International Civil Aviation Organization

WORKING PAPER

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

EIGHTH MEETING

Montréal, 1 to 12 February 2010

Agenda Item 4: Review of proposals relating to aircraft noise

REPORT OF THE INDEPENDENT EXPERTS ON NOISE TECHNOLOGY GOALS

(Presented by Independent Expert Panel)

SUMMARY

This Working Paper presents the report and findings of the Noise Technology Independent Expert Panel on the prospects for aircraft noise reduction in the mid-term, year 2018, and in the long-term, year 2028, which may result from implementation of noise reduction technologies currently under development.

Action by the CAEP is in paragraph 4.

1. INTRODUCTION

1.1 An Independent Expert Panel (IEP) was formed to review the status of aircraft noise reduction technology and the prospects for aircraft noise reduction in the Mid-Term (Year 2018) and in the Long-Term (Year 2028), per the directives of CAEP Memo/70 dated 04 January 2008. The panel membership, following nominations and CAEP Steering Group approvals, was selected as follows:

Wajid Chishty – NRC Canada
Jean Beslon – Consultant, France
Dennis Huff – NASA Glenn Research Center, USA
Yuri Khaletskiy – CIAM, Russia
Hirokazu Ishii – JAXA, Japan
Brian Tester – U. of Southampton, U.K.
Philip Gliebe – Consultant, U.S.A.

The Panel selected Philip Gliebe as Chair, assisted by Dennis Huff and Brian Tester as Co-Chairs.

1.2 The Noise Technology Independent Expert Panel (IEP or 'Panel') attended the Noise Technology Workshop as observers, held in conjunction with the CAEP Steering Group Meeting in Seattle, WA, USA, on 26 September 2008. Following the Noise Technology Workshop, a Noise Technology IEP Review was held in Seattle, on September 29 through October 1, 2008. Presentations were given by various Industry members of ICCAIA, reporting the progress of noise reduction technology research programs in the EU, USA, Canada, Russia and Japan. A summary of the Workshop, the Noise Technology IEP Review, and the subsequent formation and work assignments for the Panel were documented in IP_WG1_TTG_02, presented at the WG1/TTG04 meeting in Rome, in November 2008.

2. INDEPENDENT EXPERT REVIEW PROCESS

2.1 The Independent Expert Panel remit, taken from CAEP Memo/70, Appendix A, Paragraph 2.1, is summarized below:

- 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.

2.2 The Panel drafted a report outline following the Independent Expert Review (IER) in Seattle, and Panel members were assigned responsibility for drafting the various aircraft and engine component technologies assessments, based on material presented in the IER.

2.3 A bi-weekly telecom was arranged by the WG1 N29 Planning Committee to provide a forum for additional questions of the presenters by the IEP. The Panel itself held separate weekly telecoms to discuss progress, identify problem areas and address WG1 concerns as they arose.

2.4 The Panel, after reviewing with WG1 and obtaining consensus, agreed to evaluate four classes or categories of aircraft for future noise reduction goals, as follows:

- Regional Jets (RJ)
- Small-to-Medium Range Twin Aircraft (SMR2)
- Long Range Two-Engine Aircraft (LR2)
- Long Range Four-Engine Aircraft (LR4)

2.5 Discussions with WG1 N29 members suggested that the RJ aircraft would have similar noise reduction technology benefits to that of SMR2 category aircraft. Further, both LR2 and LR4 categories have project aircraft in the final design phases, so that, at least for the mid term goals, the Panel noise reduction goal conclusions should not be significantly different from the project aircraft noise level forecasts.

2.6 The IEP identified that the task of assessing the impacts of various component noise reduction technology concepts on total aircraft system noise was extremely difficult and complex, and that the IER material presented was insufficiently detailed to adequately assess the noise reduction potential of the technology concepts on total aircraft system noise reduction. The Panel therefore requested that WG1 N29 industry members carry out additional "system benefit" studies, utilizing Panel-defined noise reduction concept packages or combinations, subsequently called "Pilot Studies." Aircraft manufacturer members of the WG1 N29 committee graciously provided these Pilot Study results for the SMR2 aircraft category, over a period of several months. These results, along with past NASA AST Program studies (documented in NASA TM-2005-212144, "Evaluation of AST Program Noise Reduction Benefits") and Panel analysis of the CAEP Best Practices Database information, provided the Panel with the information needed to develop noise reduction goal recommendations per the CAEP Steering Committee remit summarized in paragraph 2.1.

2.7 Two face-to-face Panel meetings were held, in December 2008, and again in February 2009, in Cleveland, Ohio, USA, hosted by NASA at the Ohio Aerospace Institute. Several WG1 N29 members also attended. These meetings facilitated reviewing progress of the Panel, negotiating with the N29 members on resolution of identified problems, and getting consensus when changes in direction and/or additional information was needed. The Panel reviewed their progress and submitted draft reports for WG1 review at the WG1 meetings in April 2009 in Paris, and in September 2009 in Los Angeles. The Panel received feedback on the submitted draft reports from WG1 and incorporated suggestions and changes as appropriate for improving the clarity and consistency. Members of WG1 also presented Panel progress to the CAEP Steering Committee in Salvador, Brazil, in June 2009, on behalf of the Panel.

2.8 The Panel spent a considerable amount of time analyzing various data sources and technology presentation material to ensure that the Panel Goal recommendations are consistent from one aircraft category to another, and that they are consistent with the project aircraft Best Practices Database noise levels. In addition, the Panel developed a rational model for estimating the uncertainty associated with the Panel Noise Level Goals.

3. INDEPENDENT EXPERT PANEL CONCLUSIONS AND RECOMMENDATIONS

3.1 Noise Reduction Goals for the four categories of aircraft cited in paragraph 2.4 were developed by the Panel, as a result of intensive study of the available review material, Best Practices Database information, Pilot Study results, and results from the recently published NASA Advanced Subsonic Transport Noise Reduction System Assessment Studies. The Goals are given in terms of cumulative noise in Effective Perceived Noise Level, relative to the ICAO Annex 16, Chapter 4 limits. These Goals are summarized in Appendix A of this Working Paper.

3.2 The uncertainty in the Panel Goal noise reduction estimates has been quantified, and is also given in Appendix A, in terms of a band of plus-or-minus the tabulated amount, in Effective Perceived Noise Level, representing approximately an 80% confidence interval about the nominal Goal Level.

3.3 A graphical representation of the IEP Noise level goals, in terms of cumulative noise level in EPNL is given in Appendix B of this working paper, for the four categories of aircraft discussed in paragraph 2.4. The noise goal uncertainty bands are also indicated in these charts. Also shown are the likely trends of cumulative noise level when the initial aircraft design is certified at either higher or lower aircraft takeoff weights. The likely sensitivity of noise to aircraft weight changes has been derived from a multivariate regression analysis of the Best Practices Database, carried out by the N24 Task Group of WG1. A typical weight variation of plus or minus 25% of the initial certification aircraft weight was used for these charts, as recommended by the WG1 N24 Task Group. It is to be noted that aircraft cumulative noise level increases faster with takeoff weight than does the Chapter 4 limit line in each of the aircraft categories illustrated.

3.4 A detailed documentation of the Independent Expert Panel activities, processes, analyses, conclusions and recommendations is presented in Information Paper CAEP/8-IP/10. The executive summary of this IP has been reproduced herein as Appendix C.

3.5 The Noise Goal recommendations in the report are based on the best available information provided to the Panel on the benefits of noise reduction technologies and potential future vehicle configurations. The Panel utilized specific noise reduction technology benefits that can be realistically implemented in the mid-term and long-term timeframes, and implemented a process for projecting TRL6 technology to TRL8 readiness, using a %realization factor. However, the marketplace will determine which technologies are actually implemented in future aircraft designs, and will depend on factors well beyond the scope of this Panel study. Hence there are likely to be significant variations in new aircraft noise levels within an aircraft category that may either exceed or fall short of the projections.

4. ACTION BY THE CAEP

4.1 The CAEP is invited to:

a) note the accomplishments of the Noise Technology Independent Expert Panel concerning the Noise Technology Goal Recommendations, and is invited to review and comment on the recommended Noise Reduction Goals summarized in Appendices A, B and C;

b) review and comment on the detailed documentation of the IEP efforts and goal-establishment process contained in Information Paper CAEP/8-IP/10;

c) consider establishing a work item for CAEP/9 on assessment of noise benefit realization factor for future noise goal forecasts; and

d) note the caveats to the Panel Goal projections in paragraph 3.5.

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APPENDIX A

INDEPENDENT EXPERT PANEL NOISE GOAL RECOMMENDATIONS

A.1 Cumulative Noise Goals Relative to Annex 16 Chapter 4 Limits (EPNL):

Table A.1 – Mid-Term and Long-Term Noise Goals
Cumulative EPNL re: Chapter 4 Limits
Technology Readiness Level at TRL8

Aircraft Category	Mid-Term (2018)	Long-Term (2028)
Regional Jet	13.0	20.0
Small-Med. Range Twin	21.0	23.5
Long-Range Twin	22.0	24.5
Long-Range Quad	21.0	23.5

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.

A.2 Noise Goal Uncertainty for Cumulative Noise Levels Relative to Chapter 4:

Mid-Term Goal Uncertainty (Year 2018) - ± 4.6 EPNdB

Long-Term Goal Uncertainty (Year 2028) - ± 5.5 EPNdB

The above uncertainty bands represent 80% confidence intervals; i.e., the goal levels in Table A.1 are estimated to have 80% probability of being within the uncertainty bands indicated above.

A.3 Impact of Noise Abatement Operational Procedures:

The Panel assessment of the prospects for employing advanced Noise Abatement Operational Procedures concluded that the most likely benefits would be at the Approach or Landing condition. The Panel concluded that it seems possible to provide an additional 3 EPNdB reduction in aircraft noise level at approach.

A.4 Advanced Concepts Not Considered:

The Panel concluded that those concepts such as the Blended-Wing-Body aircraft configuration and the “Functionally Silent Aircraft” Concept were at too low a Technology Readiness Level (TRL) to be potentially certified in the medium term, and even in the long term. Also, there was insufficient information available to assess the potential noise levels of open rotor propulsion systems. It is recommended by the Panel that a review of open rotor propulsion prospects be held when data becomes available to adequately evaluate the tradeoffs between fuel burn and noise.

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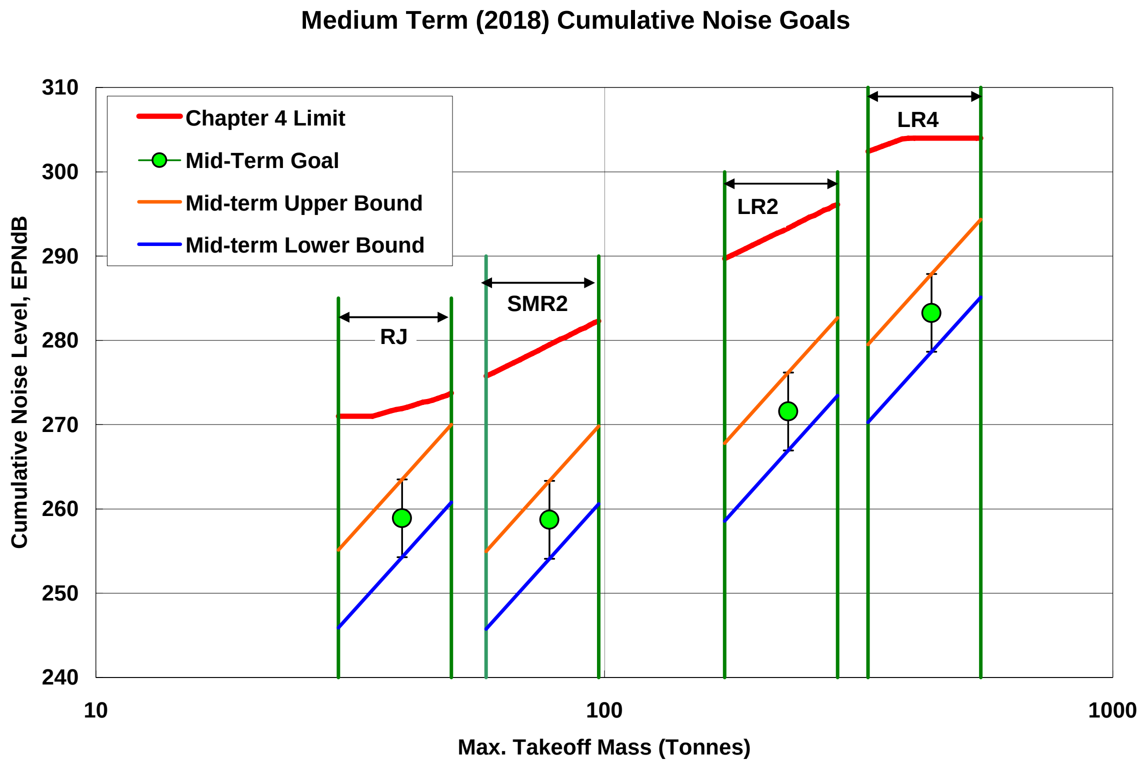
APPENDIX B

MEDIUM AND LONG TERM CUMULATIVE NOISE GOALS FOR REPRESENTATIVE AIRCRAFT FAMILIES

B.1 Medium Term (Year 2018) Noise Goals for Representative Aircraft Families



RJ - Regional Jets
SMR2 - Small-to-Medium Range Twin Aircraft
LR2 - Long Range Two-Engine Aircraft
LR4 - Long Range Four-Engine Aircraft

B.2 Long Term (Year 2028) Noise Goals for Representative Aircraft Families

RJ - Regional Jets
SMR2 - Small-to-Medium Range Twin Aircraft
LR2 - Long Range Two-Engine Aircraft
LR4 - Long Range Four-Engine Aircraft

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APPENDIX C

INDEPENDENT EXPERT PANEL NOISE TECHNOLOGY EVALUATION REPORT EXECUTIVE SUMMARY

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	4.0+2.0=6.0	6.5+1.5=8.0	12.0+5.5=17.5	16.0
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.

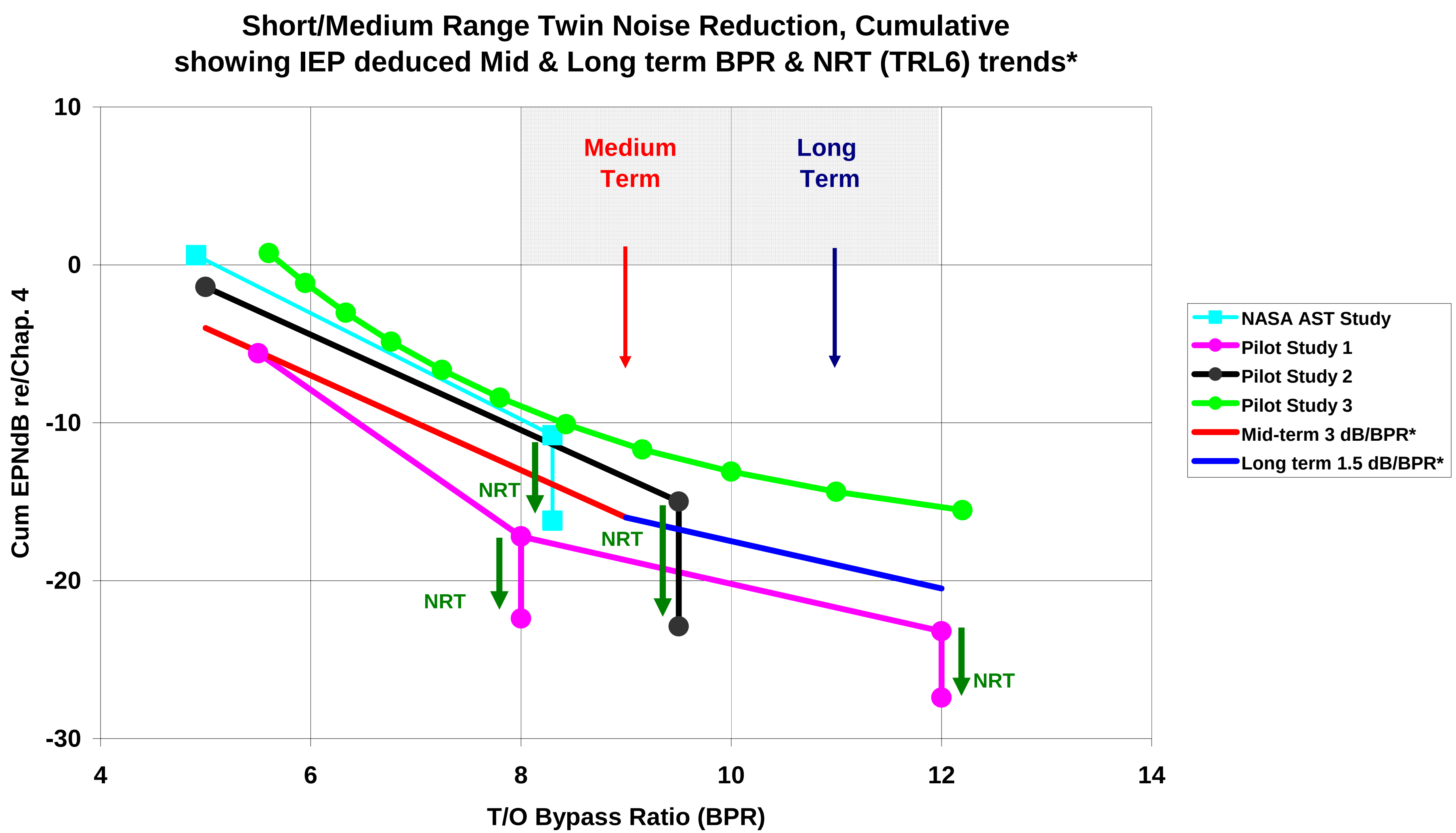

Figure 1.7.1: Short/Medium Range Twin cumulative margin noise trend with BPR (Note Pilot 3 does not include NRT)

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 propulsions 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	4.5+2.5=7.0	7.0+2.0=9.0	13.5+7.0=20.5	18.5
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 ±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 ~ $67\times\log_{10}(\text{MTOM})$. 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 ±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	22.0±4.6	24.5±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.

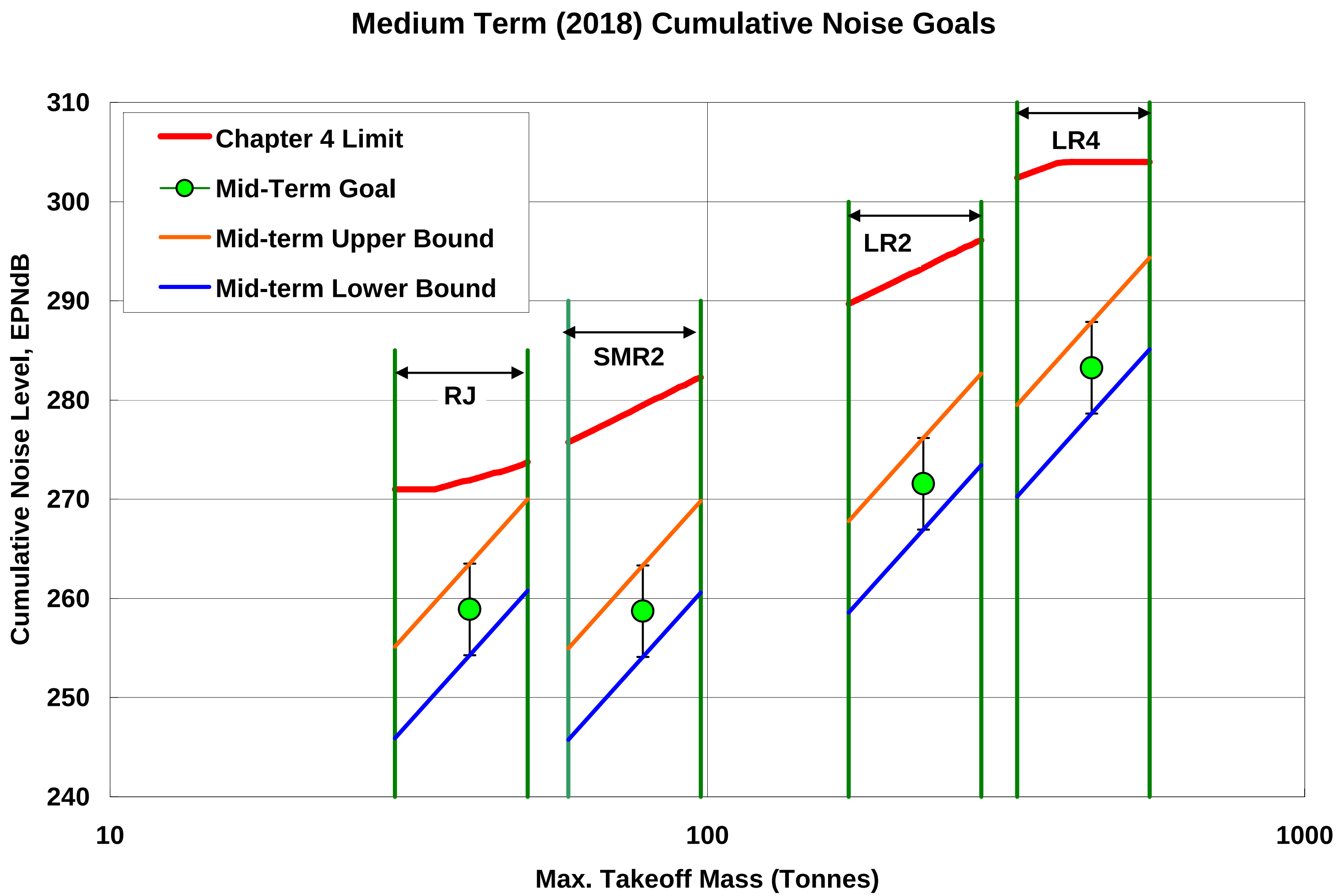

Figure 1.7.2 – Mid-Term Aircraft TRL6 Noise Goal Summary

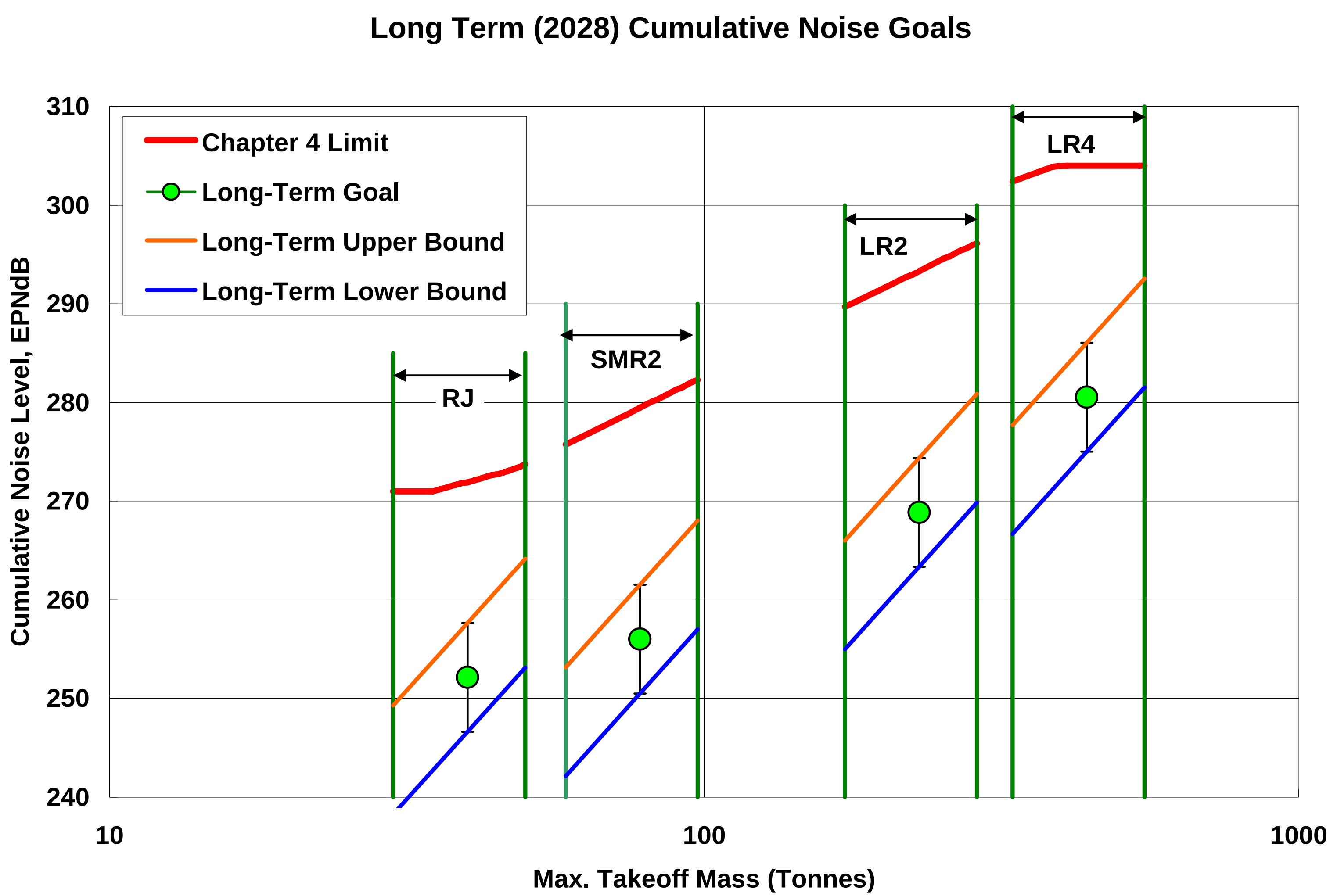

Figure 1.7.3 – Long-Term Aircraft TRL6 Noise Goal Summary

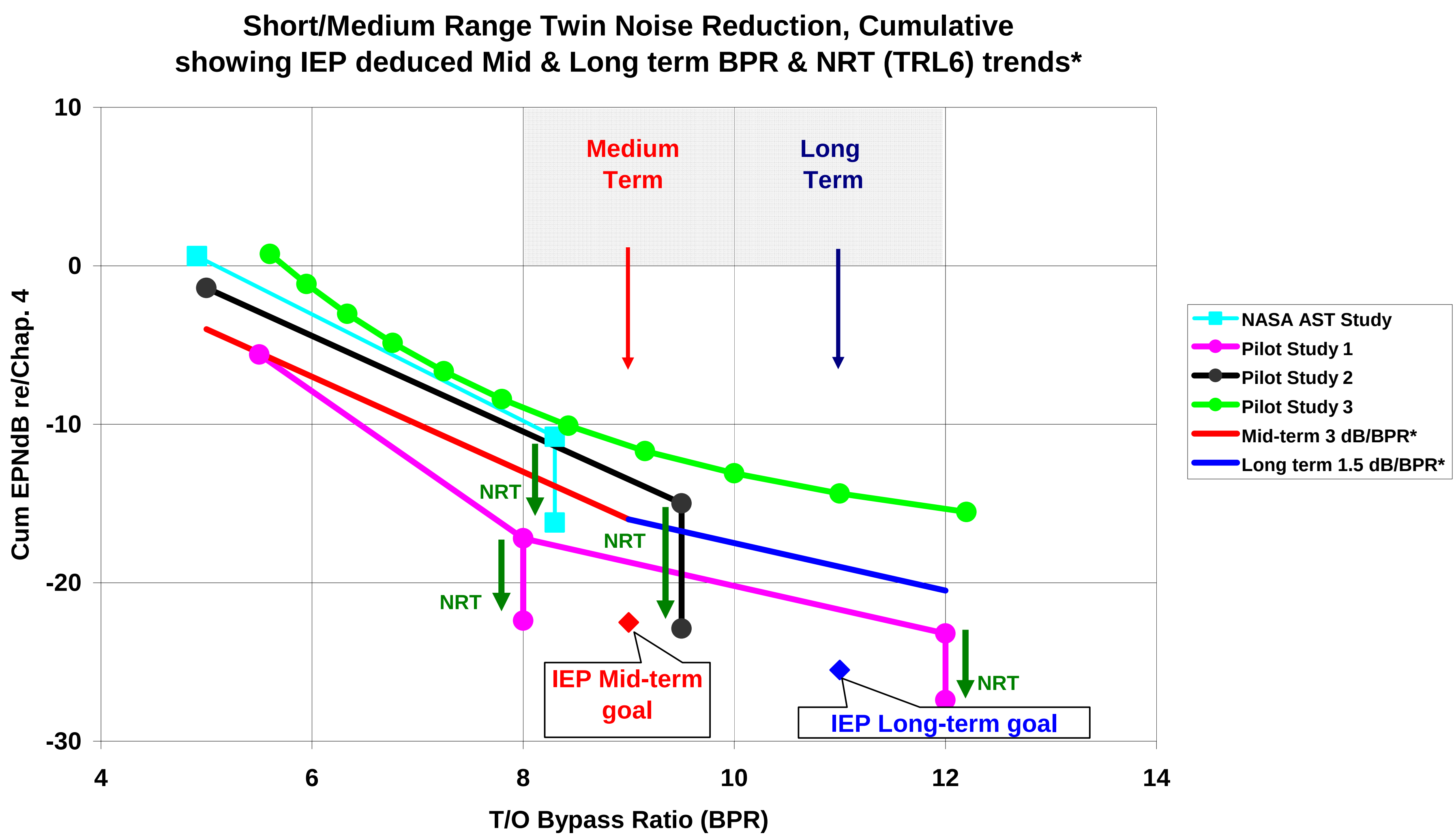

Figure 1.7.4: Short/Medium Range Twin cumulative margin noise trend with BPR (Note Pilot 3 does not include NRT)

— END —