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COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

SEVENTH MEETING

Montreal, 5 to 16 February 2007

Agenda Item 1: Review of proposals relating to aircraft engine emissions, including the amendment of Annex 16, Volume II
Agenda Item 3: Review of proposals relating to aircraft noise, including the amendment of Annex 16, Volume I
Agenda Item 4: Future work

AVIATION ENVIRONMENTAL PORTFOLIO MANAGEMENT TOOL (APMT) PROGRESS

(Presented by Canadian and U.S. Representatives)

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 and emissions, impacts on health and welfare, and industry and consumer costs, under different policy, technology, operations and market scenarios. The Aviation Environmental Portfolio Management Tool (APMT) was formally introduced to the CAEP Steering Group at the November 2004, Bonn meeting. Since that time the Steering Group, FESG, and WG2 have been kept informed of APMT research and design developments. This paper serves to update the CAEP on the progress of the APMT prototyping and assessment effort.

1. INTRODUCTION

1.1 At CAEP/6 in 2004, participants recognized that effective mitigation requires consideration of interdependencies between noise and emissions, as well as among individual emissions. CAEP/6 recommended, and ICAO's 35th Assembly subsequently adopted, three environmental goals: to limit or reduce noise exposure, limit local air quality emissions, and limit 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 concentrating primarily on setting standards 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 more stringent environmental standards, new emissions standards, technological advancements, and elements of the balanced approach (CAEP-SG/20051-IP/12) in a future work program.

1.3 Existing aircraft noise and aviation emissions analytical tools used by CAEP cannot effectively assess interdependencies between noise and emissions, or analyze the benefit-cost 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 impact, and cost and benefit analyses of aviation environmental policy options. The impact and economic analysis function of this suite of software tools has been given the rubric Aviation Environmental Portfolio Management Tool (APMT). A schematic of APMT is shown in Figure 1, which also shows its relationship to other FAA tools, the Environmental Design Space (EDS) and the Aviation Environmental Design Tool (AEDT).

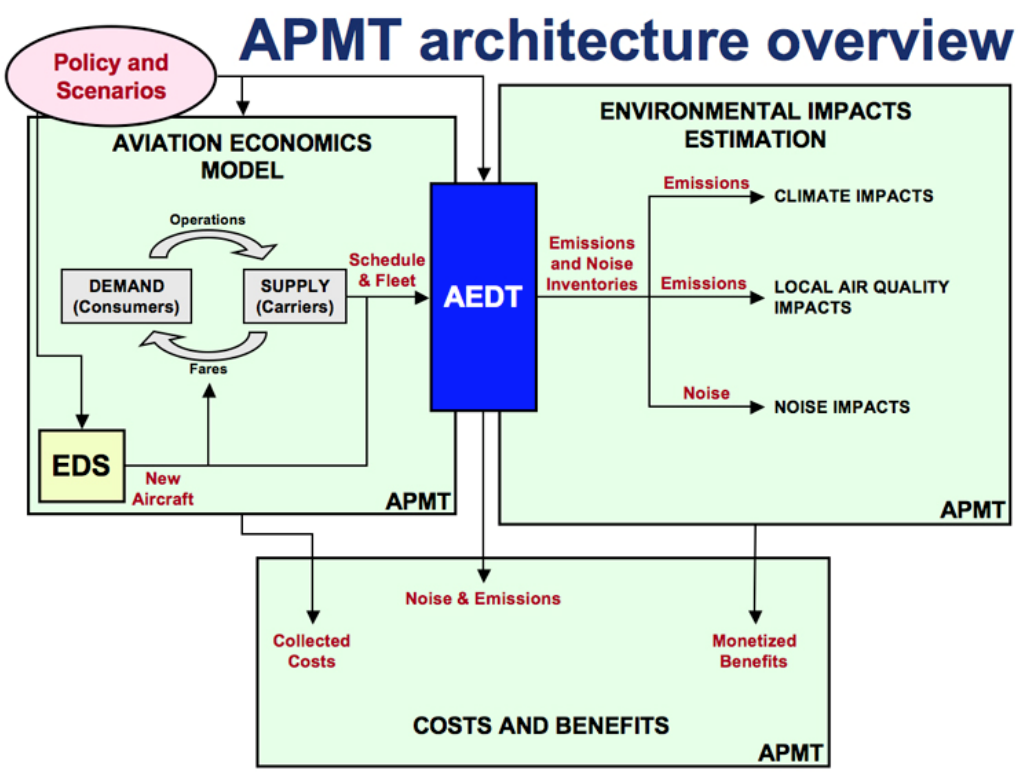

Figure 1. Schematic of the Components of the New Aviation Environmental Tool Suite.

1.4 Beginning in 2004, information on, and plans for, APMT have been submitted to CAEP and government, industry, and community stakeholders.[1] In response to CAEP-Memo/65, information regarding APMT was submitted to Working Group 2 – Task Group 2 for its consideration of candidate economic models and tools for future CAEP use. In February 2006, FESG was briefed on the completion of the APMT requirements and architecture studies, and the initiation of a prototyping effort for APMT.[2] In August 2006, the APMT development team met with the CAEP-WG2/TG2-FESG Ad Hoc Group to learn more about APMT and to begin the process of assessing APMT for CAEP acceptance. In December 2006, a detailed set of briefings on APMT activities was presented at the U.S. National Research Council, Transportation Research Board AEDT/APMT Workshop in Washington DC. Several CAEP participants attended this meeting.

1.5 This paper serves to update the CAEP on the progress of the APMT prototyping and assessment effort.

2. APMT DESIGN

2.1 As reported previously, research on the design requirements for APMT builds on the efforts of previous CAEP economic analysis tools, as well as future analysis needs and best practice guidance. The resulting architecture of APMT takes aviation demand and policy scenarios as inputs and simulates the behavior of aviation producers and consumers to evaluate policy costs.[3] Detailed operational modeling of the air transportation system within AEDT provides estimates of the emissions and noise outputs.[4] Then, a benefits valuation module is used to estimate the health and welfare impacts of aviation noise, local air quality and climate effects, using a variety of metrics. These metrics include, but are not limited to, monetized estimates of value for these changes in environmental quality. These modules jointly enable both cost-effectiveness and cost-benefit analyses of policy alternatives, as depicted in the

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[1] 2004-10 – CAEP/7-FESG2004.10/ AEDT-APMT/IP, Briefing on AEDT-APMT
2004-11 – CAEP-SG/20041-WP/7, Progress Developing Analytical Tools to Address Interdependencies Among Environmental Impacts
2005-09 – CAEP/7-FESG2005.09/ APMT/IP, APMT Overview of requirements and architecture
2005-01 – Stakeholder Workshop 3 – National Research Council, Transportation Research Board: APMT
2005-10 – CAEP-SG/20051-IP/12, Development of a Comprehensive Software Suite to Assess Aviation Environmental Effects
2005-09 – "EDS & APMT" Briefing for the PARTNER Center of Excellence 5th Advisory Board Meeting
2005-12 – APMT: Requirements Document, Architecture Study, and Prototype Work Plan
2006-02 – CAEP/7-WG2-TG2-6_IP02, APMT Prototype
2006-02 – CAEP/7-FESG2006.02/ APMT/IP-1, Briefing on APMT
2006-02 – CAEP/7-FESG2006.02/ APMT/IP-2, (paper) APMT Prototype
2006-03 – "APMT" Briefing for the PARTNER Center of Excellence 6th Advisory Board Meeting
2006-05 – CAEP/7-FESG/2006-05/APMT/IP, APMT Progress Report
2006-06 – CAEP-SG/20063-IP/7, APMT Progress
2006-07 – Briefing on APMT Progress & Plans for the CAEP-WG2/TG2-FESG Ad Hoc Group
2006-08 – Briefings on APMT Progress & Plans for the CAEP-WG2/TG2-FESG Ad Hoc Group
2006-10 – CAEP/7-FESG/2006-10/APMT/IP, APMT Progress Report
2006-12 – Briefings for Transportation Research Board AEDT & APMT Workshop

[2] Requirements Document for the APMT. Ian Waitz, et al. June 2006. (Report No. PARTNER-COE-2006-001), http://mit.edu/aeroastro/partner/reports/apmt-requirmnts-rpt2006-001.pdf
Architecture Study for the APMT. Ian Waitz, et al. June 2006. (Report No. PARTNER-COE-2006-002), http://mit.edu/aeroastro/partner/reports/apmt-arch-rpt2006-002.pdf
Prototype Work Plan for the APMT. Ian Waitz, et al. June 2006. (Report No. PARTNER-COE-2006-003), http://mit.edu/aeroastro/partner/reports/apmt-prototype-rpt2006-003.pdf

[3] The APMT nomenclature is to label changes in monetary flows as costs, recognizing that changes can be positive or negative. Changes in environmental impacts are labelled as benefits, recognizing the changes can be positive or negative.

[4] Additional information can be found in the CAEP/7 Information Paper on AEDT, CAEP/7-IP/24.

2.2 Figure 2 overview.

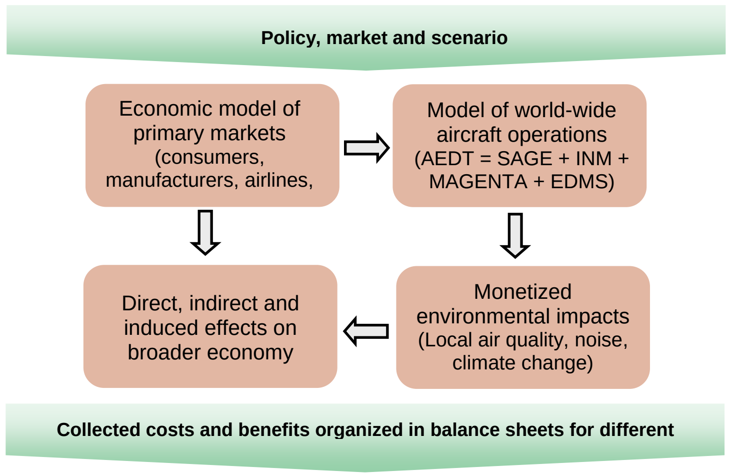

Figure 2. APMT Architecture Overview

2.2 The detailed structure of APMT is comprised of building blocks, as depicted in Figure 1.

a) the Aviation Economic Module /Partial Equilibrium Block – simulates economic flows in the aviation market;

b) the Environmental Design Space (EDS) – provides vehicle noise, emissions, flight performance, and economic characteristics to AEDT to simulate technology trade-offs for potential future vehicles when this option is desired (these trade-offs can be based on either existing technological capability or future technological capability);[5]

c) the Aviation Environmental Design Tool Block (AEDT) – converts aviation activity into quantities of emission and noise distributed in space;

d) the Environmental Impacts Estimation Block – converts the quantities of emissions and noise into health and welfare impacts, including broad socioeconomic and ecological effects; and

e) the Costs and Benefits Block – integrates collected costs, environmental inventories and monetized benefits, allows graphical analysis, and qualitatively estimates uncertainties.

3. APMT PROTOTYPE

3.1 FAA and Transport Canada are sponsoring the Partnership for AiR Transportation Noise and Emissions Reduction to research and develop APMT.[6] In 2006, this work is focused on prototype

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[5] Additional information can be found in the CAEP/7 Information Paper on EDS, CAEP/7-IP/23.

[6] PARTNER is a leading aviation cooperative research organization that fosters breakthrough technological, operational, policy, and workforce advances for the betterment of mobility, economy, national security, and the environment. An FAA/NASA/Transport Canada-sponsored Center of Excellence, PARTNER comprises 10 universities, and approximately 50 advisory board members. One of the greatest strengths of PARTNER is its advisory board's diversity and inclusiveness. Its members include aerospace manufacturers, airlines, airports, national, state and local government, professional and trade

development and assessment as outlined in the APMT Prototype Work Plan.[7] All of the elements necessary for the analyses, as well as team member roles and data requirements, and a schedule of APMT development activities are delineated in the APMT Prototype Work Plan document. In addition, the document provides a brief discussion of the steps required to move beyond the APMT Prototype to APMT Versions 1 through 3, as described in the Architecture Study.

3.2 The APMT Prototype will help to identify gaps or weaknesses in the APMT architecture and stimulate advancements in development of APMT. Therefore, the objective of the prototyping effort is to construct all of the functional modules of APMT, although with more limited capabilities than planned for the final versions. This will enable testing of the functionality of APMT for addressing various policy questions. It will also facilitate assessing and propagating uncertainties from the module level to the APMT system level to guide the determination of high priority areas for future development and refinement.

4. APMT ASSESSMENT

4.1 *APMT Assessment Overview*

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

b) the initial objective is to identify gaps in functionality that significantly impact the achievement of APMT requirements, leading to the identification of high-priority areas for further development. The longer-term objective of the assessment effort is to provide quantitative evaluation of the performance of the integrated APMT toolset relative to requirements for analyzing policy alternatives as required by CAEP. Assessment of the APMT prototype will provide a roadmap for future development, preliminary evaluation of capability with respect to fidelity requirements, and establish a procedure for future assessment efforts. Ultimately, the goal is to provide policymakers not only with estimates of costs and benefits, but also with quantitative assessments of the uncertainty in those estimates, and of the sensitivity of those estimates to a range of input parameters, scenarios, and modeling assumptions; and

c) the APMT Prototype assessment includes the following activities: a formal parametric sensitivity study and uncertainty assessment, four capability demonstration problems, consultation with experts on some modeling methods, and a comparison with AERO-MS, the most comprehensive economic modeling system used by CAEP to date.

4.2 *Formal Parametric Sensitivity and Uncertainty Assessment*

a) the formal parametric sensitivity study and uncertainty assessment are being carried out at both the APMT module level and the APMT system level. We have

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associations, non-governmental organizations and community groups, all united in the desire to foster collaboration and consensus among some of the best minds in aviation to jointly advance environmental performance, efficiency, safety, and security.

[7] The Prototype Work Plan, Architecture Study and Requirements document are all available on the PARTNER website at http://mit.edu/aeroastro/partner/projects/project3.html.

established a module-level assessment process that will be applied to the Partial Equilibrium Block (PEB), the Benefits Valuation Block (BVB), and the Aviation Environmental Design Tool (AEDT). In addition, the assessment process has been developed in coordination with parallel efforts on the Environmental Design Space (EDS) effort;

b) the assessment process is divided into five steps: (1) identify and categorize module inputs; (2) identify module outputs; (3) perform a design of experiments (DoE); (4) perform an analysis of variance (ANOVA) to identify the key inputs; (5) quantify module uncertainty; and

c) the first two steps identify the key inputs of the module that may propagate uncertainty to higher-level metrics in APMT and the important module outputs. The third step involves a screening test that will be used to down-select the number of inputs used in the assessment. The screening test is carried out by performing a composite DoE. This DoE includes linear sensitivity analysis (a parameter study), a central-composite design, and a set of random designs. The fourth step consists of performing an ANOVA on the results of the DoE from Step 3, for each output identified in Step 2 to identify the most significant input parameters. If necessary, the range of each significant input is redefined based on ANOVA results. The final step in the assessment process is to quantify module uncertainty. For this, a number of different analyses are used, depending on the problem at hand. Example analysis methods include let-all-but-one-vary Monte Carlo simulations and further analysis of ANOVA results.

4.3 *Consultation with Experts on Some Aspects of the Modeling*

a) local air quality modeling improvements are being pursued through a formal collaboration with local air quality modeling experts, professors Adel Hanna and Saravanan Arunachalam of the Center of Environmental Modeling for Policy Development at the University of North Carolina. They are completing detailed air quality modeling of the continental U.S. (36 km x 36 km grid using the US EPA/NOAA CMAQ model); other world regions will be modeled in the near future. Based on these simulations, statistical relationships are being derived between airport emissions and ambient levels of ozone and particulate matter;

b) the health effects estimation and valuation will be conducted using methods and data from the U.S. EPA Benefits Mapping Program (BenMap) and the EU ExternE Program. A full report on use of these methods has been made available to the FESG team reviewing APMT. Both of these programs have undergone extensive expert review processes. However, we have also obtained a formal review of our application of these methods by Harvard School of Public Health professors Jack Spengler and Jon Levy. Both individuals have extensive experience with local air quality health impact assessment. The letter from Professor Levy is attached as Appendix A; and

c) climate impact model assessment is being pursued through a formal collaboration with several climate-modeling experts: Professor Keith Shine (University of Reading, United Kingdom), Professor Donald Wuebbles (University of Illinois, United States), and Professor Robert Sausen (DLR, Germany). These experts have provided assistance in the refinement and assessment of the model and have completed a report on the APMT climate impact modeling methods. A paper has also been submitted to a peer-reviewed journal. The review and publication of this paper will provide initial model validation and expose the model to a wide audience for further scrutiny. The report from the climate-modeling experts is attached as Appendix B.

4.4 *Comparison of APMT and AERO-MS*

a) a qualitative comparison with AERO-MS has been carried out. The APMT development team and the AERO-MS development team have common members. These members are most knowledgeable about the differences between the two tools. Therefore, these common members wrote the report comparing the two tools. The report is included as Appendix C. AERO-MS has been extensively reviewed and has been used in many studies for ICAO/CAEP, the European Commission, IATA, and others. Comparatively, only parts of the overall APMT system (e.g. the AEDT) have so far been tested, validated, and used for actual analyses. Thus, the comparison provides guidance towards future APMT development beyond the prototype phase

b) the scope of AERO-MS and APMT was compared in terms of:

- environmental policies considered
- scope of aviation emissions computed
- scope of forecasting capabilities
- environmental impacts
- economic impacts

c) one of the key differences is that the AERO-MS model was designed and developed only to address emission policy issues; thus, it did not consider the potential the tradeoffs and interactions among noise, climate change (emissions), and local air quality issues. The APMT system is seeking to help decision makers understand the implications and balance of these tradeoffs for different types of environmental policy. This is an advantage of the APMT modeling system;

d) the report compares which responses to policies are included in both the AERO-MS and the APMT. Since APMT is at the prototype development stage, there are some policy responses that we would like to see, but have yet to be included. As part of the assessment of APMT, the report examines what further developments might be required to model these responses and prioritize their implementation against their importance for examining specific policy measures;

e) the report provides a broad comparison of the main modeling principles and assumptions in the AERO-MS and the APMT-PEB. These principles/assumptions include areas such as:

- cost-to-fare translation mechanism
- fleet choice model
- fleet retirement
- snapshot versus year-to-year forecasting
- spatial schematization
- price elasticities
- integration and model running and analysis facilities

f) the full comparison of AERO-MS and APMT is presented in Appendix C.

5. CAPABILITY DEMONSTRATOR PROBLEMS

5.1 To assess system level responsiveness and sensitivity to policy scenarios, the APMT prototype effort includes a set of four capability demonstrator problems. For these, we explicitly distinguish between a sample problem, where the tool is relatively well-developed, and a capability demonstration problem, for situations where the tool is still undergoing significant development. The set of capability demonstration problems was chosen to span a wide range of responses and to exercise many aspects of the tool suite. While any one capability demonstrator problem, taken alone, may have limited scope, together the four problems provide a broad test of the capabilities of the tool suite. It is critical to note that in these capability demonstrator (CD) sample problems, emphasis is being placed on determining the tool suite's ability to estimate policy effects and to correctly capture trends as opposed to producing an accurate final assessment.

5.2 Following is a summary of the four capability demonstrator sample problems. Example results from these analyses are included in an appendix to CAEP/7-WP/52 (CD WP).

a) ***fuel price changes***: As a simplified surrogate for estimating some of the industry and environmental responses to fuel levies and open emissions trading, we are studying the impacts of changes in fuel prices. All aspects of the tool suite are being tested, including the economic and environmental impact modeling components. This includes cases with and without aircraft/engine technology trade-off modeling capabilities, and cases with different time periods between the policy announcement and enforcement year. For the technology trades we are focusing only on the B777 seat class of aircraft;

b) ***CAEP/6 NOx emissions stringency***: The goal of this CD sample problem is to perform an analysis that is similar to the CAEP/6 NOx emissions stringency assessment. This includes enhancements demonstrated in prior AEDT analyses and documented in CAEP/7-WG2-TG2-6-WP/10 and CAEP/7-WG2-TG2-7-IP/01. The new elements beyond what is discussed in these papers are incorporation of economic modeling to assess changes in industry and consumer costs, addition of benefits valuation, and inclusion of cases with and without aircraft /engine technology trade-off modeling capabilities. For the aircraft/engine technology trade-off work we are focusing only on the B777 seat class of aircraft and only on technology trade-offs that are expected to be possible with current levels of technology as opposed to trade-offs possible with future technology assumptions;

c) ***Noise phase out***: A global phase out of ICAO Chapter 3 minus 39 dB (cumulative) aircraft is being evaluated as part of this CD sample problem. This level was chosen so that it would influence approximately 10% of the baseline year fleet. We are considering cases where noncompliant aircraft may be recertified and also different time periods between announcement and enforcement year. Similar to the prior two capability demonstrators, these policy scenarios are being modeled using all components of the tool suite, from economics to environmental impacts for noise, local air quality, and climate change; and

d) ***reduced thrust***: The reduced thrust CD sample problem is based on the assumptions outlined in CAEP/7-SG/20063-WP/30, but augmented to include an assessment of the local air quality, community noise and climate change impacts of reduced thrust.

5.3 These four capability demonstrator problems are designed to span a range of important policy responses as shown in Table 1.

Table 1
Modeling of policy responses to be considered in relation to Capability Demonstrator Sample Problems

Response types	Response in Tool Suite	Capability Demonstrator Sample Problems			
		Fuel Price	NOx Certification Standards	Noise Phase Out	Reduced Thrust
Block 1: APMT Partial Equilibrium Block					
Supply side response					
Accelerated fleet renewal (forced)	Yes			X	
Accelerated fleet renewal (financial)	Yes	X			
Redistribution of aircraft operation	No			(X) [1]	
Recertification of existing aircraft	Yes [3]			X	
Improvement of existing aircraft	Yes [3]	X			
New aircraft technology shift	Yes	X	X		
Best available technology shift	Yes [4]	X [2]	X		
New aircraft capacity shift	No	(X)	(X)	(X)	
Demand side responses					
Demand response to direct cost change	Yes	X			
Demand response to indirect cost change	Yes	X	X	X	(X)
Operational responses					
Changes in flight path	No	(X)			
Changes in flight speed	No	(X)			
Weight reduction (e.g. reduction of on board service levels)	No	(X)			
Load factors	Yes [6]	(X)			
Utilization rates	No	(X)			
Evasive responses					
Destination switching	No	(X) [1]			
Fuel tinkering	No	(X) [1] [5]			
Block 2: AEDT					
Noise	Yes	X	X	X	X
Emissions	Yes	X	X	X	X
Block 3: APMT Benefits Valuation Block					
Benefits of reduction climate impacts	Yes	X	X	X	X
Benefits of reduction noise impacts	Yes	X	X	X	X
Benefits of reduction local air quality impacts	Yes	X	X	X	X

[1] Response is only there in the case of a regional application of the policy
[2] Response is only there if a policy is applied to a significant part of global air traffic
[3] Only if data for the possibilities for recertification / modification are made available
[4] Possibilities for modeling of this response is depending on availability of inputs from the EDS
[5] Only in the case of a fuel taxation
[6] Only 'what if' changes to load factors can be tested.

6. APMT APPLICATIONS

6.1 At the CAEP Steering Group meeting in Australia, it was recognized that APMT would need to undergo a systematic review by FESG if the model is to be applied for CAEP/8 analyses. At the Australia Steering Group meeting, the FESG Rapporteurs agreed to begin this task after the

October 24-25, 2006, FESG meeting. In preparation for this effort, the APMT development team met with members of FESG to outline elements of the proposed review, details of which are included in the FESG Ad Hoc Group Working Paper (WP6.9).

7. SCHEDULE

7.1 APMT technical development is progressing on schedule. Draft algorithm design, interface control, and database definitions for all the modules in APMT were delivered on April 15 2006. All prototype modules are now complete and can be run independently. Integration of these modules is also complete. The capability demonstrator problems and module level assessments are nearing completion, with final reports expected in early 2007. Thereafter, we will be continuing development of several aspects of APMT, completing the system level assessment, and coordinating with CAEP on the definition and completion of sample problems designed to allow CAEP to judge the acceptability of APMT for use in CAEP/8.

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 among aviation-related noise, emissions, and cost valuations.

8.2 This paper serves to keep the CAEP informed of the progress of the APMT prototyping effort. CAEP participants will continue to be informed of the progress of the APMT prototype development and assessment effort.

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August 16, 2006

Professor Ian A. Waitz
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Dear Ian:

The purpose of this letter is to provide some feedback regarding the benefits valuation block of the Aviation Portfolio Management Tool (APMT).

As you know, I am an Associate Professor of Environmental Health and Risk Assessment at Harvard School of Public Health, affiliated with both the Department of Environmental Health and the Harvard Center for Risk Analysis. My research interests include modeling the health benefits of air pollution control measures, and as a component of that work, I have published multiple papers involving the development and application of methods to quantify health impacts of combustion sources [1-3] as well as constructing concentration-response functions for criteria air pollutants [4-6]. My opinions regarding APMT are therefore based on my experiences in very similar applications.

As a general point, the methodology proposed for the benefits valuation block of APMT can be characterized as health impact assessment, described elsewhere as damage function or externality assessment. This is a methodology whereby emissions from a subset of sources are characterized, population exposure increments associated with those emissions are modeled, concentration-response functions are developed to estimate health damages associated with these exposure increments, and economic values are assigned to health outcomes to provide an aggregate damage estimate. This analytical framework is broadly accepted in the environmental risk assessment and benefit-cost analysis community. For example, the US Environmental Protection Agency (EPA), in evaluating the benefits of its air pollution control programs, utilizes a similar approach [7-9]. Multiple studies of energy externalities [10,11] adopted similar methods. Thus, the approach you have proposed is widely accepted and will yield interpretable results.

Within this methodology, there are many analytical decisions that must be made. For example, there is the choice regarding which compounds to model. While there are some health impacts anticipated from all criteria air pollutants given sufficient levels of exposure, it is generally accepted that fine particulate matter ($PM_{2.5}$) and ozone (O_3) will tend to dominate the health impacts of ambient air pollution. The aforementioned health benefits analyses by US EPA [7-9] attributed nearly all health benefits to the combination of $PM_{2.5}$ and O_3. Extensive epidemiological evidence, supported by toxicological and other laboratory studies, demonstrates that these compounds contribute to both mortality and morbidity effects at current levels of exposure in the US. Your decision to focus on $PM_{2.5}$ and O_3 is therefore well supported by the literature, and you are unlikely to omit a significant portion of the health burden of criteria air pollutants with this focus (although consideration of NO_2 exposures may be justified as well).

Regarding the step to translate emissions to ambient concentrations, modeling this relationship in detail requires complex atmospheric dispersion models that may be beyond the scope of what can be incorporated into APMT. As I understand it, your simplifying assumption is to use ambient monitoring data at the county level and to presume that there will be proportionality between the incremental emissions changes and the ambient concentrations (i.e., if a control measure at a given airport reduced county-aggregate $PM_{2.5}$ emissions by 1%, ambient concentrations would decrease by 1%). The difficulty in this approach is that it potentially omits long-range transport, which we have shown to be extremely significant from a health impact perspective for power plant health risks [1,2,12,13] and important in many contexts for ground-level sources as well [14].

In complex settings such as this, with large-scale optimization models in which detailed dispersion modeling is implausible, we have had success applying the concept of an "intake fraction". This is a reduced-form measure of the total population exposure per unit emissions from a given source. The objective of this measure is to be able to take complex atmospheric modeling results from a subset of locations or from previous analyses and to be able to generalize them to new settings, when the endpoint of interest involves public health impacts and when the health outcomes appear to have linear concentration-response functions. This closely parallels your needs within APMT. I would suggest that either some of our previously-developed national-scale intake fraction estimates for ground-level sources could be applied [15], similar efforts in the US and Europe could be employed, or alternatively, that the results from modeling efforts within PARTNER could be analyzed from an intake fraction perspective to develop generalizable relationships. This would help you reduce the potential error associated with a county-specific rollback approach. Such information is less readily available for ozone modeling, but some published research provides insight in selected geographic areas [16], and modeling efforts linked to PARTNER may be able to add substantially to this literature.

In terms of the concentration-response functions themselves, you focused initially on ExternE and BenMAP. These are two of the better databases available to develop concentration-response functions for criteria air pollutants, with ExternE being used extensively in Europe and BenMAP providing the foundation for analyses by US EPA. A limitation of BenMAP, as you pointed out, is the fact that it includes estimates for many individual studies but leaves it to the user to pool them, as well as the fact that it includes many outcomes with a limited number of publications. ExternE, on the other hand, has more aggregated health outcomes and has done the synthesis already. I believe that the more aggregated framing may be more interpretable.

Without going into detail on each health outcome, there are some key issues to keep in mind. First, using BenMAP and ExternE to develop a comprehensive database of epidemiological studies from which to develop concentration-response functions is a good starting point, but it is important to incorporate the latest epidemiological evidence, which may not have yet been incorporated into either model. For example, there have been two important cohort mortality studies for $PM_{2.5}$ in the last year [17,18], which may be influential in determining the $PM_{2.5}$ mortality concentration-response function. In addition, there has been significant recent research regarding the possibility of ozone-related premature mortality [5,19,20]. Because premature mortality tends to dominate the health effects of criteria air pollutants given standard economic values, it is critical to develop these concentration-response functions using the best available information.

An additional issue is related to whether to use identical concentration-response functions for different countries. One question is whether BenMAP should be applied to US settings and ExternE to European settings. As there are some important differences between the US and Europe (i.e., the prevalence of diesel vehicles, which will influence PM composition), this is not an unreasonable approach, although research has typically shown little difference in the concentration-response functions between US and Europe, and it may be more important to utilize the full body of literature to develop the functions. A more difficult question would arise when incorporating other countries, including developing countries. This is an active area of research, but one where some preliminary estimates are plausible.

The final component of the benefits valuation block of APMT is the economic valuation of health endpoints. The approach proposed within APMT is sound, although it should be recognized that some of the differences in values between BenMAP and ExternE do not represent cultural or societal differences, but rather the differences in the ways in which economic values are assigned. In the US, values tend to be placed on willingness to pay to avoid health outcomes, with mortality valued as the "value of a statistical life". In contrast, the European mortality valuation is based on valuing life-years saved. Neither approach is inherently correct or incorrect, but it is important to recognize that this choice could have a substantial influence on the findings, and that it is not necessarily the case that different values should be applied in the US and Europe. Rather, you may wish to explore the sensitivity of your conclusions to the general valuation framework adopted.

To summarize, I applaud the APMT model team for incorporating a health benefits assessment methodology which is in agreement with the general framework used in environmental risk assessment. This will provide information directly relevant to an optimization model, and it will provide outputs that are directly comparable with outputs from related assessments. I have tried to provide some suggestions for how the benefits assessment could be modified. Some of these steps are short-term measures, while others would require more substantial investments of time and energy. However, making some of these incremental improvements will enhance the interpretability of the model and lead to more informed decisions within the aviation sector.

I would be happy to answer any questions regarding the information above, or any other aspect of health benefits analysis in relation to the APMT model. I look forward to future collaborations on this and other efforts.

Sincerely,

Jonathan Levy
Mark and Catherine Winkler Associate Professor of Environmental Health and Risk Assessment

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APPENDIX B

Comments on "Assessing the Impact of Aviation on Climate" by Marais et al.

Robert Sausen, Keith P Shine and Donald J Wuebbles

5 November 2006

1. INTRODUCTION

The purpose of this report is to provide comment on the methodology for assessing the climate impact of aviation presented by Marais et al. (henceforth MLJW). We understand that this climate component is but one of many components of the Aviation Portfolio Management Tool (APMT); we have not considered these other components or the links between the climate component and these other components.

MLJW present a methodology that extends beyond the consideration of the effects of carbon dioxide alone, and does so by adopting and adapting techniques that are already in use within the scientific literature and international climate assessments. Our overall assessment is that MLJW have developed an appropriate modelling tool, consistent with current understanding in climate science and of a complexity which is consistent with other assessment tools used more generically within climate research.

We note that our speciality is in climate modelling, atmospheric chemistry and the development and use of metrics for comparing the climate effect of emissions of different substances. Although we have some familiarity with benefit-cost analyses and damage functions, we do not specialise in these areas, nor purport to be up-to-date with the relevant literature. We strongly recommend that appropriate experts are consulted to comment on these areas of MLJW's methodology.

We also note that we have assessed the methods as presented in MLJW, and we are unable to assess, from the information given, that these methods have been correctly implemented within the code used by MLJW. We stress that, from the results that have been presented to us, we have no reason to believe that the methods have not been properly implemented.

We have given extensive technical input to MLJW on their implementation, and choice of parameters, both via email and telephone conferences; it is not appropriate to repeat this technical input here, although we note that MLJW have been very responsive to this input and to our queries in general.

We stress that our comments centre largely on an assessment of the methodology of MLJW, rather than comments on the text of the paper provided to us – i.e. we have not interpreted our brief as being that of conventional peer review for journals although we have provided some comments directly to MLJW in this spirit.

2. OVERALL STRUCTURE OF THE METHOD

State-of-the-art assessment of the impact of aviation on climate would use complex coupled climate-chemistry-ocean General Circulation Models (GCMs)[1], which require massive computer power. They are not suited to the aims of MLJW's method and, in any case, it would be found that (a) our current understanding of aviation impacts is so imprecise that researchers could not provide adequate input data to these GCMs and (b) that there would likely be significant differences between the results of GCMs developed and run by different groups. In addition, the direct perturbation from aviation on climate is too small for the climate effect to be derived in a GCM without either multiplying the perturbation by a large factor or performing very large ensembles of simulations, because of the internal variability of the climate system as observed and simulated by the GCM.

Instead, MLJW develop a parametric model, based to a large extent on the results from these more sophisticated models, which is sufficiently simple to allow (a) a very large number of exploratory calculations and (b) a very thorough analysis of the impact of uncertainties in the results. The model is consistent with the kind of models being widely used in similar assessments.

We stress, though, that the model represents the climate system via a single variable – global-mean surface temperature. Again, this is consistent with many models in current usage, but there are aspects of the response of climate to aviation emissions (and in particular to NO_x emissions) which mean that global-mean values must be used with caution.. It is, for example, plausible that a small global-mean temperature response could occur from large temperature changes of opposing signs in the two hemispheres; it is unlikely that the global-mean response would adequately reflect the impact (e.g. the damage) associated with such a response. However, we are unaware of any simple models that have, as yet, adequately addressed this generic weakness.

MLJW have chosen not to adopt simpler metrics, such as the Global Warming Potential (GWP) that is used within the Kyoto Protocol to the United Nations' Framework Convention on Climate Change, or the Global Temperature Change Potential, proposed by one of the authors of this review. While we have broad sympathy with the reasons given by MLJW, and overall we support the methods adopted by MLJW we do not feel that they have presented a compelling case that simpler metrics could not have proved adequate for the purpose of climate assessment. We understand and appreciate the fact that the APMT as a whole considers, and compares, affects other than climate; for these other factors, the simpler climate metrics are, of course, inappropriate.

One great advantage of the metrics such as the GWP is that they require relatively few input parameters and can be quite easily used by policymakers without further input from scientists; there is also a high degree of transparency in the methodology which allows other users to easily verify calculations. However, within policymaking, the use of GWPs has been largely restricted to relatively long-lived greenhouse gases, and there is an unresolved debate as to whether it is an appropriate tool for the kind of short-lived emissions associated with aviation. GWPs implicitly account for the chemical lifetime of the considered species, but totally ignore the thermal inertia of the climate system, which also plays an important role in determining the climate response for pulse emissions of short-lived species.

We also note that MLJW's method is appropriate for answering policy questions such as the impact of different scenarios of CO_2 and NO_x emissions in the future. It is not, at least in its present form, suited to

[1] These are comprehensive models, sometimes known as Global Climate Models, that comprise the coupled atmosphere-ocean-land surface climate systems including dynamics, radiation, cloud processes, sea-ice formation, chemical transforamtions etc..

fully answer questions such as (a) "what would be the impact of changing the flight levels of aircraft?" or (b) "what would be the impact of a change in routing of aircraft?" We are unaware of any published tools that would allow easy answers to such questions; to date, there have been only preliminary studies with comprehensive tools to address these questions. MLJW's methodology would be able to address the issue of the global level impact of such changes in operation for, for example, carbon dioxide emissions and perhaps for incremental changes to current operations. However, were changes in operations to lead to radical changes in the occurrence of contrails (e.g. by flying at markedly different altitudes), or the efficiency of ozone production from NO_x emissions (e.g. by flying at markedly different latitudes), we could not have confidence that MLJW's current implementation would correctly model the climate consequences.

3. TRACEABILITY AND QUALITY CONTROL

We believe that it is crucial that MLJW adopt, wherever possible, results (such as simple carbon cycle models, radiative forcings and the efficacies of these forcings), and the associated uncertainties, that have been produced as part of large international assessments, and in particular the assessments of the Intergovernmental Panel on Climate Change (IPCC). We are satisfied that, following our input, MLJW both agree with and adopt this philosophy. As an example, following our advice, MLJW have included an analysis of the significant uncertainties in the value of the climate sensitivity parameter, which determines the amount of surface warming in response to a given radiative forcing. Publication in peer reviewed journals is not in itself sufficient justification for adopting a particular methodology; MLJW have followed our advice and ensured that the tools used to derive key parameters are well respected in the science community as being state-of-the-art tools for such studies.

The extensive peer review of the IPCC assessment documents provides at least some guarantee that the results have been digested and accepted by the broader community. At the present time, this is slightly difficult as IPCC's Third Assessment Report was published back in 2001, and the Fourth Assessment Report (AR4), due to be published in 2007, is not yet in a form that can be cited. However, MLJW's method is sufficiently flexible that they will be able to quickly incorporate these new outputs once the AR4 is released.

We note that the methods used by MLJW are sufficiently simple that, for specific cases, they could be amenable to analytical solution. This would give the opportunity for verifying the veracity of the coding used in their model.

4. LONG-TERM ISSUES REQUIRING FURTHER CONSIDERATION

The development of a thorough tool for the assessment of the climate impact of aviation is hampered by some fundamental difficulties in climate science and some difficulties associated with aviation emissions in particular. We believe that MLJW have used the best available estimates, and their associated uncertainties; the purpose of this section is to indicate areas where we anticipate that there may be significant developments, and reduction in uncertainties, in the coming decade.

Radiative forcings

Probably the most profound uncertainties at the present time relate to the role of aircraft in producing contrails and in modifying cloudiness, either via these contrails, or via the particulate emissions (especially soot). Over the past decade there have been significant (and mostly downward) revisions to assessments of radiative forcing associated with persistent contrails. However, there are sufficient uncertainties in the properties of these contrails, and their regional variation, to doubt whether convergence has been reached in these assessments. In addition, global climate and weather forecast models do not generally represent atmospheric processes sufficiently well to allow a confident prediction of persistent contrail occurrence.

We particularly wish to draw attention to two areas of much active debate. One, which is included in MLJW in a way that is consistent with current understanding, is the effect of contrails on natural cirrus clouds. There are great difficulties in distinguishing ordinary cirrus clouds from those that may have been produced as a result of aviation. The current literature provides only broad guidance on this issue. Even less is known about the second issue, the extent to which soot and sulphur emissions from aircraft impact on the properties of cirrus clouds. MLJW rightly do not even attempt to include this mechanism, as there is no published literature available to allow them to do so.

There is also significant uncertainty regarding the impact of NO_x emissions although we again stress that, in part due to our input, MLJW's current methodology, and assessment of uncertainties, is drawn from state-of-the-art chemical-transport studies; hence they do as good a job as is currently possible. The complex chemistry (and the small spatial scales that much of this chemistry occurs on) is such that different models would predict significantly different results. A particular issue here is the degree of compensation between the positive radiative forcing due to NO_x-induced ozone increases, and the negative forcing associated with the NO_x-induced decreases of methane. The published literature indicates a wide range of possible results and, as noted above, the different spatial extents of these forcings leads to questions about the meaning of "compensation" when applied to global-mean values. A related problem is the degree to which these impacts are followed through. Not only does the methane change impact on radiative forcing directly, but it impacts on other processes (such as ozone formation and stratospheric water concentrations). MLJW follow through these links to the extent that they are practically possible.

A significant emerging issue is on the so-called "efficacy" of radiative forcings. This concerns whether a unit radiative forcing from mechanism A results in the same global mean (let alone regional) response as a unit radiative forcing due to mechanism B. One of the justifications for the use of radiative forcing is that different mechanisms have broadly similar efficacies. There has been growing research in this area over the past decade, for both climate change in general, and for aviation in particular. However, insufficient work has yet been performed to allow a confident assessment of efficacies, or to allow an understanding of why efficacies differ among different mechanisms. MLJW have accepted our advice that, at the present time, it is prudent to assume that all forcings have equal efficacy in their baseline calculations, but that they use the available literature to explore the possible impacts of varying efficacies.

Model structure

MLJW adopt two types of impulse-response models, one to model the carbon cycle and one to model the climate system. This two step procedure reflects the fact that the non-linearity between the concentration of a radiatively active species and the associated radiative forcing is of particular importance for CO_2, whereas a good linearization is possible for many other relevant species. As noted above, we recommend wherever possible that "assessed" versions of such models are adopted. MLJW readily agreed to this recommendation, but it is important to recognise the generic weaknesses in the models that are used in international assessments.

The carbon cycle models of the type adopted by MLJW (and used, for example by IPCC to calculate GWPs) are dependent on background CO_2 concentrations (as a consequence of the above mentioned non-linearity) and neglect possible carbon cycle feedbacks. Without further research, it is essentially impossible to estimate the impact of the neglect of such feedbacks, and we stress that MLJW have done a credible job given current understanding and have adopted an approach consistent with international assessments.

The climate models are derived from sophisticated GCM calculations, but these were not specifically "pulse" experiments and so it is unclear the extent to which these models properly represent pulses. This is a topic of current activity within, for example, the EU's QUANTIFY Integrated Programme; we anticipate that this work will lead to a refinement, rather than any major change, in the methodology adopted by MLJW. In their original form, such models do not allow an obviously self-consistent approach to including the uncertainty associated with the so-called climate sensitivity parameter, which is an acute and chronic uncertainty in climate science.

5. FINAL REMARKS

We believe that the MLJW approach is an important step in the right direction, as it opens up the possibility of including the non-CO_2 effects when estimating the climate impact of aviation. The MLJW method will facilitate the possibility of quantitative comparisons of different environmental impacts of aviation such as climate, air quality and noise effects which we understand to be the aim of APMT.

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APPENDIX C

TECHNICAL NOTE NO PB11

Title:	APMT Prototype Development
Subject:	Comparison of the AERO-MS and APMT
Ref:	C34614
Version No:	2
Date:	18 August 2006
Author:	**André van Velzen and Richard Hancox**

1. COMPARISON OVERVIEW

1.1 The purpose of this document is to provide a short comparison between the AERO-MS and APMT. At the point that this comparison is made, it is important to recognise that the development of the AERO-MS has been completed years ago, whereas the development of APMT is presently ongoing. Indeed, the AERO-MS has been extensively reviewed, validated and tested. Over the last 5 to 10 years the AERO-MS has been applied for a great many studies for ICAO/CAEP, the European Commission, IATA and others. However, it is recognised the data which underlies the AERO-MS is now considerably out-of-date (the Base Year in the AERO-MS is 1992), and would require revision for the tool to be again used in major studies. Comparatively, only parts of the overall APMT system (for example the AEDT) have so far been tested, validated and used for actual analyses, but APMT makes use of much more recent data sources.

1.2 The fact that APMT is at the Prototype development stage is an important difference in itself, and we have therefore sought to highlight our expectation of the future APMT development beyond the prototype phase against what we expect to be completed within the prototype phase.

1.3 The objectives of the APMT and AERO-MS are similar in that both are intended to test policies directed at mitigating environmental nuisance from (primarily) civil aviation, with outputs that quantify not only changes in environmental metrics as a result of policy measures but also the economic impacts of those policy measures. The AERO-MS focuses on cruise altitude GHG emissions, while the APMT has the wider remit to include also noise and local air quality. Both models are intended to facilitate trade-offs between environmental improvements and economic impacts. The wider remit of the

APMT will also demonstrate potential trade-offs between environmental effects in the different dimensions of GHG emissions, noise and local air quality.

1.4 Furthermore, the process of developing the economic forecasting elements of APMT has benefited from a wider understanding of the forecasting issues addressed using the AERO-MS. In many cases, we have the opportunity with APMT to benefit from the experience of developing and using the AERO-MS, but applying alternative techniques to address wider issues and to produce a model which will address some of the issues in a smarter way.

2. COMPARISON BETWEEN AERO-MS AND APMT

2.1 In this memo the comparison is made on the basis of the following 3 tables:

- Table 1: Comparison of the scope of AERO-MS and APMT.
- Table 2: Modelling of policy responses in AERO-MS and APMT-PEB.
- Table 3: Main modelling assumptions in AERO-MS and APMT-PEB.

2.2 Table 1 compares the scope of the AERO-MS and APMT in terms of:

- Environmental policy objectives;
- Environmental policy measures considered;
- Scope of aviation emissions computed;
- Scope of forecasting capabilities;
- Environmental impacts; and
- Economic impacts.

2.3 For the AERO-MS a distinction is made between aspects which are included and aspects which are not included. For the APMT a distinction is made between aspects which are included in the Prototype, aspects which are intended to be included after the Prototype phase and aspects for which there are currently no plans to include.

2.4 There are some important points to make about this first comparison table. Firstly, the block of the table considering environmental policies considered is particularly significant in the sense that the few X's in the boxes for APMT for 'noise reduction policies' and 'local air pollution reduction policies' provide a significantly increased scope and complexity of the modelling within APMT compared to the AERO-MS. Secondly, the benefits of being able to monetise the environmental benefits and comparing these to the total costs of a measure are also a potentially significant advance in APMT compared to the AERO-MS. Even at the prototype stage the overall scope of the APMT is significantly advanced in many areas.

2.5 Both models can consider a wide range of the key environmental measures and policy tools to examine how the policy objectives that are within their scope can be addressed. In this regard, both models currently only deal with operational measures through the flight and operations modelling of the tools. As APMT is at a prototype stage, the detail of implementation of some of the policy measures needs to be developed further to match the full scope covered by the AERO-MS when it addresses climate change reduction policies.

2.6 As reading of Table 1 suggests, the scope of global commercial aviation operations considered in both the AERO-MS and the APMT are fairly complete. In addition the AERO-MS does also include computations of the emissions by general and military aviation, however these segments are assumed not to be affected by the policy measures.

2.7 We note also that the prototype of APMT does not yet produce its own forecasts of Baseline air transport demand but makes use of exogenous forecasts prepared by others. The AERO-MS has this forecasting capability, but for many studies it took as input the forecasts of Baseline air transport growth which were prepared by others. We understand that the computation of general economic effects will be included in APMT after the Prototype Phase. The AERO-MS only considers general economic effects for the Netherlands but does output a number of aviation industry outputs which would contribute to the measurement of general economic effects.

2.8 Table 2 indicates which economic responses to policies are included in both the AERO-MS and the Partial Equilibrium Block (PEB) of APMT. A further description of these responses is provided in Appendix A to this document. With respect to the policy responses not included in the APMT-PEB prototype it is noted that no decisions are yet made regarding the responses to be included at a later stage (i.e. after Prototype Phase) and responses not to be taken into account.

2.9 Table 3 provides a broad comparison of the main modelling principles and assumptions in the AERO-MS and the APMT-PEB. These principles/assumptions should be related to aspect like for example:

- Cost-to-fare mechanism
- Aircraft prices
- Fleet choice model
- Fleet retirement
- Technology forecasting
- Snapshot versus year-to-year forecasting
- Schematization
- Price elasticities
- Integration and model running and analysis facilities
- Policy implementation

2.10 We have noted the features of AERO modelling principles and assumptions which exist and highlighted those which we expect to be present in the prototype PEB and indicated the developments we currently expect in future phases of PEB development. In some cases we note that the future PEB development will particularly depend upon the outcome of the APMT and PEB prototype assessment phase, although it is recognised that changes in modelling principles and assumptions could be developed in all areas.

Table 1. Comparison of the Scope of AERO-MS and APMT

	AERO-MS		APMT		
	Included	**Not Included**	**Included in Prototype**	**Include after Prototype**	**Not to be included**
Environmental policy objectives					
Noise reduction policies		X	X		
Climate change reduction policies	X		X		
Local air pollution reduction policies		X	X		
Environmental policies considered					
Technological	X		X		
Regulatory	X		X		
Operational	(X)		(X)		
Financial	X		X		
Scope of aviation operations computed					
Scheduled Passenger movements	X[1]		X[2]		
Scheduled Freighter movements	X		X		
Non-scheduled Passenger movements	X		X		
Non-scheduled Freighter movements	X		X		
General and Military aviation	X				X
Scope of forecasting capabilities					
Air transport passenger demand	X		X		
Air transport cargo demand	X			X	
Environmental impacts					
Fuel use and emissions by flight stage	X		X		
Emissions by grid	X		X		
Atmospheric concentrations (CO_2, NO_x, O_3, etc)	X		X		
Population exposed to noise		X	X		
Local air quality around airports		X	X		
Economic impacts					
Direct economic effects for airlines (demand, costs, revenues)	X		X[4]		
Employment airlines	X			X	
Change consumer surplus	X		X[4]		
Income to 'government' from charges	X		X[4]		
Fleet size / Aircraft prices	X		X		
Monetarized benefits of reduction environmental impact		X	X[4]		
General economic effects		X[3]		X	

[1] Base Year Movement Database is 1992. [2] Completeness of the Datum year operations needs to be verified. [3]. In the AERO-MS, general economic effects are only computed for the Netherlands. [4] The values in the prototype will not be calibrated against real world totals but can be output to facilitate the

approximation of changes which may result from policy measures.

Table 2. Modelling of Economic Policy Responses in the AERO-MS and APMT-Partial Equilibrium Block (APMT-PEB).

Response types	AERO-MS		APMT-PEB	
	Included	Not included	In Prototype	Not in Prototype
Supply side response				
Accelerated fleet renewal (forced)	X		X	
Accelerated fleet renewal (financial)	X		X	
Redistribution of aircraft operation	X			X
Recertification of existing aircraft		X [2)]	X [3)]	
Improvement of existing aircraft		X [2)]	X [3)]	
New aircraft technology shift	X		X	
Best available technology shift	X [1)]		X [4)]	
New aircraft capacity shift	X			X
Demand side responses				
Demand response to direct cost change	X		X	
Demand response to indirect cost change	X		X	
Operational responses				
Changes in flight path		X		X
Changes in flight speed		X [6)]		X
Weight reduction (e.g. reduction on board service levels)		X [6)]		X
Load factors	X		X [5)]	
Utilization rates		X [6)]		X
Evasive responses				
Destination switching		X		X
Fuel tankering	X			X

1) The shift of best available technology is User Specified

2) Procedures have been developed to take on board recertification / modification data from other models (f.e. Stratus model) in the AERO-MS. However, no actual analysis have been conducted in which improvement of existing aircraft have been taken into account.

3) Only if data for the possibilities for recertification / modification are made available

4) In the prototype the modelling of this response will make use of inputs from the Environmental Design Space (EDS).

5) Only 'what if' changes to load factors can be tested

6) These responses are not taken into account by default. However, responses can be taken into account on the basis of User Specifications.

Table 3. Comparison of the AERO-MS and APMT-PEB Modelling Principles and Assumptions

Modelling Aspect	AERO-MS	APMT-PEB	
		In Prototype	Anticipated developments beyond Prototype
Cost to Fare Mechanism			
Proportion of Policy Measure costs passed to consumers	User Specified by region pair	User Specified globally	Continue to be user specified in a similar manner to the prototype depending on the result of model assessment
Detail of profitability assessment	City pair (and combinations)	Routegroup and Carrier group	Combinations of airport pair
Baseline Scenario	User specified and adjusted through fare inputs	User specified and adjusted through fare inputs (maybe with the possibilities to reflect Baseline cost changes)	User specified and adjusted through fare inputs with the possibility to reflect Baseline cost changes
Policy Scenario	Adjusted through aircraft operating cost, fare and demand changes subject to the proportion of costs passed to consumers	Adjusted through aircraft operating cost, fare and demand changes subject to the proportion of costs passed to consumers	As prototype
Aircraft Prices			
New aircraft prices for the existing fleet	Derived from Literature search of traded aircraft prices	Derived from Literature search of traded aircraft prices	As prototype
New aircraft prices for new aircraft entering the fleet	Adjusted through scenario and policy inputs to reflect user specified developments in aircraft technology improvements	Derived from the Aircraft Price Module for EDS vehicles.	As prototype, pending assessment review. Flexible procedure to input data from EDS or alternative source in APMT-PEB
Fleet Choice Model			
Aircraft technology mix	Adjusted with respect to policy induced changes in aircraft operating costs	Adjusted with respect to policy induced changes in aircraft operating costs	As prototype
Aircraft size mix	Adjusted with respect to increases in demand and subject to policy induced changes in aircraft operating costs	User specified	Will draw from AERO methods to ensure is demand growth and cost sensitive User specified inputs will also be possible.

Modelling Aspect	AERO-MS	APMT-PEB	
		In Prototype	Anticipated developments beyond Prototype
Fleet Retirement			
By route	Implicitly modelled in the shift in technology mix	Explicit modelling of Baseline retirements and adjusted retirements with respect to policy induced changes in aircraft operating costs	It may be an option that this is changed into a fleet level retirement assessment and route allocation module.
By fleet	Modelling of the shift in aircraft ages (including the result of operation bans) results in changes in average technology characteristics.	Explicit modelling of aircraft ages in the retirement functions	Explicit modelling of aircraft ages and their retirement provided all details of aircraft types are retained.
Technology Forecasting			
Rolling technology versus specific features	Rolling technology includes projected emission technology characteristic development by generic technology classification	Emission and Noise Technology characteristics associated with each individual aircraft type is represented in detail	As prototype? The assessment of the models should determine which level of detail is optimal
New technology	What-if implementation of a range of possibilities	Possibilities for improvements within existing emissions and noise technology explicitly modelled through the EDS module	Possibilities for improvements within existing and future emissions and noise technology explicitly modelled through the EDS module or alternative source
Snapshot versus year-to-year forecasting			
Snapshot forecasts	Forecasts made for one year at a time which assume the impacts of Baseline and Policy changes have fully matured	Year-by-year forecasts to model the transition between measure announcement and enforcement	As prototype
Treatment of temporal effects	Multiple snapshot tests where the onus is on the user to ensure consistency of specification and interpretation	Year-by-year forecasts permitting NPV of costs to be computed.	As prototype

Modelling Aspect	AERO-MS	APMT-PEB	
		In Prototype	Anticipated developments beyond Prototype
Schematisation			
Spatial Operations	City pair and aggregates	Airport pair in FOM with cost implications assessed at routegroup level	To be decided
Passenger Demand	By ticket type, travel class, and city pair. Majority of data from observed sources.	All data synthesised by routegroup from average routegroup load factors	Details of the data required to be reviewed. Available data sources for observed data will be investigated
Aircraft types	Generic size and technology types	Explicit air frame and unique engine identified combinations by age represented.	To be decided
Air Carriers	Charter and scheduled carriers for 14 world regions	Carriers from 6 world regions	Legacy, low cost, charter carriers from a number of world regions to be represented separately
Price Elasticities			
Segmentation	By passenger purpose/class and routegroup	Global	Segmented at a level appropriate to the demand segmentation
Account for Surface Competition	Yes	Average Impact	Should have spatial and distance segmentation in addition to that by travel purpose/class provided demand data is modelled with increased segmentation
Integration and Interface and Input/Output Manipulation			
Integration	All tools managed using a central database in stand-alone and integrated form	Integration of data management from separate databases and structures is under development	Increased integration between tools will be made
Interface	Common procedures to specify and analyse tests in stand-alone and integrated form	Limited stand-alone facilities for input and output available	Facilities required will be developed following an assessment of the application of the Prototype

Modelling Aspect	**AERO-MS**	**APMT-PEB**	
		In Prototype	**Anticipated developments beyond Prototype**
Policy Implementation			
Global versus regional	Global, regional and some by (flexible combination of) airport pair	Global	Disaggregate implementation at a country level or various groups of countries anticipated
Policies which differentiate between carriers	Yes	No	Should be feasible using some of the principles established for AERO
Multiple policy testing	Yes, but only GHG related policies	Single policy (combinations untested)	Combinations of policies should be feasible
Handling of local airport specific Policy measures and Baseline developments	Not included	Not included	Anticipated development on the long term

Appendix A. Description of Economic Policy Responses presented in table 2.
A1. Supply side responses

Supply side responses are involved with airlines changing their fleet mix and aircraft characteristics in response to a policy measure. Supply side responses will generally directly start once a policy is announced (assuming the period between the announcement year and the enforcement year is not very long). There a quite a few different types of supply side responses that may be triggered by policies. The following provides an overview:

- Accelerated fleet renewal (both forced and financial).
- Geographical redistribution of aircraft operation.
- Recertification of existing aircraft.
- Modification of existing aircraft.
- New aircraft technology shift.
- Best available technology shift.
- New aircraft capacity shift.

Accelerated fleet renewal. This response implies that airlines replace part of their (old) fleet earlier than they would have done without a policy in place. A distinction is made between a forced and a financial accelerated fleet renewal. The first is defined as a premature replacement of non-compliant aircraft due to an operating restriction (or phase out). The second response would take place on the basis of financial considerations (where the operation of older aircraft becomes relatively more expensive).

Geographical redistribution of aircraft operation. The redistribution of aircraft across regions or routegroups is a possible response if operating restrictions are only applied to a selection of regions or routegroups. The operation of aircraft which are non-compliant in certain parts of the world would be shifted to other parts of the world where the aircraft would still be compliant.

Recertification and modification of aircraft. Another possible response to operating restrictions (both regional and global) would be the recertification of non-compliant aircraft, where the characteristics of aircraft would be changed in such a way as to turn a non-compliant aircraft into a compliant aircraft. A similar type of policy response would be the modification of existing aircraft in order to improve its fuel or environmental efficiency. In contrast with the recertification, this would be a possible response to financial policies such as fuel or emission charges that would increase the aircraft operating costs. Potentially, certain modification measures could be taken to offset part of this cost increase (e.g. engine upgrade, winglets, hull polishing).

New aircraft technology and best available technology shift. A ‘new aircraft technology shift’ pertains to a change in the purchase behaviour of airlines towards more environmentally benign new aircraft, whereas a ‘best available technology shift’ is involved with a change in the best available technology offered by manufacturers. Obviously, these airlines’ and manufacturers’ responses cannot be considered in isolation as they reflect two different sides of the same coin. Airlines responses in purchase behaviour will be based on a consideration of changes in aircraft operating costs (of compliant aircraft) under a given policy situation. In APMT the potential for a manufacturer’s response will be taken into account by making use of EDS data.

New aircraft capacity shift. The above supply side responses all relate to changes in the fleet mix within the existing capacity (seat bands) to be considered. However, with a policy in place aircraft with different mission capabilities (in different seat bands) might become more attractive. Therefore, a shift in the aircraft mix across seat bands is also to be regarded as a potential response of airlines.

A2. Demand side responses

With regard to the demand side responses a distinction will be made between a demand response in relation to direct cost effects and demand response in relation to indirect cost effects. The direct cost effects are related to the increase in costs which are directly related to impose charges. The associated demand effect will only take place from the enforcement year onwards. Indirect cost effects are related to a change in costs following from supply side responses. Compared to the situation without policies, the supply side responses will imply higher costs for airlines (otherwise the response would already have taken place in a scenario situation). Because the supply side responses will start to take place after a policy is announced, this also holds for the demand effects related to it.

A3. Operational responses

Operational responses are airline responses related to flight operation. These types of responses would aim to off-set part of the policy-induced aircraft operating costs. Relevant responses could relate to the actual flight execution in terms of changes in flight speed or flight paths or reductions in aircraft weight. Other responses might relate to the efficiency of aircraft operating logistics in terms of load factors and utilization rates.

A4. Evasive responses

Evasive responses are responses of airlines and/or passengers in order to avoid the payment of a charge. Possible evasive responses are destination switching and tankering (where the latter is only applicable in the case of fuel taxation). Evasive responses will generally only take place if financial policies are applied regionally.

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