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Agenda Item 17: Environmental protection

ENVIRONMENTAL DESIGN SPACE (EDS) PROGRESS

(Presented by Canada and the United States)

EXECUTIVE SUMMARY

The U.S. Federal Aviation Administration Office of Environment and Energy (FAA/AEE), in collaboration with Transport Canada, is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. The main goal of the effort is to develop a new, critically needed capability to assess the interdependencies among aviation-related noise, emissions, and associated environmental impact and cost valuations, including cost-benefit analyses. The Environmental Design Space (EDS) concept was formally introduced to the sixth meeting of the CAEP in February 2004, in Montreal, Canada. Since that time the Steering Group, WG1, WG2, WG3, MODTF and FESG have been kept informed of EDS research and design developments. This paper serves to update the ICAO on the progress of the EDS development and assessment effort.

Strategic Objectives:	This working paper relates to Strategic Objectives C (*Environmental Protection – Minimize the adverse effect of global civil aviation on the Environment*).
Financial implications:	Not applicable.
References:	

1. INTRODUCTION

1.1 At CAEP/6 in 2004, participants clearly recognized that to achieve effective noise and emissions mitigation requires consideration of interdependencies between noise and emissions and amongst emissions. CAEP/6 recommended, and ICAO's 35th Assembly subsequently adopted, three environmental goals: to limit or reduce noise exposure, local air quality emissions, and greenhouse gas emissions. Analytical tools and supporting databases that could account for interdependencies amongst these goals and potentially optimize the environmental benefit of mitigation measures would greatly facilitate and enhance progress toward these goals.

1.2 In assessing the scope of future analytical tools, it is important to consider the potential decisions that policy makers are likely to face. The complexity of decisions has increased over time as the remit of CAEP has gone from a primary concentration on standard setting applied to aircraft, to providing policy advice on operational issues and consideration of potential market-based options to reduce the impact of aviation on the environment. In seeking to meet the ICAO goals to limit or reduce aviation environmental impacts, CAEP may consider in a future work program more stringent environmental standards, new emissions standards, technological advancements, and elements of the balanced approach (CAEP-SG/20051-IP/12).

1.3 Existing aircraft noise and aviation emissions analytical tools used by CAEP cannot effectively assess interdependencies between noise and emissions, or analyze the cost-benefit of proposed actions. Accordingly, the Federal Aviation Administration's Office of Environment and Energy (FAA-AEE) is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. Transport Canada is collaborating with the FAA in those elements of the development effort undertaken by the Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence. The main goal of the effort is to develop a new capability to assess the interdependencies between aviation-related noise and emissions effects, and to provide comprehensive cost and benefit analyses of aviation environmental policy options. The FAA tool suite is illustrated in Figure 1. The building block of this suite of software tools that provides an integrated analysis of noise and emissions at the aircraft level is the Environmental Design Space (EDS).

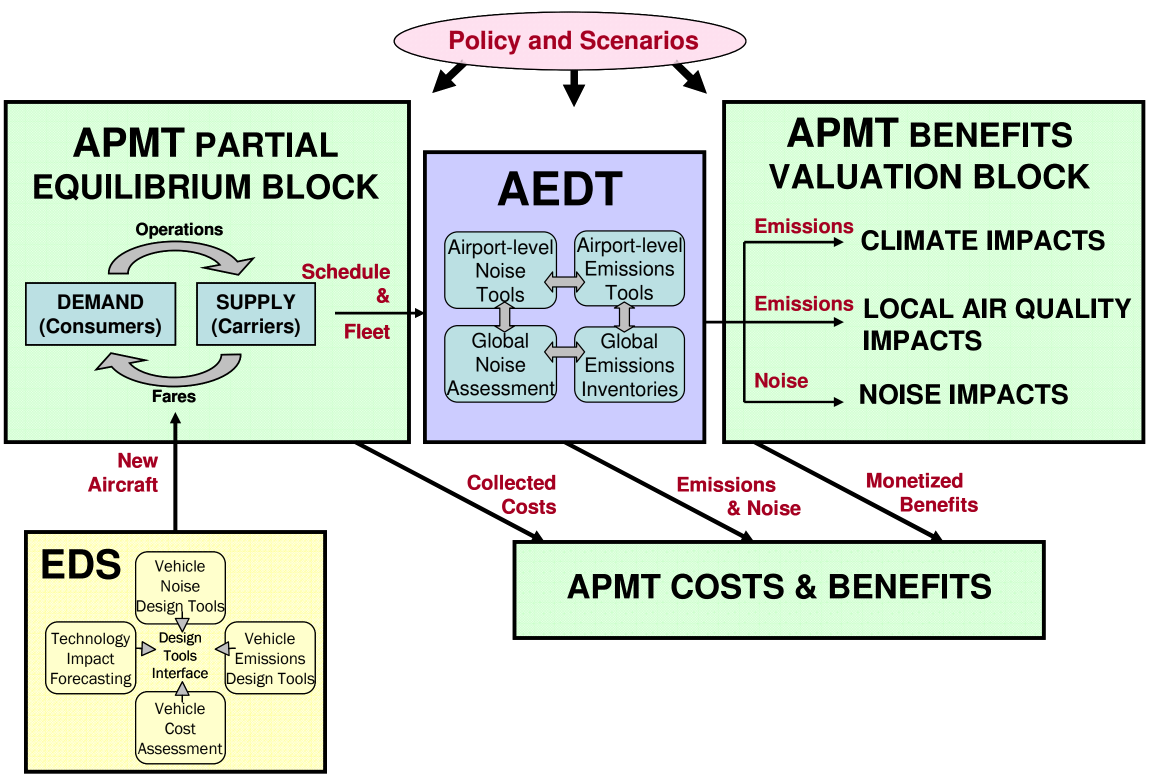

Figure 1. EDS Architecture Overview

1.4 Beginning in 2004, EDS information and plans were submitted to CAEP and government, industry, and community stakeholders[1].

1.5 This paper serves to update the CAEP on the progress of the EDS development and assessment effort.

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[1] 2003-06 –- CAEP6_SG3_WP42, "Environmental Design Space Approach to Aircraft Noise and Aviation Emissions"
2004-03 – Transportation Research Board (TRB) Workshop #1, "Environmental Design Space (EDS)"
2004-03 – Transportation Research Board (TRB) Workshop #1, "NASA led Efforts under the Vehicle Systems Program"
2004-08 – Transportation Research Board (TRB) Workshop #2, "Environmental Design Space (EDS)"
2004-11 – CAEP SG/20041-WP/7, "Progress Developing Analytical Tools to Address Interdependencies among Environmental Impacts"
2005 – Journal of Aviation Management, "Managing Aviation's Impact on the Environment: Addressing Interrelationships"
2005-04 – PARTNER Report, "An Aggregate Model for Simulating AEDT"
2005-06 – PARTNER Report, "Requirements Document for the Environmental Design Space (EDS)"
2005-06 – PARTNER Report, "Vehicle Systems Program Modeling and Simulation Environment Overview & Differences to EDS Version 1.0"
2005-07 – PARTNER Report, "Georgia Tech VSP Modeling and Simulation Environment: Assessment Overview"
2005-09 – PARTNER Center of Excellence 5th Advisory Board Meeting, "Environmental Design Space (EDS) & Aviation Environmental Portfolio Management Tool (APMT)"
2005-09 – PARTNER Report, "EDS Multi-Year Assessment Plan"
2005-10 – CAEP SG/20051-IP/12, "Development of a Comprehensive Software Suite to Assess Aviation Environmental Effects"
2005-10 – CAEP7_WG1_TTG3_WP04, "Development of the Environmental Design Space (EDS)"
2005-10 – CAEP7_WG1_TTG3_IP06, "Environmental Design Space (EDS)"
2005-10 – CAEP7_WG1_TTG3_IP07, "Environmental Design Space (EDS) Documentation"
2005-10 – CAEP7_WG1_TTG3_IP07_AppA, "Requirements Document for the Environmental Design Space (EDS)"
2005-10 – CAEP7_WG1_TTG3_IP07_AppB, "Vehicle Systems Program Modeling and Simulation Environment Overview & Differences to EDS Version 1.0"
2005-10 – CAEP7_WG1_TTG3_IP07_AppC, "EDS Multi-Year Assessment Plan"
2005-11 – CAEP7_WG3_CTG5_IP05, "Environmental Design Space (EDS) Documentation"
2006-02 – CAEP7_WG3_CTG6_IP6/3, "Development of the Environmental Design Space (EDS) Prototype"
2006-03 – PARTNER Semi-annual Advisory Board Meeting,"Environmental Design Space EDS v1.0 Technical Advisory Board"
2006-03 – CAEP7_WG1_TTG4_WP03, "Development of the Environmental Design Space (EDS)"
2006-03 – CAEP7_WG1_TTG4_IP01, "Environmental Design Space (EDS) Status Update"
2006-05 – PARTNER Report, "An Approach for Technology Impact Assessment in the Environmental Design Space (EDS) Modeling & Simulation Environment"
2006-05 – 14th Annual Aerospace Systems Design Laboratory External Advisory Board (EAB) Review, "An Overview of the Environmental Design Space (EDS) Research"
2006-06 – NASA Quiet Aircraft Technology (QAT) Close-Out Technical Working Group Meeting, "An Overview of the Environmental Design Space (EDS) Research"
2006-06 – CAEP SG/20063-IP/5, "Development of the Environmental Design Space (EDS)"
2006-10 – CAEP7_TIG_WP03, "Appraising Technology Interdependencies Capabilities to Support Future CAEP Stringency Tasks"
2006-10 – TIG_WP03A, "Appraising Technology Interdependencies Capabilities to Support Future CAEP Stringency Tasks"
2006-10 – TIG_WP03B, "Review of the Environmental Design Space (EDS) Research"
2006-10 – PARTNER Center of Excellence 7th Advisory Board Meeting, "Environmental Design Space (EDS)"

2. EDS DESIGN

2.1 EDS can provide a capability to estimate source noise, exhaust emissions, performance, and economic parameters for potential future aircraft designs under different policy and technological scenarios. The capability will allow for assessments of interdependencies. In addition, once EDS is connected to the Aviation Environmental Portfolio Management Tool (APMT) and the Aviation Environmental Design Tool (AEDT), the combined environment will be able to assess operational, policy, and market scenarios. While the primary focus of EDS is future aircraft designs (which includes technology modifications to existing aircraft), the tool will also be capable of analyzing existing aircraft designs (current technology levels) under different scenarios when there is a need to simulate existing aircraft in a higher fidelity than is possible using existing noise and emissions tools. Capturing high-level technology trends will provide a capability for assessment of benefits and impacts.

2.2 A potential additional EDS function could be to serve as a mechanism for collecting, incorporating, and quantifying long-term technology objectives and goals. This would be a tool-driven process verified and validated through expert guidance, while incorporating best practices.

2.3 The detailed modules comprising the EDS tool were originally developed by the National Aeronautics and Space Administration (NASA), and include five modules, which have been seamlessly integrated:

a) Numerical Propulsion System Simulation (NPSS) – calculates the engine thermodynamic analysis

b) Weight Analysis of Turbine Engines (WATE) – estimates component weights and dimensions based on cycle parameters calculated in NPSS

c) Emissions correlations – P3-T3 methods or NASA Glenn Research Center developed emission correlations based on NOx correlation equations for various combustors

d) FLight OPtimization System (FLOPS) – calculates aircraft weights and performance results based on mechanical model from WATE and cycle performance from NPSS

e) Aircraft Noise Prediction Program (ANOPP) – predicts certification noise levels and noise power distance curves, based on aircraft dimensions from FLOPS and engine information from NPSS and WATE

3. EDS PROTOTYPE

3.1 The FAA began development of EDS in February 2005 through the U.S.-Canada-sponsored Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence. The development plan, currently in Year 3, is envisioned as a five-year program with a functional version of EDS available for potential CAEP/8 scenario analyses. All of the elements necessary for the analyses and a schedule of EDS development activities are delineated in the EDS Multi-year Work Plan document. In addition, the document provides a brief discussion of the steps required to move beyond the EDS Prototype to EDS Versions 1 through 3 through expert engagement during the development.

3.2 The EDS Prototype will help to identify gaps or weaknesses in the EDS functionality and stimulate advancements in EDS development. Therefore, the objective of the prototyping effort is to construct all of the EDS modules and engage experts to provide a means to validate and verify the results and functionality. Additionally, the prototype will facilitate assessing and propagating uncertainties within EDS, and to AMPT and AEDT, to guide the determination of high priority areas for future development and refinement.

3.3 A linkage of EDS outputs to the necessary APMT and AEDT inputs is also contained within the prototyping effort.

4. EDS ASSESSMENT

4.1 Assessing EDS and determining its usefulness in evaluating policy options are essential if EDS is to be used with confidence by the aviation community. This section describes the progress of the EDS effort in developing a comprehensive assessment approach.

4.2 The EDS assessment plan will span the five-year program and will target modeling assumptions, accuracy, and input assumptions. The goal is to thoroughly assess the accuracy of EDS through a close collaboration with industry. The collaborative assessment will enable the accuracy of the EDS tools to be better understood, and will highlight components of EDS that should be improved. In Year 2 of the development plan, the first phase of the collaborative assessment focused on an engine-level NOx/fuel burn trade off for two of the three engines (GE and P&W) offered on the Boeing B777-200ER. This particular case was chosen as Phase I since it constrained the analysis space to the engine only; focus on modern, but known technology as a baseline example; and gain participation from different manufacturers on a consistent airframe. At the end of Phase I, the collaboration assessments provided substantial feedback as to the manner in which the EDS architecture executed. The suggestion from industry was to impart a more realistic approach to engine design, specifically taking into account multiple criteria by which an engine is design in industry. The development team incorporated the modifications and have continued into Phase II of the collaborative assessments. Boeing is also engaged through an assessment of the noise and airframe performance characteristics of a Boeing 737-800 with a CFM56-7B24; while Bombaridier has committed to supporting assessments of a CRJ700.

4.3 The assessment plan includes the formation of an advisory board to guide EDS development and facilitate industry review of EDS assumptions, methods, data, and results. The EDS Technical Advisory Board (TAB) was established, and is comprised of experts from both U.S. and international airframe and engine companies, including many CAEP participants. The EDS TAB met 1 June 2005 in Boston, Massachusetts, 26-27 January 2006 in Atlanta, Georgia, and 16 January 2007 in Atlanta, Georgia. The most recent meeting of the TAB recommended the formation of an Industry Review Group (IRG) to allow for a more thorough assessment of EDS processes and assumptions, including model components and structure, and model capabilities in predicting aircraft noise and emissions levels relative to appropriate validation data. Whereas the TAB provides more general guidance, the intent of the IRG is to identify experts from industry to review specific details of the model in the areas of engine performance, aircraft performance, noise, and emissions. The EDS IRG met 19-21 March 2007 in Cincinnati, OH and 6-7 June 2007 in Atlanta, GA. Each workshop has focused on a detailed review of the B777-200ER trade space and the associated assumptions. The next workshop is scheduled for 5-7 September 2007 in Atlanta, GA.

4.4 The future work items for both Working Group 1 and Working Group 3 include a task to "Evaluate the Environmental Design Space concept, the Technology Evaluator and other candidate systems as potential tools to aid assessment of technological responses and to identify technology trade-offs." A draft evaluation plan (CAEP8_TIG1_WP04) for a technology response tool was presented to the first meeting of the Technology Interdependencies Group (TIG) on 28 March 2007. In the case of EDS, a key element of the draft plan is CAEP Working Group engagement in the Industry Review Group (IRG) process. The TIG acknowledged the use of the IRG process to facilitate the evaluation of the EDS tool for CAEP analysis purposes and it was recommended that research establishments should also get involved in the IRG process to provide a level of "independent" review. The IRG was subsequently renamed the "Independent Review Group" and members from several research establishments were invited to participate in the IRG process. The IRG currently includes representatives of the aircraft and engine manufacturing industry, the airline industry, the EDS development team, NASA, the U.S. Federal Aviation Administration and several European research organizations.

4.5 The formal parametric sensitivity study and uncertainty assessment are being carried out at both the EDS module level and the EDS system level. A rigorous process was established and includes seven steps:

1) Identify and categorize module inputs for which public domain data exists.

2) Identify module outputs for which public domain data exists – validation data.

3) Identify outputs that propagate to other modules.

4) Perform a Monte Carlo Simulation with the results of step 1 on the desired validation engine/airframe combination.

5) Perform a statistical significance test to identify the key input drivers to the validation data.

6) Identify key input drivers that must have a higher level of accuracy.

7) Quantify module uncertainty, and propagate through EDS to identify the level of accuracy and fidelity needed for EDS.

5. SAMPLE PROBLEM

5.1 The EDS development goals for the Year 3 Prototype include completing a demonstration of functionality within AEDT and APMT for the CAEP NOx strigency sample problem. The EDS outputs generated for two FESG seat classes are being provided to APMT and AEDT for this exercise. At present, the contribution of EDS vehicles are being considered for the 2016 implementation at the 18% stringency level. The results of the EDS contribution to the sample problem will be documented for the MODTF meeting to be held on 8-10 October 2007.

6. EDS APPLICATION

6.1 The FAA is supporting the development of the EDS tool that could provide the capabilities described in this section.

6.2 *Stringency*. It is envisaged that CAEP will evaluate the EDS concept, among others, to determine what capability could support CAEP in the assessment of the prospects for further reductions of airplane noise levels and exhaust emissions standards. This evaluation will likely take into account technological feasibility, economic reasonableness, and environmental effectiveness, noting also environmental interrelationships and tradeoffs. The Appendix contains a table that delineates data and functional requirements for consideration by CAEP based on past experience, along with anticipated EDS capabilities for the CAEP/8 work cycle. This material should be helpful to the CAEP working groups assigned to evaluate technology assessment methodologies.

6.3 *Long-term goals*. It is envisaged that EDS and the other components of the tool suite — AEDT and APMT — could help CAEP to expand on the current effort to establish long term NOx technology goals for aircraft emissions reductions to refine the process for setting NOx goals, and include noise along with other exhaust emissions. Some of the EDS capabilities could include the following:

a) In concert with AEDT, quantify the gaps between CAEP's environmental goals and the state of existing technology research programs.

b) Quantify the potential benefits that could be derived from long-term goals.

c) Assess technology portfolios that address required capabilities and long-term environmental goals in noise and emissions.

d) Help the CAEP community take into account in its goal-setting process the uncertainties in the states of the art for technology assessment, design trade-offs, and economic effectiveness evaluations.

7. SCHEDULE

7.1 EDS technical development is progressing on schedule. Algorithm, interface control, and database description documents for EDS have been created based on the current architecture and assumptions utilized. Further versions will be released as the intereactions with the IRG continue and feedback on the EDS outputs, trends and sensitivities are generated.

7.2 Industry collaboration is continuing, with beneficial feedback, to tailor the future development to incorporate industry best practices. The sample problems and module level assessments are nearing completion, with documentation of the results expected in late 2007 for the sample problem and early 2008 for the assessments.

8. CONCLUSIONS

8.1 The U.S. Federal Aviation Administration is developing a comprehensive suite of software tools that will allow for thorough assessment of the environmental effects of aviation. The main goal of the effort is to develop a new, critically needed capability to assess the interdependencies between aviation-related noise, emissions, and cost valuations.

8.2 Substantial progress has been made developing the Environmental Design Space. Collaboration within CAEP on the EDS concept evaluation is welcomed. Commitment of expert input through CAEP members and observers is vital to its successful development. The Appendix contains a table that summarizes past CAEP stringency assessments, suggests how EDS could support a future assessment, and describes the capabilities that EDS could bring to such assessment.

8.3 This paper serves to inform ICAO of the progress of the EDS development effort. CAEP participants will continue to be informed of the progress of the development, and related sample problems and demonstration analyses efforts.

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APPENDIX

EDS DATA AND FUNCTIONAL REQUIREMENTS FOR CAEP STRINGENCY ASSESSMENT

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
Purpose of certification	WG1 defines the purpose as "The prime purpose of noise certification is to ensure that the latest available noise reduction is incorporated into aircraft design demonstrated by procedures which are relevant to day to day operations, to ensure that noise reduction offered by technology is reflected in reductions around airports." WG3 has not explicitly defined a purpose but its actions in the assessment of more stringent NOx standards suggest that its philosophy is consistent with that of WG1.	Since CAEP will work collegially on future stringency assessments, the groups should coalesce on a purpose that is consistent with past practices. Therefore, CAEP could look to EDS and the development team to assist in assessing technologies that have been demonstrated or proven. Adopting terminology formerly used by NASA, the technologies must be at a technology readiness level (TRL) 8 or 9, respectively. [ii]	The plan is to integrate these into the aircraft models that have been developed given appropriate definition of the component level technologies (e.g., weight, nozzle thrust coefficient, cost and noise impacts of chevrons). By CAEP/8 the plan is to have all 9 of the major FESG seat class sizes developed.
Technology evaluation			
• Best practice technologies	In consultation with the manufacturers, WG1 identified some proven technological concepts that reduce noise. Building on the information presented at the ICCAIA Emissions Technology Workshop held in conjunction with the Paris Steering Group (September 2002), WG3 identified technology advances related to emissions.	CAEP could look to the EDS Development Team to help compile a list of pertinent technologies at TRL8 and TRL9 and TRL7 if CAEP wished for longer term applicability dates for new environmental standards.	The EDS team anticipates doing this as part of the technology impact assessment work planned within the statement of work.
• Best practices database	To facilitate identification of airplanes incorporating best practices, ICCAIA developed the database (for both jet and propeller-driven, large airplane) that also included data on project airplanes. The regulating authorities reviewed and eventually accepted this database as the basis for developing stringency options. The database contained up to 3 different maximum takeoff weights for each aircraft model and series.	The WG1-WG3 Ad Hoc Group concluded that WG1 (CAEP5) and WG3 (CAEP6) used in-production databases for stringency evaluation. For future stringency assessments, WG1 and WG3 agree to establish a common aircraft/engine database for use within WG2 models to populate the generic new deliveries in the FESG future fleet forecasts with representative, realistic aircraft/engine combinations, thereby enabling the operational trends of noise and	The plan is to provide a capability to evaluate the technologies (proprietary or otherwise) through working closely with the individual manufacturers. However, the EDS team does not anticipate that it can contribute to rationalizing the kind of negotiated settlements that went into for example NOx stringency discussions during CAEP6 of what was best available at the component technology level. (In particular

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
• Best practices database (cont'd)	WG3 developed an in-production database taking into account aircraft/engine combinations which are currently in production or would enter the market within the next 3 - 5 years, referring to it as the "in-production database 2002-2006."	emissions to be assessed simultaneously and provide a trade-off analysis for proposed policy options. CAEP could look to EDS to scrutinize the combined in-production database to screen out any entry that is not representative of the best available technology. Because of manufacturers' sensitivities to having products negatively classified, the EDS screening process must be objective and data-based.	whether "best" is defined for the set of all engines or all engines made by a particular manufacturer.)
• Technology response	WG1 used the best practices database both to formulate the stringency options and evaluate the implications of each. For the purposes of costs-benefits analysis, WG1 agreed to the principle that a fraction of the aircraft fleet that could be brought into compliance by means of re-certification. Re-certification is defined as the certification of an in-service aircraft configuration in compliance with a more stringent noise standard.	WG1 and WG3 have created an ad-hoc group to carry out an historical review of past CAEP stringency processes with specific regard to the technology assessment processes. The group found that "a common philosophy for assessing technological responses would be beneficial in being able to assess technology trade-offs, integrate these into the CAEP modeling of costs and benefits, and improve the CAEP policymakers understanding of this subject."	The plan is to have the EDS team work with the CAEP working groups to answer the questions based upon initial thoughts on some responses as follows: • The best method for assessing technological responses to a new standard is an expert-driven component level technology assessment incorporated into an aircraft-level systems assessment model • CAEP working groups do require a

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
• Technology response (cont'd.)	Drawing on a process used at CAEP3, WG3 in collaboration with FESG defined a technology response matrix that established levels of technical changes (TL). All technical changes must take into consideration the requirement that none of the combustor and/or engine modifications implied in at each TL strata would compromise the aircraft mission or payload capabilities.	EDS is to be the analytical platform for the common philosophy. EDS and its development team should address the following questions raised by the ad hoc group: • What is the best method for assessing technological responses to a new standard? • Do WG1 and WG3 require a common technological assessment methodology? • What number of technology levels (TL) is required to adequately assess technological responses/solutions? • Is the identification of actual individual solutions necessary to assess noise/emissions technology trade-offs? • Can generic "technology trade-off rules" be used to describe how different stringency options could affect the noise/emissions performance of aircraft/engines (for specific technology solutions, across aircraft/engine categories or families)? • Can cost functions (e.g., ANDES) be developed for assessing technological responses to comply with a new standard?	common technological assessment methodology. • The number of technology levels (TL) that is required to adequately assess technological responses/solutions should be a function of time frame. For example, if it is for technology insertion next year then two levels will do (ready or not ready). For longer time frames, more technology levels are appropriate. • Identification of actual individual solutions necessary to assess noise/emissions technology trade-offs is not thought to be is necessary, but there must be enough component level technology existence proofs to support the level of technology advancement assumed in the aircraft systems model. Within EDS, one will have the capability to either do a bottom up technology assessment (specific technologies) or a top down assessment (a gap analysis to determine the most significant technology "areas") • Generic "technology trade-off rules" could be derived from aircraft system level trade studies in concert with the previous response assuming that industry or experts in the field are engaged

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
• Technological feasibility	WG1 initially agreed that feasible technology consists of that which (1) is incorporated into the "best practices" production airplanes (i.e., those airplanes that include the existing "best practices" in the incorporation of noise abatement technology), and (2) would be incorporated into the "project" airplanes identified by ICCAIA. However, WG1 did not reach agreement on which of the stringency options (-8 dB, -11 db, and -14 dB) were technological feasible or infeasible. WG1 reported to CAEP5 that "although it is technically possible to design a new aircraft to achieve most mission to meet a noise certification standard of –14 EPNdB, the associated costs and development times to meet the market needs may be unreasonable" with the German representative dissenting. WG3 agreed to a working assumption as follows: "In the context of technology for improved emissions performance to be used as part of the basis for ICAO standard setting, technological feasibility refers to any technology, demonstrated to be safe and airworthy, and available for application over a sufficient range of newly certificated aircraft."	WG3 now defines technological feasibility as "In the context of technology for improved emissions environmental performance to be used as part of the basis for ICAO certification standard setting, technological feasibility refers to any technology demonstrated to be safe and airworthy proven to TRL8, and available for application in the short term over a sufficient range of newly certificated aircraft. Technologies demonstrated up to and including TRL7 are appropriate for consideration in medium and long-term goal-setting and review process." WG1 is likely to adopt this definition in future work on stringency. Therefore, EDS should provide CAEP with a process involving quantitative information on the penalties (design, operational, environmental, and mission) associated with trying to achieve certain reductions in noise or exhaust emissions in order that the parties might reach consensus on what might not be feasible or reasonable. Parameters to consider would include fuel burn, other exhaust emissions, takeoff mass, thrust/weight ratio, and other factors that could affect meeting mission requirements.	The plan is to do this type of gap analysis holding technology fixed and then changing the objectives/constraints to determine how penalties change. (EDS development includes some sample problems that will exercise this functionality.) Exercising this capability will need some firm requirements for the output parameters to consider. All of this would be on a vehicle-class by vehicle-class basis, which might be able to generalize (or not) depending on the results of these 9 vehicle classes.
Other Databases			

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
• Common noise/emissions	The now official ICAO aircraft noise certification database, NoiseDB, was an early work in progress during CAEP5. WG1 used existing databases maintained by individual authorities, such as, FAA AC36, to verify entries in both the best practices and Campbell-Hill database. These databases contained only noise information. In constructing the in-production 2002-2006 database, WG3 started with the ICAO emissions databank but also found it necessary to supplement with other sources. In order to try to understand the noise emissions interrelationship WG1 and WG3 collaborated on a rudimentary mapping between the noise and emissions certification databases.	The WG1-WG3 Ad Hoc Group recommended that priority is given to the creation of combined aircraft/engine database, preferably compiled using common terminology being established by the ICAO/CAST Common Taxonomy Team (http://www.intlaviationstandards.org/). The main advantage of a common database is that it could be used within WG2 models to populate the generic new deliveries in the FESG future fleet forecasts with more representative and realistic aircraft/engine combinations, thereby enabling the operational trends of noise & emissions to be assessed simultaneously and provide a trade-off analysis for proposed policy options. This is now a term of reference for the new Technology Interdependencies Group (TIG) made up of select representatives from WG1 and WG3. The vehicle specifications in EDS for application to stringency assessment must be consistent with the reference conditions associated with aircraft noise and engine emissions certification. The noise certification reference conditions and test procedures are specified in Sections 3.6 and 3.7, respectively, Chapter 3, Annex 16, Volume I. The reference emissions LTO cycle thrust settings and times are listed in Annex 16, Volume II, Part III, Chapter 2 (Engines for subsonic propulsion).	The plan is to be fully in compliance with this as it is already a requirement for the integration with AEDT.

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
• Campbell-Hill	The in-service fleet database was so named for the consulting company hired by IATA to produce such a database for CAEP5 work. Campbell-Hill database represented best available information on the operational global fleet for the assessment of the global noise benefit. WG1's roles were to verify the certificated noise levels and to work with the other members of the Intergroup Coordinating Team to decide how the stringency/phase-out options altered the future global fleets. The Campbell-Hill database served a similar role in evaluating NOx stringency options with FESG working with the Campbell-Hill Aviation Group to develop a spreadsheet model for calculating the cost impacts using the FESG fleet forecast.	Again under contract with IATA, Campbell-Hill has updated the database to now include noise levels and LTO emissions factors for the current in-service fleet, WG1 and WG3 are concurrently verifying the contents. EDS could need to translate the technology responses it produces for various stringency options into implications for forecasting the in-service fleet. A major issue is how to map the up to 4 vehicle categories that EDS could use to the various airframe-engine combinations represented in the global fleet.	The plan includes the 9 vehicle classes based on the FESG mapping.
Stringency options			
• Standard	WG1 studied several stringency increase concepts that fell into the following categories: a) Developing new flyover, lateral, and approach limit lines while maintaining all elements of the existing scheme (for example, slope, tradeoff limits). b) Requiring that the cumulative margin of the flyover, lateral, and approach noise levels relative to the Chapter 3 noise limits exceed a certain value. WG1 promoted the cumulative margin concept for further consideration because this approach affords the manufacturer more flexibility than the traditional standards by allowing the manufacturer to tailor the incorporation of best available technology.	With the emphasis on interdependencies and tradeoffs, CAEP will want as much flexibility as possible to explore various stringency increase concepts. CAEP could look to EDS to provide data to help it lay out ranges of stringency options including solutions that would optimize reductions in noise, NOx, and other exhaust emissions. Some of the ground rules for CAEP application could include: • Provide data that are consistent with the noise and engine emissions certification conditions. • Ability to map the up to 4 vehicle categories in EDS to the airframe-engine	The plan is to determine pareto-optimal aircraft and engine designs under various scenarios, design and regulatory assumptions and constraints assuming that agreement has been reached on what constitutes best practices for technology. Development of a NOx and CO capability is well underway and with plans to develop a PM capability, but this is to be determined relative to availability for CAEP8.

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
• Standard (cont'd.)	WG3 considered different approaches in the development of options for increased stringency of the NOX standard. The key recommendation was to retain the slope of the limitation curve constant at 2.0 for engine pressure ratios (OPR) above 30 with any increase in stringency expressed as a reduction in Dp/Foo at OPR =30. For lower pressure ratios the same percentage should apply as it is at OPR 30. For small (low power 26.7 kN < Foo < 89.0 kN) engines a linear interpolation between CAEP/2 and the new standard is recommended to FESG. These options provide reductions in Dp/Foo (at OPR = 30) of - 4 g/kN, - 7 g/kN, - 10 g/kN, - 13.5 g/kN, - 16.75 g/kN, - 20 g/kN. For simplicity they are better known by their approximate percentage reductions relative to the CAEP/4 standard, namely -5%, -10%, -15%, -20%, -25% and -30%. WG3 also considered the introduction of HC and CO standards. One reason was that some technologies that reduce NOx increase HC and/or CO. WG3 did not recommend HC or CO standards because of the emphasis to reduce NOx.	combinations represented in the best practices databases. • Not prescribe specific design configurations or the incorporation of specific technologies.	
• Rule dates	For the purposes of the costs and benefits analyses and because phase-out was being contemplated, two rule dates were considered 2002 and 2006. These dates did not have any implications for the best practices database used by WG1.	At CAEP6, WG3 concluded that in theory the possible range of stringency and the date of implementation of a standard depend on each other. A long lead-time before introduction of a standard may provide possibilities for industry to develop and	The plan is to examine lower TRL technologies to the extent that experts can identify the component level performance associated with these. Commitment of experts to the process is critical.

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
• Rule dates (cont.)	WG3 decided that the proposed range of NOx stringency options fit within an applicability timeframe from 2006 to 2012. In order to evaluate possible additional economic consequences, a 2008 applicability date was also analyzed.	implement new reduction technologies to comply with more stringent standards. For example, CAEP might want to assess implementation dates beyond the 3-4 years it typically takes CAEP and ICAO to implement a new standard. EDS should be able to evaluate technology responses to such longer lead-times including examination of candidate technologies at TRL7.	
• Production cutoff	WG1 did not consider drafting a production cutoff provision for a new noise standard. However, the cost and benefits analyses assumed that market forces would lead to a de facto production cutoff for non-complaint aircraft. Production cut-off provisions were contemplated as has been done in the past when assessing NOx stringency options but CAEP6 decided against including such a provision. FESG assumed that a new NOx standard would initiate a market driven production cut-off that would take place by the date at which the new standard came into effect.	Production cut-off remains an option available to regulators, and is also a potential market response to new environmental standards. Therefore, CAEP could look to EDS to help provide quantitative information on potential for modifying/retrofitting in-production aircraft and engines to meet proposed standards.	To the extent that experts can define the component level impacts of the retrofits, EDS can assess the system-level trades. Expert input is critical, which, in some cases, may be proprietary.

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
Output to WG2	Introduced by FAA, WG2 developed MAGENTA to assess the cumulative noise benefits of the noise policy options considered by CAEP5. WG2 used the WG1 best practices database to generate both the INM aircraft mapping operations adjustment factors and the reference database in the creation of aircraft replacement database. The data supplied through the best practices database consisted of differences in certification noise levels that MAGENTA used to adjust the noise power distance curves and/or stage lengths of equivalent airplanes in the INM database (INM is the noise computation engine for MAGENTA). FESG used two models to assess the benefits of the NOx stringency options, FAA's EDMS and Boeing's GEM. EDMS requires detailed engine emissions and fuel flow data for each aircraft (airframe/engine combination). WG3 developed a database containing emissions data for in-production engine/airframe combinations. To populate the FESG forecast with real aircraft, the generic new delivery aircraft in the FESG database were replaced by airframe/engine combinations from the in-production database. The emissions characteristics for the retained 2002 year end fleet were obtained from the Working Group 3 in-production database and the ICAO Emissions Databank.	With the emphasis on interdependencies, FAA is promoting AEDT as the model to assess environmental benefits of CAEP actions. For CAEP environmental policy work, AEDT should generate airport noise exposure, local air quality data, airport level emissions inventories, and global-level emissions inventories. These data could be aggregated on various geographical levels to assist the CAEP decision makers. EDS must provide sufficient detail on the changes in vehicle characteristics (noise generation, exhaust emissions, performance, and fuel burn) that can be translated into aircraft source data that can be used by the AEDT computation modules to generate the output identified above. Since it will only have up to 4 vehicle classes available, EDS must provide a methodology that would adjust performance and source parameters in the AEDT aircraft and engine database to produce a facsimile of the technology response that was modeled by EDS for each aircraft/engine in that vehicle class.	The plan is to do this for the 9 FESG vehicle classes.

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
Output for FESG	WG1 helped FESG identify aircraft in the in-service database that would not comply with the stringency options because the economic analysis assumed that airlines would not purchase non-complying airplanes after CAEP makes a decision on a new noise standard. WG1 also helped identify candidates for modification/re-certification to enable FESG to include these costs. Re-certification costs were derived from the Aircraft Noise and Design Effects Study (ANDES). The ANDES study was completed by ICCAIA in 1994. Its original goal was to assess the cost impact of noise certification levels on new airplane design. It was the best method available to the FESG to estimate the costs of re-certification. The basis of the economic analysis of the NOx stringency option was the assignment of non-recurring and recurring costs to the various "Technology Levels" (TL) used by WG3 and FESG, in concert, to categorize technological responses to a new standard. WG3 helped FESG identify the technology response of each in-production engine to the range of stringency options.	With the emphasis on interdependencies, FAA is promoting APMT as the model to assess economic costs and benefits of CAEP actions to be used in concert with EDS and AEDT. The APMT development goal for CAEP8 is the produce an enhanced cost-effectiveness, and possibly cost-benefit. analysis capability uses inputs from AEDT to provide integrated assessment of noise, local air quality and climate variables. CAEP could use EDS to provide FESG with cost and performance estimates for modifications to airframe/engine configurations which were made as technological responses to the environmental stringency options being studied.	EDS should be able to address fuel burn impacts due to weight changes and other higher level cost impacts, but other costs require expert input to define the component level cost changes; for example for some manufacturing cost estimates.

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
Reporting to CAEP	FESG was the primary messenger reporting on the costs and benefits of the noise policy options with WG1 and WG2 in supporting roles. FESG analyzed the economic effects, over a 20 year forecast period, of 8 noise policy options. The incremental capital and operating costs to the airlines of acquiring or modifying aircraft to comply with the policy options, expressed as changes in the net present values compared to a base case, were estimated. The benefits of noise policy options were estimated as changes in the numbers of people residing within the 65 and 55 Day Night Level (DNL) noise contours around airports. Cost/benefit ratios were calculated to compare the relative merits of each of the policy options. WG3 convened an ad hoc group of technical experts to provide advice to FESG on the emissions impact of aircraft replacements developed for noise stringency options. In the end, CAEP members selected a stringency increase (-10 dB) that was not analyzed by any of the working groups.	FESG should have the lead role in any future environmental stringency assessment conducted by CAEP. A major part of its responsibility is to convey quantitative data to CAEP so that the members can fully appreciate the environmental and economic consequences of the decision at hand. With the emphasis on interdependencies and the development of a new suite of tools expressly for such studies, the objective is the fill the information gaps that might have played roles in the difficulty of earlier CAEP meetings in reaching consensus on new standards. If the CAEP decision makers are to rely on the information provided by FESG, the following must be factored in: • Have access to the best, verifiable information available. • There are real differences (in terms of costs and benefits) between the stringency options under consideration. • Subsequent advances in modeling should not show that the data basis of the	These objectives are inherent in the EDS development philosophy and part of the collaborative efforts to assess EDS with ICCAIA members.

Element	Past CAEP Efforts[i]	EDS Requirements	EDS Capability for CAEP8
Reporting to CAEP (cont'd.)	FESG reported on the economic costs and environmental benefits of more stringent NOx standards than CAEP/4 against the base case which involves no policy action. The report included cost-benefit results showing cost per tonne of NOx reduced over the landing and take-off cycle are presented for two alternative implementation dates of 2008 and 2012, using a range of discount rates. The analysis provided a ranking of the cost-benefit results for the options. FESG economic analysis did not addressed interdependencies between noise and emissions certifications standards but did look at interdependencies between NOx and CO and HC emissions. WG1 offered a rudimentary examination of the implications of the NOx stringency options upon the best practices database that had been used in the CAEP5 work on noise stringency. In the end, CAEP members selected a stringency increase (-12%) that was not analyzed by any of the working groups.	decision was wrong. • The risk of making a wrong decision should be remote. ICCAIA expressed a similar sentiment in a flimsy to CAEP20051 noting that "the development of processes for understanding and evaluating interdependencies will be extremely challenging and will require the involvement of a large number of experts in noise and emissions fields, working interactively, addressing a complex and multi-faceted subject." ICCAIA proposed that the criteria for selection of approaches to interdependencies modeling need to include the following: • Requirements on Accuracy, Repeatability, and Uncertainty (variability) • Validation Criteria • Requirements for Transparency • Protection of ICCAIA member Intellectual Property CAEP could look to EDS and the EDS Development Team to produce quantitative evidence and demonstrations to address the criteria identified by ICCAIA. EDS would also need to furnish FESG and APMT with probability functions associated with the technological responses to stringency options so that the uncertainties can be addressed in the cost effectiveness analysis.	

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[i] Includes assessment of noise reductions by WG1 leading up to CAEP5 and the WG3 consideration of more stringent gaseous emissions standards leading up to CAEP6.

[ii] The Technology Readiness Level (TRL) concept is a measure of the development status of new technology and how close it is to being available for new and derivative aircraft designs. It includes not just noise and engine emissions reduction elements, but all aspects of incorporating technology into the aircraft design. Typical classifications are:

TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated (candidate selected)
TRL 3	Analytical and experimental critical function, or characteristic proof-of-concept
TRL 4	Component (or breadboard) validation in a laboratory environment
TRL 5	Component (or breadboard) validation in a relevant environment
TRL 6	System/subsystem (configuration) model or prototype validation in a relevant environment
TRL 7	Complete system prototype validation in a relevant environment
TRL 8	Actual system completed and flight qualified by demonstration
TRL 9	Operational flight-proven

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