ICAO COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

CAEP/7 WG2 – Aircraft Operations and Modelling

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Environmental Design Space (EDS) Prototype

(Prepared by the U.S. Representative)

SUMMARY

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

A key component of this new suite of software tools that will facilitate the assessment of interdependencies is the Environmental Design Space (EDS). EDS will be the tool used to estimate source noise, exhaust emissions, performance and economic parameters for existing and future aircraft designs under different technological, operational, policy, and market scenarios.

The FAA offers to work with the other members and observers in CAEP to make EDS output available to ICAO for the assessment of future aviation environmental standards and policies. EDS methods and assumptions must be non-proprietary and, along with data generated, must be accessible to the international community.

1. Background

1.1. Determining appropriate noise and emissions standards and recommended practices applicable to a global industry has always been challenging. It requires diverse expertise, data, and models from a wide-ranging group of experts including engineers, environmental specialists, scientists, and economists.

1.2. At CAEP/6 in 2004, participants recognized that consideration of interdependencies between noise and emissions, and amongst emissions, is required to achieve effective mitigation. CAEP/6 recommended, and ICAO's 35th Assembly subsequently adopted, three environmental goals to limit or reduce noise exposure and the impact of local air quality and greenhouse gas emissions. In addition, the U.S. has recently adopted a goal in its Next Generation Air Transportation System (NGATS) Plan to reduce (in absolute terms) community noise and local air quality emissions from aviation. This will enable sustained aviation growth and minimize impacts on human health and welfare. The plan also seeks to reduce uncertainties related to aviation's impact on climate to levels

that enable appropriate action. 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 meaningful progress towards both CAEP and U.S. goals.

1.3. In assessing the scope of future analytical tools, it is important to consider the potential decisions that policy makers are likely to face in the future. The standards decisions and their complexity have increased over time as the remit of CAEP has gone from a primary concentration on standard setting applied to aircraft to providing advice on more policy level issues, related to operational issues and 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, FAA believes that CAEP may consider the following in a future work program (CAEP-SG/20051-IP/12):

- More stringent noise standard(s)
- A more stringent NOx landing and take-off (LTO) standard
- A new NOx cruise standard
- A new particulate matter (PM) standard
- Realizing environmental gains through technological advancements in CNS/ATM
- Use of market-based options, operational procedures, and land-use measures to complement more stringent environmental standards

2. New Aviation Environmental Tool Suite

2.1. Existing aircraft noise and aviation emissions analytical tools cannot effectively assess interdependencies between noise and emissions, or analyze the benefit-cost of proposed actions. Accordingly, the FAA has launched a program to develop a robust, new comprehensive framework of aviation environmental analytical tools and methodologies to perform these functions. The long-term aim is enabling a comprehensive set of tools to address all aspects of noise and emissions. The elements of this framework include:

- **Environmental Design Space (EDS)**, which will provide integrated analysis of noise and emissions at the aircraft level.
- **Aviation Environmental Design Tool (AEDT)**, which comprises EDS and the integration of existing (or new) aviation noise and emissions analytical modules to provide an integrated capability of assessing interrelationships between noise and emissions and amongst emissions at both the local and global levels.
- **Aviation Environmental Portfolio Management Tool (APMT)**, which interacts with AEDT, EDS and economic modules to provide the common, transparent benefit-cost methodology needed to optimize aviation policy in harmony with environmental policy.

2.2. This suite of tools will allow aviation stakeholders such as government agencies, industry and the public, to understand how proposed regulatory actions and policy decisions impact aviation noise and emissions. It will also enable stakeholders to understand the cumulative effects of regulatory and non-regulatory actions that affect both noise and emissions, and the potential impact of operational decisions on aviation projects. It is currently anticipated that the tool could be made available to select individuals charged with conducting an analysis.

2.3. The FAA development plan is divided into three aspects that are being considered simultaneously: the vehicles and their engines (EDS), worldwide inventories and fleet operations (AEDT), and the micro and macro economic impacts of environmental stringencies and policies (APMT). The tools will interact within a strategic policy decision-making environment, shown in Figure 1, to provide benefit-cost assessments of policy and operational options. The development schedule for EDS-

AEDT-APMT is shown in Figure 2. The schedule is closely coupled to the CAEP cycle. Although the timeline is long (2010), intermediate capabilities will be available as soon as 2006. The following paragraphs provide more details on the development of EDS.

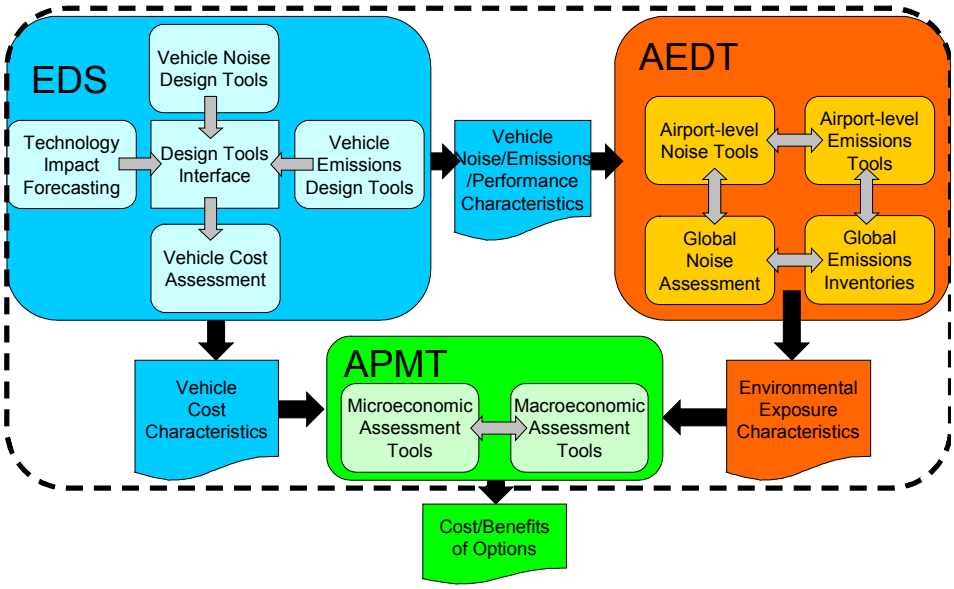

Figure 1. High-Level Schematic of the Components of the New Aviation Environmental Tool Suite

End of CY	CAEP Cycle	AEDT Deliverable
2004	End CAEP/6 Begin CAEP/7 Work Program	AEDT Work Plan Completed and Development Effort Initiated
2005		EDS Requirements and Architecture Defined APMT Requirements and Architecture Defined AEDT Prototype Demonstration (v 0.0)
2006		AEDT Version 1.0 for CAEP/7 Introduction EDS (v1) and APMT (v1) Capability Demonstration
2007	CAEP/7 Begin CAEP/8 Work Program	EDS (v2), AEDT Version 1.1 and APMT (v2) for CAEP vetting
2008		EDS (v3), AEDT Version 1.2, and APMT (v2) applied for CAEP/8
2010	CAEP/8	AEDT Version 2.0 for Airport Planning Application *Meets criteria for seamless and publicly available* APMT (v3) Capability Demonstration

Figure 2. Conceptual Development Schedule for the Toolset

3. Environmental Design Space

3.1. The Environmental Design Space (EDS) will be the tool used to estimate source noise, exhaust emissions, performance, and economic parameters for aircraft designs under different technological scenarios. Once EDS is connected to AEDT and APMT, the combined environment will also be able to assess operational, policy, and market scenarios. While the primary focus of EDS is future aircraft designs (which includes the case of technology modifications to existing aircraft), the tool will also be capable of analyzing existing aircraft designs under different scenarios when there is a need to simulate existing aircraft in a higher fidelity than possible using the techniques available in existing noise and emissions tools. Capturing high-level technology trends will provide capability for assessment of benefits and impacts. A potential additional function of EDS could be to serve as a mechanism for collecting, incorporating and quantifying long-term technology forecasts. This would be a tool-driven process verified and validated through experts.

3.2. EDS is intended to analyze aircraft noise, emissions and performance simultaneously pursuing both economic and technical performance. Additional functional requirements beyond this primary goal are imposed by EDS's intended use in support of CAEP and NGATS. The functional requirements can, therefore, be summarized as follows:

- The primary functional requirement for EDS is to provide quantitative estimates of the noise, emissions, performance and cost of modifications to existing aircraft as well as future aircraft.

- EDS must be able to consider different assumptions for technological capabilities, design choices, market scenarios, and noise and emissions policies.

- The estimates EDS produces should be provided in a manner that enables the trade-offs and interdependencies between technology, economics and environmental impacts at the aircraft level. EDS will provide data to AEDT to determine impacts in terms of emissions mass and number of people within noise contours.

- EDS must have sufficient flexibility to be employed in a parametric mode to explore potential variations within an aircraft class.

- The estimates produced by EDS must include quantitative statements of uncertainty associated with both model fidelity, and with the inputs required.

- EDS must function within the overall policy-making environment, interacting with AEDT and APMT by taking appropriate inputs and providing appropriate outputs.

- EDS methods and assumptions must be non-proprietary and, along with data generated, must be accessible to the international community.

3.3. EDS input requirements pertain to the type of specifications typically required to design an aircraft and its engine as well as to determine technological impacts. These include:

- Vehicle specifications - The parameters to be considered under this category are those typically used to size an aircraft for a particular mission, including class definition, mission

definition, material structural selections, aerodynamic inputs, and constraints, such as, maximum field length and maximum approach speed.

- Engine cycle variables -- Engines are a subsystem from the vehicle perspective, but they are a complex system in their own right, and an environmental impact assessment is not truly possible without a detailed definition of the engine used.

- Economic influences - Since a vehicle economic analysis is to be included in EDS to facilitate the link with APMT, economic parameters must also form part of the input requirements. The economic parameters generally center on a market scenario including such things as production schedule, labor rates, and fuel costs.

- Technology impacts - The parameters under this heading are intended to capture the impact of technology infusion. They may be generic in nature, such as factors used to affect aerodynamic efficiency, or they may be introduced to model specific technologies, for example, new materials or cooling techniques that allow for a higher turbine inlet temperature.

3.4. EDS output requirements pertain to the type of assessments to be carried out at the vehicle level, as well as to the types of vehicle level inputs required by the other tools in the FAA development plan, AEDT and APMT.

3.5. AEDT requires data about the aircraft source in order to calculate the noise and emissions generated by the aircraft operation. The initial version of AEDT draws upon the existing aircraft and engine databases used by FAA's legacy tools, INM, SAGE, and EDMS. As it evolves, EDS can provide the necessary data including general aircraft characteristics, aerodynamic performance parameters, engine specifications, noise-power-distance curves, and emissions indices.

3.6. APMT will ultimately use a variety of information provided by EDS to determine the effectiveness of proposed environmental measures such as those listed in paragraph 1.3. Much of this information will be passed to and acted upon by AEDT. However, there is a set of EDS information that is needed for fleet and operation planning and cost assessment directly within APMT, including airframe/engine combination costs and aircraft performance.

4. EDS Development Status

4.1. The FAA, in collaboration with NASA, began development of EDS in February 2005 through the Partnership for Air Transportation Noise and Emissions Reduction (PARTNER) Center of Excellence. The development plan is envisioned as a five year program with a functional version of EDS available for potential CAEP/8 scenario analyses. EDS development activities are grouped into four areas: tool development, expert engagement, interface with AEDT, and application and support of CAEP process.

4.2. Initial tool development has focused on identification of EDS requirements. The two foremost requirements are to provide the ability to trade-off environmental requirements, technology goals and vehicle designs, and the ability to propagate uncertainty and perform risk assessments. The EDS requirements document has been completed and has been provided as an attachment to CAEP7_WG1_TTG3_IP07_AppA. An initial version of EDS (v1.0) has been assembled, built on existing NASA tools for aircraft and engine performance, noise, and cost. These tools include NPSS, WATE, FLOPS, ANOPP, and ALCCA, which represent the current toolset that supports NASA's Vehicle Systems Program (VSP) in terms of technology assessments. A description of these tools is provided in the attachment to CAEP7_WG1_TTG3_IP07_AppB. The initial entry to

the EDS v1.0 vehicle library has been completed with a parametric representation of a twin-aisle/high bypass ratio configuration.

4.3. Part of the EDS program will be an assessment of the tools and architecture. The assessment will span the five year program and will target modeling assumptions, modeling accuracy, and input assumptions. A detailed assessment plan has been completed and is available as an attachment to CAEP7_WG1_TTG3_IP07_AppC. The goal is to thoroughly assess the accuracy of EDS through a close collaboration with industry. Industry review of EDS assumptions, methods, data and results will be required. To facilitate this, an EDS Technical Advisory Board (TAB) has been established comprised of experts from both U.S. and international airframe and engine companies. The EDS Technical Advisory Board has met June 1, 2005 in Boston, Massachusetts and 26-27 January in Atlanta, Georgia. A detailed review of EDS v1.0 including a working demonstration of the model, Year 1 work plan (Table 1) and accomplishments and the Year 2 work plan (Table 2) were presented at the January TAB. The TAB endorsed the work plan for Year 2 and recommended that a detailed description of the EDS model be presented to CAEP participants for review.

4.4. Several collaborative assessment activities are being proposed to engage industry participation in the assessment of the accuracy and fidelity of EDS. In the first phase of these activities, EDS-derived environmental and performance estimates will be compared to those obtained by industry collaborators who will use proprietary analysis tools. The collaborative assessment will enable the accuracy of the EDS tools to be better understood and will also highlight components of EDS that should be improved. The first phase of the collaborative assessment will focus on an engine-level NOx/fuel burn tradeoff for two of the three engines (GE and P&W) offered on the Boeing B777-200 and -300 aircraft. This particular case was chosen as Phase I since it will constrain the analysis space to the engine only, focus on modern, but known technology as a baseline example, and gain participation from three different manufacturers on a consistent airframe. Follow-on noise/NOx/fuel burn studies at the aircraft-level are planned for Year 2 and a collaborative assessment study with the Technology Evaluator project was proposed.

4.5. The EDS development goals for Year 3 include a demonstration of functionality within AEDT and completion of the EDS vehicle library. The goal is to achieve representation of the fleet by the end of 2007. A complete system level assessment of EDS is also planned for Year 3 and the application of EDS to a sample problem representative of CAEP/8 needs is expected by the end of 2007.

5. Summary

5.1. In the joint technologies interdependencies report (CAEP-SG20051-WP/10), the rapporteurs of WG1 and WG3 reported on the agreement of the two groups to establish a common philosophy for assessing the impact on noise, NOx, CO2 and cost of technological responses to future policy options based on the work of the ad hoc group (See CAEP-SG20051-IP/15). WG1 and WG3 also recognize that the effort would require considerable input from ICCAIA, with the support of other members. FAA envisions EDS as one of a number of possible modeling platforms that could realize the common philosophy proposed by the ad hoc group and would like to actively engage CAEP in the development process.

5.2. FAA hopes that bringing EDS development to the CAEP workgroups would produce recommendations from these groups to the Steering Group to involve CAEP in the toolset development, just as CAEP was directly involved in the development of MAGENTA for CAEP/5. FAA envisages that the recommendations from the working groups would look something like the following:

- From WG1 and WG3: “Evaluate the Environmental Design Space concept as a basis for an overall process to assess technological responses and identify technology trade-offs. Work with WG2 and FESG to integrate technology responses and trade-offs into the CAEP benefit-cost modeling.”

5.3. FAA’s goal is the development of the toolset that completes the CAEP interdependencies framework to assess both noise and emissions simultaneously when considering stringency and non-stringency policy options, as jointly proposed by the rapporteurs of WG1, W2, WG3, and FESG (See CAEP-SG2005-WP/11). Appendix A of the joint WP/11 shows a schematic of the framework. Figure 3 is one possible vision of how that framework would look with the components of the new toolset.

Table 1: EDS Year 1 Work Plan

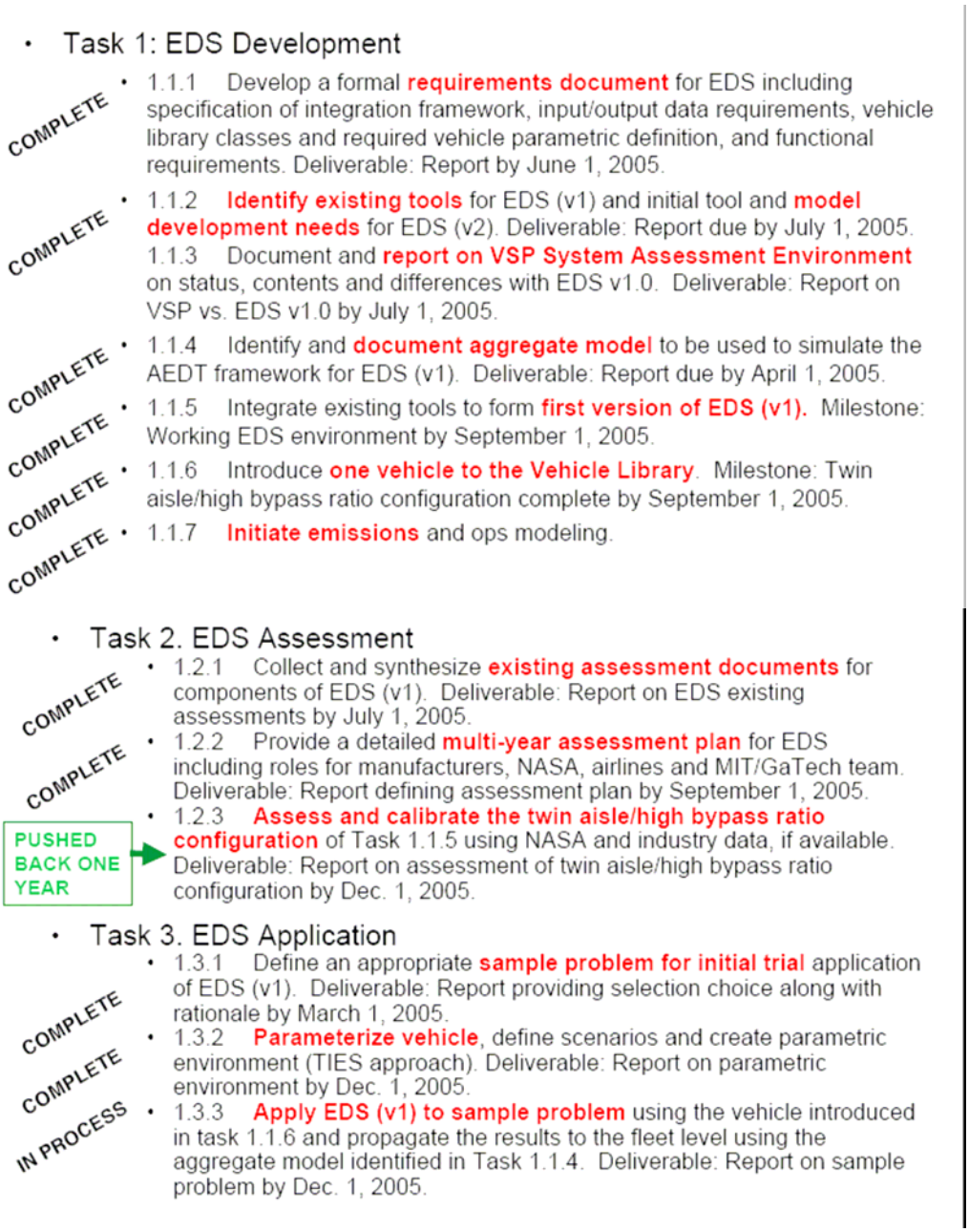

Table 2: EDS Year 2 Work Plan

- Task 1: EDS Development
  - 2.1.1 Develop improved emissions and operations models for EDS. Expected outcome: Report by June 1, 2006.
  - 2.1.2 Incorporate new models into EDS (v2). Milestone: EDS (v2) developed by Sept 1, 2006
  - 2.1.3 Demonstrate functionality of EDS within AEDT framework: Expected outcome: Report with sample model results highlighting areas for further development due by Dec 1, 2006.
  - 2.1.4 Further develop the Vehicle Library. Expected outcome: Four additional vehicles (e.g. seat classes) and associated engine models introduced by Dec. 1, 2006.

- Task 2. EDS Assessment (page 1)
  - **2.2.1. Initial EDS v. 1 (777) vehicle library assessment. Expected outcome: report due July 1, 2006 (see 2.2.2 part d).**
  - **2.2.2. Tool assessment**
    - **a) Emissions modeling beyond initial NO_x, literature review and NASA contribution –report due June 1, 2006 (see 2.2.2 part d).**
    - **b) Noise Model, complete ANOPP assessment –report due June 1, 2006 (see 2.2.2 part d).**
    - **c) Economics model – The content and requirements of these models will be determined in accordance with APMT needs. A detailed literature review will be conducted to determine public data sources for validation and calibration –report due June 1, 2006 (see 2.2.2 part d).**
    - **d) System level assessment and determining usability in CAEP8. Expected outcome– A report detailing the system-level assessment of EDS (v1) considering the impacts on fleet-level results obtained using the aggregate model as metrics, assessing the feasibility of using EDS for CAEP/8, describing the completed assessment of ANOPP, describing progress towards assessment of economics models, and describing the assessment of the twin aisle/high bypass ratio vehicle library entry, due July 1 2006.**

- Task 2: EDS Assessment (page 2)
  - 2.2.3. Methodology assessment studies will be carried out to compare methods for handling design constraints, to validate response surface methodologies, and to assess the effectiveness of fidelity measurement methods, including sensitivity analysis and error propagation analysis.
  - 2.2.4. Industry collaboration, document results and recommendations, start next one – report due August 1, 2006.
  - 2.2.5. Fidelity management system preliminary outline for the EDS fidelity management system will be drafted – report due September 1, 2006

Table 2 Continued

- Task 3: EDS Application
  - 2.3.1 Identify a specific sample problem for support of CAEP/7 needs. Expected outcome: Report providing selection choice along with rationale by March 1, 2006.
  - 2.3.2 Apply EDS (v1) to a sample problem and propagate results to the fleet level using AEDT. Expected outcome: Report on sample problem by Dec. 1, 2006.

- Task 4: EDS Technology Forecasting
  - 1.4.1 Complete the preliminary design of an expert-driven process for hosting technology forecasting activities using the EDS framework. Expected outcome: Preliminary design report due by April 1, 2006.
  - 1.4.2 Milestone: Complete a first version of the tools required to support the technology forecasting process by December 1, 2006.
  - 1.4.3 Establish and host a sample technology forecasting activity, assess the activity and define improvements. Expected outcome: Report on technology forecasting activity and requirements for future improvements due by December 1, 2006.

Figure 3: Possible Coordination Framework for CAEP Assessment of Interdependencies