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Agenda Item 2: Review of technical proposals relating to aircraft engine emissions

AVIATION ENVIRONMENTAL PORTFOLIO MANAGEMENT TOOL FOR ECONOMICS (APMT-ECONOMICS) AND ITS APPLICATION IN THE CAEP/8 NOx STRINGENCY ANALYSIS

(Presented by the United States)

SUMMARY

This paper updates the status and capabilities of the Aviation Portfolio Management Tool for Economics (APMT-Economics).[1] It also documents the use of the tool in supporting the CAEP/8 NO_X stringency analysis.

The Federal Aviation Administration (FAA), in collaboration with the National Aeronautics and Space Administration (NASA) and Transport Canada, is developing a comprehensive suite of software tools to facilitate thorough consideration of aviation's environmental effects. The main goal of this effort is to develop a critically needed ability to characterize and quantify the interdependencies among aviation-related noise and emissions, impacts on health and welfare, and industry and consumer costs, under different policy, technology, operational, and market scenarios. The APMT-Economics component of the tools suite models airline and aviation market responses to environmental policy options.

The ICAO CAEP Forecasting and Economic analysis Support Group (FESG) reviewed and concluded that APMT-Economics was appropriate for use on the CAEP/8 NO_X stringency analysis.[2] APMT-Economics analysis results, using both the Operations-led and Economics-led modes, are included in the Appendix.

1 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 MODTF have been kept informed of APMT research and demonstration developments. CAEP/7_IP/25, APMT Progress
2 CAEP-SG/20082-IP/06

1. INTRODUCTION

1.1 In the past, modeling tools that supported CAEP generated either noise or emissions outputs, against which policy costs were calculated. CAEP considered the cost to implement a policy against a single environmental performance indicator (e.g., noise emitted). With the advent of the work on common databases and inputs, for a given policy scenario CAEP will have the ability to consider noise, local air quality, fuel burn, greenhouse gas emissions, plus industry and consumer cost interdependencies. The Federal Aviation Administration (FAA), in collaboration with Transport Canada and the National Aeronautics and Space Administration (NASA), is developing a comprehensive suite of software tools to facilitate thorough consideration of aviation's environmental effects. The main goal of this effort is to develop a critically needed ability to characterize and quantify the interdependencies among aviation-related noise and emissions, impacts on health and welfare, and industry and consumer costs, under different policy, technology, operational, and market scenarios. The component of the tools suite that models airline and aviation market responses to environmental policy options is entitled the Aviation Portfolio Management Tool for Economics (APMT-Economics).[3]

1.2 Beginning in 2004, information on APMT has been submitted to CAEP and stakeholders, including the initial APMT requirements and architecture studies and prototyping plan.[4] APMT Progress was last reported to the CAEP in February 2007, in CAEP/7_IP/25.

1.3 In accordance with Task F.03, the Forecasting and Economic analysis Support Group (FESG) reviewed the economic components of the Aviation Environmental Portfolio Management Tool, namely the APMT-Economics. The review was completed and results presented to the CAEP Steering Group in September 2008. APMT-Economics was subsequently used in the CAEP/8 NO_X stringency analysis.[5]

1.4 This paper serves to update CAEP on the progress and capabilities of APMT-Economics.

2. NO_X STRINGENCY ANALYSIS AND COMPARISON

2.1 CAEP tasked FESG and the Modelling and Database Task Force (MODTF) to conduct an analysis of stringency scenarios to reduce emissions of nitrogen oxides (NO_X) relative to the ICAO CAEP/6 standard as an element of the CAEP/8 work programme. Ten stringency options were analysed for two potential implementation years, 2012 and 2016, with potential changes ranging from between 5% and 20% compared to the current standards. The analysis was based on an assessment of the extent of the technology, environment and costs that would result from modifying, where appropriate, the existing in-production engines to meet the range of scenarios. For the analysis, MODTF assessed emissions reductions and potential environmental trade-offs for the scenarios. FESG established the costs assumptions and assessed overall cost-effectiveness of the stringencies. The final cost-effectiveness

3 APMT-Economics was formerly named the APMT Partial Equilibrium Block (PEB)

4 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

5 The FESG NO_X Cost Spreadsheet Model (NO_X-CSM) was used as the primary tool in the economic assessment of the NO_X stringency scenarios under consideration for CAEP/8. APMT-Economics was used to compare results to the FESG NO_X-CSM for a selected number of scenarios. [CAEP/8-IP/14]

results were presented as costs per tonne of NO_X reduction for the ICAO Landing Take-Off (LTO) cycle in a joint MODTF-FESG paper to CAEP/8 (WP015).

2.2 For the CAEP/8 NO_X stringency analysis, the NO_X Cost Spreadsheet Model (NO_X-CSM) was the principal tool used for calculating costs, and APMT-Economics was used to verify the results. Specifically, APMT-Economics was used to compute cost-effectiveness for two of the higher stringency scenarios, with high range cost assumptions, using the different APMT-Economics modes. The Operations-led mode employed MODTF representation of the FESG forecasts of aircraft operations. The Economics-led mode used APMT-Economics representation of the FESG forecasts.

2.3 Prior to analyzing all of the scenarios with the NO_X-CSM, the cost outputs from APMT-Economics in both operations-led and economics-led modes were compared to the results from equivalent tests using the NO_X-CSM. APMT-Economics and NO_X-CSM employ different approaches; namely, the NO_X-CSM computes costs derived from the differences in aviation activity computed by MODTF, while the APMT-Economics approach is to compute the total industry costs with and without the stringency options and then compare the total cost differences. Consequently, there are some differences in the computation and treatment of individual cost components; these effects, however, are understood and are reasonable given the differences in modelling approaches. Indeed, as the figure illustrates the results from the alternative modelling approaches show a consistent ranking and a consistent contribution to the overall costs is made from the various components.

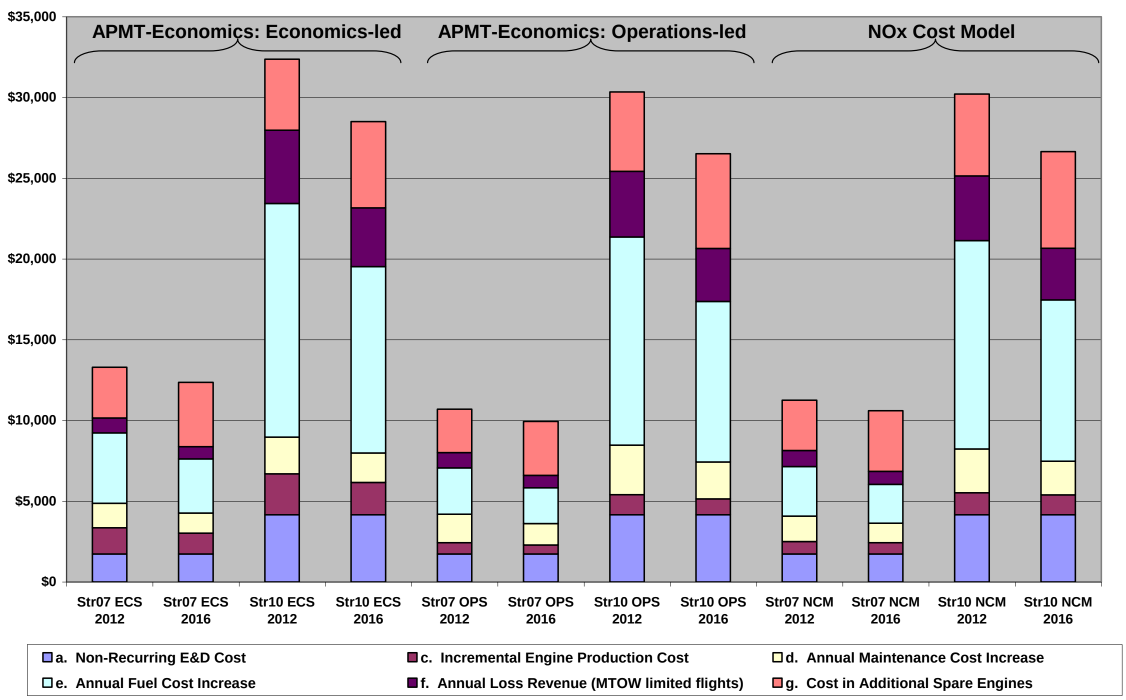

Figure 1: Comparison of Costs by Component between APMT-Economics and NO_X-CSM

2.4 The consistency of the overall forecasts is robust. Particularly when the range of total cost outputs ($1Bn to $4Bn) resulting from the two modelling approaches are viewed in the context of the overall airline industry costs, which are projected to range between $420Bn in 2006 to approximately $1,600 Bn in 2036.

3. **CONCLUSION**

3.1 Through this analysis APMT-Economics demonstrates its application to a NO_X stringency analysis. It also demonstrates flexibility in employing assumptions that match those prepared by the ICAO CAEP FESG. Further, when applied in economics-led forecasting mode, APMT-Economics produces comprehensive and internally consistent forecasts of NO_X stringency effects, including consistent demand responses to cost changes.

3.2 In the economics-led mode APMT-Economics demonstrates sufficient fidelity to reliably and consistently model the demand and costs of interventions relative to a Baseline, that invoke only relatively small cost changes, down to the level of a 0.2% annual increase in overall airline operating costs. The demand responsive and comprehensive cost forecasting features of APMT-Economics proved true the FESG assumption that demand effects can be largely ignored for the main CAEP/8 stringency analysis.

3.3 The APMT-Economics results compare well to those of the NO_X-CSM overall. Despite using different approaches to modelling the stringency measures and the overall scale of aviation industry costs, the results at a component level were shown to have a good degree of consistency. CAEP-FESG can therefore have confidence that the results from the NO_X-CSM were independently confirmed for a sample of the stringency tests being undertaken for CAEP/8.

3.4 A comprehensive description of APMT-Economics and analysis results, using both the Operations-led and Economics-led modes, are included in the Appendix.

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APPENDIX

APMT-ECONOMICS AND ITS APPLICATION IN THE CAEP/8 NOx STRINGENCY ANALYSIS

APMT-Economics and Its Application in the CAEP/8 NOx Stringency Analysis

Report for the U.S. Federal Aviation Administration, Office of Environment and Energy, and the US DOT Volpe National Transportation Systems Center

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Summary

This report contains an update on the status and capabilities of the Aviation Portfolio Management Tool for Economics (APMT-Economics). It also documents the use of the tool in supporting the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) NOx stringency analysis prepared for the CAEP/8 Meeting in February 2010.

Through this study APMT-Economics demonstrates its application to a NOx stringency analysis. It also demonstrates flexibility in employing assumptions that match those prepared by the ICAO CAEP Forecasting and Economic Support Group (FESG). Further, when applied in economics-led forecasting mode, APMT-Economics produces comprehensive and internally consistent forecasts of NOx stringency effects, including consistent demand responses to cost changes.

In the economics-led mode APMT-Economics demonstrates sufficient fidelity to reliably and consistently model the demand and costs of interventions relative to a Baseline, that invoke only relatively small cost changes, down to the level of a 0.2% annual increase in overall airline operating costs. The demand responsive and comprehensive cost forecasting features of APMT-Economics proved true the FESG assumption that demand effects can be largely ignored for the main CAEP/8 stringency analysis.

The APMT-Economics results compare well to those of the NOx Cost Spreadsheet Model (NOx-CSM) overall. Despite using different approaches to modelling the stringency measures and the overall scale of aviation industry costs, the results at a component level were shown to have a good degree of consistency. CAEP-FESG can therefore have confidence that the results from the NOx-CSM were independently confirmed for a sample of the stringency tests being undertaken for CAEP/8.

1 Introduction

1.1 Background

1.1.1 The Federal Aviation Administration (FAA), in collaboration with the National Aeronautics and Space Administration (NASA) and Transport Canada, is developing a comprehensive suite of software tools to facilitate thorough consideration of aviation's environmental effects. The main goal of this effort is to develop a critically needed ability to characterize and quantify the interdependencies among aviation-related noise and emissions, impacts on health and welfare, and industry and consumer costs, under different policy, technology, operational, and market scenarios. The APMT-Economics component of the tools suite models airline and aviation market responses to environmental policy options.[6]

1.1.2 In 2007, CAEP was tasked to conduct an analysis of stringency scenarios to reduce emissions of nitrogen oxides (NOx) relative to the ICAO CAEP/6 standard. Ten stringency options were analysed for two potential implementation years, 2012 and 2016, with potential changes ranging from between 5% and 20% compared to the current standards. The analysis was based on an assessment of the extent of the technology, environment and costs that would result from modifying, where appropriate, the existing in-production engines to meet the range of scenarios. For the analysis, the CAEP Modelling and Database Task Force (MODTF) assessed emissions reductions and potential environmental trade-offs for the scenarios. The CAEP Forecasting and Economic Support Group (FESG) established the costs assumptions and assessed overall cost-effectiveness of the stringencies. The principal tool used for calculating costs was the NOx Cost Spreadsheet Model (NOx-CSM) developed by FESG; APMT-Economics was used to verify the results calculated with the NOx-CSM. The final cost-effectiveness results were presented as costs per tonne of NOx reduction for the ICAO Landing Take-Off (LTO) cycle in a joint MODTF-FESG paper to CAEP/8 (WP015).

1.2 NOx Stringency Analysis and Comparison Overview

1.2.1 For the CAEP/8 NOx stringency analysis, the FESG NOx-CSM was the principal tool used for calculating costs; APMT-Economics was used to verify the NOx-CSM results. Specifically, APMT-Economics was used to compute cost-effectiveness for two of the higher stringency scenarios, with high range cost assumptions.

1.2.2 APMT-Economics can be applied in two ways for a stringency analysis.

- Using the forecast mix of aircraft operations by aircraft type for future years generated by other models – in this case using aircraft operations by aircraft type supplied by MODTF after applying the FESG fleet and operations forecasts. This is referred to as the **Operations-led** mode.

[6] APMT-Economics was formerly named the APMT Partial Equilibrium Block (PEB)

- Generating a forecast mix of aircraft operations by aircraft type for future years by applying the FESG fleet and operations forecasts directly, and therefore the mix of new aircraft introduced to the fleet in forecast years is sensitive to the forecasts of aircraft operating costs. This is referred to as the **Economics-led** mode.

1.2.3 Prior to analyzing all of the scenarios with the NOx-CSM, the cost outputs from APMT-Economics in both operations-led and economics-led modes were compared to the results from equivalent tests using the NOx-CSM. APMT-Economics and NOx-CSM employ different approaches; namely, the NOx-CSM computes costs derived from the differences in aviation activity computed by MODTF, while the APMT-Economics approach is to compute the total industry costs with and without the stringency options and then compare the total cost differences. Consequently, there are some differences in the computation and treatment of individual cost components; these effects, however, are understood and are reasonable given the differences in modelling approaches. Indeed, as the figure illustrates the results from the alternative modelling approaches show a consistent ranking and a consistent contribution to the overall costs is made from the various components.

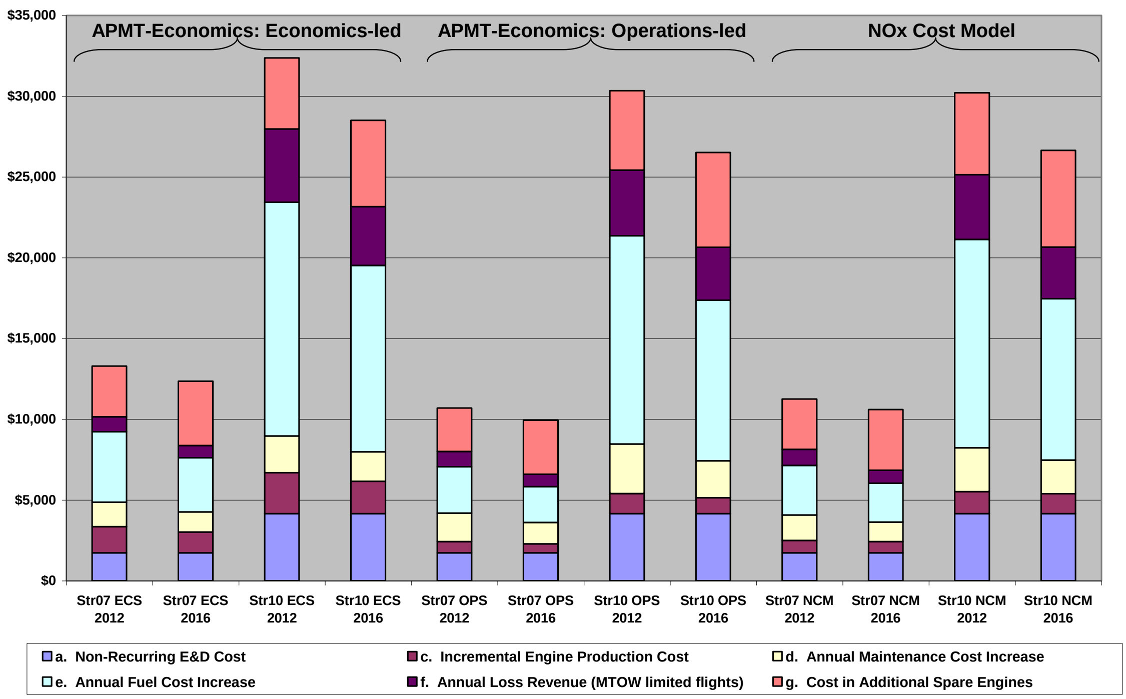

Figure 1: Comparison of Costs by Component between APMT-Economics and NOx-CSM

1.2.4 The consistency of the overall forecasts is robust. Particularly when the range of total cost outputs ($1Bn to $4Bn) resulting from the two modelling approaches are viewed in the context of the overall airline industry costs, which are projected to range between $420Bn in 2006 to approximately $1600Bn in 2036.

1.3 Report Structure

1.3.1 Chapter 2 presents a brief description of the APMT-Economics model and notably describes the calibration and validation statistics for the version of the model employed in this analysis.

1.3.2 Chapter 3 provides an overview of the modelling processes; describing the inputs and assumptions to the analysis, the cost and environmental outputs, the processing steps required and highlighting observations on the process and any difficulties that were encountered.

1.3.3 Chapter 4 presents the outputs from applying APMT-Economics in Economics-Led mode and includes the effects of demand effects that might result from increases in costs if all of these costs are assumed to be passed to consumers.

1.3.4 The comparison of the results from the NOx-CSM and APMT-Economics with Operations-Led Approach are presented in Chapter 5 focusing on the comparative environmental outputs, overall and detailed costs and finally illustrating the similarities in the overall cost-effectiveness metrics. A comparison is made between the outputs from APMT-Economics in operations-led and economics-led mode is presented at the end of this Chapter.

1.3.5 Chapter 6 presents conclusions.

2 The APMT-Economics Model

2.1 Introduction

2.1.1 The following sections describe the Aviation Environmental Tools Suite, APMT-Economics and a validation of the Datum and Baseline.

2.2 The Aviation Environmental Tools Suite

2.2.1 The Federal Aviation Administration (FAA), in collaboration with the National Aeronautics and Space Administration (NASA) and Transport Canada, is developing a comprehensive suite of software tools to facilitate thorough consideration of aviation's environmental effects. The main goal of this effort is to develop a critically needed ability to characterize and quantify the interdependencies among aviation-related noise and emissions, impacts on health and welfare, and industry and consumer costs, under different policy, technology, operational, and market scenarios.

2.2.2 Figure 2.1 is a schematic of the Aviation Environmental Tools Suite[7]. The main functional components of the Tools Suite are as follows:

- **Environmental Design Space (EDS)**: estimates source noise, exhaust emissions, and performance for potential future and existing aircraft designs;
- **Aviation Environmental Design Tool (AEDT)**: models aircraft performance in four- dimensional space and time to produce fuel burn, emissions and noise;
- **Aviation environmental Portfolio Management Tool for Economics (APMT-Economics)**: models airline and aviation market responses to environmental policy options;
- **Aviation environmental Portfolio Management Tool for Impacts[8] (APMT-Impacts)**: estimates the environmental impacts of aircraft operations through changes in health and welfare endpoints for climate, air quality and noise; and
- **Cost Benefit with the Aviation environmental Portfolio Management Tool (APMT-Cost Benefit)**: combines Tools Suite output to perform cost benefit analyses.

[7] Additional information is available on the FAA website at http://www.faa.gov/about/office_org/headquarters_offices/aep/models/.

[8] Additional information on APMT-Impacts is available at http://www.apmt.aero.

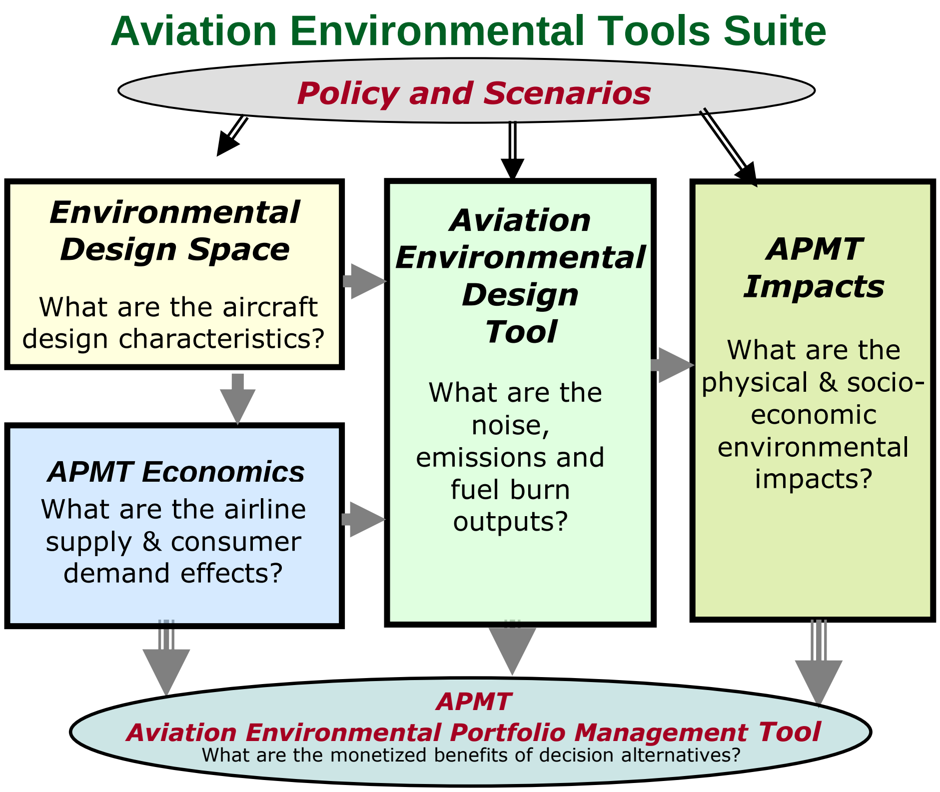

Figure 2.1 Modelling Blocks within the Aviation Environmental Tools Suite

2.3 APMT-Economics

2.3.1 APMT-Economics is designed to model aviation market responses to a range of aviation scenarios and environmental policy measures that directly affect the aviation industry. The model is centred on the decisions that would be made by airlines in response to future market conditions where these decisions lead to changes in aviation demand, supply and environmental factors. It operates at a relatively disaggregate spatial level of detail, but includes a detailed representation of individual aircraft types, aircraft ages and fleets.

2.3.2 From an established Datum (Base) year database of air transport demand, supply and costs, APMT-Economics projects the future aviation:

- operating costs;
- demand projections and capacity requirements;
- fleet development projections; and
- fleet assignment to an aggregate set of operations.

2.3.3 APMT-Economics produces a set of internally consistent forecasts of the Baseline (projection without scenario measures) and Policy (projection with scenario measures) situations, allowing for a wide range of aviation industry and consumer responses to the potential introduction of environmental policy measures. A principal aim of the model is to contribute to the APMT assessment of the interdependencies between aviation-related noise and emissions effects and associated environmental costs, and to provide a comprehensive analysis of aviation environmental and economic impacts.

2.3.4 A number of different types of main policy responses are distinguished, specifically:

- **supply side responses**: airlines changing their fleet mix and/or characteristics of aircraft in their fleet and measures considered as evasive responses such as responses of airlines or airline clients to avoid payment of a charge or taxation;
- **demand side responses**: changes in air transport demand through fare increases following from cost increases; and
- **operational responses**: airlines changing their flight operation to off-set policy induced cost increases

2.3.5 The main objective of APMT-Economics is to establish a comprehensive projection of air transport demand and supply, while taking into account:

- the need for additional future aircraft capacity, given the projected air transport demand and the retirement of aircraft from the existing fleet;
- a scenario and policy sensitive selection of fleet replacement and flight operations; and
- the cost-driven relationships between demand and supply.

2.3.6 The matching of demand and supply within APMT-Economics is based on a so-called partial equilibrium approach. In this approach, the analysis of changes is limited to the market for air transport only, without directly taking into consideration how changes in the air transport market might imply changes in other markets. In the context of APMT, this means that a new equilibrium is brought about in the market for air travel after a change in policy, and the effect of that change on the travelling public and air carriers. Within the APMT-Economics functionality, changes in costs to air carriers are translated into changes in air fares, leading to an adjustment of air transport demand. Where appropriate, exogenous effects that are consistent with the scenario specification can also be input to the model; for example, some research has shown that higher fuel prices could lead to lower GDP and while APMT-Economics would not compute the GDP effects directly, these could be input to the model as part of the scenario specification.

2.3.7 Main functional requirements of APMT-Economics include:

- the handling of different **Baseline** projections of relevant factors affecting air transport demand (passengers and freight) and air transport supply (fleet development and flight operations);
- the assessment of alternative aviation scenarios and the effect of a variety of different air transport related environmental policy measures;

- the provision of a coherent and detailed description of present and future air transport activities (flight operations) on global, regional, national and local scale; and
- the provision of a detailed set of inputs for the computation of the economic effects on relevant actors in terms of costs, revenues and other direct economic effects.

2.3.8 Figure 2.2 is a diagram of the main steps in the APMT-Economics tool.

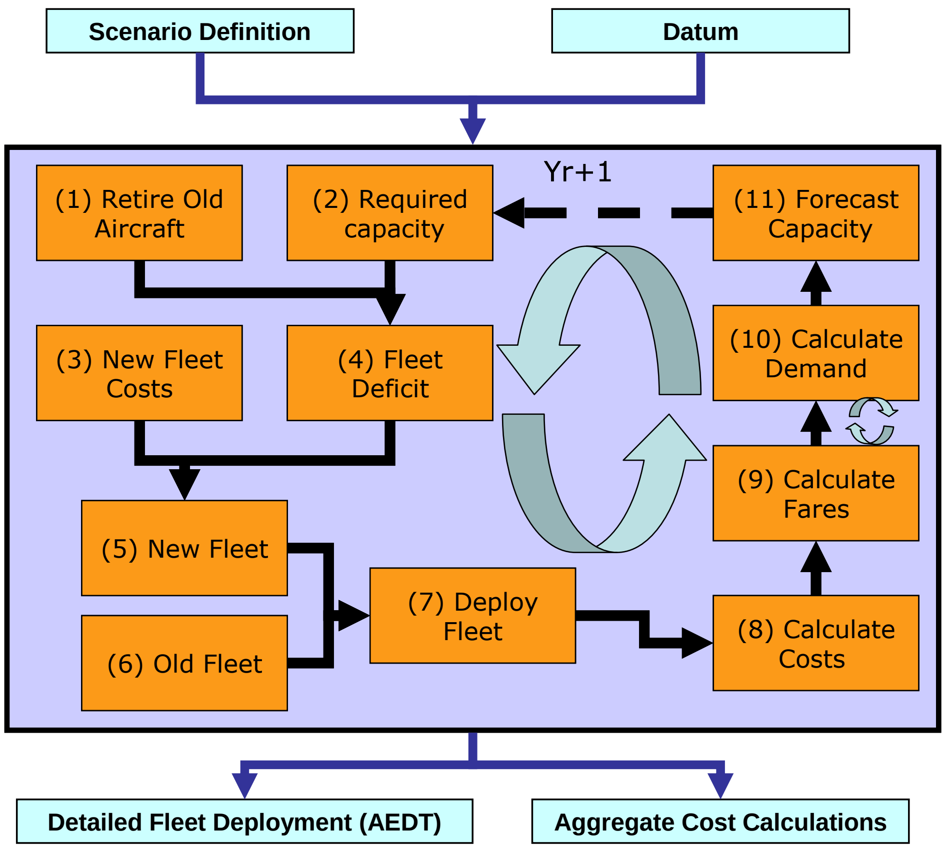

Figure 2.2 Main processes in APMT-Economics

2.3.9 Given the present air transport demand and operations for a set reference or Datum year, an aggregate future air transport demand projection (in terms of passengers and freight by country pair) is provided from external sources. Future fleet capacity is adjusted to match demand requirements, taking into account the retirement of aircraft from the existing fleet. Newly purchased aircraft to replace and expand existing fleet capacity are drawn from a set of candidate aircraft designs based on both existing and new technology.

2.3.10 The actual selection of newly purchased aircraft depends on the set of eligible candidate designs and a comparison of unit aircraft operating costs (costs per seat). In this selection process, the effects of policies (such as operating restrictions or charges that increase certain cost components) are taken into account. Changes in aircraft operating costs due to the effects of policies may lead to a change in fares, subsequently leading to a change in demand. Based on a translation of changes in unit costs to changes in fares, the partial equilibrium between air transport demand and supply is approximated within the APMT-Economics module.

2.3.11 Following the achievement of the partial equilibrium, the (adjusted) information on demand projection, aircraft retirements and aircraft replacements for the forecast situation is provided to AEDT. In contrast with the APMT-Economics module, which operates on a country-pair[9] level of spatial aggregation, AEDT works on the level of individual airport pairs with fully specified aircraft flight characteristics. Given the specification of the detailed flight operations in the present situation (based on the information in the Current Air Transport Database), the information provided by the APMT-Economics module is used to make the detailed future flight operations projection as required by the AEDT. The detailed forecasts are generated by applying a series of distributions to the APMT-Economics aggregate forecasts. These distributions apply splitting factors for country pair to city pair, engine family to UID and carrier region to carrier code.

2.3.12 Within the APMT-Economics module, detailed computations of aircraft operating costs take place for all relevant aircraft types, as well as computations of air fares and revenues. The information on costs and revenues generated in the APMT-Economics module provides the basis for the assessment of actor specific direct economic effects. In addition to the air carriers, relevant actors might include: manufacturers, airports, the air traffic management operators, and the repair, overhaul and maintenance sector, as well as consumers and governments. Direct economic effects may include: (changes in) operating costs, revenues and results, employment effects, loss in fleet value, income from charges and consumer surplus.

2.3.13 Further details of the functionality of APMT-Economics are contained in the Algorithm Design Document (ADD).

2.4 Reported Validation APMT-Economics Datum for NOx Stringency

2.4.1 This section reports the outturn validation of the Datum and Baseline for the version of APMT-Economics used for the CAEP/8 NOx Stringency analysis. It is important that the model is validated well against available data in order that it may be considered to be a reliable basis from which to analyse the effect of introducing aviation policies. For the NOx stringency analysis, the validation of the volume of traffic and fleet is of greater importance than the underlying cost validation. The reason for this is that the costs of implementing the stringency were provided as additional costs to the industry per engine or engine family. So the industry costs of the stringency are derived by applying the additional costs to the number of engines affected so the absolute level of cost validation is less important.

[9] Each country-pair flow is disaggregated into groups of routes with common stage lengths and the combination of country-pairs and stage lengths are referred to as 'schedules'.

2.4.2 The APMT-Economics Datum was calibrated using a dataset that contains the aircraft operations and traffic that is consistent with the MODTF work for CAEP/8 Goals analysis. This dataset was used for the Datum calibration of APMT-Economics because it is a more complete dataset, which includes aircraft of all sizes and is most appropriately calibrated to match the FESG fleet and ICAO cost information. However, a different dataset and assumptions were used for NOx Stringency analysis and these underlying analysis assumptions have some effect on the completeness and the overall level of validation.

2.4.3 APMT-Economics was not re-calibrated specifically for the NOx Stringency analysis and therefore the level of validation obtained is not as good as that obtained with the full dataset. In particular, the APMT-Economics model application for NOx stringency employs the previously calibrated metrics, such as aircraft annual utilisation. It also shares commonality of underlying assumptions with AEDT/the NOx-CSM including the following:

- assumes flights follow great circle routes (i.e., not actual distances flown);
- excludes underlying higher growth between airport pairs with longer stage lengths;
- excludes aircraft with fewer than 20 seats Russian-built aircraft

2.4.4 The MODTF NOx Stringency analysis uses great circle distance for future aircraft operations rather then more accurate representations of aircraft routings based on radar track information. This approach was employed as a simplification for the emissions modelling and has no effect on the ranking of alternatives. Great circle distances were used in the APMT-Economics analysis. The use of great circle distances lead to greater variation from observed data than in previously reported Datum validations[10]. Metrics such as total distance and number of aircraft (as fewer aircraft will be required as the distance flown is shorter) and cost data that are based on aircraft kilometres or block hours flown will be affected by this approach.

2.4.5 The FESG forecasts include an inherent increase in average distance by distance band through time, which is not captured in the MODTF data that were derived by applying factors by stage length (and route group and seat class) to the Datum representation. In order to mirror the NOx-CSM as closely as possible, no growth in average distance through time was modelled in APMT-Economics. This lead to further deviation of operating costs and revenues in the Baseline from the outturns that would be obtained using all aspects of the FESG forecasts.

2.4.6 The 2006 Datum was developed from a six week sample of operations from the MODTF consensus dataset (AEDT), consistent with the base data used to generate the forecasts used in the NOx-CSM analysis. The data was processed to remove freighter operations and passenger aircraft with fewer than 20 seats. The data was then matched to fleet data for 2006 from Campbell Hill and FESG to provide the characteristics of the fleet undertaking the operations. This data provided the starting point from which the FESG demand and supply forecasts were applied to establish the Baseline.

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[10] Analysis of Aviation & Fuel Price Scenarios for U.S. Participation in the ICAO Group on International Aviation and Climate Change; MVA Consultancy, May 2009

Supply and Demand

2.4.7 The validation of the Datum was undertaken against available data from FESG, ICAO and AEDT. Table 2.1 contains a summary of the supply and demand validation at a global level.

Table 2.1 Datum Year Validation against 2006 Global Supply and Demand

Metric	APMT-Economics	Observed	Δ	% Δ	Observed Data Source
Total Aircraft	15783	17310[11]	-1527	-9%	FESG
Operations (m)	23.3	25.6	-2.3	-9%	AEDT, but including aircraft < 20 seats
Distance (bn km)	32.6	34.4	-1.9	-5%	ICAO
Passenger km (bn km)	4195.8	4222.0	-26.3	-1%	ICAO
Passenger load factor (%)	75	76	-1	-1%	FESG
Fuel use (bn kg)	177.0	175.5	1.5	1%	AEDT, but including aircraft < 20 seats

2.4.8 As noted above, the average aircraft utilisation rates (aircraft hours per annum) were calibrated so that the APMT-Economics model for an equivalent of the CAEP/8 Goals analysis matches the number of aircraft in the FESG fleet, adjusted to remove Russian-built aircraft since these are excluded from the MODTF analysis. The calibration was undertaken on a seat class basis, so each seat class replicates the corresponding FESG value. The seat class aircraft utilisations have then been applied to the NOx problem version of APMT-Economics. As noted earlier, the calibration was undertaken for the 'Goals' version of the model as it has a more realistic representation of aircraft movements as actual flight distances are included. The reduced distances flown in the NOx analysis version of APMT-Economics means that less aircraft are required to undertake the operations, since the calibrated individual aircraft utilisations have not been adjusted for the specific NOx stringency analysis.

2.4.9 The number of operations undertaken was validated against the number of operations in the 2006 AEDT operations, and used as the basis for the NOx-CSM modelling. Table 2.1 shows that the APMT-Economics operations are within 9% of the AEDT operations. The 9% difference is due to the inclusion of aircraft with fewer than 20 seats in the AEDT but not in APMT-Economics. There are 23.3m (0% different) operations in AEDT by aircraft with greater than 20 seats. Data from ICAO suggests that there were approximately 27 million movements per annum in 2006, which would include operations of aircraft with fewer than 20 seats.

[11] Minus Russian-built aircraft and those <20 seats.

2.4.10 The number of aircraft kilometres (34 billion km) operated in 2006 according to ICAO is slightly higher than in APMT-Economics due to the additional operations by small aircraft included in the ICAO data. The passenger demand estimates in APMT-Economics were taken directly from the FESG reported data. APMT-Economics has slightly lower passenger kilometres in the Datum than the ICAO equivalent.

2.4.11 The fuel and NOx per km and per cycle for airframe/engine combinations was derived from the MODTF (AEDT) dataset used for the NOx stringency analysis. The global fuel consumption and NOx emissions are within 1% of the AEDT equivalents.

Costs and Revenues

2.4.12 ICAO also produces cost and revenue data that was used for validation and calibration of the Datum representation in APMT-Economics. A summary of the validation is shown in Table 2.2. This validation is affected particularly by the assumption for NOx stringency to work with great circle distances rather than actual flights and the result of this is that the model is expected to under-represent the costs and revenues associated with air transport operation.

2.4.13 Validating against costs and revenues is not as straightforward as validating against supply and demand data, given different reporting of the data by aircraft type. Average operating costs for individual aircraft types in APMT-Economics are based on Form 41, reported regional variations in labour costs, aircraft prices from AVMARK, fuel use from AEDT, and the average Quarter 1 fuel price for 2006. Fares were calibrated so that the global profit margin reported by ICAO for 2006 was achieved. All cost and revenue metrics were validated against ICAO data.

Table 2.2 Datum Year Validation/Calibration at 2006 Global Costs and Revenues

Metric	APMT-Economics	Observed	Δ	% Δ
Crew costs ($bn)	32.2	31.9	0.3	1%
Maintenance costs ($bn)	33.9	41.7	-7.9	-19%
Depreciation & Finance ($bn)	57.0	61.6	-4.6	-7%
Landing costs ($bn)	14.9	15.5	-0.6	-4%
Route costs ($bn)	9.0	9.8	-0.8	-9%
Total fuel cost ($bn)	105.6	105.7	-0.1	0%
Operating expenses ($bn)	384.2	439.5	-55.3	-13%
Unit costs (Op exp/ATK) U.S. cents	66.5	71.0	4.5	-6%
Operating revenues ($bn)	396.8	452.5	-55.7	-12%
Yields (Op rev/RTK) U.S. cents	93.5	96.0	-2.5	-3%

2.4.14 The results that airlines report to ICAO are open to considerable interpretation about the data items that go into each category and therefore we have allowed a higher deviation from the validation data. Given the lower number of operations and aircraft in APMT-Economics than in the ICAO reported data, the data in Table 2.2 shows that APMT-Economics is within 10% on most items which is considered to be an acceptable level of validation, given a level of uncertainty in the reported aggregate data.

2.4.15 The validation against **crew costs** is very close as the overall unit labour costs were adjusted downward on a regional basis to meet the overall target.

2.4.16 The **maintenance costs** in APMT-Economics for NOx Stringency are somewhat lower than the reported level from ICAO yet the global maintenance costs in the Goals calibration version are around 9% lower than ICAO data. The lower number of aircraft in the fleet in the NOx stringency version has a large effect on the reported maintenance cost validation which also affects the reported overall operating cost and revenue validation for the NOx stringency version of the model. A future task could be to improve the maintenance cost information used in APMT-Economics.

2.4.17 **Capital, landing and route costs** in APMT-Economics are close to, but slightly less than the ICAO equivalents and these costs are all low due to the assumptions employed in the NOx stringency version of the model. Capital costs in APMT-Economics include all ownership and leased costs since it is not possible to separate these costs, and they must all be included for the fleet selection algorithm in APMT-Economics.

2.4.18 The APMT-Economics Datum uses fuel consumption data from AEDT and an average fuel price of 60 U.S. cents/kg, with regional variation from ICAO data. The resulting overall fuel cost in APMT-Economics is very close to that published by ICAO.

2.4.19 Overall Operating Expenses and Revenues in APMT-Economics are just over 10% less than the data reported by ICAO, however the yields and unit costs in APMT-Economics are only 3-6% lower than the ICAO data.

2.4.20 At a global level, the cost and revenue results of APMT-Economics appear to validate reasonably well against the ICAO data, despite the removal of Russian aircraft, aircraft with fewer than 20 seats and not considering actual flight distances. . As noted above, the absolute level of cost validation is not critical to the NOx stringency analysis as the Intervention models additional costs to the industry.

2.5 Baseline Calibration

2.5.1 A 30 year Baseline was modelled using the FESG demand and capacity forecasts and applying the FESG retirement curves to the fleet. For the purposes of the NOx stringency analysis an underlying growth in average distance through time was not included in the APMT-Economics representation to maintain similarity to the AEDT/NOx-CSM modelling. The average utilisations by seat class were modified through time so that the fleet by seat class matches the FESG fleet by seat class. As with the Datum utilisations, the utilisation calibration is based on the Goals representation. There are no improvements in the underlying aircraft technology – it is 'frozen' at the technology offered in the Datum. The NOx stringency analysis assumptions (see Chapter 3) dictate that the fuel price increases from an average 60 cents/kg in 2006 to 97 cents/kg in 2016, and remains constant at this rate until the end of the forecast period.

2.5.2 The key trends in demand and supply in the NOx Problem Baseline are illustrated in Figure 2.3:

- Passenger demand grows faster than seats – implying higher load factors (consistent with FESG);
- Seats grow faster than flights - implying increases in aircraft size;
- Aircraft kilometres grow faster than flights – implying an increase in aircraft trip length (and there is also an increase in passenger and seat km); and
- Aircraft km grow faster than Fleet – demonstrating higher aircraft utilisation.

2.5.3 The underlying passenger data from APMT-Economics and the FESG forecast is also provided, and shows that the 10 year period growths in the key elements is within 2 percentage points for all metrics apart from the fleet. Note that the APMT-Economics fleet was calibrated to the FESG fleet, adjusted to remove Russian aircraft

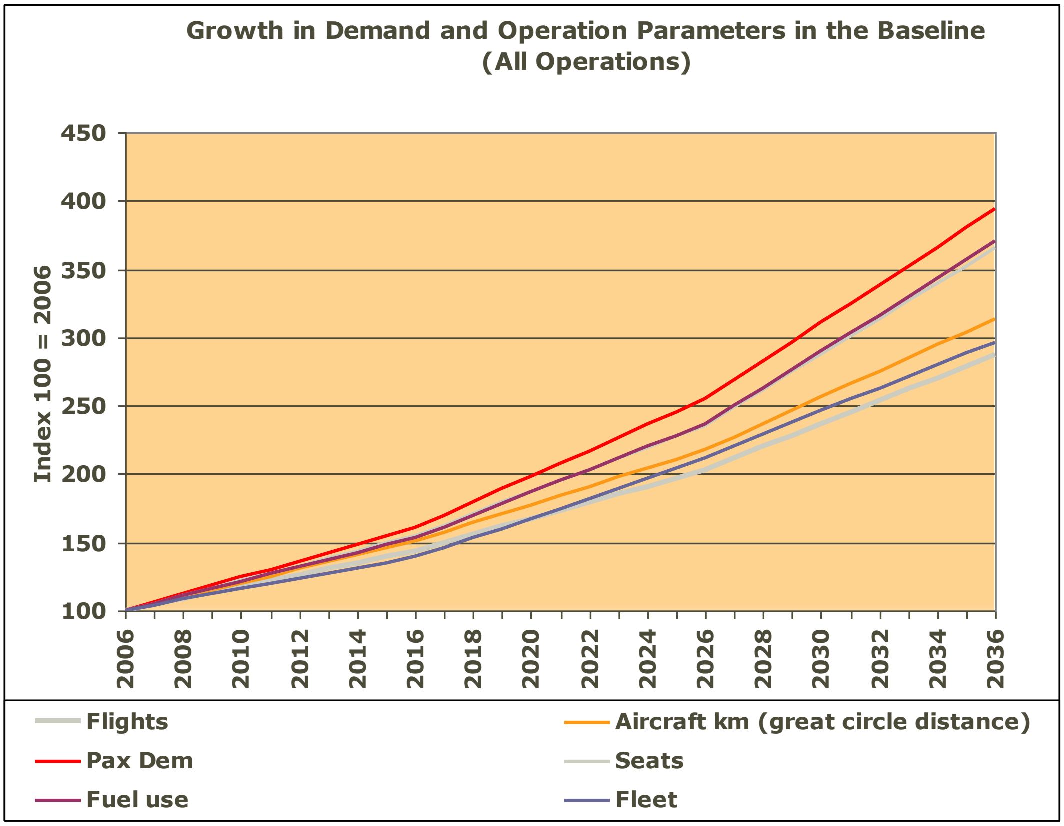


Figure 2.3 Forecast Growth in Demand and Operational Parameters

Table 2.3 Comparison of APMT-Economics and FESG Passenger Forecasts

APMT-Economics	**2006**	**2016**	**2026**	**2036**	**Growth 2006-2016**	**Growth 2016-2026**	**Growth 2026-2036**
ASK (bn)	5585	8880	13719	21281	59%	54%	55%
RPK (bn)	4196	6927	11073	17152	65%	60%	55%
Fleet in Service	15754	22265	29957	41680	41%	35%	39%
Flights (m)	22.2	31.9	44.7	63.1	43%	40%	41%
Total Km (m)	30593	45784	65381	93170	50%	43%	43%
FESG Data	**2006**	**2016**	**2026**	**2036**	**2006-2016**	**2016-2026**	**2026-2036**
ASK (bn)	5666	8989	13837	21341	59%	54%	54%
RPK (bn)	4269	7024	11196	17247	65%	59%	54%
Fleet in Service	18773	25906	34787	47503	38%	34%	37%
Flights (m)	27.1	38.7	54.1	75.7	43%	40%	40%

Total Km (m)	32550	48410	68634	96720	49%	42%	41%

2.5.4 Figure 2.4 illustrates the growth in costs in the Baseline. The growth in direct operating costs is accelerated in the initial years of the forecast, driven by the assumed increase in fuel price during this period.

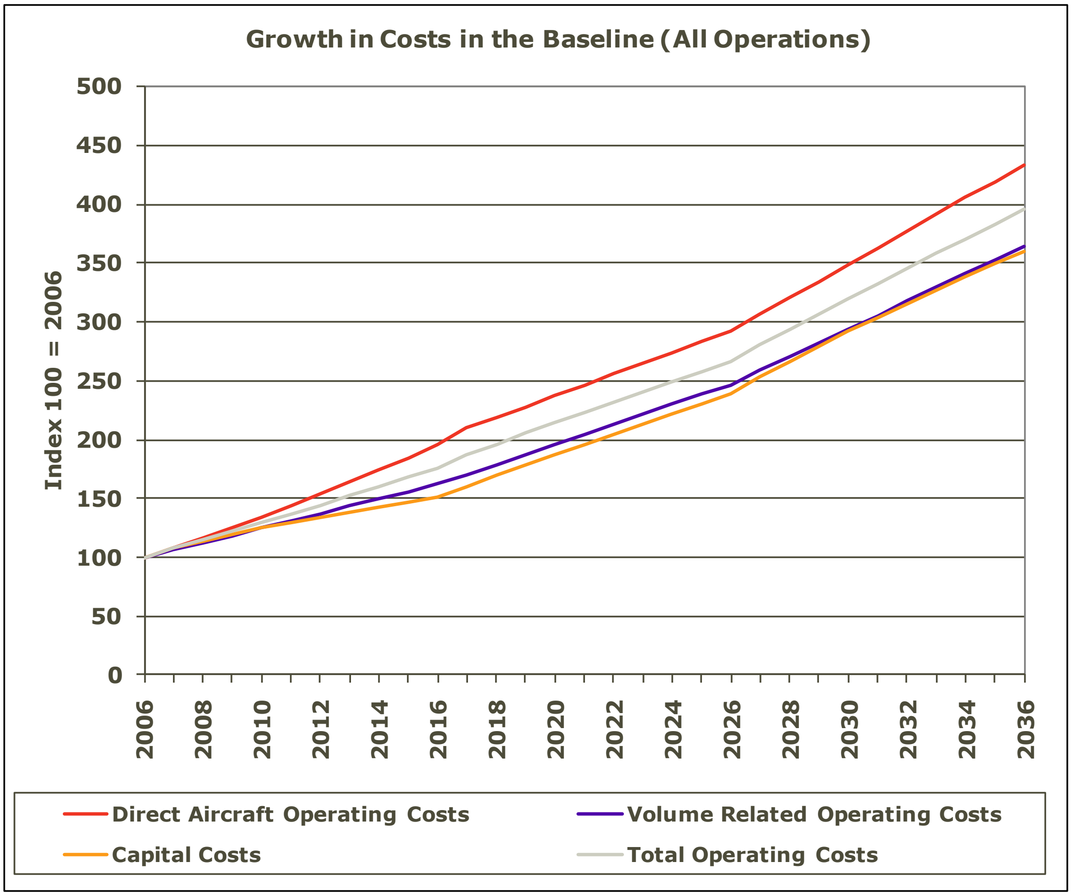


Figure 2.4 Growth in Costs in the NOx Problem Baseline

2.5.5 These effects on demand and supply lead to the following changes in costs:

- the outturn unit costs are forecast to reduce, despite the cost components not changing through time and this is due to changes in the forecast mix of aircraft types and the natural retirement and turnover of the fleet;
- Fuel/RTK decreases by about 17% by 2036, as old, less fuel efficient are retired and replaced by more efficient aircraft. Increases in load factors and changes in aircraft size type also lead to fuel use efficiencies;
- Direct operating costs increase initially, driven by the assumed increase in fuel price to 2016, and then reduce steadily over time, due to changes in aircraft sizes and associated crew to passenger ratio efficiencies; and

- Total unit costs fall slightly slower since there are capital costs of new aircraft to consider and these do not fall so quickly in unit terms.

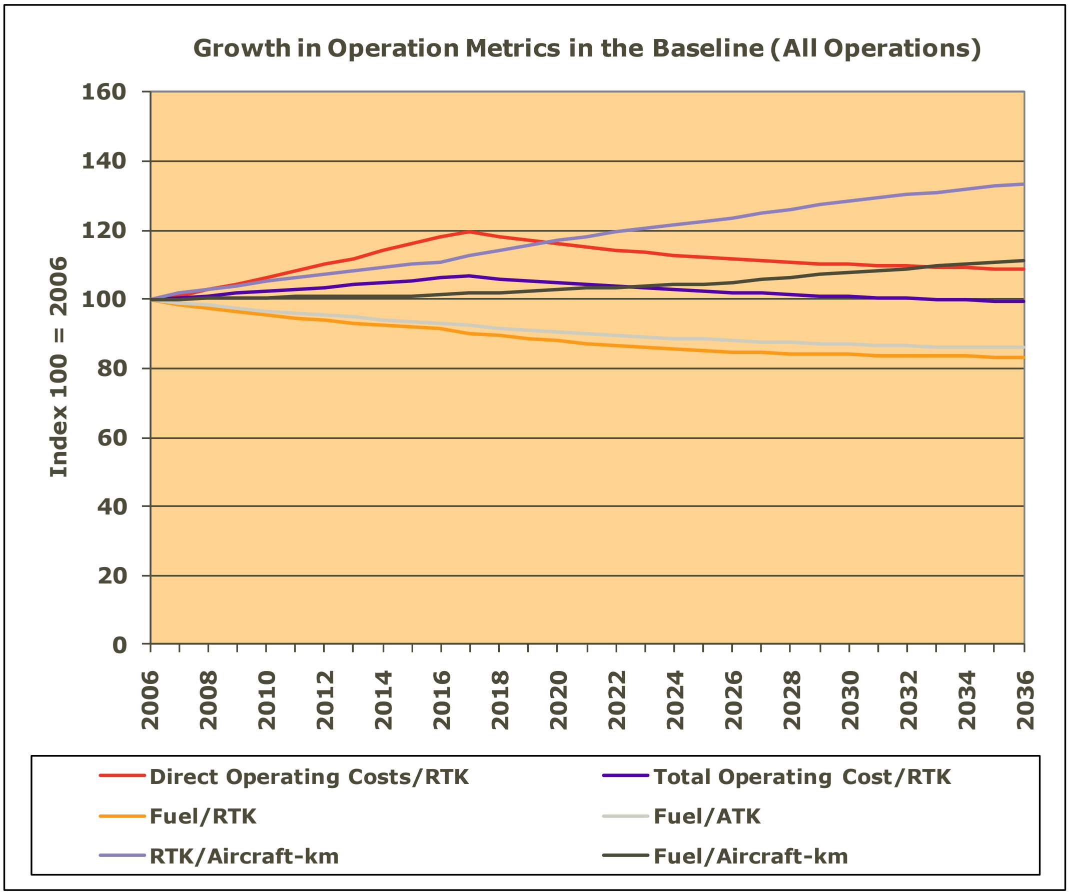


Figure 2.5 Baseline Growth in Key Operations Metrics

3 The Analysis and the Modelling Processes

3.1 Introduction

3.1.1 Ten NOx stringency cases are being analysed as part of the CAEP/8 work programme (Table 3.1) with alternative potential implementation dates of 31 December 2012 and 2016.

Figure 3.1 NOx Stringency Cases

NOx Stringency Case	Small Engine (26.7kN / 89kN)	Large Engine	(Slope>30OPR)
1	-5% / -5%	-5%	2
2	-10% / -10%	-10%	2.2
3	-10% / -10%	-10%	2
4	-5% / -15%	-15%	2.2
5	-15% / -15%	-15%	2.2
6	-5% / -15%	-15%	2
7	-15% / -15%	-15%	2
8	-10% / -20%	-20%	2.2
9	-15% / -20%	-20%	2.2
10	-20% / -20%	-20%	2.2

3.1.2 The CAEP analysis method focuses on the effects on engine and aircraft types that are currently or scheduled to be in production. Each of the currently 'available' engine types is assessed for compliance against each of the potential stringencies and each passes or fails a compliance test for their NOx emissions. CAEP Working Group 3 (WG3) has then provided an assessment of the modifications that would be needed to make these current engine types compliant with each stringency level and this assessment is based on the margin by which the existing engine would fail the stringency.

3.1.3 The modifications were grouped by engine family type and categorised in ascending level of requirement for technological improvement and cost into three levels:

- **MS1** – minor changes to engine requiring no substantive material change to engine combustor hardware or operating costs.
- **MS2** – scaling up of best-proven technology to ensure compliance of the engine with the stringency.

- **MS3** - applying new combustor technology from research programmes.

3.1.4 A common set of cost assumptions was agreed by FESG with the support of other CAEP Working Groups. The classification of the aircraft engines into these modification categories to ensure compliance at each stringency level is key to the analysis and this is reflected in the definition of the cost and operational modelling assumptions.

3.2 Scope of APMT-Economics Modelling and Output Comparisons

3.2.1 As previously described, the NOx Cost Model is being used by CAEP FESG to prepare the main cost and cost-effectiveness analysis of NOx Stringency for the CAEP/8 work programme. In this context, APMT-Economics is being used as an alternative tool to cross check these findings for a sample of the NOx Stringency test cases. For the purposes of demonstrating the capability of APMT-Economics and comparing the results from the two models, APMT-Economics was used for two of the more stringent cases only: case 7 and case 10 (highlighted in Table 2.1). These two stringency levels were chosen for comparison because they were expected to give rise to the largest cost changes of all of the tests since these required some aircraft engines to undergo MS3 modifications to comply with the stringencies. The comparisons are made for both the 2012 and 2016 implementation scenarios.

3.2.2 As described below, the two tools use different computational methods to derive the costs of the stringency measures, but the analysis is based on the same detailed projections of aircraft operations used by MODTF to compute the environmental effects.

3.2.3 The focus of the overall CAEP analysis is to present the cost-effectiveness of the stringency measures in reducing NOx emissions associated with the LTO cycle and therefore this is the key comparison that is made between the two sets of modelling results. In addition, it is appropriate to show the comparison of the overall costs and, where possible, the breakdown of the costs by component.

3.2.4 The categorisation and components of costs considered in the analysis are summarised as follows:

Non-recurring Costs

The 'one-time' costs for manufacturers associated with developing the new technology engine designs and undertaking the aircraft certification process

- Research and development costs for new engines – a high and low range of non-recurring costs that could be incurred by manufacturers is presented, noting that it is assumed that these costs would not be passed to airlines (or consumers) through higher aircraft purchase prices. For the purposes of the stringency test analysis, the non-recurring costs are assumed to be incurred by the manufacturers equally in each of four years prior to the implementation of the stringency (so for the 31 December 2016 implementation the costs are assumed to be spread across 2013 to 2016)

Recurring Costs

Ongoing additional costs would be incurred in production of future new purchases of compliant engines which for APMT-Economics are assumed to be reflected in their purchase price. Furthermore some additional operating costs would be incurred by airlines in operating aircraft with the compliant engine types.

- **Incremental Engine Production Costs** – the additional costs associated with the production of new engines through more expensive manufacturing processes.
- **Annual Maintenance Cost Increase** – there are some additional maintenance costs associated with engines that are compliant with the stringency.
- **Annual Fuel Cost Increase** – there is a potential fuel use penalty associated with ensuring the engines are compliant with the NOx stringency of between 0% (no penalty) and 0.5% for the MS3 modified engines. For the purposes of the comparison with the NOx-CSM, the maximum 0.5% penalty is assumed.
- **Annual Loss in Revenue** (MTOW limited flights) – given the potential for the fuel use penalty there is the likelihood that for longer flights, the MTOW will be limited and in some operational instances this would result in the need to limit payload and hence a potential loss in revenue.
- **Additional Spare Engines** as a measure of the potential requirement for aircraft to hold two sets of replacement engines for their fleet where they hold both stringency compliant and non-compliant engines together.

3.2.5 There is a further cost component associated with the **Loss in Value** for existing fleets where the aircraft are fitted with engines that become non-compliant (and potentially less tradable between airlines) following the introduction of the stringency. The APMT-Economics analysis and comparison to the NOx-CSM presented without this cost component.

3.2.6 In the full NOx-CSM analysis a range of discount rates of 0%, 3%, 7% and 9% are applied to the costs and the LTO NOx emissions to establish the present value of the cost-effectiveness under a number of discounting scenarios. The analysis with the NOx-CSM has illustrated that the discounting does not affect the rank ordering of the stringency effects. As a simplification the comparison work with APMT-Economics was undertaken without discounting of the costs and benefits.

3.2.7 The full CAEP analysis with the NOx-CSM splits the effects between those for the small and large engines. For the purposes of the comparison between the NOx-CSM and APMT-Economics, the combined effect alone was presented since in cost terms this is dominated by the potential compliance costs associated with the large engines for the stringency options analysed with APMT-Economics. However, it is noted that in cost-effectiveness terms the cost of reducing LTO NOx through stringency on the small engines is significantly higher than that for the large engines.

3.3 Modelling the NOx Stringency

Steps Required for the NOx Stringency Analysis with APMT-Economics

3.3.1 Following the calibration of the APMT-Economics Datum and Baseline, the steps involved in the NOx Stringency Analysis with APMT-Economics in either operations or economics led modes require the:

- Allocation of named aircraft engine types to compliance categories MS1 to MS3 (and non-compliance or non-modified) for each of the stringencies.
- Creation of model inputs to represent the new compliant aircraft types as copies of the existing replacement fleet with appropriate modifications to reflect the cost and operational changes necessary to make the existing aircraft compliant, at the appropriate enforcement year. Effectively an input database is required for each stringency test because the modifications required to define each of the replacement aircraft differ between the stringencies (for example, an aircraft may need an MS2 modification under one stringency scenario and an MS3 modification under a scenario with a more stringent certification standard).

3.3.2 In **Operations-Led** mode the steps are then to:

- Run the stringency scenario for APMT-Economics in Economics-Led mode to establish the fleet age profile.
- For each stringency scenario and forecast year (2016, 2026, 2036), a separate APMT-Economics single year database is created for the Baseline and Intervention (i.e. with stringency applied) by importing the forecast of aircraft operations provided by MODTF and applying the fleet age profile determined from the Economics-led run. This essentially requires a 'match' between the aircraft operations and the APMT-Economics representation of fleet.
- Once the aircraft operations are input to the database, the APMT-Economics Datum cost calculations are performed to generate the overall operating costs by aircraft type for either the Baseline and Intervention situations.
- The complete output databases are then interrogated to provide the necessary data for a standard APMT-Economics output scorecard spreadsheet to facilitate the interpolation of data for intervening years.

3.3.3 In **Economics-led** model the processing is more straightforward:

- The FESG forecasts are input to the model by seat class, stage length and route-group.

- The Baseline is executed from each of the input databases and the output results are exported from the database to the standard APMT-Economics scorecard[12].
- Intervention tests are executed for each of the stringency test databases for each of the potential implementation years. (A single run of APMT-Economics in Economics-led mode forecasts on a year-by-year basis and therefore no post processing interpolation to obtain the intervening year outputs is required.)
- The output databases are interrogated to provide additional analysis specific computations of number of spare engines, lost revenue and, where appropriate, the loss in aircraft value.

Summary of Modelling Differences

3.3.4 There are some differences in the modelling approaches between the computations in the NOx-CSM and operating APMT-Economics in **operations-led** mode which will contribute to different, though explainable, results being output. These are summarised as

- **Recurring Manufacturing Costs:** APMT-Economics treats these costs as an increase to the new aircraft purchase price and consequently an increase in the annual capital (finance and depreciation) costs in any one forecast year. The additional purchase costs that reflect the manufacturing costs are therefore spread across the whole life operation of the aircraft. The NOx-CSM treats these additional costs as occurring wholly in the year in which a modified aircraft is purchased. Consequently, the recurring manufacturing costs computed from the NOx-CSM should be expected to be slightly lower than those computed from APMT-Economics.
- **Maintenance Costs:** The APMT-Economics cost functions include an increasing penalty for maintenance costs as aircraft age, but the NOx-CSM does not include information about fleet ages so constant maintenance costs are assumed. Consequently the maintenance costs would be slightly higher from the APMT-Economics calculation compared to the NOx-CSM.
- **Fuel Costs:** The APMT-Economics interpolation of the fuel costs takes into account the assumed growth in fuel costs based on a change in oil price from $65 per barrel in 2006 to $100 per barrel in 2016. The NOx-CSM applies a constant fuel price for all forecast years. The consequence of these slightly different assumptions is that for the 2012 implementation there is a marginally lower average cost of fuel in the APMT-Economics outputs.

3.3.5 The balance of the contribution of these slightly different modelling treatments will effect on the overall differences in output costs.

[12] In this analysis the Baseline results are identical for these two stringency levels as the effect of the different aircraft definitions is only invoked in the model's Intervention responsive mode.

3.3.6 There are also some differences in the modelling approaches between APMT-Economics in **operations-led** and **economics-led** modes which will contribute to different, but consistent, results being output, as follows:

- **Retirement:** In economics-led mode, APMT-Economics applies the FESG aircraft retirement curves on a year-by-year basis compared to the one-time application and effect on the Datum aircraft fleet that is applied by MODTF. Consequently a greater number of new replacement aircraft would be needed in the APMT-Economics forecasts and this would be expected to lead to higher costs of the stringency measure compared to the outputs from the operations-led mode.
- **Fleet Market Share:** The MODTF forecasts include a fixed and equal market share across all replacement aircraft types within an aircraft seat category. APMT-Economics computes the market shares using a model that is sensitive to the cost per seat and consequently forecasts a lower market share.

Further NOx Stringency Analysis Capability of APMT-Economics

3.3.7 The APMT-Economics model (in economics-led mode) has a demand responsive functionality which, by FESG defined assumption, is switched-off for the purposes of the main analysis, since the stringency measures are not expected to generate large costs overall. However, to confirm the validity of the fixed-demand assumption the APMT-Economics, demand sensitive forecasting procedures were invoked for a series of sensitivity tests for one of the higher costs NOx stringency specifications.

Analysis Observations

3.3.8 Few difficulties were encountered in preparing the comparison of the NOx-CSM and APMT-Economics in operations-led mode.

3.3.9 However, in making the comparison between APMT-Economics in operations-led and economics led mode, it was discovered that the MODTF processing had only partially applied the FESG forecasts such that:

- Aircraft in new seat class 10 (over 600 seats) were omitted.
- There are no operations in the MODTF forecasts for some seat classes that were not represented in the 2006 Common Operations Database (COD), where these had been introduced through the FESG forecasting process.

3.3.10 These omissions do have some bearing on the overall forecasts and the magnitude is described in Chapter 5. However, there is no effect or bias anticipated on the ranking of results.

3.4 Assumptions Employed

3.4.1 Common assumptions are employed in the analysis undertaken by the APMT-Economics and the NOx-CSM, although the differences in modelling structures requires that in some cases these assumptions are input to the process in different ways.

3.4.2 Table 3.2 presents a summary of the common modelling assumptions. There are some detailed underlying analysis assumptions that underpin the derivation of the parameters for the revenue loss calculation and the recurring manufacturing costs; these are described in Appendix A.

Table 3.1: Common Modelling Assumptions

Modelling Item	CAEP/8 Assumptions	Comments
FESG Traffic and Fleet forecasts	Central forecasts on the basis of unconstrained demand	Forecasts assume that airport and airspace capacity is available to meet projected demand growth.
Underlying trend in NOx technology	No change over time	Simplifying assumption in view of difficulty in making projections of trend in NOx emissions and not essential for assessment of NOx stringency – frozen technology assumption will not affect ranking of options
Future tightening of NOx stringency	No further stringency beyond options under consideration	Isolate assessment of costs and NOx savings to stringency options being analysed
Product compliance	Market driven production cut-off that takes effect on implementation date (2013 or 2017)	Consistent with evidence following past stringency standards, but sensitivity tests to be applied to reflect alternative outcomes, in particular for 2013 changes requiring MS3
Time-in –mode and thrust settings	ICAO certification factors used	Likely to over-estimate NOx savings from stringency but more work necessary before performance based settings can be used
Market shares	Equal market split between manufacturers within each seat category	Simplifying assumption that avoids difficult assessment of market share projections for future years
Technology Response Categories	MS1, MS2, MS3	ICCAIA cross-reference to CAEP/6 NOx stringency analysis TL concept: MS1=TL1, MS2=TL2, MS3=TL5A
NOx Stringency Options	5% to 20% from CAEP/6	Increments of 5%. When considering stringency proposals for small and large engines, the resulting number of stringency options to be evaluated is 10. See Table 1 in Appendix A
Base Year	2006	The base year fleet is based on the Campbell-Hill Aviation Group's commercial airline fleet database updated to represent the 2006 year-end.
Time Horizon	2006 – 2036	FESG CAEP/8 20-yr fleet forecast with 10 year extension
NOx Stringency Implementation Years	2013, 2017	NOx stringency implementation starts on 1 January of 2013 or 2017

Modelling Item	CAEP/8 Assumptions	Comments
Fuel Price	$1.50 - $4.50 per gallon (aver. = $3.00/gallon)	Recommendation for CAEP/8 is to use crude oil prices of $50 - $150/bbl, with $100/bbl the midpoint. Multiply crude oil price by 1.25 to arrive at fuel price per barrel. (42 barrels per gallon)
Financial discount rates	0%, 3%, 7%, 9%	Use same discount rates as CAEP/6
Non-recurring costs	MS1= $1M - $15M MS2= $50M - $100M MS3= $100M - $500M	See CAEP/8 Seattle SG paper number CAEP-SG/20082-WP/18 For further description of the NOx technology response. Non-recurring costs applied once per engine family
Cost from increased noise tradeoff for NOx technology response	Incremental non-recurring for MS3 = $0, $10M, $100M [3 sensitivity runs]	Per WG1 recommendation, NSTG to conduct a cost sensitivity analysis on three different non-recurring (E&D) scenarios as shown to the left. Applied only to MS3 technology response
Incremental recurring manufacturing (production) costs	MS1 = $0 MS2 = 0-0.5% (0.25%) $ 20,000 MS3 =0.2-0.8% (0.5%) $ 40,000	For CAEP/8 analysis, continue to use the CAEP/6 method for estimating recurring costs. Recurring engine manufacturing cost increase is due to complexity, material, etc. (does not include amortized non-recurring costs).
Incremental fuel burn	MS1= 0% MS2= 0% MS3= 0% - 0.5%	From WG3 / ICCAIA Technology Response assumptions.
Incremental engine maintenance cost ($/EFH)	MS1= $0 MS2= $0 - 2 (aver.= $1) MS3= $0 - 4 (aver.= $2)	ICCAIA recommendations shown to left.

Modelling Item	CAEP/8 Assumptions	Comments
Lost revenue due to incremental fuel burn effect from MS3 technology response. Aircraft payload / range capabilities not preserved. Instead, estimate cost of lost revenue	Percent of Annual Trips MTOW limited: -Twin-Aisle aircraft: 5% -Single-Aisle aircraft: 0.5% Representative distance for MTOW limited flights: Single aisle = 2100 NM Twin aisle = 5000 NM Revenue offload Single Aisle = -1 PAX (100kg) For Twin Aisle: 750lb (340 kg) Revenue Yields at representative stage lengths: Passenger rev. yield = $0.075/RPK Cargo rev. yield = $0.26/RTK	For CAEP/8, the FESG NOx stringency task group agreed to replace the CAEP/6 approach, which assumed aircraft mission and payload maintained, with a method to calculate the revenue loss resulting from an increase in 0.5% fuelburn for MS3 technology response. This loss of revenue would be incurred on long-range MTOW limited missions. The frequency of operating at the payload / range limits may be a few percent of the annual utilization.
Cost for Incremental Spare Engine Inventory	ICCAIA had recommended engine inter changeability as follows: MS1 - 100% MS2 - 100% MS3 - 50%	For the MS1 and MS2, where the engines are assumed to be 100% interchangeable with the same engine models being manufactured before NOx stringency was implemented, then no incremental spare engines would be required. For MS3, 50% of the engines receiving MS3 technology response will require incremental spare engines to support the fleet after NOx stringency is implemented due to lack of commonality and inter changeability

Modelling Item	CAEP/8 Assumptions	Comments
Engine price for spare engines	Average = $8.6 M For the 15% stringency for Large Engines, a weighted average price for engines requiring MS3 was estimated to be $24.3M For the 20% stringency for Large Engines, the weighted average price for engines requiring MS3 was estimated to be $12M	The average engine price for the CAEP/8 analysis based on review of the mid-2008 AVITAS Engine Value Guide for new engine prices and applying engine cycles for the engines to be delivered as growth and replacement over the 30 year time horizon as weighting factors is estimated to be $8.6M. A more detailed assessment was used to estimate a weighted average engine price to be used for spare engines, considering only those engines that would require a MS3 technology response for each stringency option. Only the 15% and 20% stringency options required MS3 responses for some of the engine families.
Spare engine function	Use CAEP/6 spares curve	Spares curve from CAEP/6 to be used: # installed engines vs. % spares The equation for estimating the number of spare engines required at the global fleet level is: number spare engines = 0.5891 * number installed engines ^ -0.3758
Loss of Asset Value (Residual Value)	ICCAIA recommends using CAEP/6 values MS1 = no modification MS2 = $250,000 per engine MS3 = $500,000 per engine	Loss of Asset Value is a cost applicable to the production models that will not comply with NOx stringency being delivered before the stringency implementation year. Once stringency is implemented these same non-compliant engine models receive the MSx technology responses.

4 Results from APMT-Economics with the Economics-led Approach

4.1 Introduction

4.1.1 This Chapter presents APMT-Economics results for CAEP/8 NOx Stringency Options 7 and 10, which comprise potential stringencies on the certification of new engines as follows:

NOx Stringency Case	Small Engine (26.7kN / 89kN)	Large Engine	(Slope>30OPR)
7	-15% / -15%	-15%	2
10	-20% / -20%	-20%	2.2

4.1.2 The results described in this Chapter are obtained from running APMT-Economics in its primary **Economics-led** mode.

4.2 APMT-Economics Cost-effectiveness Results

4.2.1 Figure 4.1 presents the cost-effectiveness results, in terms of the cost per tonne of LTO NOx reduced, obtained from APMT-Economics assuming the high recurring development costs. The figure plots the trade-off between the reduction in LTO NOx (horizontal axis) and the increase in CO2 (vertical axis) with the size of the 'bubbles' representing the LTO NOx reduction cost-effectiveness. The rank order of the cost-effectiveness results appears intuitively rational such that:

- Absolute effects on LTO NOx (and CO_2) for stringency option 10 are higher than those for stringency option 7;
- The rank ordering of the effects on LTO NOx match the rank ordering of effects on CO_2.
- Delaying implementation from 2012 to 2016 reduces the relative cost-effectiveness of the measure since the reduction in LTO NOx is smaller but the overall costs are similar.

4.2.2 The breakdown of costs by component is displayed in Figure 4.2. The largest effect for Stringency option 10 is that on fuel cost. However, for Stringency Option 7 the effects on fuel costs are lower, since fewer engines require an MS3 adjustment but there is an increasingly significant contribution to the overall costs from the estimated cost of holding spare engines, where the approach adopted is similar to that used in the NOx-CSM.

Figure 4.1 Cost-effectiveness of NOx Stringency Options with Outturn NOx Reduction and CO2 Increase Trade-Off

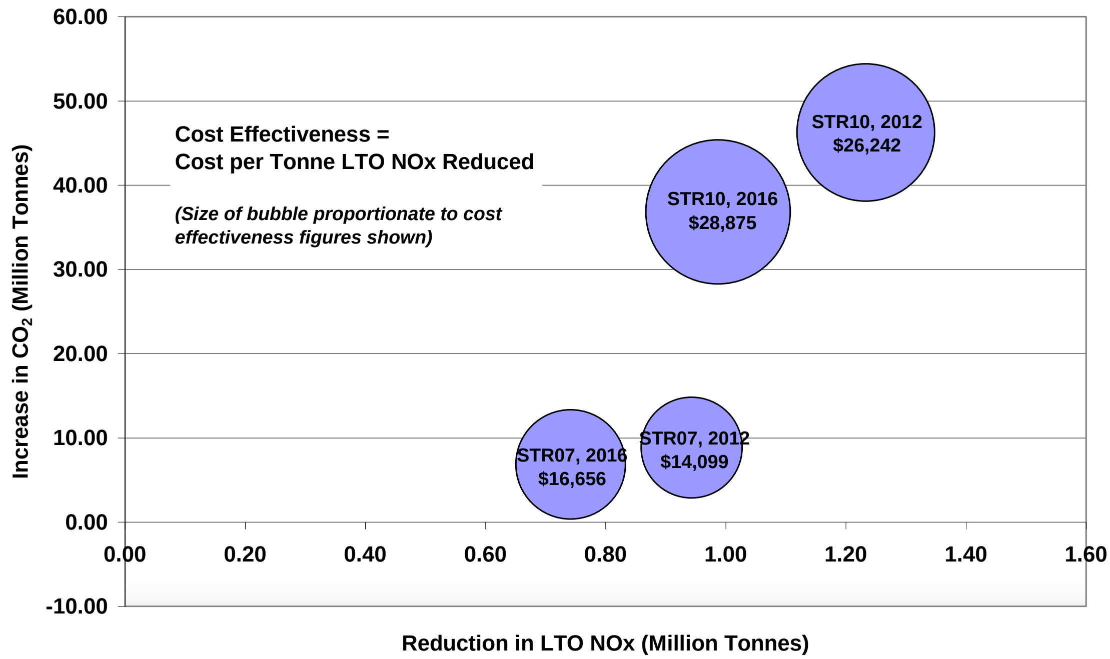
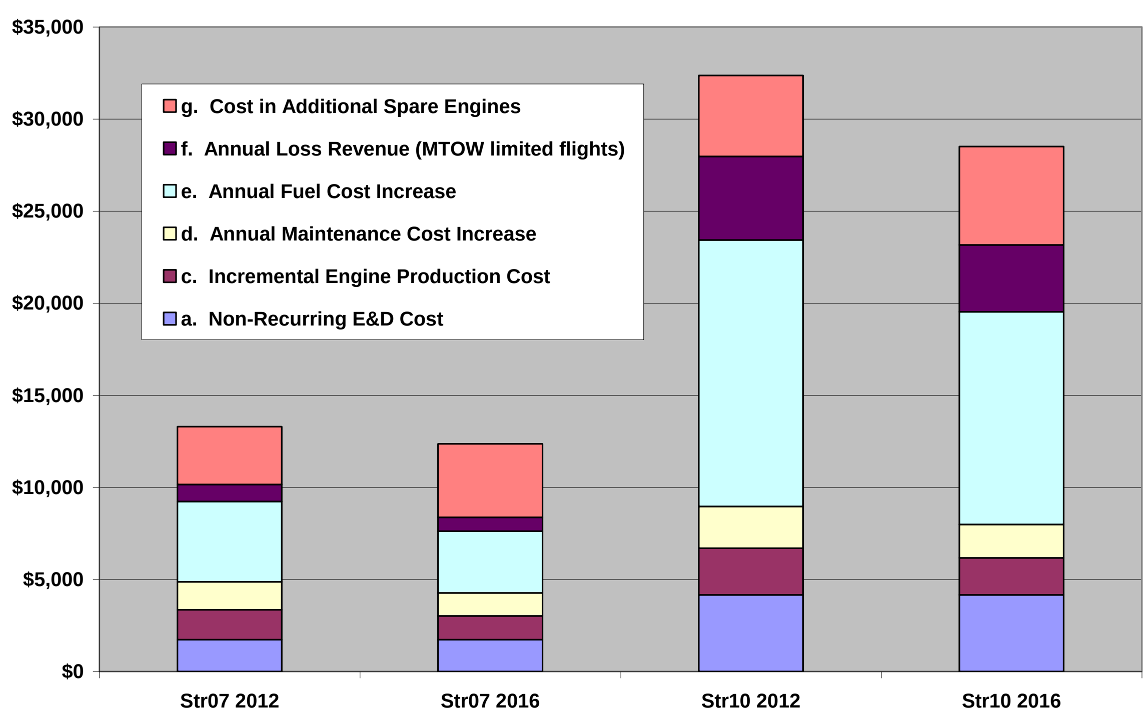


Figure 4.2 NOx Stringency Effects by Cost Component from APMT-Economics



4.2.3 The overall effects for a sample of APMT-Economics output metrics for these tests relative to the Baseline are illustrated in Table 4.1. The table shows the cumulative effect over the forecast years from 2012 to 2036 compared to the forecast Baseline outcome. By test assumption there no effects on demand (RTK), operations and aircraft km and it is noted that:

- **Fleet**[13] - The cost sensitive replacement aircraft selection in APMT-Economics results in a very small reduction in the number of aircraft required with the interventions compared to the Baseline forecast. The reason for this is that within each seat class there is a very small shift to operating aircraft with more seats.
- **Fuel Use and Total CO2**[14] - The percentage effect on fuel use and CO2 relative the Baseline forecast of overall industry output is small, 0.14% or less. **Total NOx**[15] - as the driver for the stringency is forecast to reduce significantly, by up to 6.8%.
- **Total Cost** – due to the stringency measure the modelled airline operating costs are expected to increase by at most $28.0 Billion (0.09%) in the default forecast. The total costs reported here are those that relate to the recurring costs due to additional fuel, maintenance and production costs. The loss in revenue and the costs of holding additional spares are computed through post-processing of the model outputs. Effectively these costs are assumed not to be passed to consumers by airlines but if they were included they would add a maximum of $9Bn to the costs and increase the largest percentage increase from 0.06% to 0.08%.

4.2.4 Sensitivity tests were conducted and reported below been conducted to illustrate the effect of including all of the costs using the demand responsiveness capability of APMT-Economics invoked, since no demand effects are included as a core assumption for the NOx stringency analysis.

[13] 2036 Outturn rather than cumulative total

[14] APMT-Economics approximate calculations based on input data from AEDT

[15] Note that this is full flight NOx and APMT-Economics approximate calculations based on input data from AEDT

Table 4.1 Total Effects from 2006 to 2036 of NOx Stringency calculated with APMT-Economics

			Stringency 7			
Metric	**Unit**	**Baseline**	**2012 Absolute Difference**	**2012 Percentage Difference**	**2016 Absolute Difference**	**2016 Percentage Difference**
2036 Fleet	aircraft	41680	-2	0.00%	-2	0.00%
Fuel Use	Million tonnes pa	10821	4.3	0.04%	3.3	0.03%
Total CO2	Million tonnes pa	34139	13.5	0.04%	10.4	0.03%
Total NOx	Million tonnes pa	157	-8.4	-5.37%	-6.7	-4.28%
Total Costs	billion US$	30048	12.1	0.04%	12.2	0.04%
			Stringency 10			
Metric	**Unit**	**Baseline**	**2012 Absolute Difference**	**2012 Percentage Difference**	**2016 Absolute Difference**	**2016 Percentage Difference**
2036 Fleet	aircraft	41680	-3	-0.01%	-3	-0.01%
Fuel Use	Million tonnes pa	10821	14.3	0.13%	11.4	0.11%
Total CO2	Million tonnes pa	34139	45.3	0.13%	36.1	0.11%
Total NOx	Million tonnes pa	157	-10.7	-6.82%	-8.5	-5.43%
Total Costs	billion US$	30048	28.0	0.09%	24.3	0.08%

4.3 Demand Sensitive Forecasts with APMT-Economics

4.3.1 Two sensitivity tests were undertaken with APMT-Economics for NOx stringency option 10 with a 2012 implementation year to illustrate that the demand effects that might result from stringency measures would be relatively small:

- The first of the two tests assumed that the airlines would pass-on all of their increased recurring costs of additional fuel, maintenance and production costs (affecting purchase prices) through increased fares; and
- The second of the tests assumed that additionally the airlines would also incur the non-recurring costs of engine upgrades and they would pass-on all of these costs and the increased recurring costs through increased fares.

4.3.2 The effects of a sample of APMT-Economics output metrics for these tests are illustrated in Tables 4.2 and 4.3 as a cumulative effect over the forecast years from 2012 to 2036.

- **RTK** – The stringency costs would be expected to only have a small effect on the demand forecasts, reducing the total RTK over the period 2006 to 2036 by up to 0.07% of a total cumulative forecast of 32420 billion RTK.
- **Aircraft Operations and Aircraft KM** – Given small changes in forecast RTK there are correspondingly lower forecasts of aircraft activity.
- **Fleet**[16] - Given the smaller total requirement for aviation activity then the model estimates that the fleet in 2036 would comprise at most just 45 fewer aircraft (0.09%) than for the Baseline forecast.
- **Fuel Use and Total CO2**[17] - Fuel use is forecast to increase by 14.3 million tonnes (0.13%) due to the stringency measure without demand effects and this increase is for fuel use to increase by a smaller amount, 10.1 million tonnes (0.09%)
- **Total NOx**[18] - is forecast to reduce by 6.8% and is forecast to reduce by very slightly more due to the demand effects.
- **Total Cost** – due to the stringency measure is expected to increase by $28.0 Billion tonnes (0.10%) in the default forecast.

4.3.3 These outputs confirm the premise underlying the analysis that the effects of the costs of stringency on demand are relatively small and for the purposes of ranking the stringency options in cost-effectiveness terms can reasonably be ignored for the purposes of ranking NOx stringency options.

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[16] 2036 Outturn rather than cumulative total

[17] APMT-Economics approximate calculations based on input data from AEDT

[18] Note that this is full flight NOx and APMT-Economics approximate calculations based on input data from AEDT

Table 4.2
Effects of Costs on Demand for Selected Metrics from 2009 to 2036 for Stringency Option 10 Implemented in 2012

			No Demand Effects		Demand Effects		Demand Effects and Recurring Costs	
Metric	**Unit**	**Baseline**	**Absolute Intervention Effect**	**% Intervention Effect**	**Absolute Intervention Effect**	**% Intervention Effect**	**Absolute Intervention Effect**	**% Intervention Effect**
RTK	billion RTK pa	32420	0.0	0.00%	-19.5	-0.06%	-22.4	-0.07%
Operations	million flights pa	1281	0.0	0.00%	-0.7	-0.05%	-0.7	-0.06%
Aircraft Km	billion ac-km pa	1894	0.0	0.00%	-1.0	-0.05%	-1.1	-0.06%
2036 Fleet	aircraft	41680	-3.0	0.00%	-41.1	-0.09%	-45.5	-0.10%
Fuel Use	million tonnes pa	10821	14.3	0.13%	10.1	0.09%	9.2	0.09%
Total CO2	million tonnes pa	34139	45.3	0.13%	31.9	0.09%	29.0	0.09%
Total NOx	million tonnes pa	157	-10.7	-6.80%	-10.7	-6.84%	-10.7	-6.84%
Total Costs	billion US$	30048	28.0	0.09%	15.6	0.05%	16.4	0.05%

Table 4.3 Relative Effect of Costs on Demand and Other Metrics from 2009 to 2036 for Stringency Option 10 Implemented in 2012

Metric	**Unit**	**Demand Effect**	**Recurring Cost and Demand Effect**
RTK	billion RTK pa	-19.5	-22.41
Operations	million flights pa	-0.7	-0.73
Aircraft Km	billion ac-km pa	-1.0	-1.13
2036 Fleet	aircraft	-38.1	-45.5
Fuel Use	million tonnes pa	-4.2	-5.1
Total CO2	million tonnes pa	-13.4	-16.2
Total NOx	million tonnes pa	-0.1	-0.1
Total Costs	billion US$	-12.4	-11.6

5 Comparing APMT-Economics and NOx-CSM Results

5.1 Introduction

5.1.1 The results from the APMT-Economics tests can be compared to those from the NOx-CSM for both the 2012 and 2016 implementation scenarios for these two stringency levels. The results from APMT-Economics presented in Chapter 4 are from the model operating in **economics-led** mode and as noted earlier the model can also be run in **operations-led** mode where the operations forecasts by aircraft type are those used by MODTF.

5.1.2 This chapter reports a comparison of the consistency of the results from APMT-Economics in operations-led mode with the NOx-CSM and then with APMT-Economics in economics-led mode:

- The operations-led to NOx-CSM comparison illustrates the degree of commonality between the cost computations and processing of the MODTF application of the FESG forecasts.
- The operations-led to economics-led comparison illustrates the effects of the economics-led modelling approach and application of the FESG forecasts.

5.2 Comparing APMT-Economics Operations-led Results with the NOx-CSM

5.2.1 The presentation of the comparison between APMT-Economics in operations-led mode and the NOx-CSM is broken down as follows:

- Emission comparison, noting that the APMT-Economics computations of Fuel use and NOx are approximations of the computations made by AEDT;
- Overall comparison of the costs and a comparison of the cost components; and
- The comparison of the outturn cost-effectiveness measures

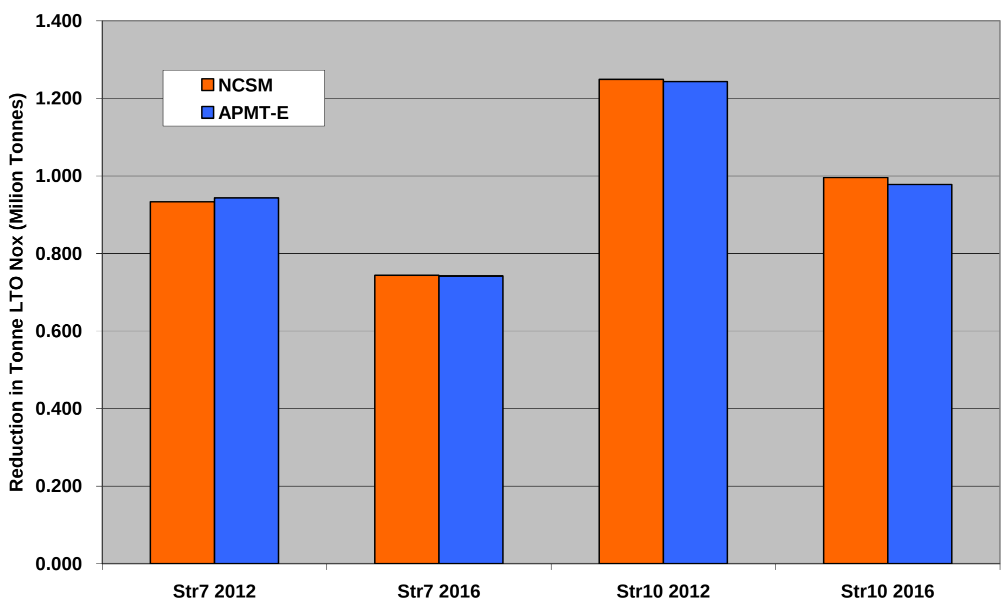
5.2.2 The outputs for both the APMT-Economics and the NOx-CSM are based on the sum of the effects between 2009 and 2036.

Emission Outputs

5.2.3 Figure 5.1 presents a comparison of the total saving in NOx used in the two modelling approaches for the cost-effectiveness analysis. The NOx-CSM does not itself compute NOx emissions and the figures shown here are from the Local Air Quality forecasts prepared by MODTF. The APMT-Economics model approximates the computation of NOx based on inputs from AEDT, however for the purposes of this comparative analysis these outputs have needed to be calibrated to the values computed from the MODTF local air quality modelling.

5.2.4 As Figure 4.1 shows, the LTO NOx used in the comparison of the Cost-effectiveness is very similar.

Figure 5.1 Forecast Total Saving in LTO NOx

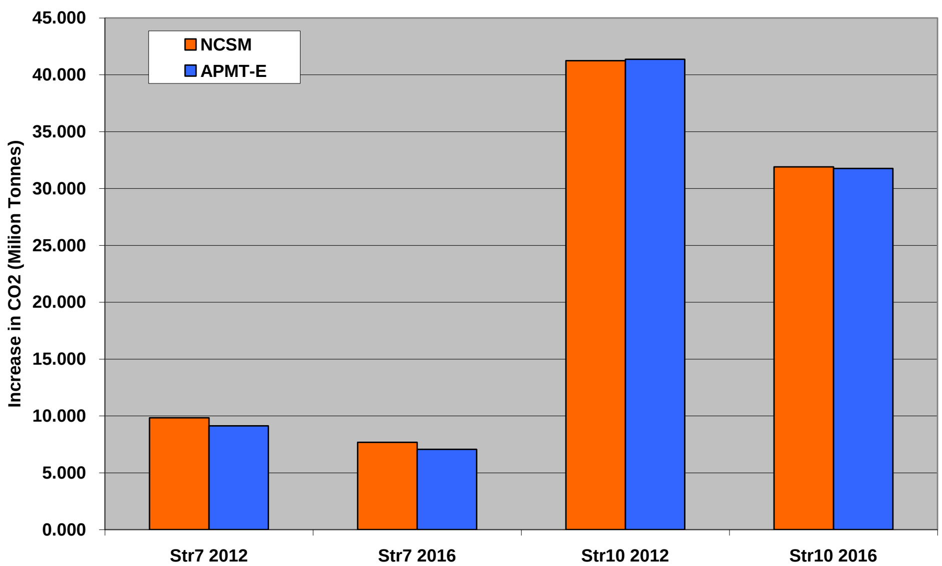


Stringency	Implementation Year	NCSM	APMT-E	% Difference	Absolute Difference
7	2012	0.933	0.943	1.1%	0.010
7	2016	0.744	0.742	-0.2%	-0.002
10	2012	1.249	1.243	-0.4%	-0.006
10	2016	0.995	0.978	-1.8%	-0.017

Reduction in LTO NOx (Million Tonnes)

5.2.5 Figure 5.2 illustrates the changes in fuel use implied from the two modelling approaches. The CO_2 values for APMT-Economics are approximations based on the detailed computations of fuel use and CO_2 from AEDT. The NOx-CSM does not compute fuel use or CO_2 and the values used in the comparison are drawn directly from the MODTF models. For NOx Stringency Option 10 the results are shown to demonstrate a particularly close match.

Figure 5.2 Forecast Increase in Full Flight CO_2 Emissions due to NOx Stringency



Stringency	Implementation Year	NCSM	APMT-E	% Difference	Absolute Difference
7	2012	9.831	9.121	-7.2%	-0.709
7	2016	7.679	7.055	-8.1%	-0.624
10	2012	41.234	41.361	0.3%	0.126
10	2016	31.900	31.759	-0.4%	-0.141

Increase in CO_2 (Million Tonnes)

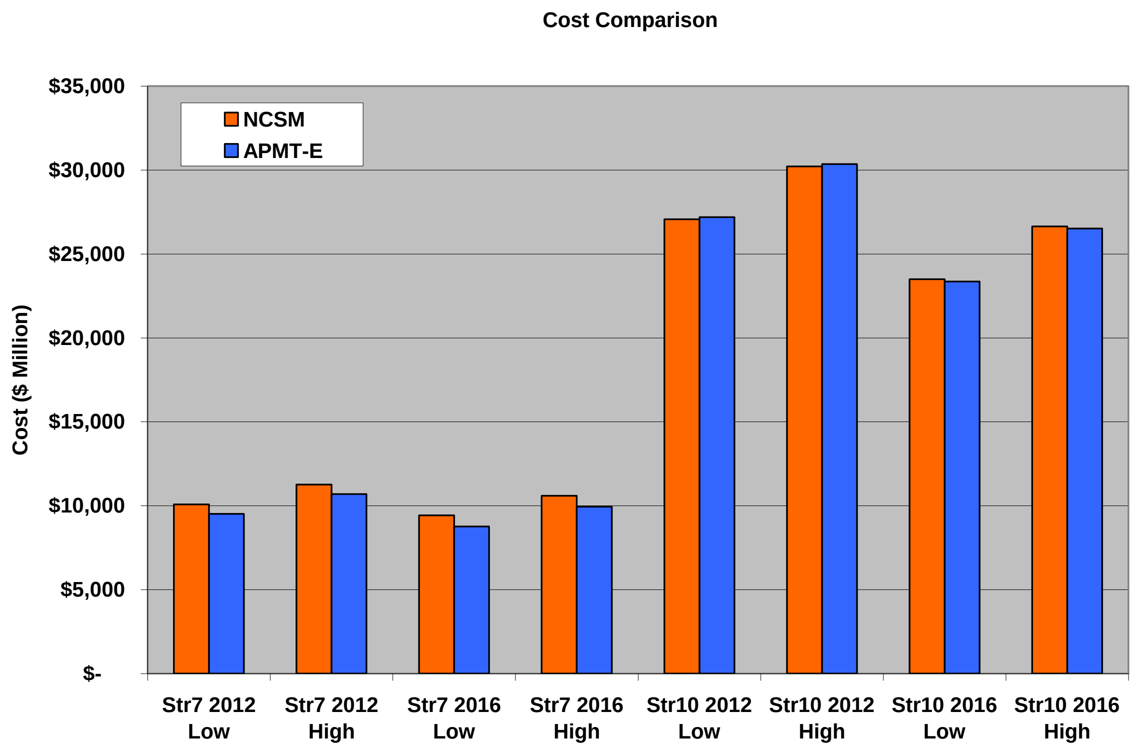
Forecast Cost Effects

5.2.6 The APMT-Economics computations of costs are made without discounting and including the maximum assumption for the MS3 fuel use penalty, since this will illustrate the maximum effect and when compared to the NOx-CSM expose the maximum absolute differences between the two models.

5.2.7 Figure 5.3 demonstrates that overall there is strong agreement between the total costs of the NOx stringency measures computed from the NOx-CSM and APMT-Economics. The results from using the different models, with the same input assumptions, compare well with the largest difference between the two models being 7%. The computed values between the two models are very close for Stringency option 10, within 1%.

5.2.8 APMT-Economics consistently computes smaller cost effects of stringency measures and the contribution of the individual components are described below.

Figure 5.3 Total Cost Outputs from APMT-Economics and the NOx-CSM (0% Discount Rate)



Stringency	Implementation Year	Recurring Cost Scenario	NCSM	APMT-E	% Difference	Absolute Difference
7	2012	Low	$ 10,084	$ 9,516	-5.6%	$ -568
7	2012	High	$ 11,262	$ 10,694	-5.0%	$ -568
7	2016	Low	$ 9,421	$ 8,763	-7.0%	$ -658
7	2016	High	$ 10,599	$ 9,941	-6.2%	$ -658
10	2012	Low	$ 27,060	$ 27,190	0.5%	$ 130
10	2012	High	$ 30,216	$ 30,346	0.4%	$ 130
10	2016	Low	$ 23,487	$ 23,360	-0.5%	$ -127
10	2016	High	$ 26,643	$ 26,516	-0.5%	$ -127

Costs in $Millions

5.2.9 Figure 5.4 demonstrates the similarities between the APMT-Economics and NOx-CSM computations of the stringency effects by cost.

5.2.10 There are some differences in the computation of the other individual cost components and each component makes a varying contribution to the overall comparison. The individual differences in computations therefore only make a limited contribution to the total cost difference and given the different modelling approaches the differences are sometimes more marked at a detailed level. Generally there is a consistency in the pattern of differences between the two approaches and the following observations and explanations for the differences between the two modelled estimates can be made:

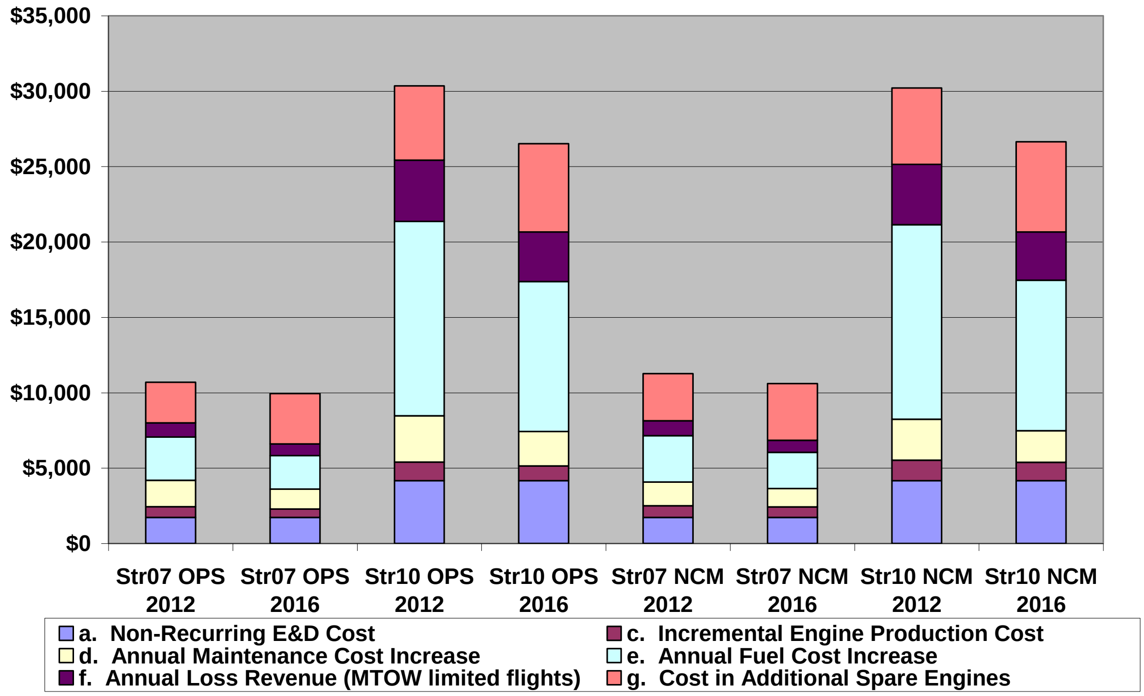
- **Production Costs** – Account for 8% of the total NOx-CSM costs for Stringency option 7 and 5% of the total NOx-CSM costs for Stringency option 10. APMT-Economics computes recurring production costs that are slightly lower that those computed by the NOx-CSM. The reason for this is the different treatment of the additional production costs in the two models. In the NOx-CSM, the costs are assumed to be incurred in the year that new aircraft are purchased and in APMT-Economics the new aircraft purchase price is increased to account for the additional production costs and then manifests itself in the computation of annual capital costs (through the sum of ongoing depreciation and finance costs) in each forecast year. In absolute terms, the differences between the two methods are not large and APMT-Economics would be expected to compute a lower effect since the additional costs for the purchase of an individual aircraft are spread over the aircraft’s lifetime.

- **Maintenance Costs** – Account for 16% of the total NOx-CSM costs for Stringency option 7 and 10% of the total NOx-CSM costs for Stringency option 10. APMT-Economics consistently computes slightly (13%) higher maintenance costs than the NOx-CSM across each of the stringency options and implementation years. The difference is explained by the APMT-Economics modelling of maintenance costs that assumes that these costs increase as aircraft age. In this analysis, the maintenance cost of the response to the stringency was assumed to apply to the maintenance costs for a new aircraft and therefore increases on an annual basis compared to the static assumption employed in the NOx-CSM.

- **Fuel Costs** - Account for 27% to 32% of the total NOx-CSM costs for Stringency option 7 and 44% to 50% of the total NOx-CSM costs for Stringency option 10. APMT-Economics computes a lower fuel cost than the NOx-CSM in all scenarios. In percentage terms the difference is approximately 8% for Stringency Option 7, and less than 1% for stringency option 10 implemented in 2016. As noted above there is a small difference in the fuel use/CO_2 effects used by the two models, and this cost difference is explained by the different treatment of the fuel price. In the NOx-CSM the fuel price is fixed however APMT-Economics takes account of the change in the fuel price from its value in the calibrated 2006 Datum situation and the interpolation between the outputs for 2006 and 2016 for the forecast years 2012 to 2015 includes a steadily growing fuel price up to the fixed 2016 level. Therefore in the 2012 implementation, the effective average fuel price in the APMT-Economics computation is expected to be less than that employed in the NOx-CSM.

- **Lost Revenue** – Accounts for 10% of the total NOx-CSM costs for Stringency option 7 and 15% of the total NOx-CSM costs for Stringency option 10. The APMT-Economics for Lost Revenue is lower than that for Stringency Option 7 and slightly higher for Stringency Option 10. Overall the percentage and absolute differences between the two modelled computations are relatively small.
- **Spare Engines** – Account for 33% to 42% of the total NOx-CSM costs for Stringency option 7 and 19% to 27% of the total NOx-CSM costs for Stringency option 10. Again the largest differences between the two computations are for Stringency option 7 where the individual differences are up to 14%.

Figure 5.4 Differences between APMT-Economics and NOx-CSM by Cost Component

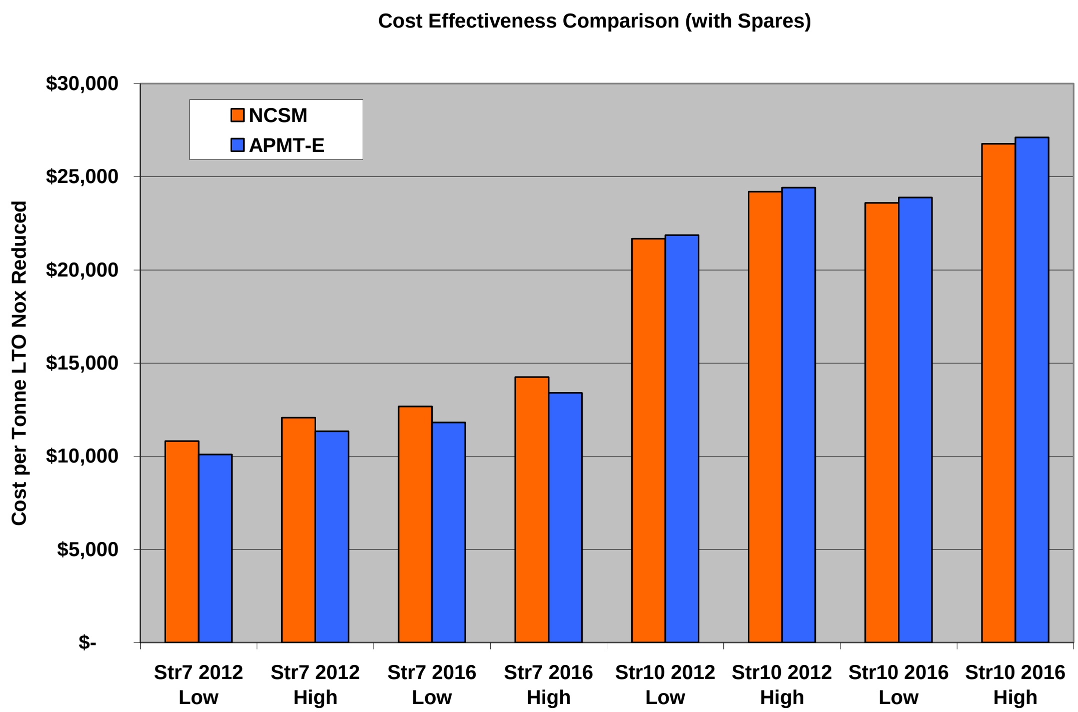


APMT-Economics Forecasts of Cost-effectiveness

5.2.11 The overall cost-effectiveness comparison is presented in Figure 5.5 for eight tests as combinations of stringency options, non-recurring cost estimate and implementation year, assuming no application of discounting (0% rate). Given the previous presentation of very similar NOx saving outputs and the similarities in the overall cost computations, the overall cost-effectiveness comparisons are consistently close between APMT-Economics and the NOx-CSM[19].

[19] It is noted that there is a difference in the assignment of one engine type where the NCM has this classified as an MS2 modification and APMT-Economics modeling has assumed it to be compliant. However, this engine would

Figure 5.5 Comparison of Overall Cost-effectiveness Results (0% Discount Rate)



Stringency	Implementation Year	Recurring Cost Scenario	NCSM	APMT-E	% Difference	Absolute Difference
7	2012	Low	$ 10,807	$ 10,089	-6.6%	$ -718
7	2012	High	$ 12,070	$ 11,337	-6.1%	$ -732
7	2016	Low	$ 12,669	$ 11,812	-6.8%	$ -857
7	2016	High	$ 14,253	$ 13,400	-6.0%	$ -853
10	2012	Low	$ 21,669	$ 21,870	0.9%	$ 201
10	2012	High	$ 24,196	$ 24,408	0.9%	$ 213
10	2016	Low	$ 23,593	$ 23,886	1.2%	$ 293
10	2016	High	$ 26,763	$ 27,113	1.3%	$ 349

Cost per Tonne LTO NOx Reduced

only be used on less than 3% of flights and the costs of MS2 modifications are relatively small (i.e., no fuel effects and small production and > maintenance costs relative to those for MS3) so this is not sufficiently material to explain the higher difference between the NCM and APMT-Economics for stringency 7.

5.3 Comparison of the APMT-Economics Results from Economics-led with the Operations-led Approach

5.3.1 The comparison between APMT-Economics in operations-led and economics-led modes needs to be made with the default assumption that there is no effect on demand in response to cost changes; effectively using the common assumptions employed in the NOx-CSM.

5.3.2 There will be some differences in absolute forecasts from APMT-Economics in Operations-led and Economics led mode because even though the same underlying operating cost processing is used, the forecasts are based on different forecasts of aircraft operations and representations of the FESG fleet forecasts at an aircraft level. However, the cost differences between the two approaches are expected to be broadly of the same order and the rank ordering of effects expected to be consistent.

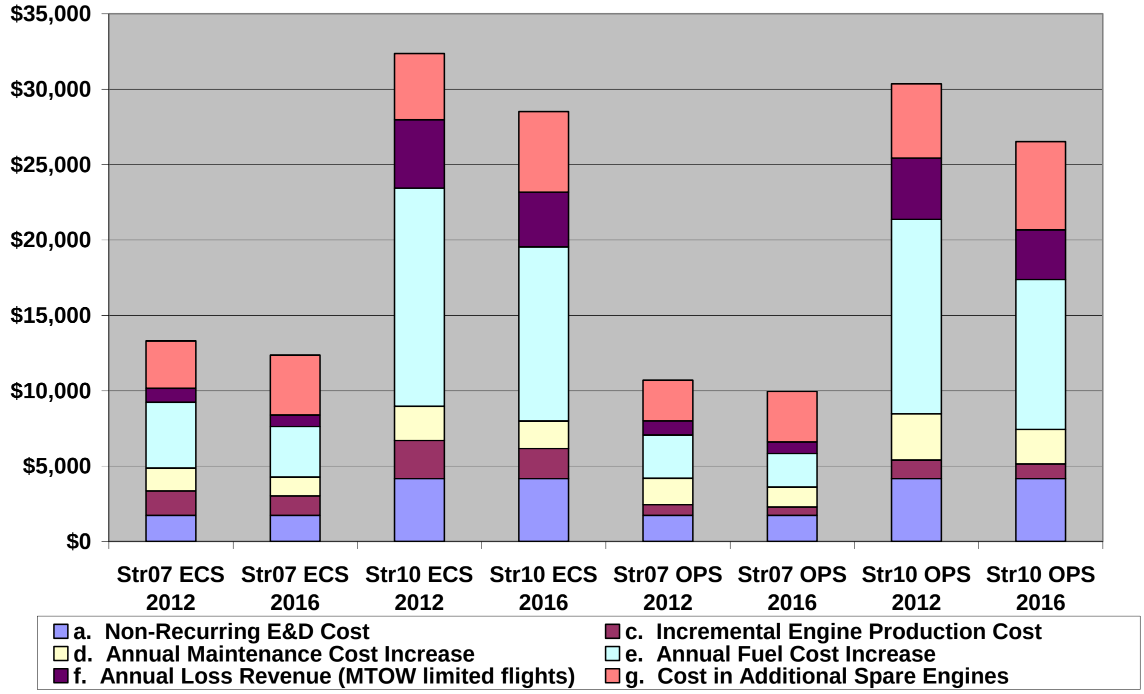
5.3.3 Figure 5.6 illustrates the total costs of stringency option 7 and option 10 tests for the economics-led and operations-led approach approaches. As expected, the costs of the stringency measures are forecast to be consistently higher from the tests using APMT-Economics in both percentage and absolute terms. Overall the economics-led computations are 15% higher for Stringency option 10 and 30% higher for stringency option 7. Importantly, the ranking of the effects of the measures is intuitively consistent and the contribution of each of the cost components to each of the outputs is also consistent.

5.3.4 Part of the cost difference is explained by the inclusion of a greater part of the FESG fleet and operations forecasts in the Economics-led tests; as noted in Chapter 2 the MODTF application of the FESG forecasts excluded seat class, route-group and stage length combinations that were not present in the 2006 Datum. Therefore, the economics-led figures are produced from a slightly larger volume of underlying aviation activity. This accounts for approximately one third of the absolute difference, $1.3Bn in absolute total cost terms. Without this effect, the size of the differences between the two approaches would be much smaller and separate tests where the operations are more closely matched demonstrate that the costs would be higher by between 10% and 20%.

5.3.5 At a detailed level, the remainder of the difference in results can primarily be explained by the difference in treatment of aircraft retirement; where, in the economics-led mode there is a continual retirement of aircraft for the model to remain internally consistent and this leads to an increased requirement for new fleet turnover and hence an increased effect on all cost components.

5.3.6 The size of the differences in the forecast of the effects between the two approaches of $3Bn need to be put in context of the overall airline industry costs of approximately $420Bn per annum in 2006 and forecast to rise to approximately $1600Bn in 2036. At this level the total costs of stringency option 10 ranges from between $30Bn to $35Bn across all forecast years from 2012 or 2016 to 2036.

Figure 5.6 Comparison of Total Costs from Economics-led and Operations-led APMT-Economics Tests (High Recurring Costs, 0% Discount)



6 Concluding Remarks

6.1.1 Through this study the APMT-Economics tool has demonstrated its application to a NOx stringency analysis. It has demonstrated flexibility in employing assumptions that match those prepared by FESG and also importantly, when applied in economics-led forecasting mode, can produce comprehensive and internally consistent forecasts of the effects of NOx stringency measures including consistent demand responses to cost changes.

6.1.2 In economics-led model APMT-Economics has demonstrated that despite being a complex and detailed model it has the fidelity to reliably and consistently model the demand and costs of interventions relative to a Baseline, that invoke only relatively small cost changes, down to the level of a 0.2% annual increase in overall airline operating costs.

6.1.3 The APMT-Economics results compare well to those of the NOx-CSM overall. At a detailed level, despite using different approaches to modelling the stringency measures and the overall scale of aviation industry costs, the results at a component level were shown to have a good degree of consistency.

6.1.4 The overall benefits of undertaking this analysis with APMT-Economics are that:

- The APMT-Economics tool has demonstrated its ability to provide consistent results in two modes of operation.
- The demand responsive and comprehensive cost forecasting features of APMT-Economics have proved valuable in demonstrating to some CAEP-FESG members that the underlying assumption that demand effects can be largely ignored for the main stringency analysis using the NOx-CSM is reasonable.
- CAEP-FESG can have confidence that the results from NOx-CSM were independently confirmed for a sample of the stringency tests being undertaken for CAEP.

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