fan nacelle bypass duct to increase the treatment area and change the length/height ratio to increase the noise absorption. Estimates show an increase of 2 to 6 dB noise reduction over exhaust duct liners without splitters. However, the performance losses could be significant and, in the case of the long bypass duct splitter, integration with the thrust reverser is a challenge. Future development of this technology should concentrate on methods to reduce the performance losses before higher TRL can be achieved.

Active/passive liners hold the same promise as the optimized zone liners with the added ability to change the impedance throughout the operating range of the engine. This is accomplished by introducing a second source within the liner that is linked to a control system to vary the amplitude and phase until the desired impedance is obtained to optimize sound absorption for a given engine speed. Strategies can be employed to integrate the active system with a passive liner to make it more effective. It is also possible to use the active system for lower frequencies while the same liner provides higher frequency attenuation. Test performed so far have targeted tones and have shown reductions from 2 to 7 dB. This technology is appropriate for the longer term and requires development of reliable, low-cost, low-weight, high amplitude actuators and control systems.

The IEP notes that the Nacelle/Liner technologies for fan noise reduction are also interactive with the fan source noise reduction concepts discussed in this section, and are therefore their benefits are not necessarily additive.

On the average, with the exception of the active control technologies, these concepts were estimated to yield 1.5 to 4 dB additional reductions over and above that provided by the Medium term technologies. Alternatively, the anticipated potential benefits are approximately an additional 2.5 EPNdB in fan component EPNL, plus or minus 1.5 EPNdB, over and above that provided by the Medium term technologies. The total aircraft system impact will of course depend on the propulsion system cycle, the aircraft performance and the component contributions of other noise sources.

5.2.2 Jet

The presentation in reference IER2008-05 described several technologies at low TRL that are being pursued in various research programs that may reach maturity in the long term, by the year 2028. These are summarized in Table 5.2.2.1 below.

Table 5.2.2.1 – Jet Noise Reduction Long-Term Technologies Summary

Technology	Noise Reduction Potential	Current TRL	Key Integration Issues
Fluidic Injection	1 – 2 EPNdB at Takeoff and Lateral	3 to 4	Air source - Cycle impact and sizing; Design maturation; Complex issues with implementation
Bevelled Nozzle	1 – 3 EPNdB at Takeoff and Lateral	4	Thrust vectoring addressed by nozzle tailoring
Microjets	1 – 3 EPNdB at Takeoff and Lateral	3 to 4	Air source - Cycle impact and sizing; Design maturation; Complex issues with implementation
High-Frequency Excitation	~ 1-2 EPNdB at Lateral and Takeoff	5 to 6	Air source - Cycle impact and sizing; Design maturation; Complex issues with implementation

A difficulty with assessing the potential benefits of the advanced jet noise reduction technologies listed in Table 5.2.2.1 above is that it is not clear whether these benefits would apply to very high bypass ratio jets. Further, it is not clear whether they can be additive to the Medium term technology concepts, or whether they replace the Medium term technology concepts. Of the four technologies listed above, only the Bevelled Nozzle concept appears to be separate and distinct from the others, so that most likely the others can conceivably augment the Bevelled Nozzle noise reduction, but not each other. In other words, Fluidic Injection, Microjets and High-Frequency Excitation are all viewed to be variants of the same family of technologies, and are potentially competing concepts, from which only one will reach maturity for a given aircraft application.

It is the view of the IEP that these long term technologies would most likely be applicable to propulsion systems with BPR on the order of 6 to 9, and that they would not be as effective, either on a component jet noise reduction basis, or on an aircraft system noise level basis, for very high BPR propulsion systems, say 12 to 13 or higher. The IEP further questions the maturity of the “High-Frequency Excitation” concept, since no evidence was given that it has been tested in an engine environment.

On the average, with the exception of the active control technologies, these long term concepts for jet noise reduction were estimated to yield 1 to 3 EPNdB reductions, but it is not clear whether this is over and above that provided by the Medium term technologies. Further, it is not clear that these benefits on jet noise reduction will be as effective on very high BPR jets. To the extent that we may expect at least some new aircraft classes to have very high BPR propulsion systems, the IEP opinion is that these long-term technologies may not be effective in reducing total aircraft system noise. For new aircraft with BPR less than 9 or 10, they may offer some additional noise reduction over the Medium term technology concepts, assuming that they can augment the jet noise reduction of those technologies. However, they may not be additive, and the combined benefit may be less than the sum of the separate benefits.

The IEP view is that the anticipated potential benefits on the average are approximately an additional 1.0 EPNdB in jet component EPNL, plus or minus 1.0 EPNdB, over and above that provided by the Medium term technologies. The total aircraft system impact will of course depend on the propulsion system cycle, the aircraft performance and the component contributions of other noise sources.

5.2.3 Airframe

5.2.3.1 Landing gear

Starting from a low noise design, the only technology which may be available for additional noise reduction uses flow control, today at TRL 1 to 2. The expected noise reduction is no more than 1 dB at the component level, which is additive to the benefit of the low noise design, but is so small that it would be not very significant at the aircraft level.

The IEP concluded that no additional noise reduction can be expected for a conventional configuration (under the wing installed engine). It appears that the only way to obtain more landing gear noise reduction at the approach condition seems to be the development of fuselage mounted short landing gear, which of course necessitates corresponding change of the aircraft structure, as described in Reference IEP05.1.

5.2.3.2 High lift devices

Slat and flap low noise designs (including in particular the slat cove filler), today at TRL 1 to 2 are expected to be at TRL 6 by 2020 with a potential of 5 dB maximum reduction at the component level.

These technologies, their projected benefits and their anticipated integration issues are summarized in table 5.2.3.1 below based on slide 17 presented in “Airframe noise,” reference IER2008-08.

**Table 5.2.3.1 – Airframe Noise Reduction Technologies
Long Term (2028)**

Component	Technology	Potential gain EPNL at Component level	2008 TRL	Main implementation issues
Landing gear	Flow control	Up to 1dB	1 to 2 dB	Weight, structural and system integration; air/energy supply
Slats and flaps	Low noise design	Up to 5dB	1 to 2 dB	Potential impact on L/D; retraction; Stability and control

The current TRL of these technologies is too low and the benefits too uncertain to obtain credible estimates on the benefit at the aircraft level which in any case will be small with conventional aircraft configurations.

5.2.4 Core

The assessment of long-term core noise reduction technologies, expected to mature in the next 20 years are presented here. No long term technologies were presented to the IEP at the CAEP-WG1 Workshop/Review and therefore the technologies presented in this section are based on a review of available literature.

Taking into consideration that the noise contributions from fan, jet and airframe will be significantly reduced with the introduction of higher bypass ratio engines and other advanced noise reduction technologies, the core noise contribution is expected to be of greater concern in the long term. In general, since it is a matter of priorities for the limited research funding available, technologies related to fan, jet and airframe noise (and open-rotor noise) remain the priority. However, more aggressive research is required to be conducted to understand and to predict core noise sources. Also the impact of new technologies such as low-NOx combustors and the effect of using alternative fuels should be assessed.

For turbine noise reduction, a promising technology is the application of over-the-rotor treatment. This technology was stated to have potential for suppressing fan noise and IEP feels that, although faced with implementation challenges, the technology may also have a benefit in turbine noise reduction. The expected combined tonal and broadband noise reduction could be as much as 3dB. Until the physical mechanisms for how casing treatment affects the aerodynamic behaviour and associated noise reduction, it is difficult to translate results for Low TRL fan noise test results to multi-stage turbines.

From a liner treatment perspective, ceramic and metal foams increase the temperature range, but are heavy and need to address contamination issues in an engine environment. The TRL of these liners was reported to be low (TRL 1 to 3).

In the case of combustor, the technologies with noise reduction potentials include: multi-stage combustor design and application of aerated injectors instead of high pressure injectors. Another combustor noise suppression method includes enlarging chamber cross-section area at locations where combustion takes place. The trade-off with respect to emissions will have to be assessed.

For compressor noise reduction, long term technologies may include the application of active clearance control. However, since no supporting data is yet available, it is not possible to predict the noise reduction gain.

For core noise in general, the long term noise reduction potential beyond the mid-term 2018 time period relies on very low TRL technologies, for which no quantitative evidence is available to project their benefits. The IEP therefore cannot project core noise reduction benefits beyond 2018, other than perhaps suggesting that the mid-term technology reductions might achieve better noise reductions following additional development and refinement.

5.2.5 Nacelle & Liners

Nacelle and liner technologies that were identified at the Review for Long term applications include optimized zone liners, aft cowl liners, acoustic splitters in the bypass duct, and active/adaptive liners. Scarf inlets were discussed earlier under the Medium term time frame but have been added to the long-term technology list due to uncertainties over aerodynamic performance penalties. The IEP also suggests that HQ Tubes will not be matured until they can demonstrate higher noise reduction and therefore has been moved to the long-term technology list. The TRL for long-term technologies ranges from 3 to 4. Some of these technologies may be applied to other noise sources such as the core, but the primary target appears to be the fan noise.

6. Noise reduction prospects

The IEP has reviewed the various noise reduction technology concepts and progress made in developing them, as described in the previous section, and has selected the technologies most likely to succeed to product applications for both the medium term (within the 10 years) and for the long term (within the next 20 years). These selections were made based on a critical review of the presentation material given in the Review, as well as the IEP expertise and experience. Having defined “packages” of noise reduction technologies that are most likely to find their way onto an aircraft system, considering both the medium and long term time scales as well as the aircraft classes to which they may be applicable, assessments were made of the total aircraft system noise reductions that could be realized for the various classes of aircraft in the time frames previously defined. These results are summarized below.

6.1 Aircraft Category Selection and Engine Bypass Ratio Projections

6.1.1 Aircraft Category Selection

There was considerable discussion as to what classes of aircraft the Panel should consider in carrying out the assessment, as described in the remit (see sections 2.2 – 2.4), as the Panel was requested to select a baseline from which to evaluate potential noise reductions and mid- and long-term technology goals. At the request of the WG1 Technology Planning Committee, a study was carried out by MODTF to evaluate the most important categories of aircraft in the fleet today, from the standpoint of their impact on population exposure. Mr. Gregg Fleming provided a summary of the MODTF study to the Panel and Planning Committee, documented in reference IEP1.2, which showed that aircraft in seat classes from 101-150, 151-210, 211-300, and 301-400 seats accounted for 86% of the noise energy exposure at takeoff and 84% of the energy exposure at approach. These results are summarized in Table 6.1.1 below, taken from Reference IEP1.2.

Table 6.1.1: Noise energy contribution by seat class

Seat Class (-)	Number of Seats	T/O Energy Contribution (%)	APP Energy Contribution (%)
1	<20	1.3%	1.5%
2	20-50	0.9%	3.1%
3	51-100	0.9%	2.2%
4	101-150	13.2%	20.2%
5	151-210	18.8%	17.2%
6	211-300	36.2%	31.1%
7	301-400	17.8%	15.6%
8	401-500	10.9%	9.0%

The Panel concluded that seat classes 3 through 7 were of most importance. Further discussions with the WG1 Planning Committee resulted in the following guidelines for focusing the Panel assessments:

- Business jets, seat class1, were dropped from further consideration, based on the MODTF results summarized in Table 1.4.1, and at the recommendation of the WG1 Planning Committee.
- Regional jets in the mid-term (2018) would not be introduced which are completely new designs. Rather, small, retrofits of noise reduction features will most likely be introduced as they become mature. Regional jets are not likely to have bypass ratios greater than 9 in the mid-term time frame, and the technology benefits are likely to be comparable to those for short-medium range twin aircraft.
- Long range 2-engine (twin) and 4-engine (quad) aircraft in the mid-term (2018) are likely to have the same acoustic performance as the current project aircraft already entered into the “Best Practices Database” and these entries should be representative of what is achievable in the mid-term.

6.1.2 Engine Bypass Ratio Projections

There are two major approaches to reducing aircraft noise that can contribute to both Medium term and Long term noise reduction goals. These are: (1) advanced noise reduction design features or Noise Reduction Technology (NRT) for the various components of both the propulsion system and the airframe, and (2) advances in propulsion system design which normally require increased Bypass Ratio (BPR) and therefore lower exhaust velocities.

The IEP therefore focused on these two approaches. It was concluded that, for current aircraft propulsion systems, jet exhaust mixing noise is a dominant contributor to the total propulsion system and aircraft noise at takeoff, and that the most effective approach to reducing jet mixing noise is to increase bypass ratio. The IEP therefore requested and received input from the Working Group 1 (WG1) planning committee an estimate of the range of bypass ratios that are likely to be developed for the mid term and the long term, for several classes of aircraft. The recommended mid-term and long-term bypass ratio ranges for the selected reference aircraft categories provided by ICCAIA through the WG1 N29 Planning Committee are presented in figure 6.1.1.

The IE Panel developed the following average bypass ratio variations from reference to mid-term to long-term aircraft designs based on: (1) the Best Practices Noise Database from which the reference aircraft were derived, and (2) the recommended bypass ratios provided by ICCAIA through WG1 for the mid- and long-term shown in Fig. 6.1.1. These projected BPR variations are shown in Table 6.1.1.

Table 6.1.1 – Potential Engine Bypass Ratio (BPR) Variations

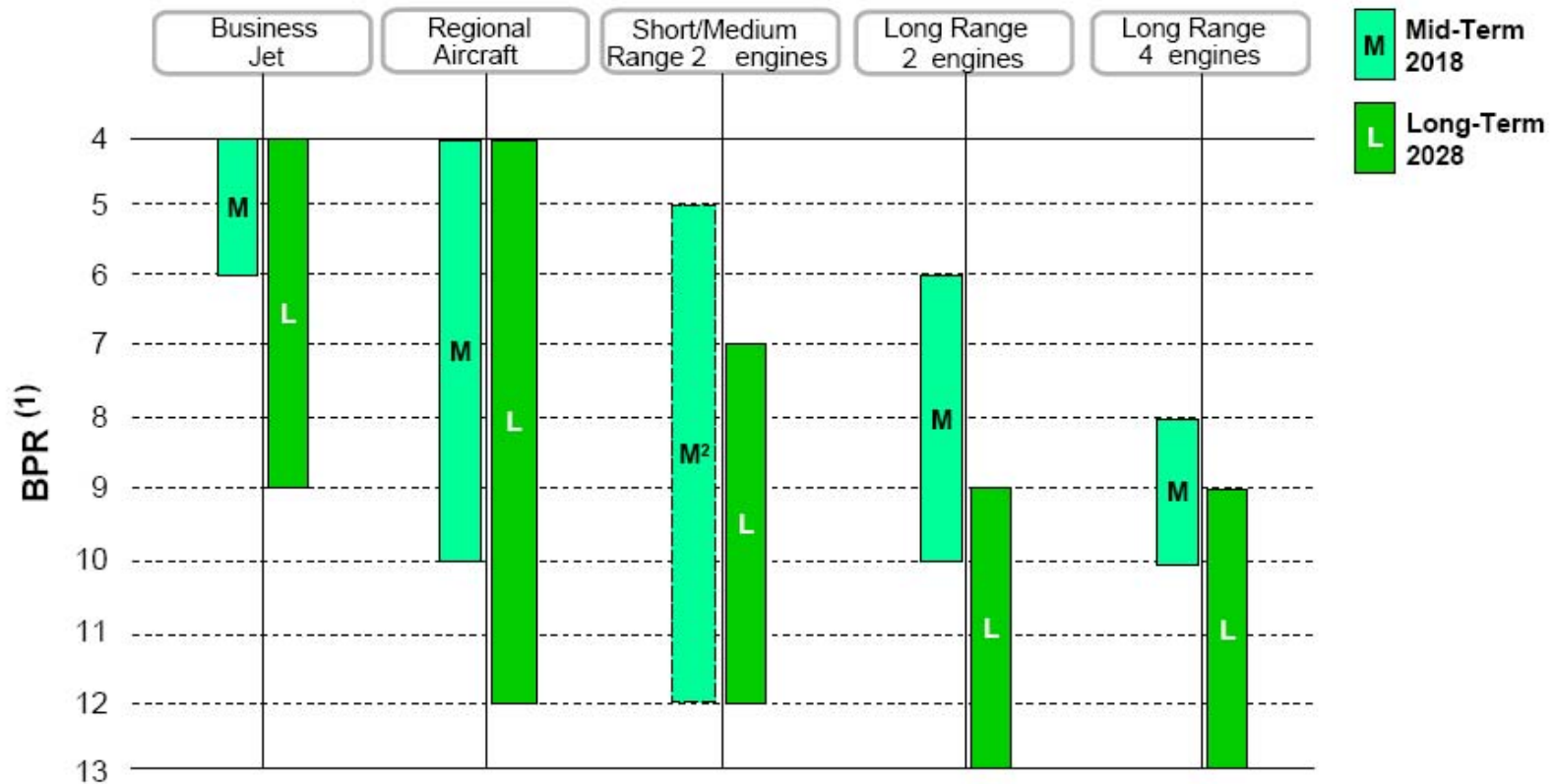
Aircraft Category	Reference BPR	Mid-Term BPR	Long-Term BPR
Regional Jet	5	7 (+ or -) 1	9 (+or -) 1
Small-Med. Range Twin	5	9 (+ or -) 1	10 or 11 ¹ (+ or -) 1
Long Range Twin	6	10 (+ or -) 1	11 (+ or -) 1
Long Range Quad	5	9 (+ or -) 1	11 (+ or -) 1

¹ BPR=10 for a conventional wing aircraft or BPR = 11 for a high-wing aircraft

Predicted Evolution of Bypass Ratio (BPR) enabled by engine technology - Open Rotors excluded



CAEP Noise Technology
Independent Experts
Goals Review



(1) All BPR correspond to sea level static rated thrust conditions

(2) Entry in service of most products in this category is not certain as of 2008

Figure 6.1.1: Projected Bypass ratio trends, provided by WG1.

6.2 Pilot Studies

6.2.1 Introduction

During the IEP preliminary assessment, it became clear that the information provided on the noise reduction benefits of the technology packages would be insufficient, on its own, to determine the benefits on aircraft system noise. System noise reductions are determined not only by the component noise reductions (fan, jet, core and airframe) but the relative levels of each component. This source component balance varies with certification point, aircraft class (e.g. Regional jets, Short/medium range aircraft and Long-range aircraft), engine type and manufacturer and so on. Although it is possible to make approximate estimates of the source balance, details on this are generally of a proprietary nature, as are details of the component noise reductions.

However, bearing in mind that we are attempting here to establish trends in aircraft system noise reduction, the IEP proposed that a 'Pilot Study' assessment be conducted by the one or more aircraft companies, to provide an example of the system noise benefits in the Short/Medium range class due to (a) a significant increase in engine bypass ratio, and (b) the noise reduction technologies selected by the IEP for the Medium term, relative to a baseline aircraft. Two companies agreed to carry out a Pilot Study, designated Pilot 1 and Pilot 2.

If successful, it was anticipated that a similar study could be conducted in the Long-range aircraft class; however, the companies involved were not prepared to do this for the following reasons. Trends in the noise of long range *twin* aircraft in the Medium term is already determined by the future introduction into service of the Boeing B787 and the Airbus A350, for which noise estimates have already been published. Further, these anticipated new aircraft introductions will have several of the component noise reduction technologies previously discussed already incorporated. Finally, no other additional conventional long range twin aircraft are expected in the Medium term. The same applies in the Long term, although it is conceivable that an un-conventional aircraft may be launched within this time frame (see Section 6.3). Arguably an assessment should be made as to the benefit of noise technology packages to, say, growth versions of long range twins, but this requires some working knowledge of the source balance of both existing twins and the new twins mentioned above. *This could be attempted if the source balance data were made available.*

Similar arguments apply to the long range quads; in the Medium term we will see the introduction of the B747-8, for which noise estimates are available. Otherwise no new or growth versions are anticipated in this class. In the long term an assessment should be made as to the benefit of noise technology packages to, say, growth versions of long range quads but again this requires some working knowledge of the source balance of both existing quads and the 747-8. *This could be attempted if the source balance data were made available.*

6.2.2 Pilot Study Specification

At the WG 1/IEP meeting on 2 December 2008, it was agreed that the two ICCAIA companies would supply information to the IEP in the form of System/Component sensitivity and 'Δ Component EPNL' data for a high BPR Virtual Platform (VP) in

the Short/Medium Range Twin class, termed the 'VP SR High'. This VP would incorporate most if not all the noise reduction technologies identified by the IEP.

These pilot studies would support the current IEP assessment and if successful would be repeated for VP's in other classes of aircraft.

The IEP agreed to outline the pilot process and to supply a definition of the information required, which is given below.

- IEP to specify Noise Reduction Technology Package (NRTP) list for this "Virtual Platform" (VP).
- Pilot 1 & 2 studies to produce the following information.
 1. The System EPNL of the Reference Aircraft at the three certification points.
 2. Confirm BPR of VP SR High (BPR=7-13).
 3. Δ System EPNL at the three certification points for the VP relative to the reference aircraft.
 4. Component Δ EPNL reductions for each NRTP item per noise source component
 5. System sensitivity for each noise source component, i.e. Δ System EPNL/ Δ Component EPNL

The recommended Noise Reduction Technology (NRT) packages suggested by the IEP are summarized in Table 6.2.1.

**Table 6.2.1 Noise Reduction Technologies for Short/Medium range
Twin Pilot Study**

Small Twin Vehicles – Regional Jet to A321 size			
Component	Technology	Medium Term (TRL 8 by 2018)	Long Term (TRL 8 by 2028)
Fan	Rotor Sweep	X	
	Stator Sweep & Lean	X	
	Fan Speed Optimization	X	
	Variable Area Nozzle	X	X
	Acoustically Lined “Soft” Vane		X
	Over The Rotor Treatment		X
	Active Stator		X
	Active Blade Tone Control		X
	Zero Hub Fan		X
Jet	Fixed Geometry Chevrons	X	
	Variable Geometry Chevrons	X	
	Higher BPR Cycle	X	
	Advanced Long-Duct Mixer	X	
	Fluidic Injection		X
	Bevelled Nozzle		X
	Microjets		X
	High Frequency Excitation		X
	Off-set nozzles		X
Nacelle/Liner	Zero Splice Inlet	X	
	Scarf Inlet	X ²	X
	Nose Lip Liner	X ³	
	High Temp. Lightweight Liner	X	
	LDMF (CNA) Liner	X	
	HQ Tubes		X
	Optimized Zone Liner		X
	Aft Cowl Liner	X	
	Acoustic Splitter		X
Active/Adaptive Liner		X	
Turbine	Blade/Vane Ratio Optimisation	X	
	Optimized Aerodynamics	X	
	Speed Optimisation	X	
	Over The Rotor Treatment		X
Combustor	Combustor Liner (Baffles/Cavity		
	Acoustic Plugs/ Micro-Perforated Liner		
	Cavity Septum)	X	
	Staged injection		X
Compressor	Blade/Vane Ratio	X	
	Missing Technologies?		
Bleed Valve	Teeth Design	X	
	Exit Screen	X	

² Potential operability and engine sensitivity issues

³ Anti-icing integration issue

Landing Gear	Fairing & Flaps	X	
	Low-Noise Design	X	
	Flow Control		X
	Missing Technologies?		
Slats	Low-Noise Design		X
	Missing Technologies?		
	Slot Cove Filler	X	
Flaps	Low-Noise Design		X
	Missing Technologies?		
	Continuous Mold Line Flap	?	X
	Porous Side Edge	X	

6.2.3 Pilot Study Results

Pilot 1 produced noise reduction results based on the Medium term NRT aircraft with a BPR = 8 engine “Virtual Platform” relative to a reference aircraft with BPR = 5.5, with a MTOM of 75.5 tonnes. The “Virtual Platform” airplane model at each step of the study (increased BPR or NRT incorporation) was re-designed and re-sized to be able to meet the same operational requirement as the baseline airplane model. At each step all the factors influencing performance and noise (weight, thrust, engine installation, landing gear, aerodynamic configuration, etc.) were taken into account in the model. For example, the MTOM reduction step between the baseline model and the model "BPR=8 without NRT" was as much as - 4%. The Pilot 1 results are summarised in Table 6.2.2.

Pilot 2 produced noise reduction results based on the Medium term NRT aircraft with a BPR = 9.5 engine “Virtual Platform” relative to a reference aircraft with BPR = 5, with a MTOM of 79 tonnes. The re-sized airplane (with 9.5 BPR engines) was at a lower takeoff weight of 77.6 tonnes (down 2%). The Pilot 2 results are summarised in Table 6.2.3.

Table 6.2.2 –Pilot Study 1 Results for Short/Medium Range Twin Aircraft Virtual Platform – Medium term

Baseline BPR 5.5	Approach EPNL	Flyover EPNL	Sideline EPNL
	95.5	84.7	93.5
VP SR High BPR 8	Approach Δ System EPNL re Baseline	Flyover Δ System EPNL re Baseline	Sideline Δ System EPNL re Baseline
w/o techno	1.4	3.2	7.0
with techno	3.0	5.4	8.4
	92.5	79.3	85.1
Components / NRTP BPR 8	Δ System EPNL / Δ Component EPNL Before / After techno application	Δ System EPNL / Δ Component EPNL Before / After techno application	Δ System EPNL/ Δ Component EPNL Before / After techno application
Landing gear	0.3 / 0.2	0	0
Slats	0.3 / 0.3	0.1 / 0.2	0.1 / 0.1
Flaps	0.1 / 0.1	0.1 / 0.1	0 / 0
Inlet Fan	0.2 / 0.2	0.4 / 0.1	0.3 / 0.1
Aft Fan	0.1 / 0.3	0.3 / 0.4	0.2 / 0.3
Jet	0. / 0.	0.2 / 0.2	0.3 / 0.4
Turbine	0. / 0.	0. / 0.	0. / 0.
Combustor	0. / 0.	0. / 0.	0. / 0.1

Table 6.2.3 –Pilot Study 2 Results for Short/Medium Range Twin Aircraft Virtual Platform – Medium term

Baseline BPR 5.0	Approach EPNL	Flyover EPNL	Sideline EPNL
	94.5	87.5	92.4
	Approach	Flyover	Sideline
VP SR High BPR 9.5	Δ System EPNL re Baseline	Δ System EPNL re Baseline	Δ System EPNL re Baseline
Delta EPNL (BPR only)	-2.2	-5.6	-5.8
Delta EPNL (BPR + all tech)	-5.6	-7.9	-8.0
System EPNL	88.9	79.7	84.4
Components / NRT BPR 9.5	Δ System EPNL / Δ Component EPNL	Δ System EPNL / Δ Component EPNL	Δ System EPNL/ Δ Component EPNL
Airframe	0.3	0.2	0.2
Inlet Fan	0.2	0.1	0.1
Aft Fan	0.2	0.2	0.2
Jet	0.0	0.1	0.3
Turbine	0.2	0.0	0.0
Combustor	0.1	0.0	0.0
Compressor	0.2	0.0	0.0
Bleed valve	0.2	0.0	0.0

NOTES:

1. BPR is calculated at the flight condition for the Lateral point. For the Baseline aircraft the BPR=5.0, and for the Virtual Platform aircraft BPR=9.5
2. The Sensitivity values shown in Table 6.2.3 correspond to EPNL changes at the system level for a 1 dB change in the component level.
3. The expected improvement for the combustor component assumes the total elimination of the combustor noise, and therefore, corresponds to the expected benefit of all the listed technologies.
4. The expected improvement for the compressor component assumes the total elimination of the LPC noise, and therefore, corresponds to the expected benefit of all the listed technologies.

Pilot 1 also produced noise reduction results based on the Long term NRT for a BPR = 12 powered virtual platform relative to the same reference BPR = 5.5 aircraft. The results are summarised in Table 6.2.4.

Table 6.2.4 –Pilot Study 1 Results for Short/Medium Range Twin Aircraft Virtual Platform – Long term

Short Medium range twin a/c	Approach EPNL	Flyover EPNL	Lateral EPNL
Baseline BPR 5.5	95.5	84.7	93.5
Technology Platform BPR 8	Δ System EPNL re Baseline	Δ System EPNL re Baseline	Δ System EPNL re Baseline
w/o MT techno	-1.4	-3.2	-7.0
with MT techno	-3.0	-5.4	-8.4
	Approach EPNL	Flyover EPNL	Lateral EPNL
TP BPR8	92.5	79.3	85.1
Components / NRTP BPR 8	Δ System EPNL / Δ Comp. EPNL Before / After techno application	Δ System EPNL / Δ Comp. EPNL Before / After techno application	System EPNL / Δ Comp. EPNL Before / After techno application
Landing gear	0.3 / 0.2	0	0
Slats	0.3 / 0.3	0.1 / 0.2	0.1 / 0.1
Flaps	0.1 / 0.1	0.1 / 0.1	0 / 0
Inlet Fan	0.2 / 0.2	0.4 / 0.1	0.3 / 0.1
Aft Fan	0.1 / 0.3	0.3 / 0.4	0.2 / 0.3
Jet	0. / 0.	0.2 / 0.2	0.3 / 0.4
Turbine	0. / 0.	0. / 0.	0. / 0.
Combustor	0. / 0.	0. / 0.	0. / 0.1
Compressor	0. / 0.	0. / 0.	0. / 0.
Technology Platform BPR 12	Δ System EPNL re Baseline	Δ System EPNL re Baseline	Δ System EPNL re Baseline
w/o MT techno*	-1.8	-4.9	-10.9
w/o LT techno**	-3.2	-6.0	-11.2
with MT & LT techno	-3.8	-6.4	-11.6
	Approach EPNL	Flyover EPNL	Lateral EPNL
TP BPR12	91.7	78.3	81.9
Components / NRTP BPR 12	Δ System EPNL / Δ Comp. EPNL After techno application	Δ System EPNL / Δ Comp. EPNL After techno application	System EPNL / Δ Comp. EPNL After techno application
Landing gear	0.2	0.0	0.0
Slats	0.3	0.3	0.2
Flaps	0.1	0.1	0.1
Inlet Fan	0.2	0.1	0.1
Aft Fan	0.2	0.3	0.4
Jet	0.0	0.1	0.1
Turbine	0.0	0.0	0.0
Combustor	0.0	0.2	0.2
Compressor	0.0	0.0	0.0

Note: In the above table, technologies included in the BPR12 virtual platform are:
*Mid term: zero splice intake, lip liner, negatively scarfed intake, low frequency hot stream liners, low noise LP compressor, low noise LP turbine, low noise landing gears design, high lift add on treatment
**Long term: Bypass duct splitters, Active fan stators

The IEP Chair, Phil Gliebe, conducted a mini-pilot study to complement the manufacturer-supplied pilot studies, and enable the IEP to independently assess trends. This was based on a proprietary empirical correlation of component EPNL as a function of cycle parameters. It used the A321-200 of MTOM 93 tonnes as a reference aircraft and ‘perturbed’ the reference engine cycle by varying jet exhaust mixed velocity, computing other cycle parameters including BPR, while holding net thrust and core airflow constant. It re-computed the component EPNL values and summed these to obtain new system noise levels vs. BPR, anchored to reference aircraft levels. The results may be optimistic in that the method neglected the increase in nacelle drag as fan diameter increases, and neglected potential reduction in fan liner suppression if treatment L/D cannot be maintained. Aircraft re-sizing was also neglected. The results were used to confirm Pilot study 1 & 2 trends and helped define Noise vs. Bypass Ratio trend lines.

6.2.4 Summary of Pilot Study Noise Reduction Technology results

The reductions obtained in the Pilot 1 & 2 studies for the benefits of NRT are summarised below for the Mid-term NRT and the combined effect of Mid-term and Long-term NRT, in Table 6.2.5. For the Mid-term NRT, The IEP has also assessed the NRT results obtained in the AST studies, and generated statistical averages of the 1, 2 and AST values, which are also shown in the table. Based on all three values, the IEP recommends the values shown in the following line. For the combined Mid-term and Long-term NRT, there are only the Pilot 1 and AST results.

Table 6.2.5 – Pilot Study NRT EPNL noise reductions for Short/Medium Range Twin (SMR2)

	Mid-term NRT			
Pilot	Approach	Flyover	Lateral	Cumulative
1	1.6	2.2	1.4	5.2
2	3.4	2.3	2.0	7.9
AST	1.6	2.1	2.0	5.7
IEP	2.0	2.0	1.5	5.5
	Mid-term & Long-term NRT			
1	2.0	1.5	0.7	4.2
AST	1.8	2.1	2.0	5.7
IEP	2.5	2.5	2.0	7.0

6.3 Assessment of noise reduction trends with bypass ratio (BPR) and Noise Reduction Technology (NRT)

6.3.1 Bypass Ratio Effects Methodology

Historical trends in aircraft noise reduction are often viewed as a function of engine bypass ratio (BPR) because this has had a strong influence on jet mixing noise, the major noise component on aircraft with low-bypass ratio engines. However it should be emphasised that medium to high bypass turbofan engines have significant fan noise and other noise source components. The cycle change represented by an increased BPR requires these components to be re-designed, which normally leads to lower component noise source levels. Thus the benefit of increased BPR arises not only from reductions in jet mixing noise but also reductions in fan noise and other components. It is probably better to think of the engine cycle being changed to improve fuel burn, say, and the resulting changes in the engine design almost invariably lead to an increased BPR (at least up till the present time).

Noise data are presented below as a function of BPR for different maximum take-off mass (MTOM). This means that the absolute margins are not strictly comparable because it is well established that aircraft noise increases rapidly with MTOM. But what we are trying to establish here is the rate of change of the noise margin with engine cycle, represented by BPR, in order to separate out this strong, inevitable noise reduction benefit from the reduction due to noise technology. As long as we view the gradient or sensitivity to BPR for each subset of data at an approximately constant MTOM, which is the case for the Pilots 1 & 2 and the AST study aircraft (reference IEP 6.6), we should not confuse BPR benefits with effects due to changes in MTOM.

We review noise trends in this way, in Appendix A, for the Short/Medium range and Long range classes, at each certification point, using the Best Practices Database provided and the results of the Pilot studies outlined above. Data is shown as the margin relative to Stage 3, rather than absolute levels. Those results are summarised below by considering the trends in the cumulative margin (sum of margins at the three conditions).

6.3.2 Short/Medium Range Class

The cumulative margins help to summarise the trends identified above. Fig. 6.3.1 shows the SMR2 cumulative data together with the Pilot results and the AST results. On average the Pilot 1 & 2 results appear to follow a trend line of 3 dB per unit BPR as indicated by the red line and the Medium term NRT offers a benefit of between 5 and 8 dB.

Over the range BPR=9 to 12, Pilots 1 & 3, the former with or without NRT, appears to follow a trend line of about 1.5 dB per unit BPR, as indicated by the blue line. Most of this comes from the Lateral condition. The Pilot 1 NRT appears to provide a slightly smaller benefit at BPR=12 compared to that at BPR=8. Regional Jet aircraft are expected to exhibit the same sensitivity to BPR as deduced for the SMR2 aircraft.

These trends are described in more detail at each certification condition in Appendix A.

6.3.3 Long Range Class

The Long range Quad cumulative data shown in Fig. 6.3.2 agrees very well with the 3 dB/BPR trend line from the SMR2 study over the range BPR=5 to 8.3 and falls below the A380 as expected. However there is insufficient data in the BPR=8.3 to 12 range to be certain that the same trends would apply. The A380 at BPR=9 is at the same level as the AST Study Large Quad Aircraft B747-400 with the P&W ADP engine at BPR=13.

Likewise the LR2 cumulative data shown in Fig. 6.3.3 also supports the 3 dB/BPR trend line from the SMR2 study over the range BPR=5 to 8.3, based on BPD data for the A330 and B777 at MTOM of 230t and 247t respectively. These were selected to bracket the MTOM of the A350 and B787 which are 245/265t and 220t respectively. The extrapolated trend line exceeds the margins predicted for the new A350 and B787 aircraft by up to 5 dB but as these are predicted rather than certified levels, this difference may turn out to be smaller in reality. On the other hand this difference may also be caused in part by a flattening off of the sensitivity to BPR, observed in the data discussed above for the SMR2 and LR4.

For the categories of aircraft studied, within the variability and data scatter of the information available, the cumulative noise levels for a new design aircraft will have an approximate dependence on the take-off BPR as follows.

- 4≤BPR≤9: Cum EPNL sensitivity ~ 3.0 EPNdB per unit change in BPR
- 9≤BPR≤13: Cum EPNL sensitivity ~ 1.5 EPNdB per unit change in BPR

Short/Medium Range Twin Noise Reduction, Cumulative showing IEP deduced Mid & Long term BPR & NRT (TRL6) trends*

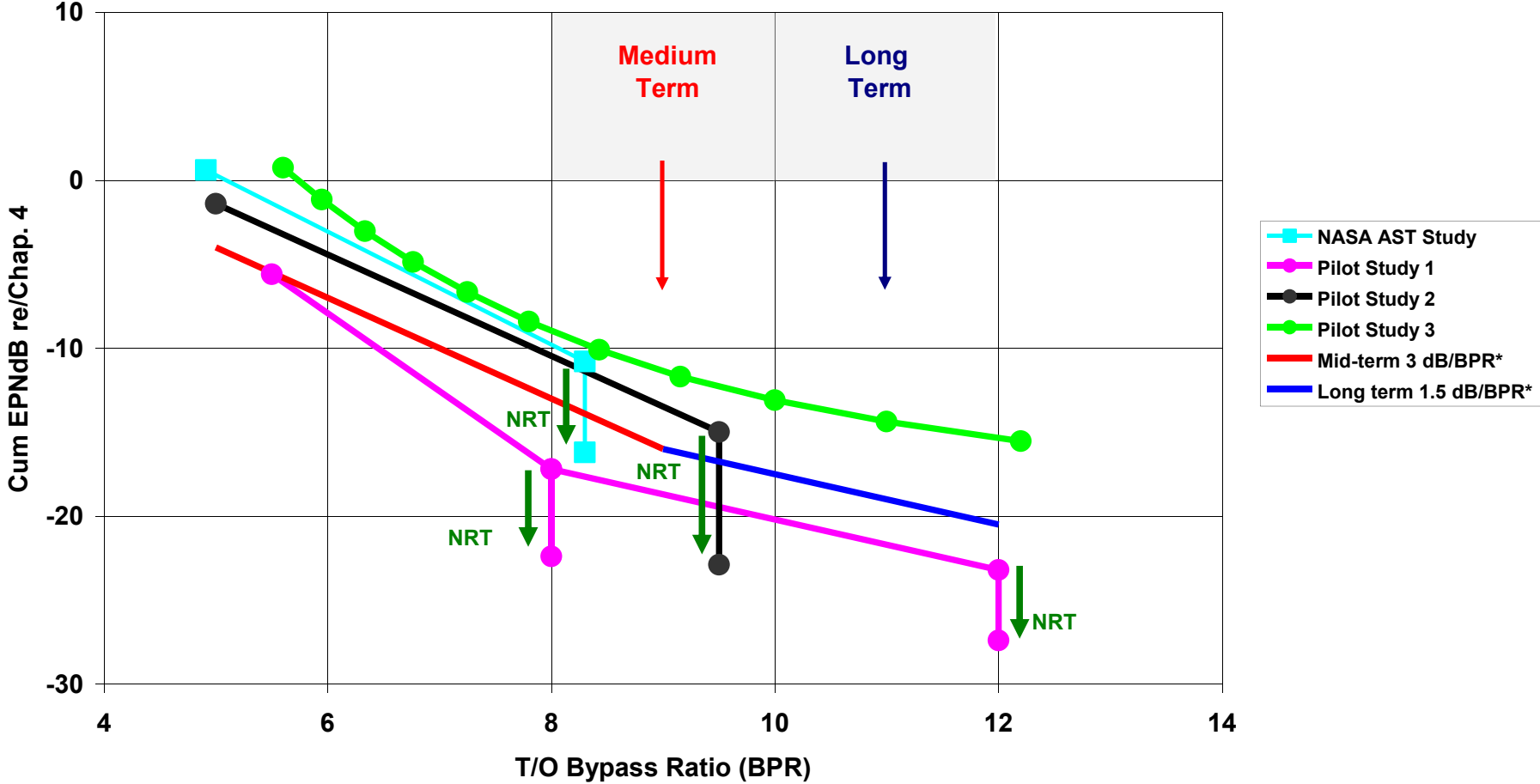


Figure 6.3.1: Short/Medium Range Twin cumulative margin noise trend with BPR & NRT (Note Pilot 3 does not include NRT)

Large Quad Noise Data, Cumulative compared with IEP deduced Mid & Long term BPR trends

Squares - Studies for Engine BPR Change Only (No Noise Reduction Technologies)

Triangles - Best Practices Data Base

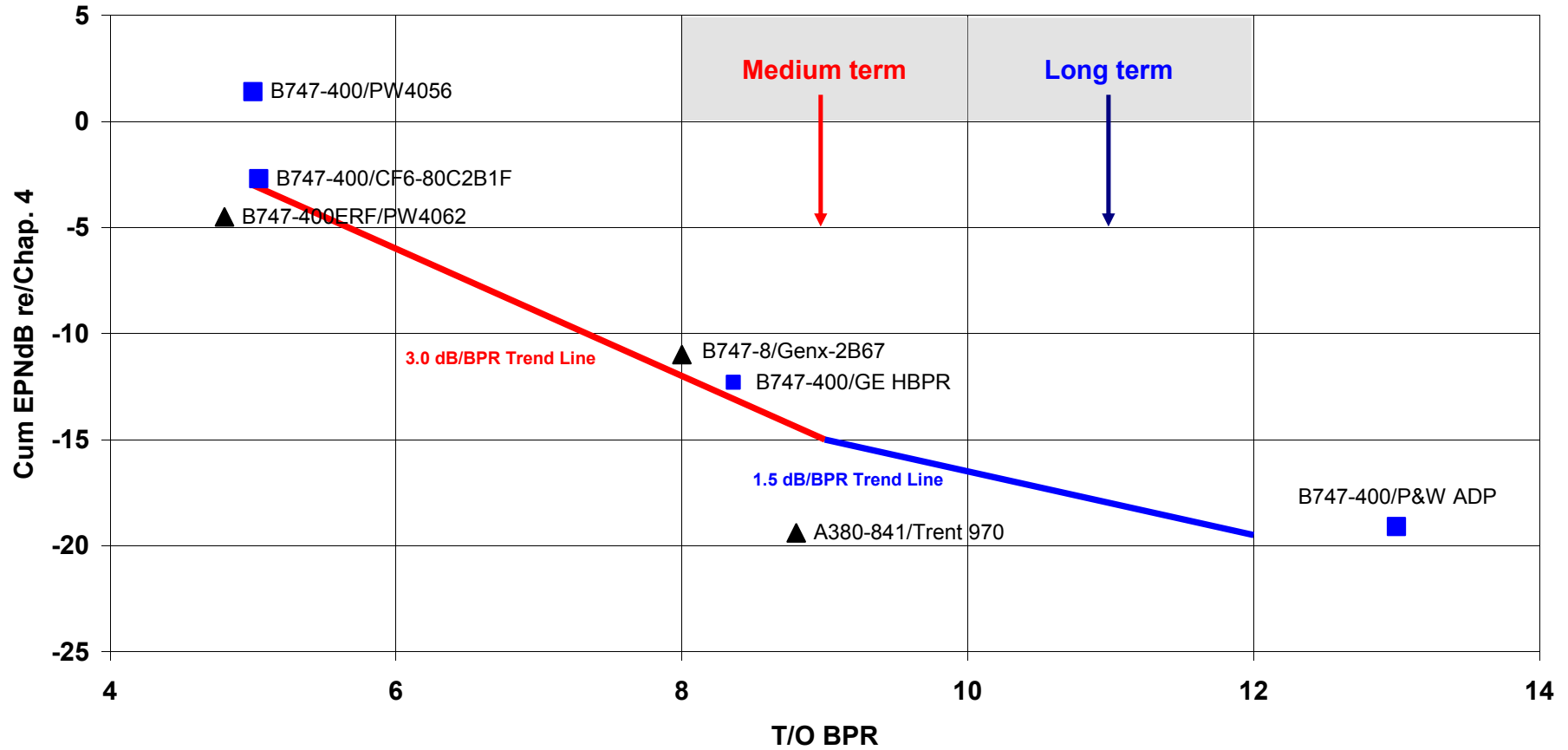


Figure 6.3.2: Long Range Quad Cumulative noise data *versus* IEP BPR trend lines

Long Range Twin Noise Data, Cumulative compared with IEP deduced BPR trends

Squares - AST LR2 Study for Engine BPR Change Only (No Noise Reduction Technologies)
 Other symbols - Best Practices Data Base

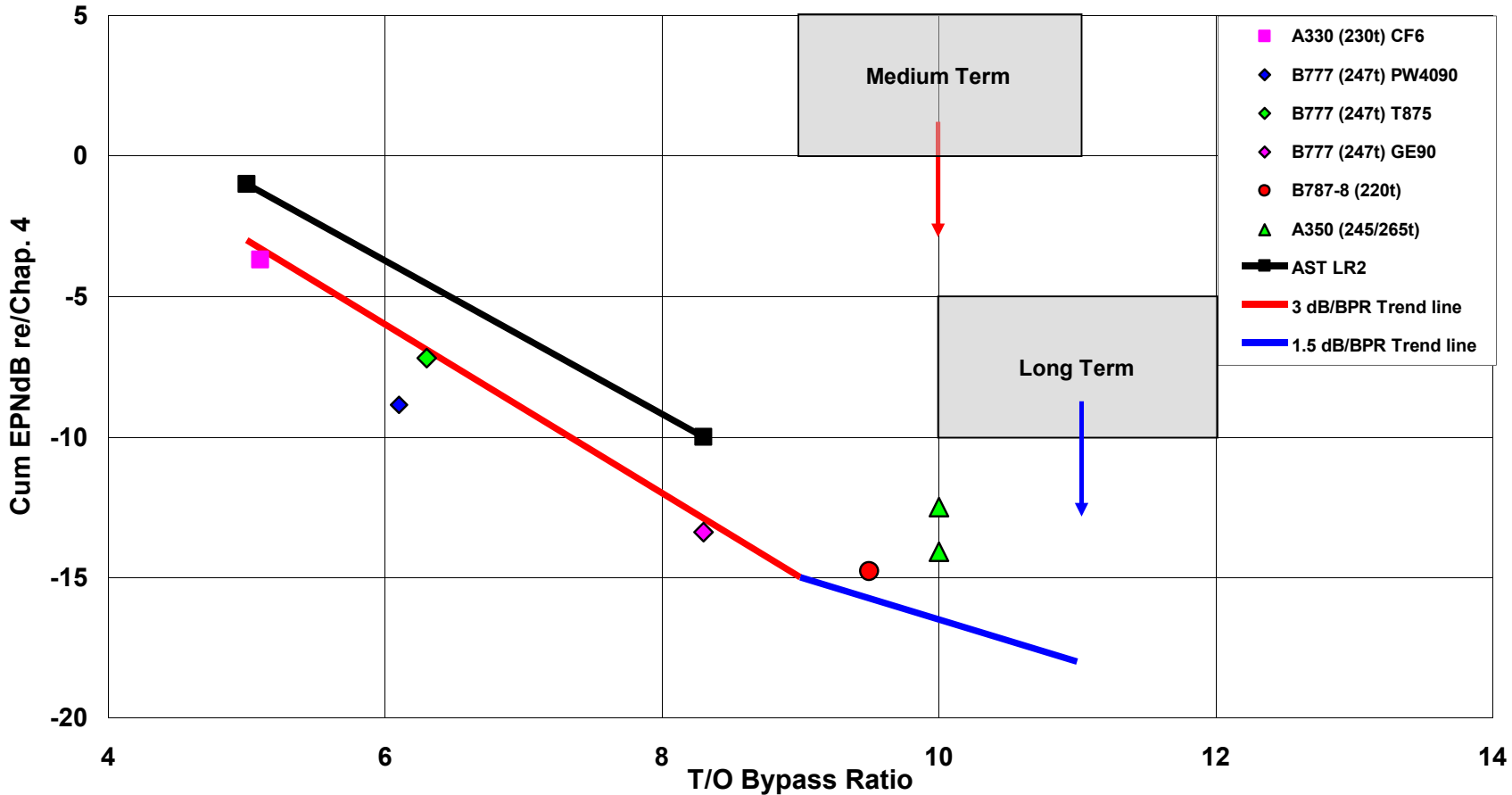


Figure 6.3.3: Long Range Twin Cumulative margin data versus IEP BPR trend lines

6.4 Novel Engine & Airframe Concepts

The noise levels of future novel engine and airframe concepts were addressed in the Review under the headings of 'Propulsion Systems' and 'Future Concept Aircraft Configurations'. The former concerned the 'Open Rotor' and 'Geared TurboFan', the latter various system concepts including the 'Blended Wing Body (BWB)' and the 'Hybrid Wing Body'. It should be noted that here we are considering completely new design concepts and just not noise reduction technology for particular airframe or engine components.

6.4.1 Propulsions Systems

Both the Open Rotor and Geared Turbofan offer the potential for significant reductions in fuel burn and therefore operating cost but the Review offered little information on the noise levels of these types of engines, apart from a qualitative trend chart that indicated the Geared Turbofan engine to be quieter but the Open Rotor engine to have a lower fuel burn. This is understandable as these engines have yet to enter service. GE, Pratt & Whitney and Rolls-Royce have tested model scale fan and other rigs and both GE and Pratt & Whitney have tested flight demonstrators of the Open Rotor concept during the 1980's, suggesting that the Open Rotor concept is at TRL 6. Only recently a full scale Geared Turbofan (GTF) demonstrator has been flight tested and hence has also achieved TRL 6.

In view of the importance of fuel burn and the projected modest noise margins of the Open Rotor, the IEP recommends that when more information becomes available, *a follow-on review should consider the noise - fuel burn interdependencies of the Open Rotor Concept. Noise reduction goals for Open Rotor fan propulsion has to take into account the trade-offs between noise and fuel burn, and there is insufficient data available at the present time to conduct such trade studies.*

6.4.2 Aircraft Systems

Most of the novel airframe/engine concepts currently being developed and evaluated within the aviation industry today have to be viewed as one integrated system and cannot strictly be assessed separately. The low noise characteristics of these concepts are partly due to the shielding of the engine noise (fan inlet, fan exhaust, core and jet) by the Blended-Wing-Body (BWB) and partly airframe noise reduction features such as low noise landing gear and the omission of flaps. Benefits of about 11 EPNdB cumulative were quoted relative to a conventional State-of-the-Art reference aircraft but more research is in progress on those noise reduction features as well as installation effects before these noise reduction concepts can be quoted with reasonable confidence.

For example, NASA conducted a preliminary system noise assessment of a hybrid wing configuration (2003-2005) that included two conventional, high bypass ratio turbofan engines mounted on top of the hybrid wing body at the trailing edge, which suggested significant shielding of forward radiated noise. In contrast, aft-radiated noise is not shielded creating a significant challenge for maximizing the potential of this configuration. One approach examined was to move the engine pods two diameters forward, and estimate the maximum impact of moving part of the jet sources upstream, in addition to overall jet noise source reduction of the distributed

source downstream of the nozzles. The hybrid wing body promises to impact airframe sources levels with a more distributed lift and the absence of the traditional high lift system. However, there is a scarcity of experiments and prediction methods, and a number of assumptions had to be made to produce the preliminary estimates that the airframe noise component could be reduced 6 dB. This preliminary system noise assessment using, best available information, estimated that the hybrid wing body could reach 42 dB cumulative below Chapter 4, see Fig. 6.4.2.1

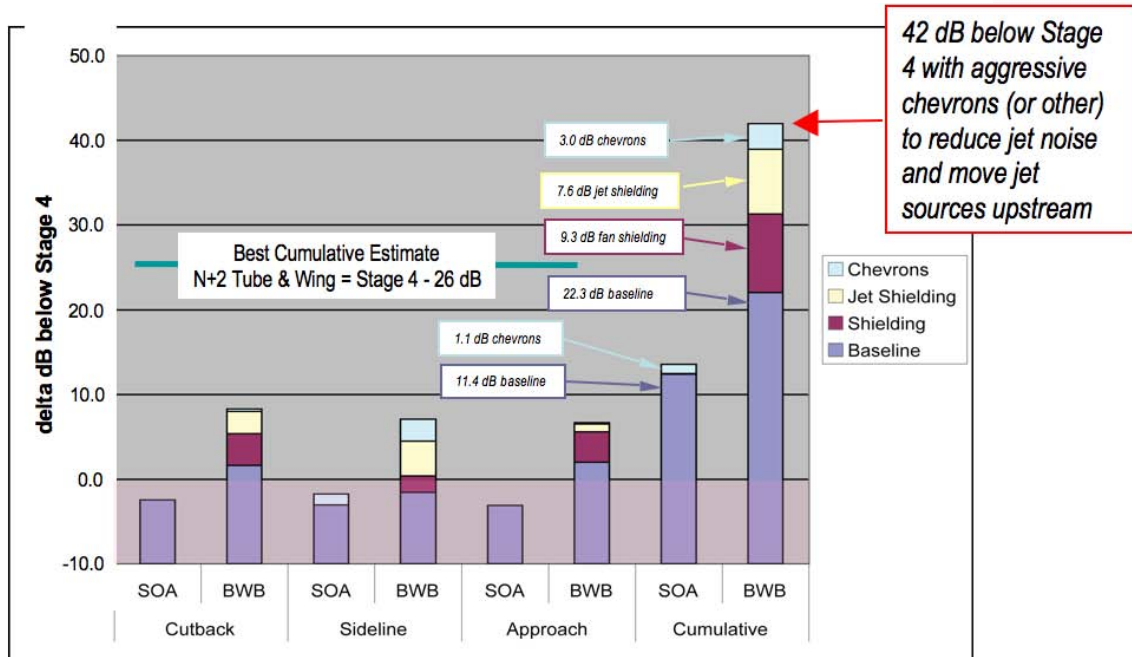


Fig. 6.4.2.1: Predicted noise reduction for BWB aircraft

2016 Subsonic Airplane

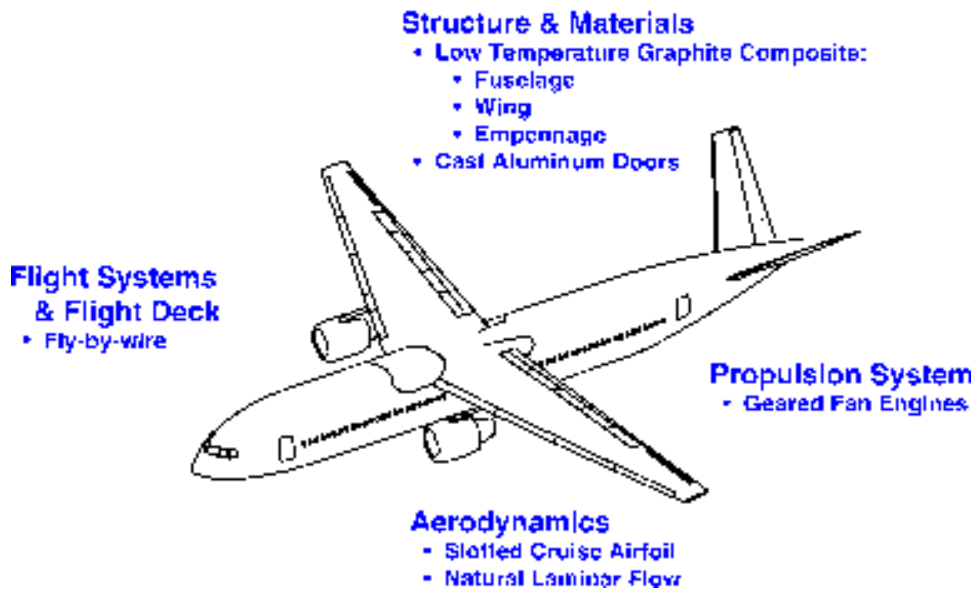


Fig. 6.4.3.1: Taken from the 1996 Wright Brothers Lecture in Aeronautics by Philip M. Condit, the Boeing Company, October 22, 1996 ref. IEP6.3

More recent experiments by the European ROSAS project (Research on silent aircraft concepts) used more sophisticated jet and fan noise simulators sources and documented the shielding for tail mounting configurations on a traditional tube and wing configuration. These types of experiments have been used to supply key shielding attenuation information for preliminary system noise assessments of these two fundamental directions for low-noise, advanced aircraft configurations.

Taking the most optimistic view the timescale for the research & technologies required for all the system and its components to reach TRL 6 must be at least 10 years, although this may be shortened if a military system is developed first (targeted IOC 2020 at the moment).. The actual development of such an aircraft system would take at least another 5-10 years, thus placing this type of aircraft beyond the time line (2028) of this Independent Expert Review.

6.4.3 High-Wing Aircraft

Although high-wing aircraft configurations were not mentioned in the Review, this type of aircraft could offer a simple means of achieving much lower landing gear noise with a short fuselage-mounted design. This would also offer easier integration with large-diameter UHB powerplants. A previous 'vision' from Boeing in 1996 showed UHB turbofans on a high wing aircraft, reproduced in Fig. 6.4.3.1.

6.4.4 'Functionally Silent' Aircraft Concept

The Cambridge-MIT Institute, through the Silent Aircraft Initiative (ending in 2006), created a concept aircraft with low noise as the primary, but not only, design objective, see Fig. 6.4.4.1. The SAX-40 final design used a broader set of higher risk technologies including an embedded, boundary layer ingesting propulsion system with three engine clusters each of which is comprised of a single core driving three fans, a configuration that has a very high effective bypass ratio and allows for extended duct lengths for additional liner attenuation. Together with airframe technology and operational benefits, the study assessed noise at some 75 dB below Stage 4 while having the potential for a 25% fuel efficiency improvement relative to current configurations (see reference IEP6.4). However, due to the higher risk, lower TRL technologies employed in this concept the implementation time frame is expected to be well beyond 2028.



Fig. 6.4.4.1: Silent Aircraft Initiative: SAX-40 Concept, taken from reference IEP6.5

7. Recommended noise reduction goals

The projections in this report are based on best available information on the potential benefits of noise reduction technologies and expected future vehicle configurations. Specific noise reduction technologies have been used in the IEP evaluation that can be realistically be implemented in the mid and long term timeframes. However, the marketplace will determine which technologies are actually selected for a particular vehicle. So while the results in this report show what can be done, what actually happens over the next ten and twenty years will depend on factors well beyond the scope of this study. This is why there will continue to be significant variations in noise levels for aircraft within a vehicle class that may either fall short or exceed the projections.

7.1 Mid Term – Year 2018

In the previous section, the IEP developed a set of trend lines which provided guidance on the amount of noise reduction that can be achieved for the various classes of aircraft, and used these trend lines to infer how much noise reduction might be possible based on bypass ratio improvements alone, and then with advanced noise reduction design features included.

Following an assessment of the various NRT packages currently under development, as reported in the Review, it was concluded that these packages can provide small but not insignificant reductions in total aircraft system noise at takeoff, but that the addition of increased BPR designs provide a substantial improvement in takeoff noise. For approach noise, the increased BPR benefits are not as great as at takeoff, but the NRT packages have a more substantial benefit at approach than at takeoff.

As outlined in Section 6, the IEP had requested that the WG1 industry members provide some sample aircraft noise estimates for a couple of BPR scenarios and for a Medium term and a Long term set of NRT packages, to supplement the information provided in the Review. The information was provided by two industry members for a “Short-Medium Range Twin” virtual platform aircraft and gave the IEP critical information needed to assess the separate effects of NRT packages and increased BPR, as well as assess the likely uncertainty in the noise reduction benefits due to NRT package variations, BPR variations and also manufacturer implementation variations.

From the above-described information in Section 6, for the Medium term (year 2018), the following recommended aircraft noise reduction technology goals are given in Table 7.1.1, relative to reference aircraft noise levels (derived from current Best Practice Noise Database aircraft noise levels), for consideration by CAEP.

For each class and at each condition, three noise reduction numbers are given in Table 7.1.1: the first is the noise reduction due to the change in Bypass Ratio (BPR) based on the projected (Medium term) BPR change shown in Table 6.1.1; the second is that due to the (Medium term) Noise Reduction Technology (NRT) package features, and the third is the simple sum of those two.

**Table 7.1.1 – Estimated Mid-term EPNL noise reductions
(Relative to Current Reference Aircraft)
(BPR + NRT = Total)**

Aircraft Category	Approach	Flyover	Lateral	Cumulative (TRL 6)	Cumulative (TRL 8)
Regional Jet	0.5+1.5=2.0	2.0+1.5=3.5	3.5+1.0=4.5	6.0+4.0=10.0	9.0
Small-Med. Range Twin	1.5+2.0=3.5	4.0+2.0=6.0	6.5+1.5=8.0	12.0+5.5=17.5	16.0
Long Range Twin	1.5+2.0=3.5	3.5+2.0=5.5	5.5+1.5=7.0	10.5+5.5=16.0	14.5
Long Range Quad	1.5+2.0=3.5	4.0+2.0=6.0	6.5+1.5=8.0	12.0+5.5=17.5	16.0

The noise reductions at each condition plus the first column of cumulative figures listed in Table 7.1.1 are based upon NRT benefits at TRL6. To estimate the corresponding cumulative figures at TRL8, a realization factor of 0.9 (90%) was applied to the TRL6 projected noise reduction benefits (relative to the selected 2008 baseline aircraft for each category) to bring the goal to TRL8. The selection of 90% realization factor was the best estimate the IEP could make based on information available and Panel member experience. It is recommended that an in-depth analysis of realization factor be conducted as a work item for CAEP/9. Note that these are goals, not recommended rule limits.

In line with the IEP approach of analyzing Bypass Ratio (BPR) effects and component noise reduction technology (NRT) effects separately and then combining the two to provide estimated aircraft system noise reduction goals, the IEP estimated the uncertainties in the projected noise reduction goals for BPR effects and NRT effects separately, as detailed in Appendix A. The uncertainty bands for these estimates are given in Table 7.1.2.

**Table 7.1.2 - Estimated Cumulative EPNL Noise Reduction Goal Uncertainty Bands (One Standard Deviation)
(±BPR / ±NRT / ±Total)**

Aircraft Category	Mid-Term	Long-Term
Regional Jet	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3
Small-Med. Range Twin	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3
Long Range Twin	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3
Long Range Quad	±3.4 / ±1.3 / ±3.6	±3.8 / ±2.2 / ±4.3

7.2 Long Term – Year 2028

In addition to advances in conventional aircraft configurations that might occur, novel concepts such as the Blended-Wing-Body (BWB) aircraft, Open-Rotor Fan Propulsion, and the Functionally Silent Aircraft were reviewed by the IEP, to the extent that quantitative information was available. It was concluded that the Blended Wing-Body (BWB) aircraft concepts and the Functionally Silent Aircraft concept were at too low a Technology Readiness Level to become viable products by 2028,

and so the IEP conclusions and recommendations are based on conventional Wing-and-Tube aircraft architecture. The IEP concluded that propulsions systems could achieve larger bypass ratios than has been considered for the Medium term, based on input from the WG1 Planning Committee and individual ICCAIA member representatives.

From the above-described information and the NASA AST and Pilot Study results, the following recommended aircraft noise reduction technology goals are given in Table 7.2.1, relative to reference aircraft noise levels (derived from current Best Practice Noise Database aircraft noise levels), for consideration by CAEP. As before, for each category and at each condition, three noise reduction numbers are given: the first is that due to the change in Bypass Ratio (BPR) from reference aircraft value to the maximum BPR in the Long Term projected by the Panel (see Table 6.1.1), the second is the noise reduction due to the Long Term Noise Reduction Technologies (NRT), and the final figure is the sum of the first two numbers. The goal Noise Reduction uncertainty bands are the same as for the Mid-term given in Table 7.1.2.

**Table 7.2.1 – Estimated Long-term EPNL noise reductions
(Relative to Current Reference Aircraft)
(BPR+NRT=Total)**

Aircraft Category	Approach	Flyover	Lateral	Cumulative (TRL 6)	Cumulative (TRL 8)
Regional Jet	1.5+2.0=3.5	4.0+2.0=6.0	6.5+1.5=8.0	12.0+5.5=17.5	16.0
Small-Med. Range Twin	2.0+2.5=4.5	4.5+2.5=7.0	7.0+2.0=9.0	13.5+7.0=20.5	18.5
Long Range Twin	2.0+2.5=4.5	3.5+2.5=6.0	6.5+2.0=8.5	12.0+7.0=19.0	17.0
Long Range Quad	2.0+2.5=4.5	4.5+2.5=7.0	7.0+2.0=9.0	13.5+7.0=20.5	18.5

The cumulative noise reduction benefits listed in Table 7.2.1 are at TRL6 and at TRL8, where the latter has been estimated from the former by assuming a 90% realisation factor, as for the Mid-term.

7.3 Medium and Long Term Summary

From the Noise Reduction Benefit goals summarized in Tables 7.1.1, 7.1.2 and 7.2.1, the resulting noise Reduction Goals referenced to ICAO Annex 16, Chapter 4 were evaluated. This evaluation included incorporating representative reference aircraft noise levels relative to Chapter 4, and selecting a representative maximum Take-off mass for each category.

A study was made of the current Best Practices database noise levels for each of the above aircraft categories. Noise levels relative to ICAO Annex 16 Chapter 4 were

studied as a function of certified Maximum Takeoff Gross Mass. From these data analyses, it was observed that various models of aircraft designs certified over the years exhibited an increasing cumulative noise level as the aircraft grew in capacity (MTOM) to meet customer requirements. For some aircraft categories, deviations from the nominal trends were identified which could be related to either introduction of non-optimum noise reduction features for specific customer requirements, or more advanced design features not present in other aircraft in the same category. Taking into account these deviations from common design practice, the Panel arrived at the following reference cumulative levels relative to Chapter 4, for the four aircraft categories listed above.

Table 7.3.1 – Reference Aircraft Take-off Weight and Noise Levels

Aircraft Category	MTOM, tonnes	Cum Level re: Ch. 4,
Regional Jet	40	-4 EPNdB
Small-Med. Range Twin	78	-5 EPNdB
Long-Range Twin	230	-6 EPNdB
Long-Range Quad	440	-5 EPNdB

It was recommended by the ICCAIA members of the WG1 N29 Planning Committee that the Panel apply a “realization factor” to the recommended Noise Goal levels, to recognize the likelihood that some of the projected noise reduction concept benefits would erode as they are designed into a production aircraft system, and to recognize that there is an erosion in aircraft noise performance as it progresses from a TRL6 design definition to final aircraft certification. The ICCAIA recommendation was to add 5 EPNdB to the Panel TRL6 Noise Goal Levels to account for these effects. This correction represents the possible loss in noise benefits due to design compromises made as the design definition matures to a certifiable configuration, and due to certification flight test variability and uncertainty.

After several discussions with the WG1 N29 Planning Committee members, the Panel felt collectively felt that it was still unclear as to what parts of the above-described realization factor causes have already been taken into account in their goal assessments and the uncertainty analysis that had been carried out. However, the Panel recognizes that a realization factor should be applied to the noise reduction benefits associated with both the Bypass Ratio benefits and the Noise Reduction Technology benefits that result from design implementation from TRL6 demonstration to final manufactured product certification.

Therefore the Panel chose to apply a % realization factor to the cumulative noise benefit for each aircraft category. The factor chosen was 90%, i.e., 90% of the cumulative noise benefit demonstrated at TRL6 is estimated to be realized at aircraft certification. This factor was based on very little quantitative data, and the Panel used what little information it had available, plus several Panel members’ past experience in choosing the above value of realization factor. The Panel therefore recommends that an in-depth study of “Realization Factor” be the subject of a future CAEP work project, as a step toward improving the goal forecasting process established in the present Panel Review effort. This study could include quantifying the effects of aircraft category, certification point (not just cumulative level), and Bypass ratio.

The Panel therefore offers the following Noise Goal levels, in cumulative noise level EPNL, relative to Chapter 4, with the understanding that they are based on TRL8 Noise Reduction Technology Benefits. It is important that CAEP realize that they are based on a somewhat arbitrary estimate of the realization factor employed to project benefits from TRL6 to TRL8. The Goal Levels given below in Table 7.3.2 have an uncertainty in their estimates, as described in section 7.1 above. Therefore an uncertainty band around the goal was estimated using the standard deviation values in Table 7.1.2, multiplied by a factor of 1.282 to yield an 80% confidence interval. Thus the band represents the range within which there is 80% probability that the goal can/may be achieved.

Finally, it is known that a aircraft initially certified will potentially be certified and offered in either higher or lower maximum take-off weights (or MTOM) during the life cycle of the aircraft design. The average MTOM variation is typically on the order of $\pm 25\%$ of the initial certification MTOM. Further, from studies of the existing Best Practices Noise Database, the N24 Task Group of WG1 carried out a multi-variate regression study of certified noise levels as a function of various aircraft and engine parameters listed in the Database. The N24 study found that, on the average, cumulative noise levels varied as $\sim 67 \times \log_{10}(\text{MTOM})$. The N24 task group recommended that the IEP use this sensitivity of noise on MTOM to graphically show how an aircraft goal noise level might vary over its likely MTOM range of $\pm 25\%$.

Table 7.3.2 below gives the Panel recommendations for TRL8 Cumulative Noise Goal Levels relative to Chapter 4.

**Table 7.3.2 – Mid-Term and Long-Term Noise Goal Recommendations
Cumulative EPNL re: Chapter 4 Limits at TRL8**

Aircraft Category	Mid-Term (2018)	Long-Term (2028)
Regional Jet	13.0 \pm 4.6	20.0 \pm 5.5
Small-Med. Range Twin	21.0 \pm 4.6	23.5 \pm 5.5
Long-Range Twin	20.5 \pm 4.6	23.0 \pm 5.5
Long-Range Quad	21.0 \pm 4.6	23.5 \pm 5.5

These goals, their uncertainty bands, and their expected variation with changes from initial certification MTOM, are illustrated in figures 7.3.1 and 7.3.2, for Mid-Term and Long-Term, respectively.

Finally, the potential benefits of advanced Noise Abatement Operational Procedures were evaluated, based on information provided at the Independent Experts Review. The Panel assessed that the landing or approach condition was the most likely candidate for application of advanced Noise Abatement Procedures (NAP's) and it may be possible to provide an additional 3 EPNdB reduction in aircraft noise level at approach. This would offset the somewhat smaller noise reductions forecast for approach noise resulting from increasing BPR and adding NRT packages.

Medium Term (2018) Cumulative Noise Goals

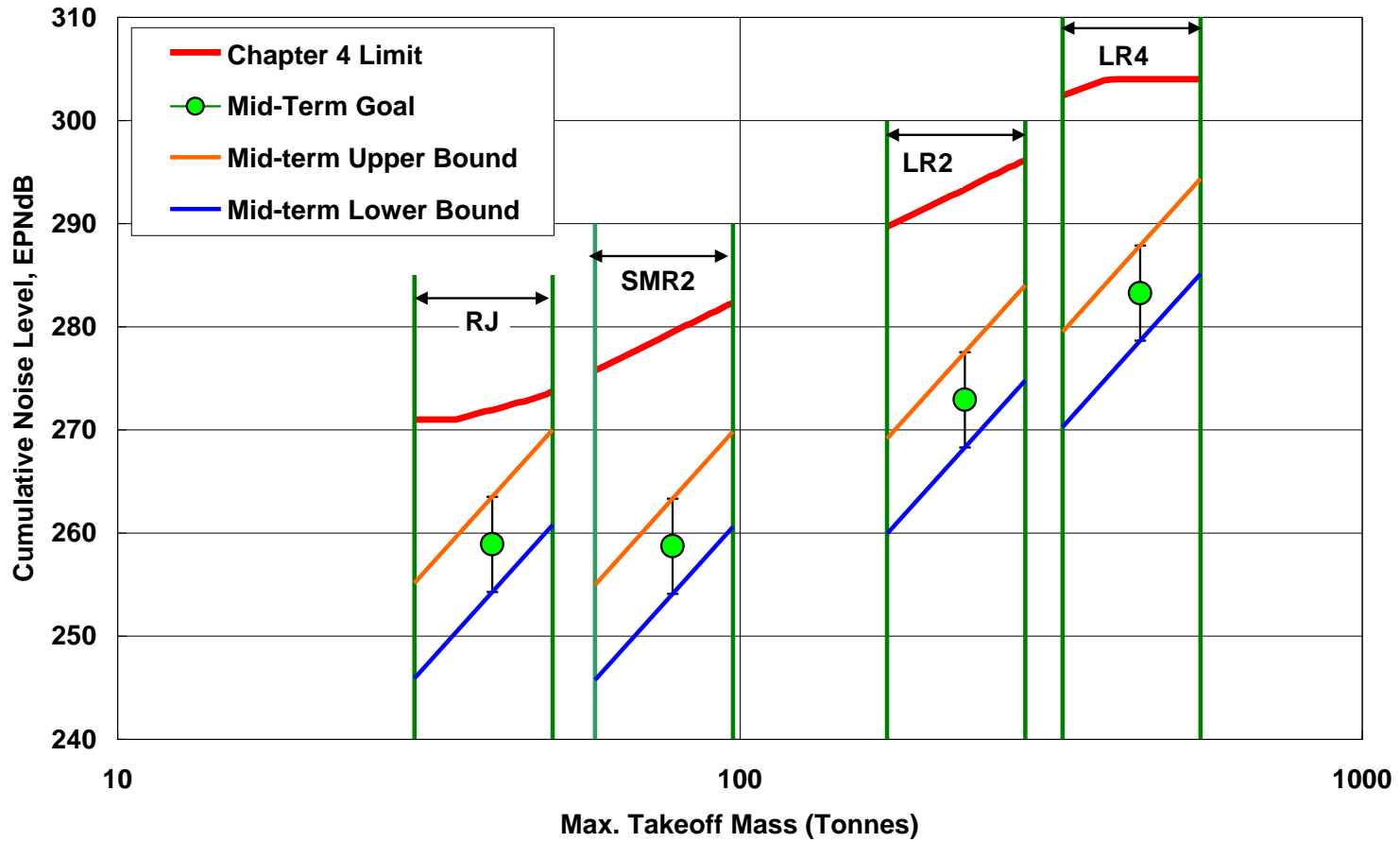


Figure 7.3.1 – Mid-Term Aircraft TRL8 Noise Goal Summary

Long Term (2028) Cumulative Noise Goals

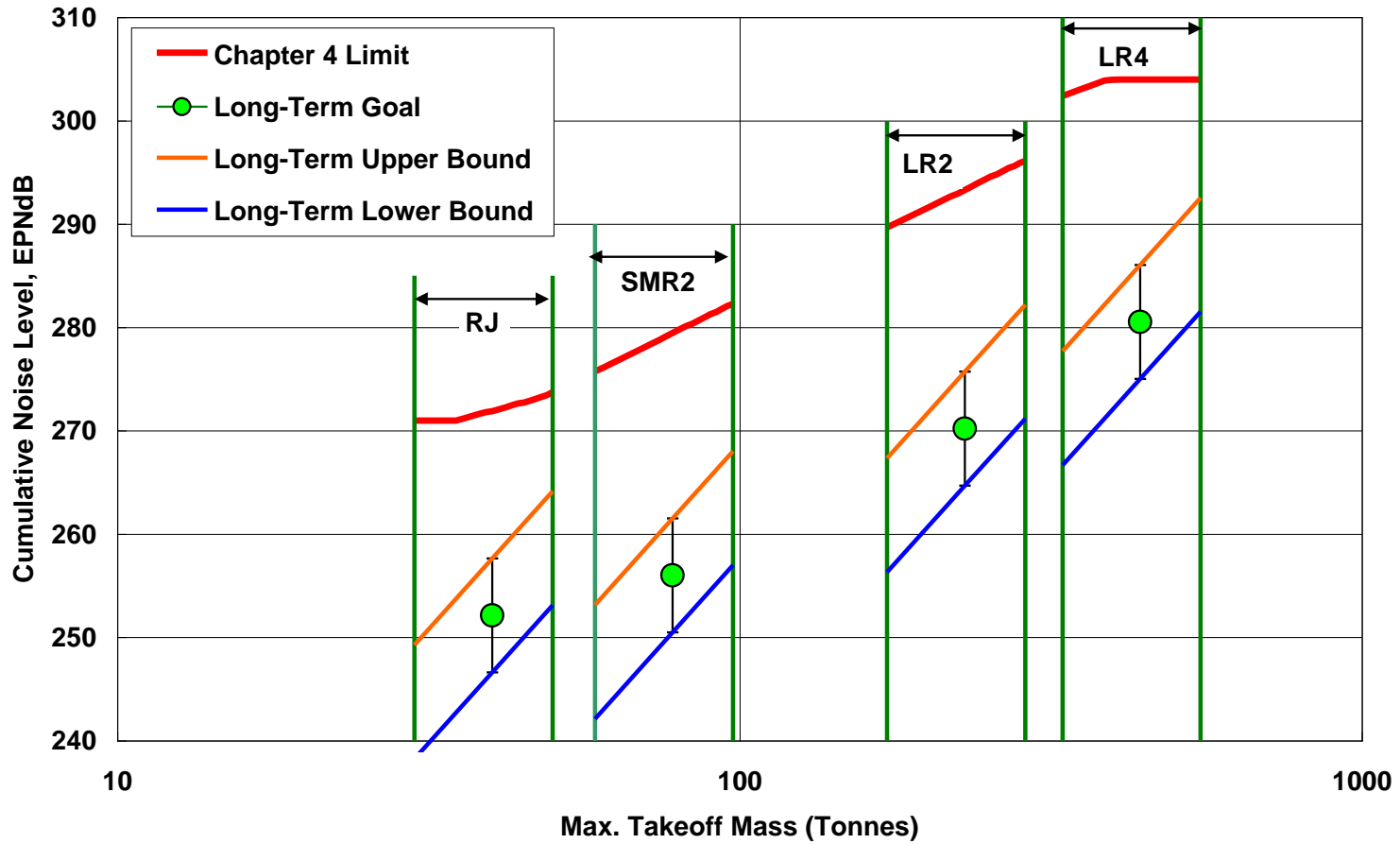


Figure 7.3.2 – Long-Term Aircraft TRL8 Noise Goal Summary

7.4 Comparison between IEP Targets and Research Goals

Concerns over increase in aircraft noise with the anticipated increase in air traffic have resulted in launch of strategic research plans and funding of a number of research programs under their agenda to explore source noise reduction technologies. Table 7.4.1 lists some of the more recent US and European initiatives along with their respective noise reductions goals.

Table 7.4.1: US and European Noise Reduction Research Programs

Initiative	Noise Reduction Goals
NextGen Continuous Lower Energy, Emissions and Noise (CLEEN)	Certifiable aircraft technology that reduces noise levels by 10dB (30dB cumulative) relative to 1997 subsonic jet aircraft technology.
NASA Subsonic Fixed Wing (SFW)	Conventional (2012-2015) (cumulative below Stage 3): -42dB. Hybrid Wing (2018-2020) (cumulative below Stage 3): -52dB
Advisory Council for Aeronautics Research in Europe (ACARE)	Reduce perceived noise by half (from 2000 to 2020) (interpreted as -10 EPNdB / Operation)
NASA Quiet Aircraft Technology (QAT)	Reduce the perceived noise impact of future aircraft by one half (10dB) from today's (1997) subsonic aircraft within 10 years, and by three quarters (20dB) within 25 years

Research goals inherently tend to be more aggressive compared to the actual realization of the technology benefit as the technology matures during the product development process. In addition, the time required for full technology integration almost always exceeds the initial estimates.

The Panel was requested by the N29 Planning Committee to compare the IEP Goal recommendations with the published research goals for the research programs listed in Table 7.4.1. Although this request was not part of the IEP remit, the Panel agreed to do so. However, direct comparison with these research goals was found to be very difficult to do because of the variations in starting point time scales and program durations among the research programs.

The Panel identified two ways to compare research goals with IEP goals. the first approach was to compare the slopes of the noise reduction vs. time trends, to assess how the time-rate of expected improvement compares with the Panel goals. This comparison is shown in Figure 7.4.1, where the average margin in noise reduction is plotted against the time stipulated for the realization of these target/goals. Note that these comparisons are made at TRL6, since all the published research goals are quoted at TRL6. Also, the goals are given as the as the average of the three certification points, or cumulative divided by three. Both similarities and differences exist between IEP predictions and research goals. Whereas the IEP Regional Jet targets follow the historical 0.3 dB/year trend, the IEP mid term (10 years) targets for rest of the three aircraft classes show a more aggressive trend as compared to the trends anticipated by the research goals. However, the IEP target trend levels off beyond the mid term period. Overall in the 20~25 years time period the average noise reduction benefit as evaluated by IEP and as set by the research goals almost match within 3 EPNdB (Cum of 9 EPNdB). The IEP targets are much closer to ACARE goals compared to the goals of NASA programs, which are more aggressive. This may be because the NASA programs assume a different architecture.

The second approach was to compare on the basis of consistent Technology Readiness Level. The N29 Planning committee suggested a format for doing this, and this is shown in figure 7.4.2.

The aggregate noise reduction trend envisaged by IEP for the 20~25 years period for the Short-Medium Range Twins, Long Range Twins and Long Range Quad aircraft classes is 0.35 dB/year. This prediction seems very conservative in comparison with the US and European research goals beyond the 20~25 years timeframe. IEP feels that this trend is more realistic given the noise reduction technologies and their development status that were present at the Review. IEP also believes that achievement of research goals beyond this time period can only be realized via the application of novel propulsion and airframe architectures, some of which have been discussed in Section 6.4.

IEP Noise Reduction Goals vs. US and European Research Goals

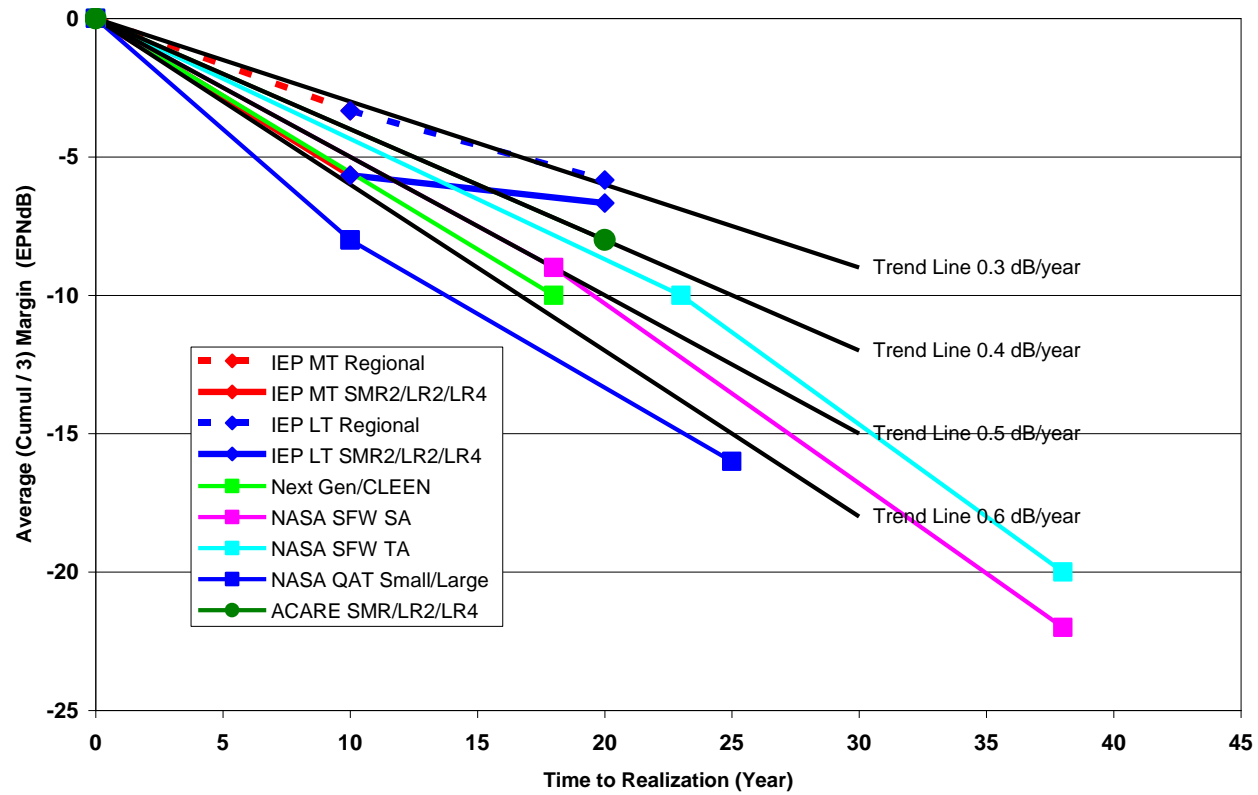


Fig. 7.4.1: IEP predicted noise reduction target versus US and European research goals

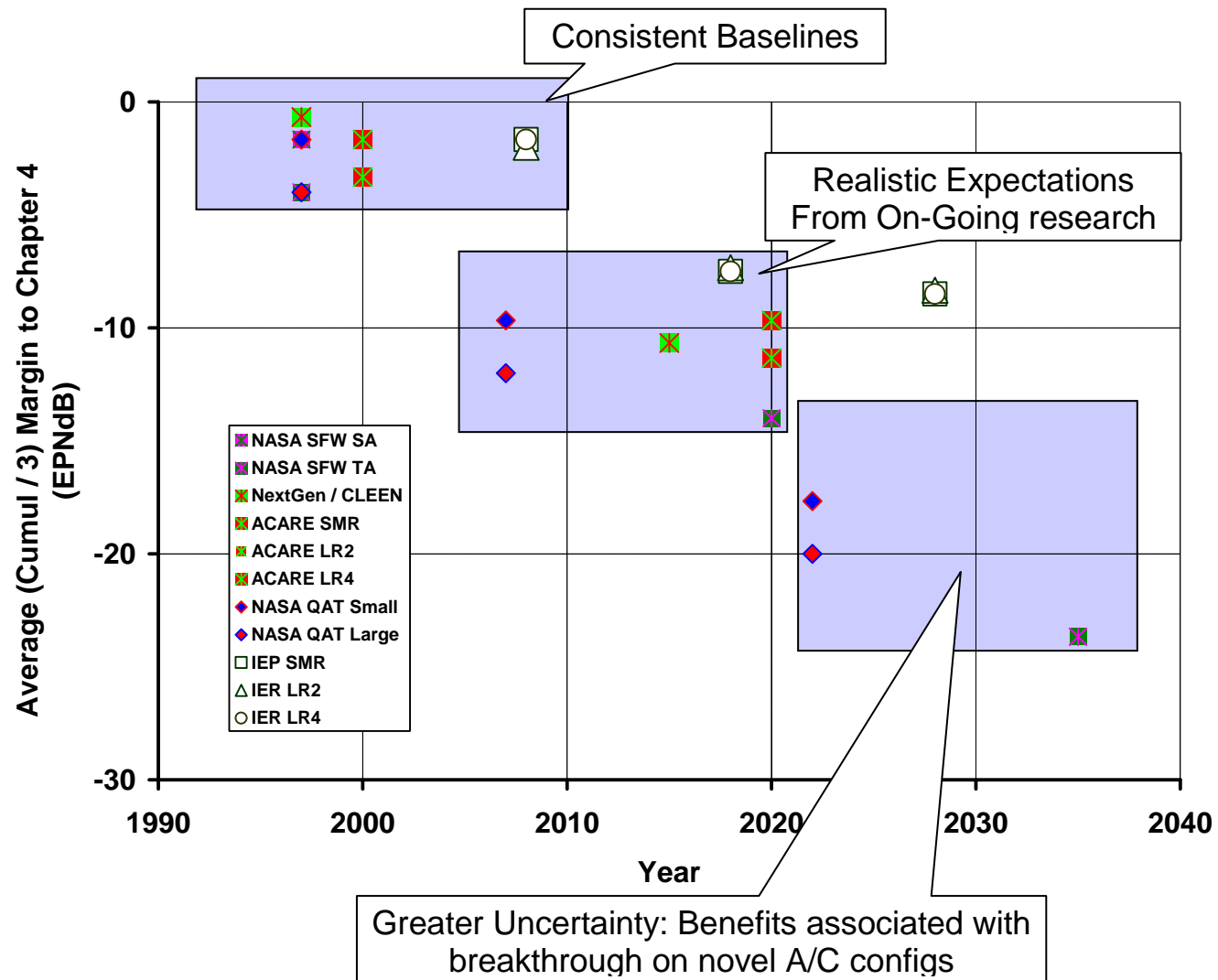


Figure 7.4.2: Comparison of IEP Goals with European and U.S. Research Goals based on TRL Equivalence

8. Other considerations

8.1 Trade-offs

The IEP recognizes that noise reduction efforts must be balanced with other environmental and operational requirements such as aircraft performance, fuel burn, emissions, operating costs, etc. A summary of some of these trade-offs is shown in Figure 8.1.1.

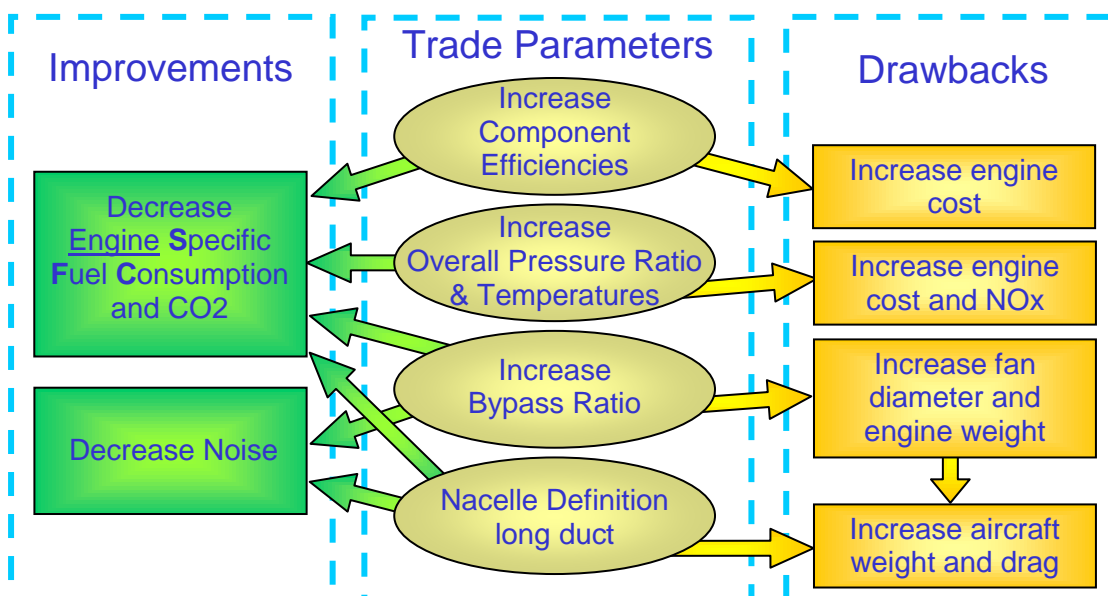


Fig. 8.1.1: Environmental trade-offs as a result of cycle and technology improvements. Ref. IER2008-01 (slide 47)

The Panel had previously concluded that the two primary paths to aircraft noise reduction were increasing Bypass Ratio (BPR) of the propulsion system cycle, and component noise reduction technologies (NRT). For the first path, increasing BPR beyond the demonstrated level of 9 or so has the following issues that require resolution.

- Nacelle weight and drag as fan diameter increases
- Engine-out drag and consequent effect on tail control surface size
- Landing gear length for nacelle ground clearance
- Core size limitations and auxiliary bleed requirements
- Fan stall and stability control during extreme shifts in operating line from sea level to cruise.

Some of the NRT concepts discussed in Section 5 and assessed as viable for noise reduction are also likely to either benefit or detriment other environmental concerns, e.g. NO_x emissions. For example the use of aerated injectors and staged combustion can also reduce emissions whereas enlarging combustor cross section area can increase emissions. Similarly, development of noise reduction technologies (NRT) that require active control systems and/or complex manufacturing processes will not only add weight, cost and complexity to the aircraft system, but may reduce fuel burn, and the added noise reduction benefits have to weighed against the potentially

detrimental effects of fuel burn and operating cost, reduced reliability, and maintenance costs. The net trade-off benefit of these technologies will therefore have to be weighed via overall system optimization. System level analysis using tools like the Carpet-Plots, similar to the one shown in Figure 8.1.2, may be very useful to achieve a balance.

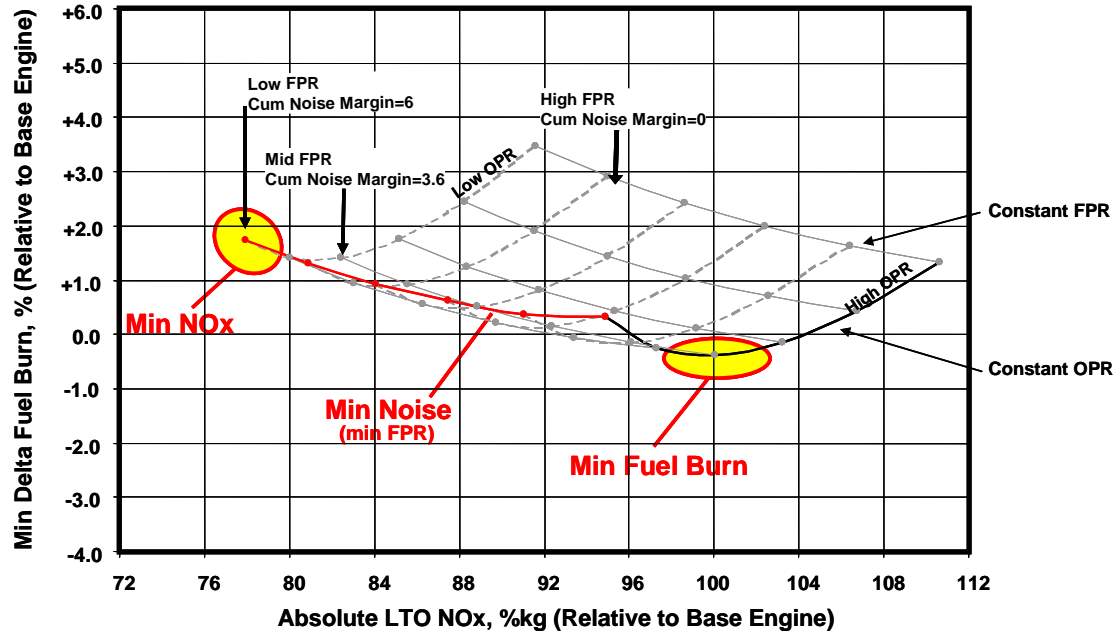


Fig. 8.1.2: Overall System Optimization – Carpet plot for Noise/NOx/Fuel Burn trade-off. Ref. IER2008-01 (slide 46)

8.2 Noise Abatement Operational Procedures

Detailed assessment of Noise Abatement Operational Procedures (NAP) is the responsibility of WG2, made up of Air Traffic Control experts, Airline representatives, Airline Pilot representatives, and aircraft manufacturer representatives. However, the WG1 Planning Committee requested that the Independent Expert Panel (IEP) address NAP methods, to evaluate how and when Noise Abatement operational Procedures might be used to supplement new noise reduction technology developments in the next 10 years, to further reduce noise exposure around the airport community, as well as during climb and descent.

A very significant improvement in cumulative noise reduction is expected from the introduction of NRT and increased BPR, but this improvement is not expected to be the same between takeoff and landing, most of this improvement occurring at take-off (lateral and flyover) with much smaller benefits predicted at approach. Tables 7.1.1 and 7.2.1 show that the benefits at landing/approach are ~3 to 4 dB less than at departure. The main contributor at landing, at least for the SMR and LR classes of aircraft, is the undercarriage-generated noise, even when engine noise has a non-negligible contribution. So the difference between take-off and landing suggests a difference in the potential role of operational procedures for aircraft noise reduction. NAP may be useful for reducing noise exposure at take-off, but may be essential for the final approach, depending on what noise levels are ultimately deemed acceptable.

Takeoff

For takeoff, improvements are likely to be provided mainly by increased BPR, but also to source noise reduction technologies. Standard takeoff procedures are already in place that incorporates a power cut-back at 1000 ft. altitude, followed by acceleration before the continuation of the climb. The cut-back altitude may be reduced to 800 ft., if the aircraft systems allow it, to better protect more sensitive areas closer to the airport. In contrast, cut-back may be delayed to a higher altitude for a better benefit over areas further from the airport. Hence the takeoff NAP may be very specific to the airport locale from which the aircraft is operating. As an example, for a short-medium range aircraft, the expected noise reduction may be ~6 to 7 dB at flyover. However, it is likely to be very difficult to do more with the procedures, except possibly in very specific cases.

Climb

At the climb rating, which is close to the takeoff rating, it may be expected that the increased BPR and the associated noise reduction technologies will yield a noise reduction equal to or better than that achieved during takeoff. This effect, plus the increasing attenuation due to the increasing altitude, should reduce considerably the footprint at a given noise level. Further, the flight management system (FMS) may be optimized to avoid more sensitive areas and simplify the crew tasks.

Landing

For the final approach, the effect of the increased BPR is small and the expected noise level reductions will also be small, even with noise reduction technologies, which are expected to be clearly smaller than at takeoff. As an example, for the SMR2, for an increase in BPR from ~5 to between 8 and 9, the reduction is estimated to be only ~0.5 db/BPR unit for BPR changes alone, and ~1.2db/BPR unit with the noise reduction technologies included.

As previously discussed, even if the engine noise stills play a role in the noise signature at approach, the undercarriage becomes the dominant noise source, at least for the SMR and LR aircraft classes. Further, it may be speculated that with the conventional under-the-wing engine-aircraft architecture, above a given BPR, the increased diameter of the nacelle will lead to an increased size of the undercarriage, which will further negate some of the noise benefits potentially achievable from increased BPR and noise reduction technologies. The anticipated small noise reduction benefits of new configurations, and the risk of decreasing these benefits with increasing BPR show that significant noise reductions at approach, comparable to that anticipated at take off, may only be achievable with adequate noise abatement procedures.

One way to do it might be to fly over the approach certification point at a higher altitude, using, for instance, an increased ILS slope, today set for certification purposes at 3°, which is common practice. A 4° slope could potentially reduce approach noise by about ~4 dB, while a 3.5° glide slope may only provide ~2dB appreciable reduction. The benefit is there, but the question is how to get it, in coordination between airlines, ATC, aircraft manufacturers, and airline pilots, without increasing the noise somewhere else. Note that a 3.5° glide slope is already used at some airports for environmental reasons (mountains ...), showing the feasibility of the concept.

It will be relatively easy to use a 3.5 (or a little more) I.L.S slope ,without modification, sometimes with limitation (for tail wind). At or above 4° slope airbrakes/spoilers would have to be used. Such a procedure cannot be generalized, but might be envisaged for very specific airports. As an example, this type of procedure has been validated for one aircraft type – an SMR2 – at the request of one airline, for landing with a 5.5° slope at London City Airport (steep approach procedure certification).

Current procedure is that the aircraft will be stabilized in a landing configuration (gear down, flaps and slats fully deployed) 6 to 10 kilometres before the runway threshold on the glide path. At the end of the descent, the flare may raise some difficulties due to the increased vertical speed. The aircraft manufacturers have to define the procedure, manual or automatic (automatic control of the spoilers and airbrakes), for this final phase of flight. The airlines would be required to introduce the new procedure in their own internal flight procedure documents and pilot training. ATC is also necessarily involved to insure compatibility with the other procedures. The goal benefit is promising, between 2 to 4dB. A lot of work remains to be done, but it seems possible that the aircraft which will fly in 2018 will be able to use this type of procedure when and where the infrastructure is available.

Descent

Continuous descent approach (CDA) is still under study, mainly to save fuel, but noise exposure reduction is also a benefit of this procedure. The challenge is to combine the aircraft deceleration and the rate of descent from the end of cruise to the final approach (with the gear down), under ATC rules. To avoid increasing noise exposure, the trajectory adjustments have to be minimized in particular at low altitude, and the gear operation cannot be earlier than in the current practice. As the engines, during this phase of flight, are at or close to idle, the noise reduction technologies and increased BPR have no appreciable noise exposure benefit.

Conclusion

The difference in noise reduction technology benefits (including increased BPR) between takeoff and landing suggests a different potential role of operational procedures on aircraft noise exposure - useful for reducing noise at take off, but potentially essential for final approach.

At takeoff, increased BPR and NRT bring a very significant noise reduction. It is likely that after takeoff and during the climb towards the cruise altitude, this noise reduction will be maintained at climb rating. Small additional benefits may be obtained in optimizing the flight profile to avoid sensitive areas.

For the final approach (gear down and flaps and slats fully deployed), at least for SMR and LR aircraft, the aircraft noise is dominated by the airframe noise (undercarriage) even if the engine noise is a significant contributor. To achieve significant noise reduction, both sources have to be reduced in parallel. The increased BPR and the NRT have a small effect during this phase of flight. A significant additional benefit might be obtained through operational procedures based on an increased glide slope for the ILS. A 3 to 4 db benefit might be obtained all along the final approach. It seems possible to define and implement such a procedure in the

next ten years, through the working group dedicated to this task. For the continuous descent approach (CDA), the clean configuration of the aircraft and the engine running at idle (or close to idle) are not affected by the change in BPR and addition of NRT. At this stage, it is impossible to predict the noise benefit associated with this procedure.

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Appendix A

Assessment of noise reduction trends with bypass ratio (BPR) and Noise Reduction Technology (NRT) at each certification point

A.1 Noise Reduction at Approach

Noise reduction trends with bypass ratio (BPR) and noise reduction technology (NRT) are reviewed for the Short/Medium range and Long range classes, at each certification point, using the Best Practices Database provided and the results of the Pilot studies outlined in Section 6. Data is shown as the margin relative to Stage 3, rather than absolute levels. These results have been combined and expressed as trends in cumulative margin reduction, as summarised in Section 6.3

Short/Medium Range Class

The data shown in Fig. A.1 for the noise margin at the Approach condition exhibits a weak sensitivity to BPR, which is not unexpected for medium to high BPR powered aircraft at this condition and one that was highlighted at the IER. The Pilot 1 & 2 results - without most of the NRT packages - agree closely even though they differ in BPR (8 v. 9.5). The Pilot 3 result, computed over a range of BPR, also agrees closely with the other two pilots. The NRT packages provide an increased margin of 2-4 dB according to the Pilot 1 & 2 results over this BPR 8-9.5 range. This is almost completely due to airframe noise technology reduction. This has been confirmed by a separate study within Pilot 3 where a 5 dB airframe noise benefit has been applied, resulting in similar reductions in aircraft system noise, i.e. a substantial fraction of 1 dB system noise benefit per 1 dB of airframe noise reduction. The Long term result for a BPR=12 aircraft shows no significant improvement without NRT, according to Pilot 1, and the Long term NRT packages have negligible effect because these do not include airframe noise reduction. The red trend line is an approximate indication of the benefit of increased BPR at Approach, with a gradient of 0.4 dB per BPR over the Medium term and the blue trend line of 0.3 dB per BPR in the Long term. These simple trend lines are introduced here as a means of comparing results across the different classes for each condition in turn.

The overall trend is that higher BPR engines on future aircraft – driven by fuel burn – will deliver very little system noise benefits at Approach, unless effective airframe noise reduction technology is included in the design.

Long Range Classes

The Long range 2- and 4-engine aircraft (LR2, LR4) have not been the subject of the Pilot studies, as in the Short-Medium Range Twin (SMR2) class. Therefore we have only the Best practices database to guide us, plus previous study aircraft, such as the AST study. Starting with the LR4 class, Fig. A.2 shows data for various existing versions of the 747, the A380 and the two AST study versions of the 747-400 powered by the GE HBPR and the P&W ADP. The red trend line from the SMR2 results passes through the ‘real’ aircraft points here but exhibits considerably less sensitivity than that of the AST results. The A380 is also well below that trend, which may be due to some airframe and other NRT in its modern design relative to that of the 747 versions. For the LR2 class, Fig. A.3, the red trend line from the SMR2

results also passes through the ‘real’ aircraft points here but again exhibits considerably less sensitivity than that of the AST results.

A.2 Noise Reduction at Flyover

Short/Medium Range Class

At Flyover, the effect of BPR is more significant, see Fig. A.4, probably due to the more significant jet noise component. Here results from Pilot 1 (BPR=8) and Pilot 2 (BPR=9.5) differ somewhat both without and with NRT. This may be due to some differences in opinion as to what is *existing* technology (e.g. swept fans) and what is Medium term NRT. The IEP Pilot does show a ‘flattening’ of the trend beyond BPR=9, consistent with the jet noise component becoming less significant at the higher BPR engines. The trend line at this condition is estimated to be 1 dB per unit BPR, which is an approximate average of the Pilot 1 & 2 sensitivities.

Pilot 1 & 2 agree that the Mid-term NRT should yield a benefit of about 2 EPNdB.

In the longer term the Pilot 1 sensitivity to BPR between the BPR = 8 and BPR=12 without NRT is certainly reduced compared to that between BPR = 5 and BPR=8 and even more so with the Mid-term NRT. This ‘flattening off’ in the Pilot 1 results without NRT is consistent with the Pilot 3 results in terms of the change, rather than the absolute margins, between BPR = 8 and BPR=12 . Furthermore the benefit of Long term NRT at BPR=12 is very small according to Pilot 1 so noise reduction is likely to be completely reliant on Medium term NRT but once that is cashed in, the benefits of BPR or Long term NRT at this Flyover condition are quite small.

Long Range Class

Fig. A.5 shows the LR4 data for existing aircraft and two study aircraft, the 747-400 with the GE HBPR at BPR=8.3 and the P&W ADP at BPR=13. In this case the trend line of 1 dB/BPR from the SMR2 data is in reasonable agreement with the AST study aircraft but somewhat steeper than that exhibited by ‘real’ aircraft margins from the Best Practices Database. Again the A380 is well below the trend line and at BPR=9 is quieter than the P&W ADP at BPR=13 *without NRT*. Although the A380 does have some NRT that is Medium term relative to the current 747-400, this strongly suggests there is little or no benefit of BPR at this condition beyond BPR=9. This supports the tentative conclusions outlined above for the SMR2 class. The LR2 data in Fig. A6 exhibits more scatter about our trend line but the deviations are judged to be acceptable.

A.3 Noise Reduction at Lateral

Short/Medium Range Class

Fig. A.7 shows the SMR2 data at the Lateral condition with a markedly increased sensitivity to BPR. A trend line of 1.6 dB per unit BPR appears to follow the pilot data quite well, on average. The Pilot 2 result shows more sensitivity to Medium term NRT than does the Pilot 1 although this may be due to a slightly different mix of NRT packages.

However, when the range BPR=8 to 12 is considered, Pilot 1 and the Pilot 3 exhibit a similar benefit of about 3-4 dB, or no more than 1 dB per unit BPR.

At BPR=12 both the Mid-term and the Long term NRT is ineffective, according to the Pilot 1. Beyond BPR=12 it is likely to be zero with little or no Long term NRT benefits.

Long Range Class

The LR4 data at the Lateral condition in Fig. A.8 supports the above conclusions with the trend line of 1.6 dB/BPR passing close to all the data up to BPR=9, including the A380. This suggests that the A380 has little or no Mid-term NRT at this condition, in particular for the presumably significant jet noise component. The P&W ADP falls above an extrapolation of this trend line unless NRT is applied, which the IEP understands is not available for individual certification points at this point in time. The trend line compares favourably with the LR2 data in Fig. A9 and agrees well with the B787-8 projected margin.

Short/Medium Range Twin Noise Reduction at Approach condition showing IEP deduced Mid & Long term BPR & NRT (TRL6) trends*

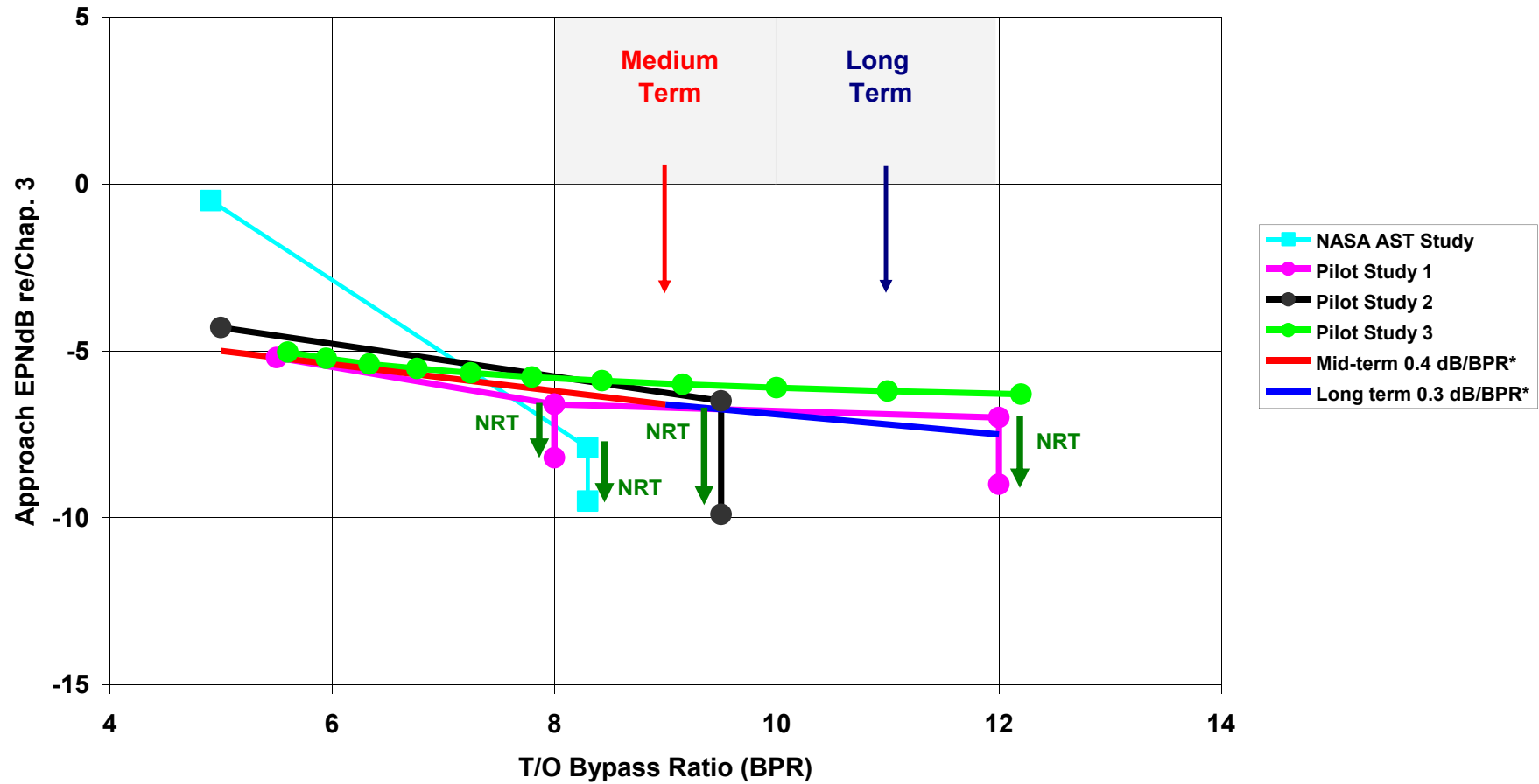


Figure A.1: Short/Medium Range Twin Approach noise trend with BPR

Large Quad Noise Reduction at Approach condition compared with IEP deduced Mid & Long term BPR trends

Squares - Studies for Engine BPR Change Only (No Noise Reduction Technologies)
 Triangles - Best Practices Data Base

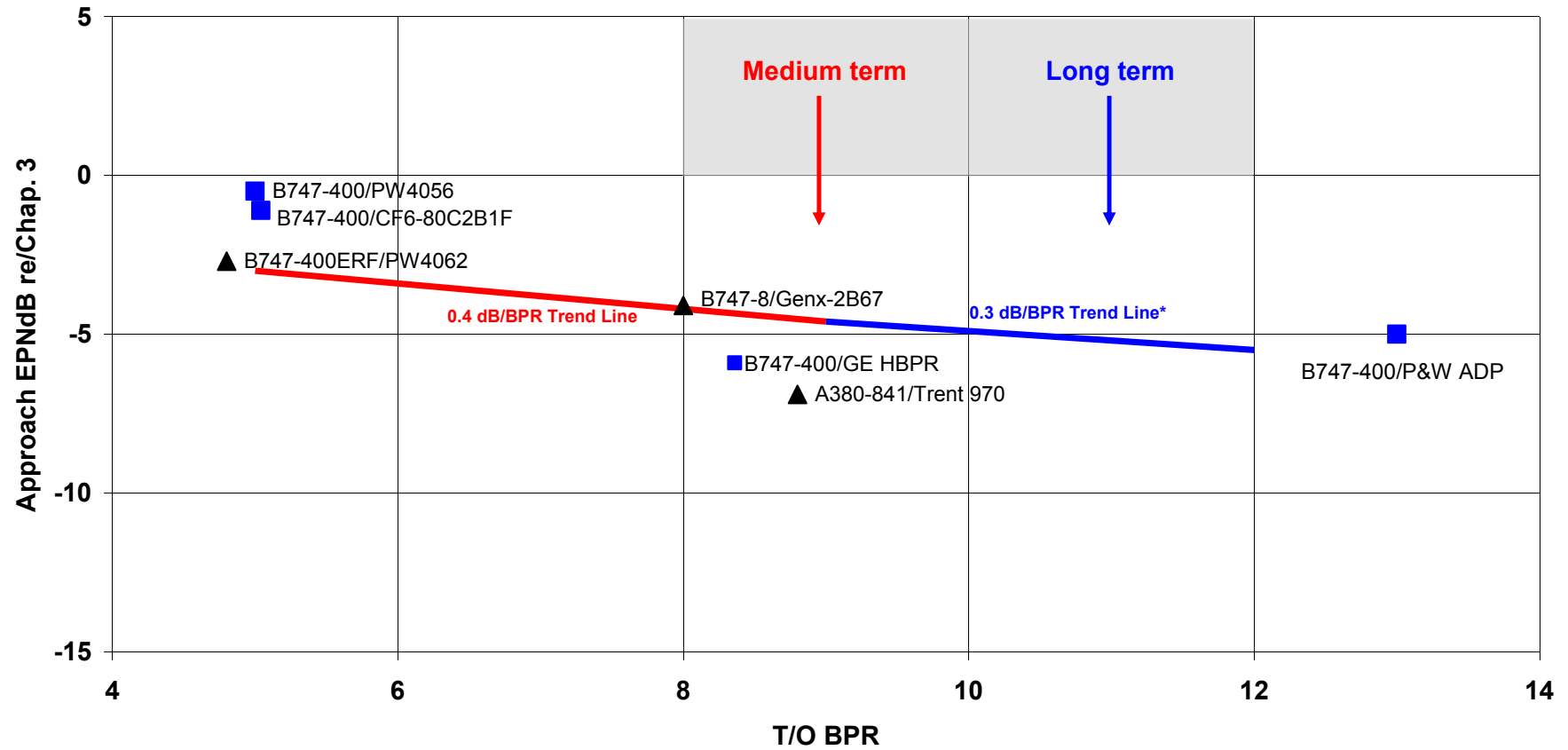


Figure A.2: Long Range Quad Approach noise trend with BPR

Long Range Twin Noise Data at Approach condition compared with IEP deduced BPR trends

Squares - AST LR2 Study for Engine BPR Change Only (No Noise Reduction Technologies)
 Other symbols - Best Practices Data Base

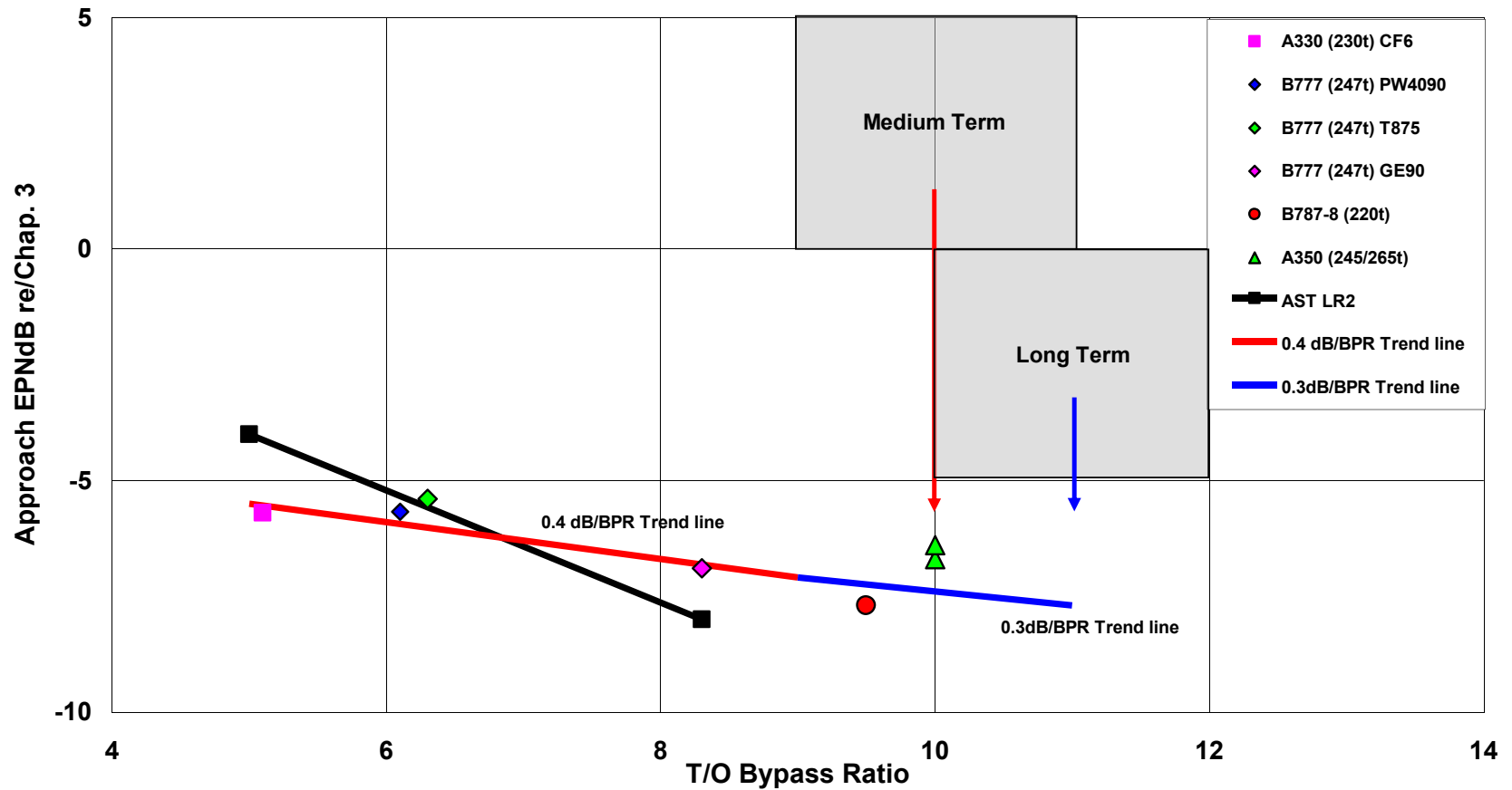


Figure A.3: Long Range Twin Approach noise trend with BPR

Short/Medium Range Twin Noise Reduction at Flyover condition showing IEP deduced Mid & Long term BPR & NRT (TRL6) trends*

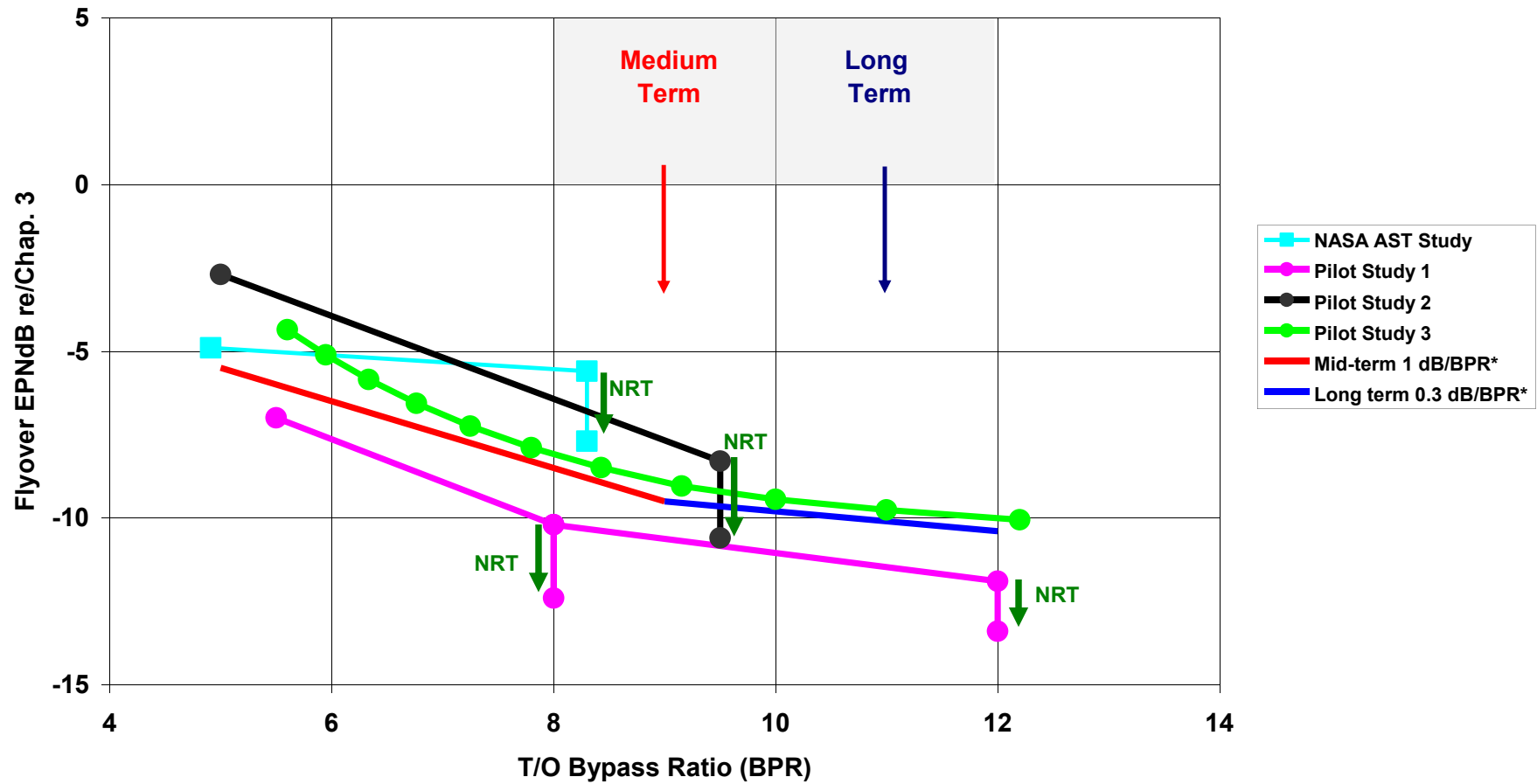


Figure A.4: Short/Medium Range Twin Flyover noise trend with BPR

Large Quad Noise Reduction at Flyover condition compared with IEP deduced Mid & Long term BPR trends

Squares - Studies for Engine BPR Change Only (No Noise Reduction Technologies)

Triangles - Best Practices Data Base

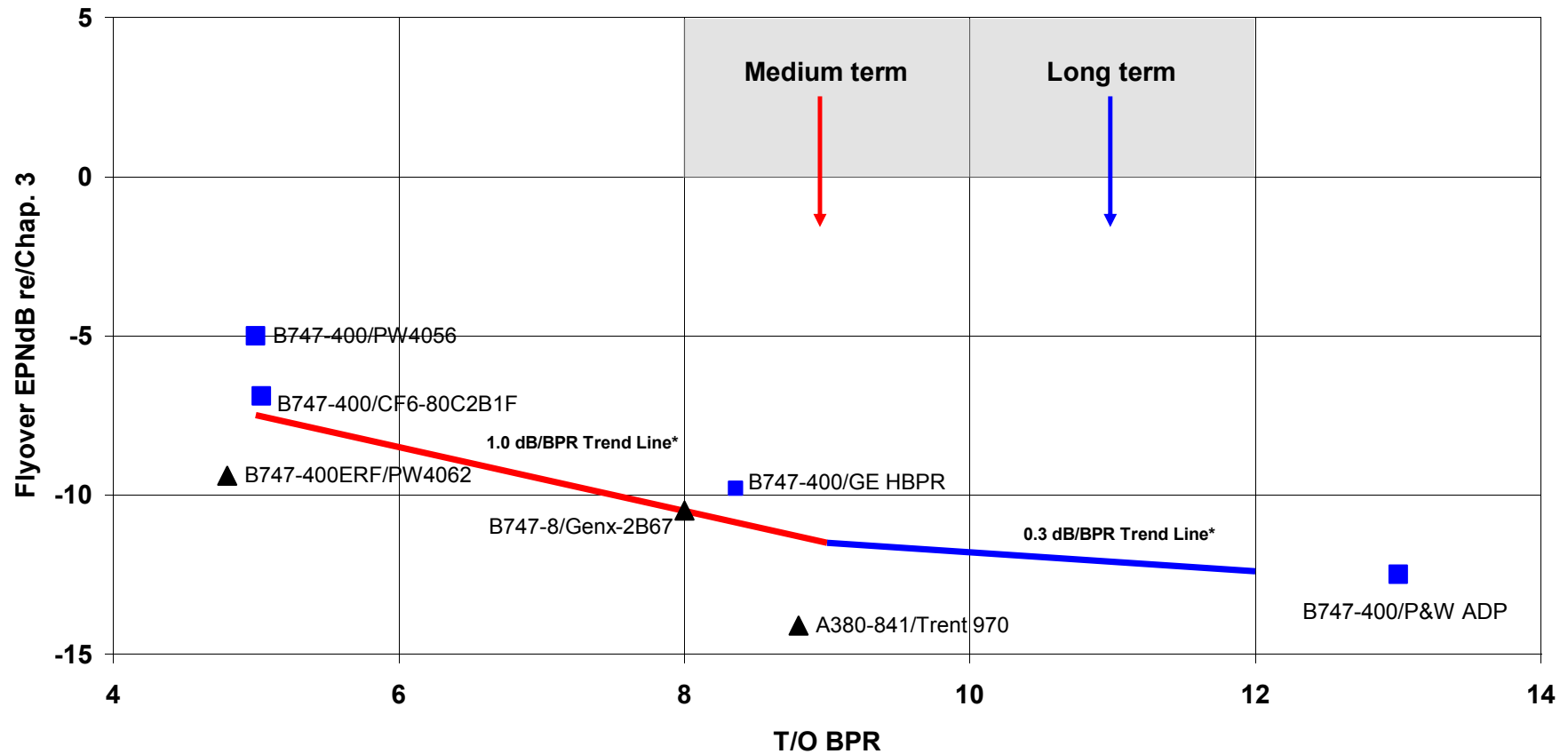


Figure A5: Long Range Quad Flyover noise trend with BPR

Long Range Twin Noise Data at Flyover condition compared with IEP deduced BPR trends

Squares - AST LR2 Study for Engine BPR Change Only (No Noise Reduction Technologies)
 Other symbols - Best Practices Data Base

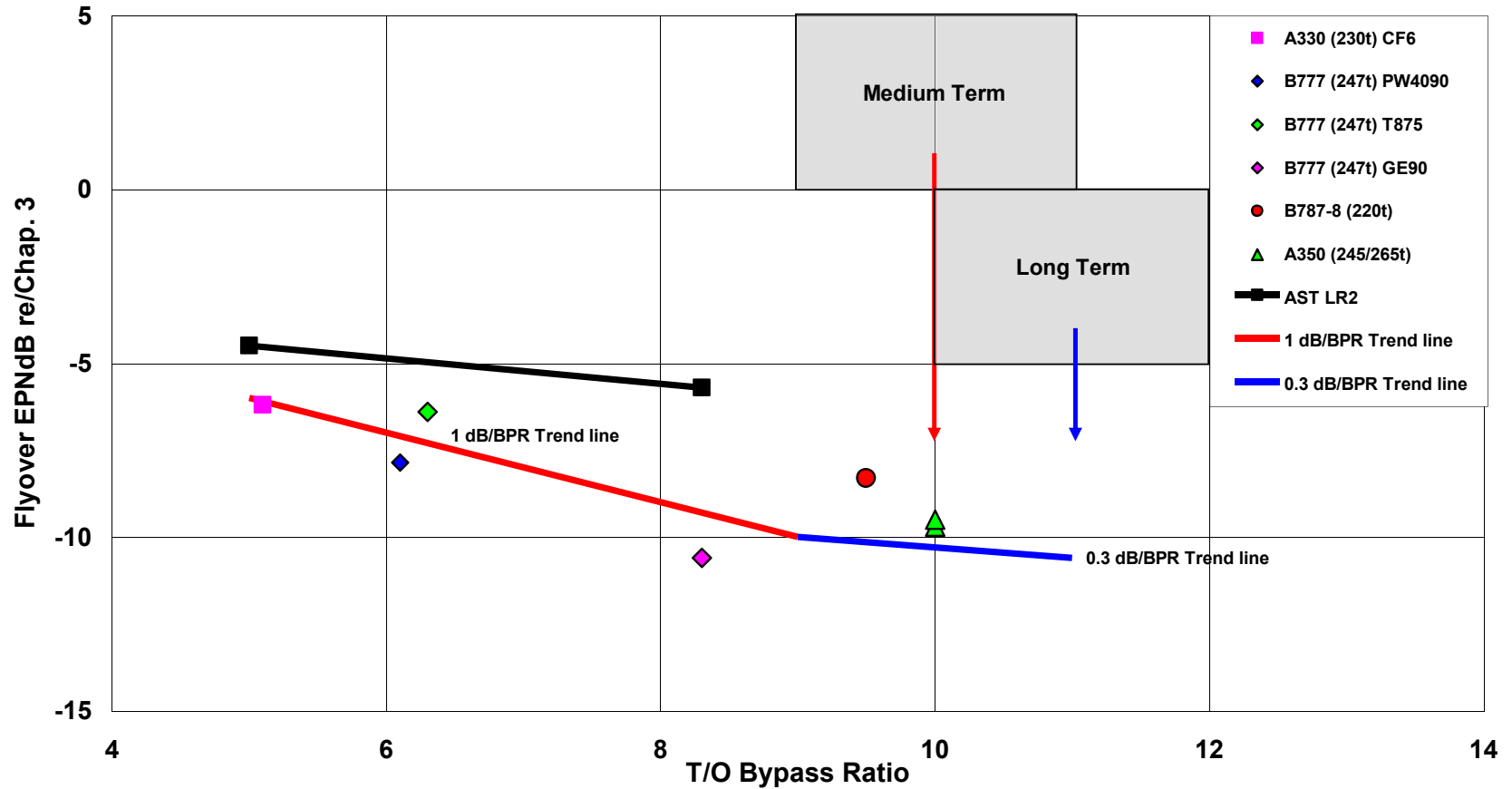


Figure A.6: Long Range Twin Flyover noise trend with BPR

Short/Medium Range Twin Noise Reduction at Lateral condition showing IEP deduced Mid & Long term BPR & NRT (TRL6) trends*

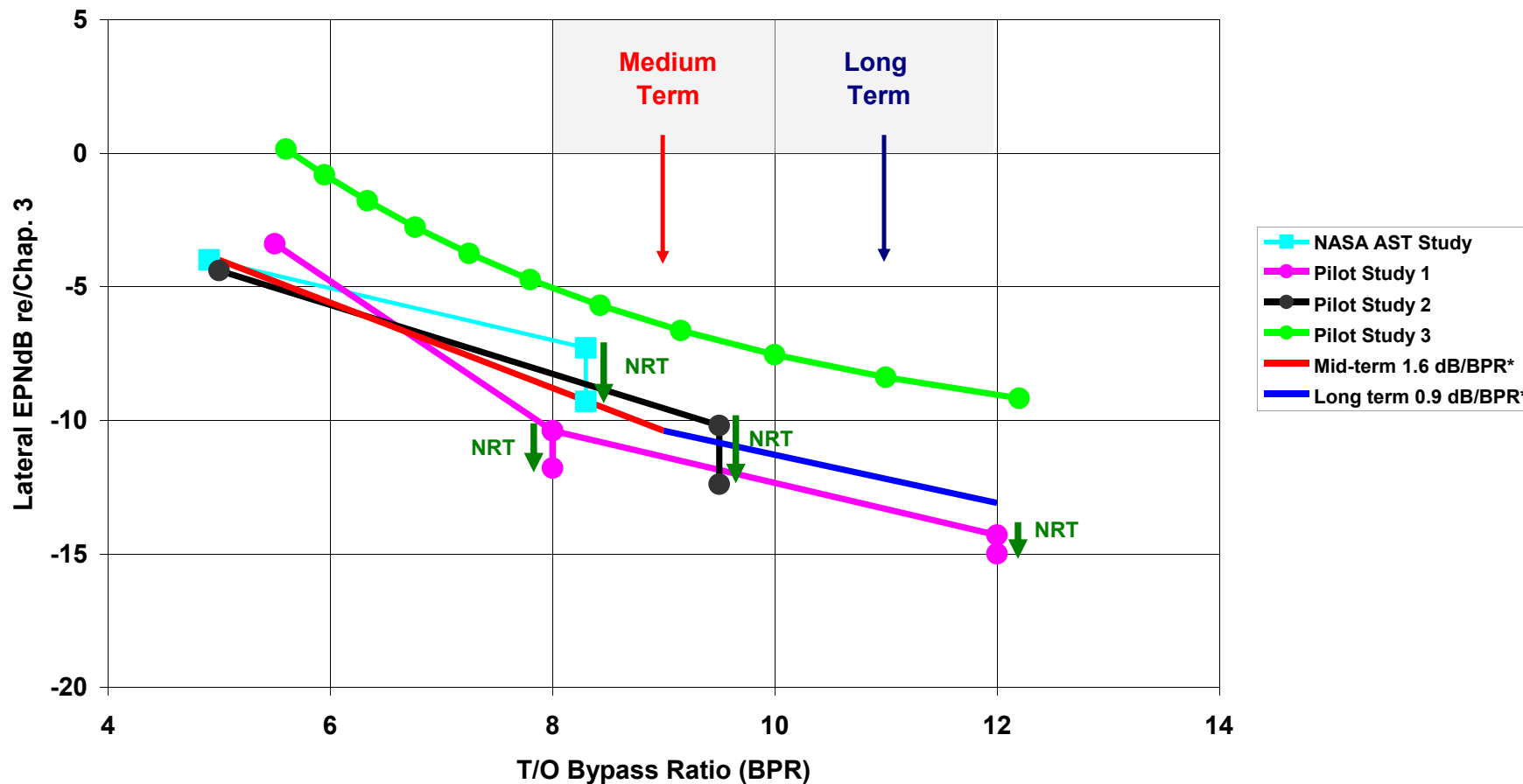


Figure A.7: Short/Medium Range Twin Lateral noise trend with BPR

Large Quad Noise Reduction at Lateral condition compared with IEP deduced Mid & Long term BPR trends

Squares - Studies for Engine BPR Change Only (No Noise Reduction Technologies)
 Triangles - Best Practices Data Base

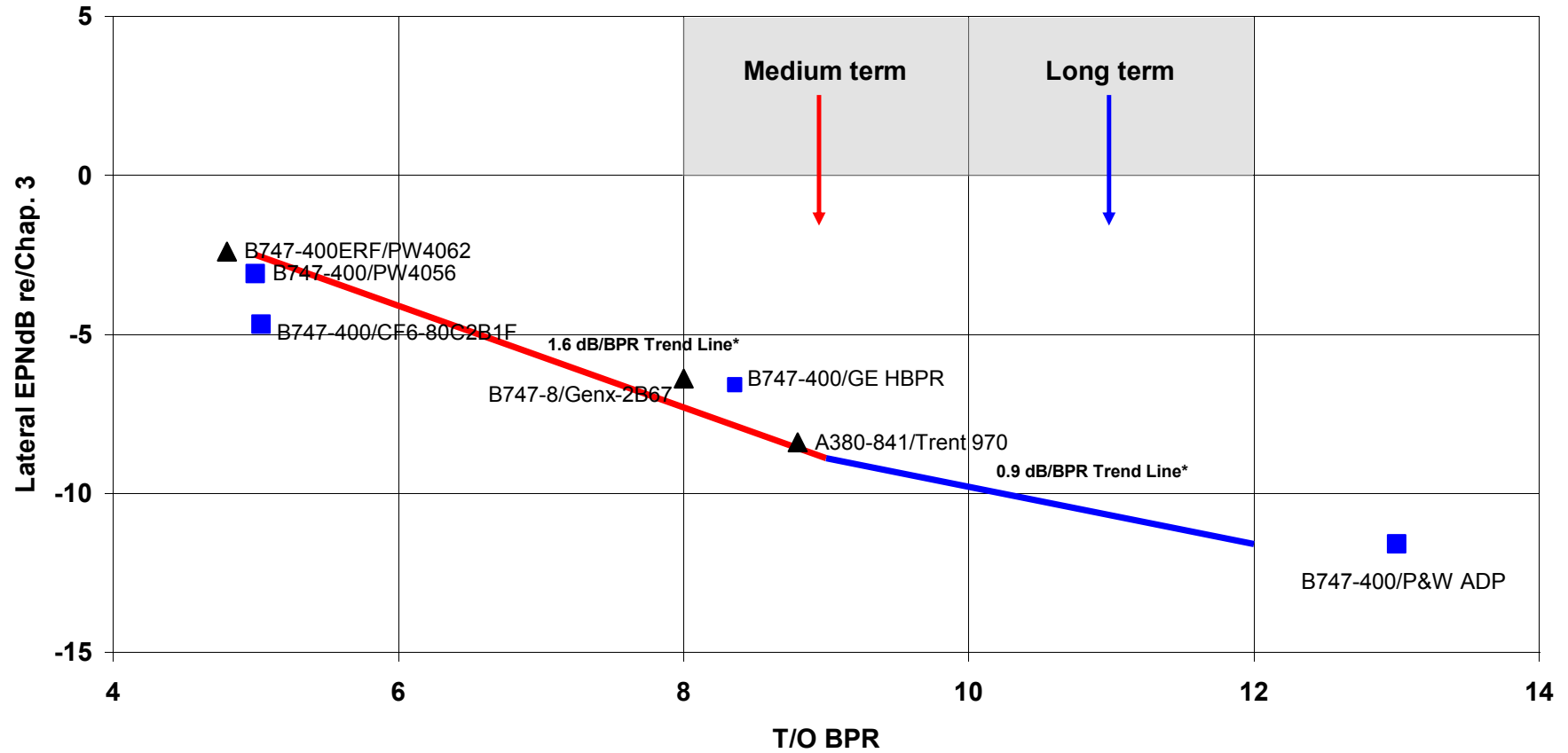


Figure A.8: Long Range Quad Lateral noise trend with BPR

Long Range Twin Noise Data at Lateral condition compared with IEP deduced BPR trends

Squares - AST LR2 Study for Engine BPR Change Only (No Noise Reduction Technologies)
Other symbols - Best Practices Data Base

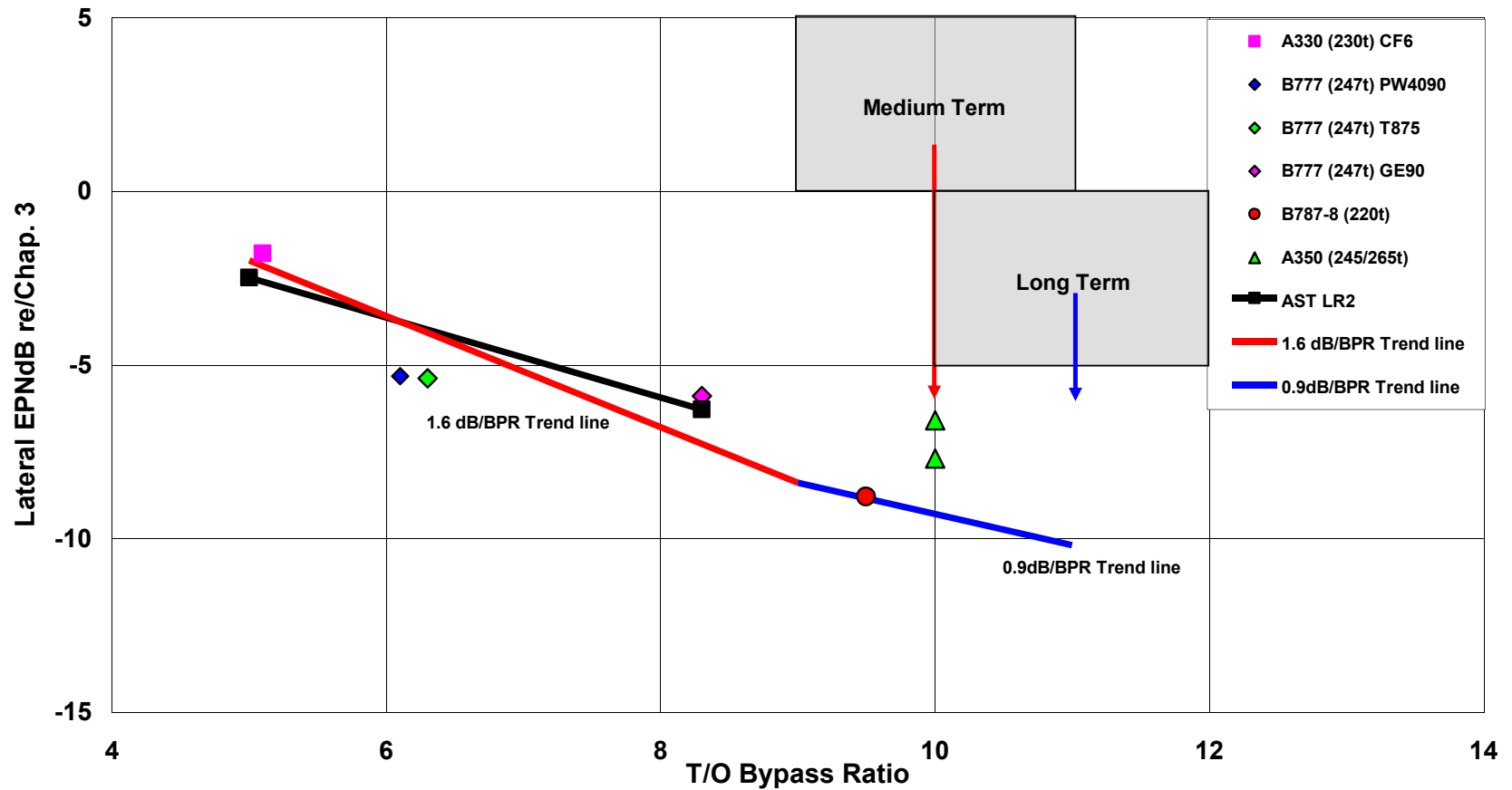


Figure A.9: Long Range Twin Lateral noise trend with BPR

Appendix B

Uncertainty Estimates for Noise Reduction Goals

In line with the IEP approach of analyzing Bypass Ratio (BPR) effects and component noise reduction technology (NRT) effects separately and then combining the two to provide estimated aircraft system noise reduction goals, the IEP also looked at estimating the uncertainties in the projected noise reduction goals for BPR effects and NRT effects separately.

B.1 Engine Cycle Change Effects Uncertainties – Mid Term

The uncertainty in forecasting potential aircraft noise reductions due to improved engine cycles which incorporate higher bypass ratio designs was based on the IEP judgment on the likely level of BPR that would be introduced into products in the Mid-Term (2018) and in the Long-Term (2028). These estimated BPR levels are tabulated in section 6.1, Table 6.1.1. The Panel concluded that there is a reasonable probability of achieving these levels, within ± 1 unit of bypass ratio. For each class of aircraft, and for each certification point, the sensitivity of noise level to BPR was determined, either by correlating pilot study results, NASA AST study results, and/or Best Practices Database correlation results. For example, if a given class of aircraft were projected to have a bypass ratio of 10 by the Mid-Term time (2018), and, from one or more of the above correlations, a sensitivity of 2.0 EPNdB per unit BPR were projected, then the uncertainty in BPR effects on noise reduction would be $\pm 1 \times 2.0 = \pm 2.0$ EPNdB.

The above estimate of uncertainty represents the uncertainty in achieving the target BPR, but does not specifically account for the uncertainty associated with the noise benefit achievable for a given BPR change. However, information gleaned from the various pilot studies and the results of the NASA AST studies reported in Reference IEP 7.1 have provided the Panel some additional insights, as described in the paragraphs below.

First, three aircraft assessment studies from the NASA AST Program evaluated the cycle change benefits (from BPR = 5 to BPR = 8.3), but for three different classes of aircraft, i.e., SMR2, LR2, and LR4. These results showed the cumulative noise benefit due to cycle change to vary 9.0 EPNdB to 11.4 EPNdB, with a standard deviation of ~ 1.2 EPNdB.

Second, two additional pilot studies for the SMR2 aircraft class were carried out at the request of Panel, but two aircraft manufacturers. Pilot Study A showed an 11.6 EPNdB cycle change benefit for a BPR change from 5.5 to 8.0. Similarly, Pilot Study B showed a cycle change benefit of 13.6 EPNdB for a BPR change from 5.0 to 9.5.

The Panel also carried out a study to independently evaluate BPR change effects, using a proprietary aircraft noise simulation model available to one of the Panel members. This study evaluated cycle change effects only, but over a wide range of BPR from 5.6 to 12.2. The results for this study were compared with the cycle change results from Pilot Studies A and B, and these comparisons are tabulated below.

Table B.1 – Summary of Cycle Change Effects from Various Study Results

Data Source	Aircraft	Bypass Ratio		Δ BPR	Δ EPNL	Sensitivity
		Baseline	Target			
Pilot Study 1	SMR2	5.5	8.0	2.5	11.6	4.64
Panel Study 1	SMR2	5.6	7.8	2.2	8.3	3.77
Pilot Study 2	SMR2	5.0	9.5	4.5	13.6	3.02
Panel Study 2	SMR2	5.6	10.0	4.4	12.1	2.75
NASA AST	SMR2	5.0	8.3	3.3	11.4	3.45
Panel Study 3	SMR2	5.6	9.2	3.6	10.9	3.03
NASA AST	LR2	5.0	8.3	3.3	9	2.73
NASA AST	LR4	5.0	8.3	3.3	10.6	3.21

The above study aircraft have different values of baseline BPR and different “target” (advanced technology) values of BPR, which can affect the resultant cumulative noise benefits being predicted. However, if the BPR sensitivity is examined, i.e., the cumulative noise benefit per unit increase in BPR, then some of these differences can be at least partially factored out. The resulting changes in BPR and cumulative noise reduction per unit change in BPR are tabulated in the last two columns in Table B.1. From the above tabulated results, the average sensitivity (8 samples) is 3.33, with a standard deviation of 0.64. The corresponding average BPR *change* is 3.39, with a standard deviation of 0.80. Note that now we have a bypass ratio uncertainty for a give average sensitivity, and a sensitivity uncertainty for a given average value of BPR. The two contributions to cycle change uncertainty are then:

Uncertainty due to uncertainty in future BPR: $\pm 0.80 \times 3.33 = \pm 2.68$ EPNdB
 Uncertainty due to uncertainty in effect at target BPR: $\pm 0.64 \times 3.39 = \pm 2.15$ EPNdB

Taking the square root of the sum of the squares for these two uncertainties gives a net cycle change uncertainty of ± 3.43 EPNdB.

The question arises as to whether this should be applied to all classes of aircraft. Since we have used three different classes in the study results employed, and since we have utilized two different manufacturer study results, and since we have used four different prediction models (Pilot Study 1, Pilot Study 2, Panel Study, and NASA AST), we can conclude that the above estimate includes all the above variability and is, within the limited quantitative data available to the Panel, applicable to all the aircraft classes being considered in this report. However, it is applicable for mid-term technology aircraft (2018 time period), not for the long-term technology (2028 time period).

B.2 Noise Reduction Technology Benefit Uncertainties – Mid Term

The uncertainty associated with component noise reduction technology (NRT) effects was more straight-forward. First, based on examining six different study cases where NRT and BPR effects were separately evaluated, taking the average values for BPR effects and NRT effects. These samples came from the pilot studies, and from the

NASA AST system evaluation studies. It was found that the standard deviations for NRT effects were found to be as follows:

Sideline:	± 0.33 EPNdB
Flyover:	± 0.16 EPNdB
Approach:	± 0.95 EPNdB
Cumulative:	± 1.24 EPNdB

The sample size is rather small, so it is probably not wise to take these results too literally, but it can reasonably surmised that the sideline and flyover standard deviations are ~ 0.5 EPNdB or less, and that the Approach and Cumulative standard deviations are around 1 to 1.3 EPNdB. These samples cover the range of short-medium range twins, large twins and large quad aircraft. The estimated NRT benefits came from two manufacturers and NASA. Thus the uncertainties comprise variations in aircraft type, engine/airframe manufacturer prediction process variations, NRT concepts selection variations, and NRT concept maturity variations (NASA predictions were done 6 years earlier than the pilot study predictions).

B.3 Combined Uncertainties in Cycle Change and NRT Benefit

For the Cumulative noise benefit, the combined noise benefit uncertainty was computed from the square root of the sum of the squares of the BPR change uncertainty and the NRT uncertainty. The cumulative noise benefit net uncertainty is estimated to ±3.60 EPNdB.

B.4 Long-Term Cumulative Noise Benefit Uncertainty

Three study samples were gleaned from the above-mentioned study sources that would be relevant to Long Term technology aircraft, as they all have target bypass ratios of 12 or higher. These are summarized in Table B.2.

Table B.2 – Cycle Change Effects for Long Term Technology Study Aircraft

Data Source	Aircraft	Bypass Ratio		ΔBPR	ΔEPNL	Sensitivity
		Baseline	Target			
NASA AST	LR4	5.0	13.0	8.0	18.9	2.36
Pilot Study 1	SMR2	5.5	12.0	6.5	17.6	2.71
Panel Study 3	SMR2	5.6	12.2	6.6	14.5	2.20

Using the same logic as was described in Section B.1, the net cycle change benefit uncertainty, based on these three samples, was found to be ±2.74 EPNdB. This is smaller than that for the medium-term number derived above (3.43), but this is because the sensitivity is smaller when projecting to higher BPR, and because the three samples gave very similar sensitivities, i.e., the standard deviation on sensitivity was only 0.26 EPNdB. The Panel feels this value of cycle change benefit uncertainty may be optimistic (too small), because the sample size available in the estimate is too small, and it doesn't reflect the potential degradation in noise performance caused by the much larger BPR engine-wing interactions and aerodynamic interference, and the additional noise sources caused by these effects. In addition, the substantially larger nacelle sizes required potentially required longer landing gears, which can produce greater approach airframe noise. The Panel felt it was not unreasonable to add 1.0

EPNdB to this number, given all the effects not accounted for in the data from which the estimates were made.

For NRT benefit uncertainties, there is much less quantitative information to go by. However, the NASA AST Study aircraft did have some long term technologies in their original estimates. These results, for cumulative noise benefit, are summarized below:

AST LR4 with GDF (BPR =12.8):	8.8 EPNdB
AST LR4 with DDF (BPR = 8.4):	6.7 EPNdB
AST LR2 with DDF (BPR = 8.3):	6.4 EPNdB
AST SMR2 with DDF (BPR = 8.3):	6.0 EPNdB
Pilot Study 1 SMR2 with GDF (BPR = 12.0):	4.2 EPNdB

These samples yield an average NRT benefit (cumulative) of 6.4 EPNdB, with a standard deviation of 1.65 EPNdB. Since most of the above estimates were made with results from fairly low TRL data, the Panel chose to add 0.5 EPNdB to this number.

The net long term cumulative noise benefit uncertainty was finalized as follows:

Cycle change effect (BPR) Uncertainty:	$\pm(2.74 + 1.0) = \pm 3.74$ EPNdB
NRT Effect Uncertainty:	$\pm(1.65 + 0.5) = \pm 2.15$ EPNdB
Net Long Term Uncertainty:	± 4.3 EPNdB

B.5 Noise Goal Uncertainty Assessment Summary

In summary, the net uncertainties, applicable to all four aircraft categories studied, are summarized in Table B.3 below.

Table B.3 – Noise Reduction Goal Uncertainties (one standard deviation)

Time Frame	BPR Uncertainty	NRT Uncertainty	Total Uncertainty
Mid-Term (2018)	3.4	1.2	3.6
Long-Term (2028)	3.7	2.1	4.3

Appendix C Reference Aircraft Selection – MTOM effect on Cumulative EPNL re: Chapter 4

The Panel reviewed the CAEP Best Practices Database for the four categories of reference aircraft to select representative reference aircraft for evaluating goal noise levels. The selection was made on the basis of cumulative noise level in EPNdB, for current best practices aircraft in production. The data for each aircraft category are shown in figures C.1 through C.4. Also shown on these figures are the selected reference aircraft values, in terms of MTOM and cumulative EPNL. These values are listed in Tables 1.5.1 and 7.3.1.

Figure C.1 shows the cumulative noise levels vs. MTOM for Regional Jets (RJ). Also shown on this plot is the selected reference aircraft datum. Note that the selected reference aircraft is toward the higher weight range (MTOM) of the Best Practices Database certified aircraft. Figure C.2 shows the cumulative noise levels for Short-Medium Range Twin aircraft (SMR2), along with the selected reference aircraft datum. Note that the selected reference aircraft is very close to the reference or baseline aircraft used in Pilot Studies 1 and 2.

Figure C.3 shows the cumulative noise levels for the Long-Range Twin (LR2) Best Practices Data, along with the selected reference aircraft datum. Note that some of the more recently certified aircraft (e.g., GE90-powered B777) already have some of the Noise Reduction Technologies (NRT's) and significantly higher Bypass Ratio (BPR), and so the Panel, with support of the WG1 N29 Planning Committee, chose to treat those aircraft as “advanced,” and therefore selected a reference which was closer to the conventional bypass engine-powered aircraft. The selected reference aircraft nominal MTOM was chosen to be close to the project aircraft shown in figure C.3, as these project aircraft represent the best estimates of aircraft size likely to be introduced in the mid-term.

Figure C.4 shows the cumulative noise levels for the Long-Range Quad (LR4) Best Practices Data, along with the selected reference aircraft datum. Note again that the selected MTOM was chosen to be representative the project aircraft (B747-8). The A380 data are also shown, and at first glance it suggests that it should set the standard for all new LR4 aircraft. However, the Panel was informed by the WG1 N29 Planning Committee Industry members that it is an exceptional aircraft, in that it was designed specifically to meet the London Airport night time quota count category QC2, and hence many compromises were made in terms of overall aircraft performance optimization because of its very high MTOM. Future LR4 aircraft designs may not incorporate such compromises, and aircraft which are derivatives of existing LR4 aircraft may not be able to do so.

Regional Jet Cumulative Level re: Ch. 4

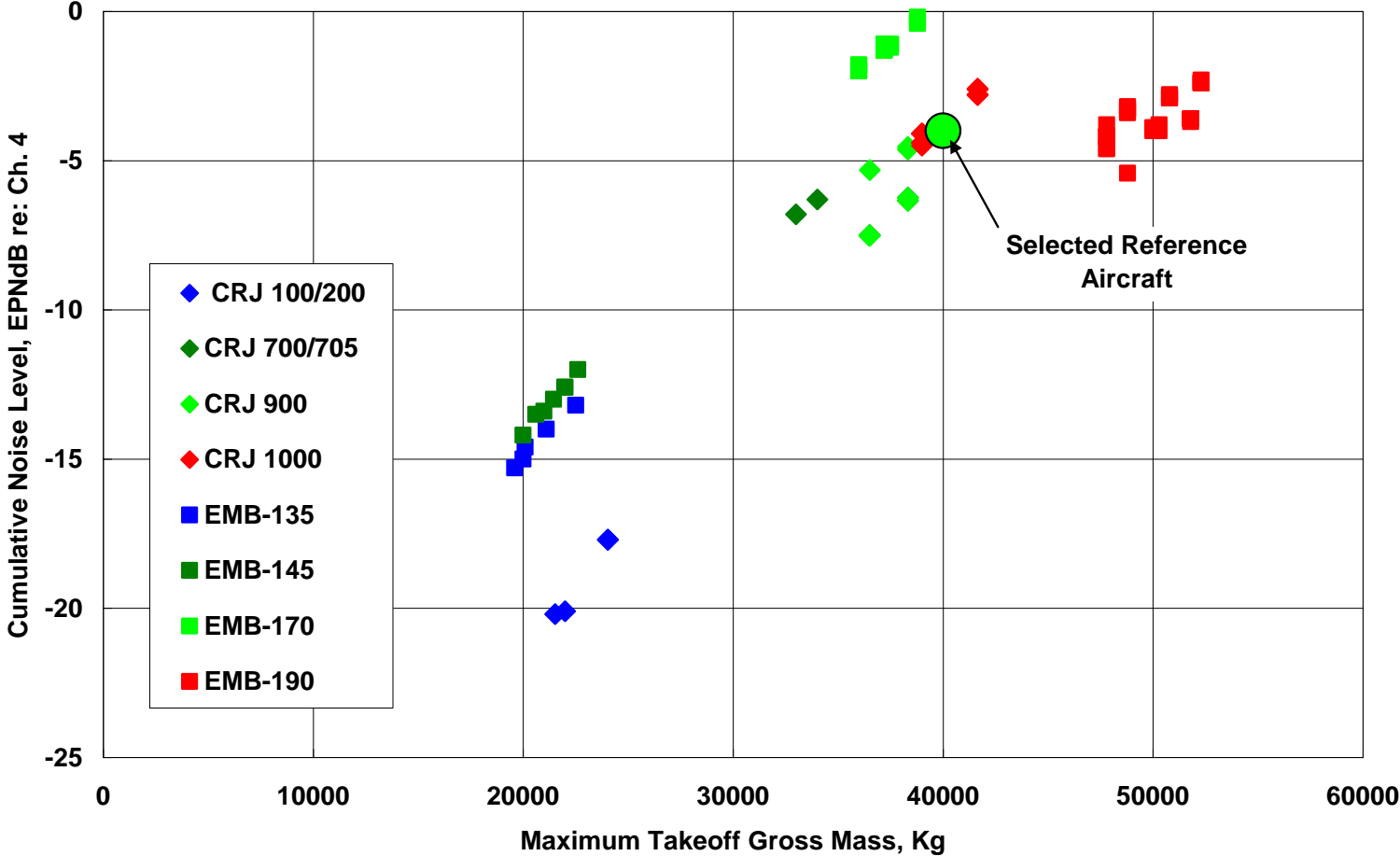


Figure C.1: Regional Jet Reference Aircraft Selection Process

Small-Medium Range Twin Cumulative Level re: Ch. 4

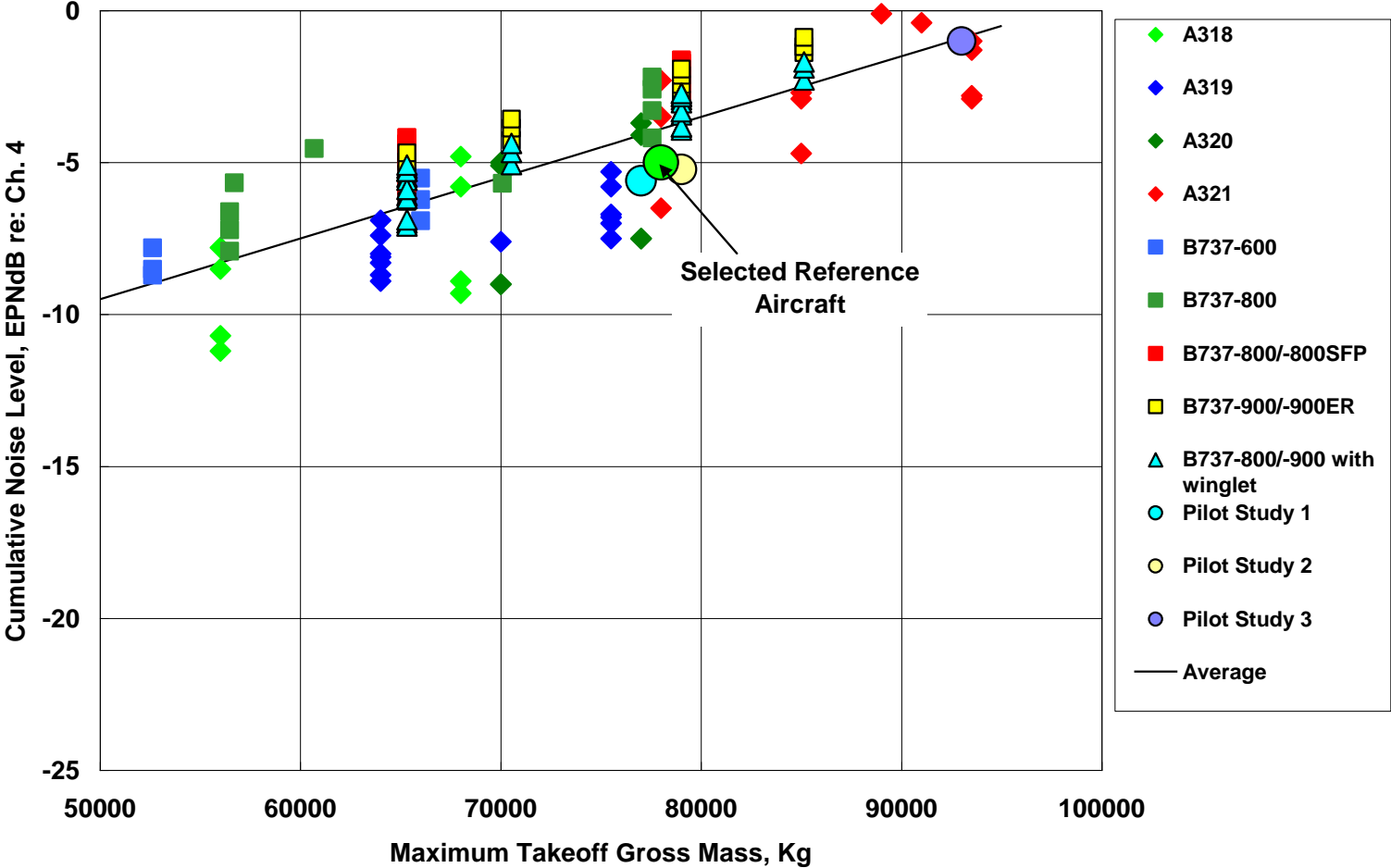


Figure C.2: Small-Medium Range Twin Reference Aircraft Selection Process

Long Range Twin Cumulative Level re: Ch. 4

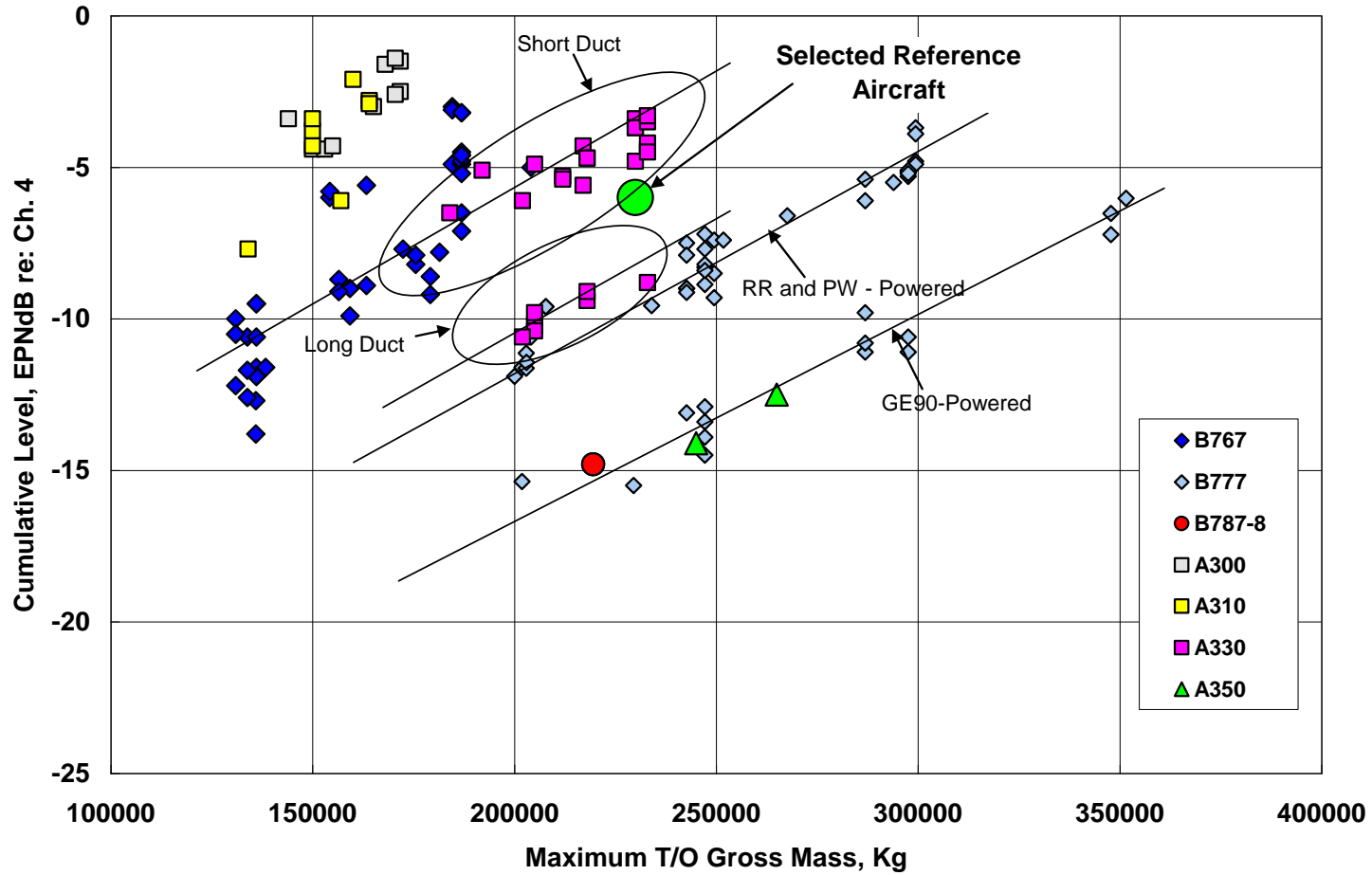


Figure C.3: Long-Range Twin Reference Aircraft Selection Process

Long Range Quad Cumulative Level re: Ch. 4

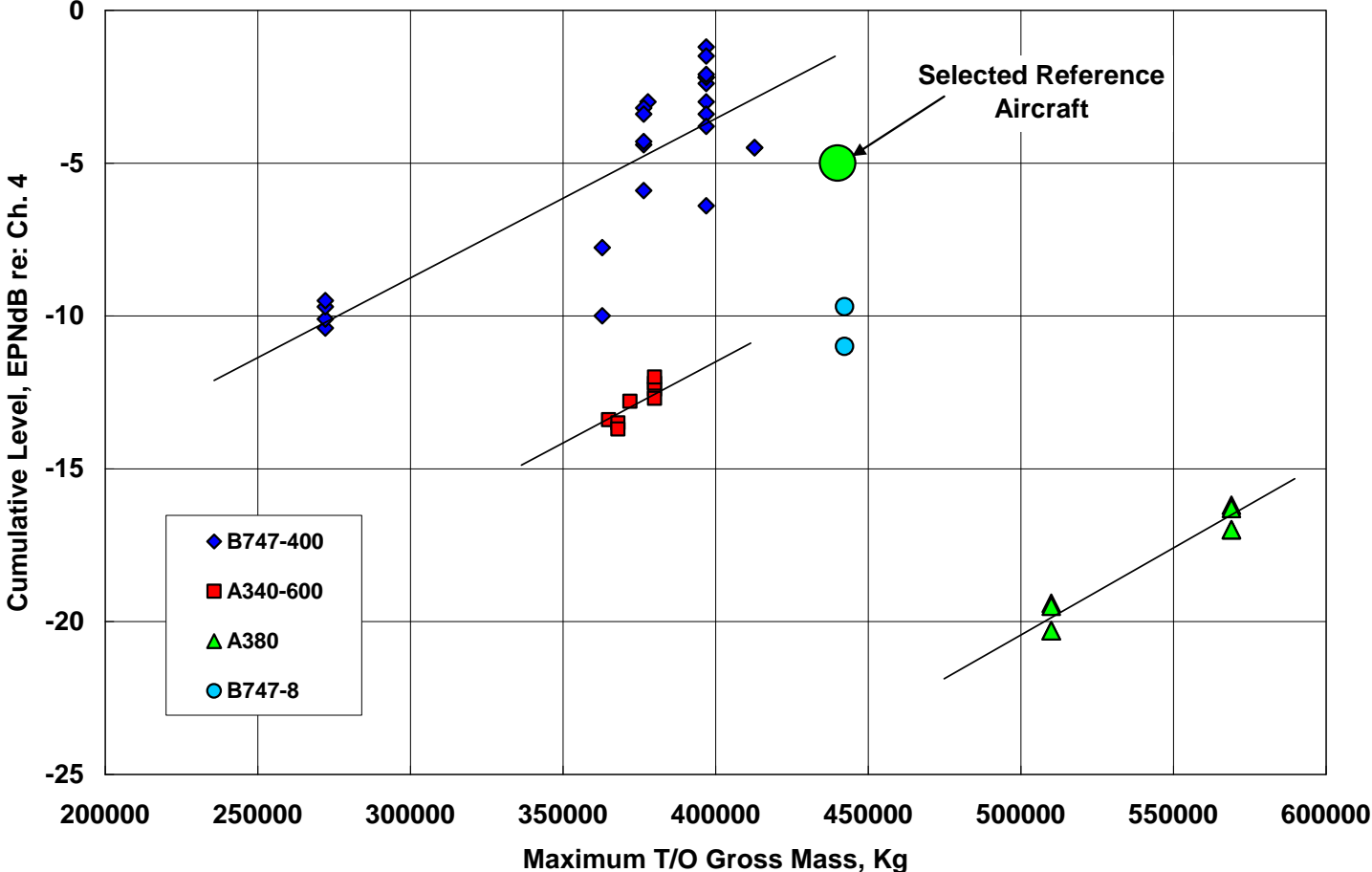


Figure C.4: Long-Range Quad Reference Aircraft Selection Process

Corrigenda

The following corrections have been made to the version presented to CAEP/8:

Item	Section	Page	Figure	Table	Correction
1	1	10	-	1.7.1	Following the correction to Fig. 6.3.3, the Mid-term 'Long Range Twin' Cumulative level reductions in the last 2 columns are reduced by 1.5 dB. Underlying corrections at Flyover and Lateral follow from the corrected figures in Appendix A
2	1	12	-	1.7.2	Following the correction to Fig. 6.3.3, the Long-term 'Long Range Twin' Cumulative level reductions in the last 2 columns are reduced by 1.5 dB. Underlying corrections at Flyover and Lateral follow from the corrected figures in Appendix A
3	1	15	-	1.7.4	The 'Long-range twin' Mid-term and Long-term noise goals are reduced by 1.5 dB
4	1	16	1.7.2	-	The 'Long-range twin' Mid-term noise goal is 273 dB cum level
5	1	17	1.7.3	-	The 'Long-range twin' Long-term noise goal is 270 dB cum level
6	6	60	6.3.3	-	The red mid-term trend line has now been correctly terminated at BPR=9 (was BPR=10) and a long term (blue) trend line added.
7	7	67	-	7.1.1	Following the correction to Fig. 6.3.3, the Mid-term 'Long Range Twin' Cumulative level reductions in the last 2 columns are reduced by 1.5 dB. Underlying corrections at Flyover and Lateral follow from the corrected figures in Appendix A
8	7	68	-	7.2.1	Following the correction to Fig. 6.3.3, the Long-term 'Long Range Twin' Cumulative level reductions in the last 2 columns are reduced by 1.5 dB. Underlying corrections at Flyover and Lateral follow from the corrected figures in Appendix A
9	7	70	-	7.3.2	The 'Long-range twin' Mid-term and Long-term noise goals are reduced by 1.5 dB
10	7	71	7.3.1	-	The 'Long-range twin' Mid-term noise goal is 273 dB cum level
11	7	72	7.3.2	-	The 'Long-range twin' Long-term noise goal is 270 dB cum level
12	7	75	7.4.1	-	The IEP Mid-term (MT) and Long-term (LT) SMR2/LR2/LR4 average goals have been corrected due to the 1.5 dB change in LR2
13	7	76	7.4.2	-	The IEP LR2 goals have been corrected by 1.5 dB
14	A	89	-	A.3	Vertical axis label now corrected. The red mid-term trend line has now been correctly terminated at BPR =9 (was BPR=10) and a long term (blue) trend line added.

15	A	91	-	A.5	Vertical axis label now corrected.
16	A	92	-	A.6	Vertical axis label now corrected. The red mid-term trend line has now been correctly terminated at BPR=9 (was BPR=10) and a long term (blue) trend line added.
17	A	94	-	A.8	Vertical axis label now corrected.
18	A	95	-	A.9	Vertical axis label now corrected. The red mid-term trend line has now been correctly terminated at BPR=9 (was BPR=10) and a long term (blue) trend line added.

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