EUROPEAN AVIATION SAFETY AGENCY
AGENCE EUROPÉENNE DE LA SÉCURITÉ AÉRIENNE
EUROPÄISCHE AGENTUR FÜR FLUGSICHERHEIT

Research project EASA.2009/OP15

Study on AViation and Economic modelling (SAVE)

19 November 2010

easa.europa.eu

Systems that Deliver

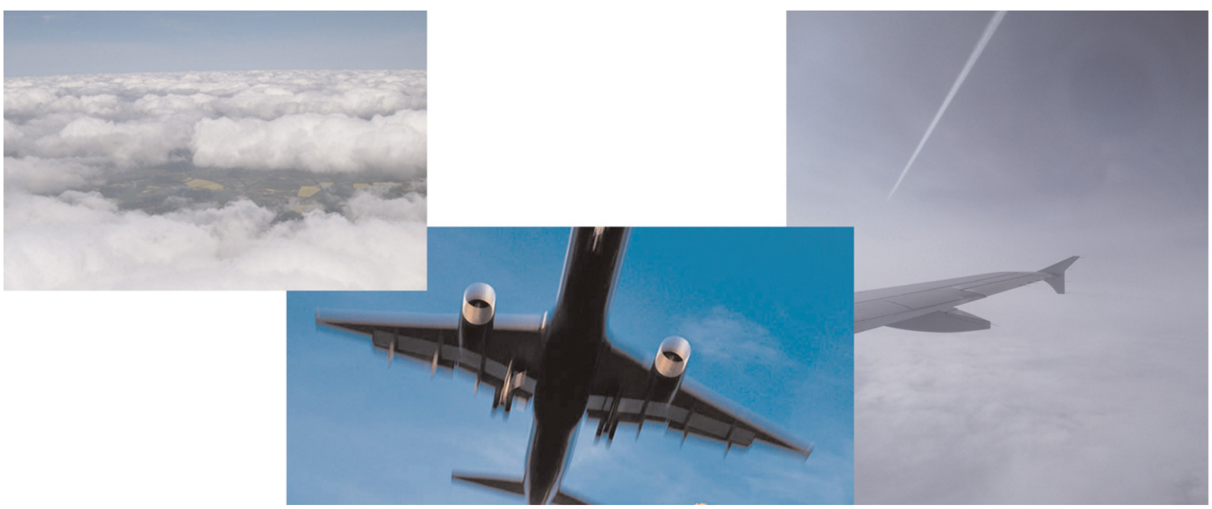
MVA in association with NLR, TAKS, QinetiQ, DLR

November 2010

Study on Aviation and Economic Modelling (SAVE)

Final Report

European Aviation Safety Agency Contract EASA.2009.OP.15



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Document Control

Project Title:	Study on Aviation and Economic Modelling
MVA Project Number:	C3936900
Document Type:	Report
Directory & File Name:	B:\C3936900 Aero (Save)\6. Reporting\2. Final Report\Final Report\Final\With Comments Still In\20101119 C3936900 Save Final Report Vfinal.Doc

Document Approval

Primary Author:	TAKS
Other Author(s):	MVA, NLR, QinetiQ, DLR
Reviewer(s):	Steve Lowe, Andre Van Velzen, Gerrit Baarse
Formatted by:	MVA

Distribution

Issue	Date	Distribution	Comments
1	02/09/2010	TAKS	Internal Review
2	09/09/2010	MVA	Internal Review
3	15/09/2010	EASA	Chapters 1-9 for review
4	10/11/2010	EASA	Final

Management Summary

The Aviation Emissions and evaluation of Reduction Options Modelling System (AERO-MS) has been developed in the period 1994 - 2000, and is aimed at the assessment of the global aircraft engine emissions. The AERO-MS can be used to assess the effects of a range of possible measures to reduce aircraft engine emissions taking into account the responses of and effects on all relevant actors (airlines, consumers, governments and manufacturers). The value of the AERO-MS has been demonstrated by its successful application in a considerable number of international studies in the period 1996 - 2008.

The AERO-MS primary input data on world-wide aircraft movements, air-service demand and aircraft technology characteristics was based on 1992. Therefore, for the continued use of the AERO-MS, an update of these data was becoming increasingly necessary. In July 2009 EASA initiated the project SAVE (Study on Aviation Economic modelling). The SAVE project was assigned to a consortium consisting of MVA Consultancy, National Aerospace Laboratory (NLR), Transport Analysis and Knowledge Systems (TAKS), DLR - German Aerospace Center and QinetiQ. The SAVE project was executed in the period December 2009 to November 2010.

SAVE's objectives have been to deliver a stand-alone, PC based updated and enhanced version of the AERO-MS. This involved the following tasks:

- The update of all relevant model inputs and associated databases.
- Implement a number of model and data structure enhancements
- Implement software technical enhancements.
- The calibration of the updated AERO-MS.
- The testing and validation of scenario and policy options.

The Base Year of the updated AERO-MS is 2006. As part of the SAVE project, all model inputs have been updated and brought in line with this new Base Year. Hereby use is made of the WISDOM Operations Database as a basis for the AERO-MS Unified Database which contains a detailed record of aviation movements in the Base Year. For 2006, the Unified Database records 123,025 airport-pairs with 33.1 million civil flights. Airline cost and fare data were updated using IATA and ICAO data. The update of aircraft type input data was based on fleet inventory properties from the EUROCONTROL PRISME Fleet 2, OAG Fleet Databases, ICAO emissions databank as well as the FESG retirement curves. For the specification of aircraft operational characteristics use of the EUROCONTROL BADA data was used to the furthest extent possible.

The main model and data structure enhancements implemented in the updated version of the AERO-MS relate to:

- Consideration of airport pairs instead of city pairs;
- Consideration of Low Cost Carriers (LCCs);
- Update of the regionalisation of countries to account for geo-political changes since 1992.

The main software technical enhancements to the AERO-MS are the migration of the AERO-MS models and the User Interface to up-to-date software platforms and the establishing of a data access layer on top of the AERO-MS databases.

The calibration aimed to have the updated AERO-MS produce the correct outputs for the Base Year. The calibration focused on various output categories: i) air transport demand; ii) airline operating costs, revenues and operating result; iii) airline employment; iv) aviation fuel burn and emissions; and v) aircraft fleet size and composition. The overall conclusion was that the revised AERO-MS calibrates generally very well against empirical estimates and the outputs of other models.

The AERO-MS computes the effects of policy options relative to a baseline future development without policy options in place (scenario). The main scenario considered in the SAVE project is the CAEP/8 Medium Growth scenario for 2016, 2026 and 2036. Also a number of variations to the main scenario are considered. The overall conclusion from the testing of scenario options is that all scenario user facilities in the updated AERO-MS still function correctly. The CAEP/8 Medium Growth scenario was taken on board in the AERO-MS as a starting point for the analysis of the effects of policy options for the reduction of aviation emissions.

The testing of policy options was aimed at the verification of the proper functioning of the updated AERO-MS and the illustration of its analysis capabilities. The following steps were taken: i) testing of main global policies; ii) testing on the specific behaviour of policies under different conditions and for different regional applications; and iii) testing of a number of illustrative sample cases. The sample cases were: i) possibilities for achieving a fuel efficiency improvement target; ii) effects of open rotor; and iii) effects of variations on the EU emission trading system.

Policies were tested by comparing the policy effects of the updated version with the old version of the AERO-MS. The results of the comparisons have shown that the general patterns of policy responses across the various types of policies are comparable between the old and new version of the AERO-MS. Differences observed can be explained well, given the updates in input data, dimensions and schematisation. The results of the policy tests thus provide strong reassurance that the SAVE project has been successful in achieving the intended updating, as well as in not introducing unintended consequences. Moreover the sample cases have shown that the AERO-MS is capable of supporting the analysis of policy options for the reduction of aircraft emissions which are presently discussed in international forums.

Finally as part of the SAVE project proposals for further improvements to the AERO-MS have been explored. Also the necessary structure and data protocols to establish interfaces between the AERO-MS and EUROCONTROL environmental models have been investigated.

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Executive Summary

Chapter 1 Introduction

In 1994, the Dutch government's Civil Aviation Department started the development of the Aviation Emissions and evaluation of Reduction Options Modelling System: the AERO-MS. The value of the AERO-MS has been demonstrated by its successful application in a considerable number of high-profile international studies in the period 1996 - 2008.

In July 2009 EASA initiated the project SAVE (Study on Aviation Economic modelling). SAVE's objectives have been to deliver a stand-alone, PC based working version of the AERO-MS; to provide an update of all relevant input data; and to enhance its modelling capabilities.

In November 2009 the execution of SAVE was assigned to a consortium consisting of:

- MVA Consultancy - Lead Consultant
- National Aerospace Laboratory (NLR)
- Transport Analysis and Knowledge Systems (TAKS)
- DLR - German Aerospace Center
- QinetiQ.

MVA, NLR and the founding directors of TAKS comprised the original core AERO-MS team. The addition of DLR and QinetiQ has broadened the expertise of the team to deliver additional benefits for EASA.

The SAVE project was executed in the period December 2009 to November 2010. An Interim Report was delivered at the end of the inception phase (in February 2010). The present, Final Report provides a full description of the AERO-MS update procedure and the successful completion of the SAVE project.

Chapter 2 Overview and history of the AERO-MS

The AERO-MS was designed to provide a quantitative description of the present and future air transport system aimed at the assessment of aircraft engine emissions. The specific capabilities of the AERO-MS are directed towards assessing the effects of a range of possible measures to reduce aircraft engine emissions taking into account the responses of and effects on all relevant actors (airlines, consumers, governments and manufacturers).

The economic and technical modelling of air transport within the AERO-MS consists of five complimentary core models, which cover:

- Aircraft technology characteristics based on fleet development (model ATEC)
- The future demand for air services and aircraft flights (model ADEM)
- The aircraft operating costs of the flight activity (model ACOS)

- The aircraft fuel use and aircraft engine emissions in 3-dimensional space (model FLEM)
- The cost and revenues and other direct economic impacts of air transport (model DECI).

In addition, the AERO-MS contains an efficient User Interface to facilitate the interaction between the five AERO-MS models and the interaction between the user and the system.

The AERO-MS is capable of handling a great many scenario developments and policy options. Scenarios reflect different expectations of autonomous developments with respect to air transport and flight activities. Policy options include a variety of financial, technological and operational measures.

Policy options are evaluated in the context of alternative future "business-as-usual" scenarios for the aviation sector. In this respect, the AERO-MS distinguishes between three different modelling situations:

- The Base situation representing the best possible knowledge of the air transport system in today's world
- Projections of future scenario's containing alternative, autonomous economic and technological developments without policy options (referred to as the Datum situation)
- Projections of alternative (sets of) policy options within a specified scenario context (referred to as the Forecast situation).

The AERO-MS has proved to be a very powerful tool in the evaluation of policy options to reduce the environmental impact of aircraft engine emissions. However, its primary input data on world-wide aircraft movements, air-service demand and aircraft technology characteristics was based on 1992. Therefore, for the continued use of the AERO-MS, an update of these data was becoming increasingly necessary.

The SAVE project provides a complete update of data used in the AERO-MS, together with a selective number of enhancements. Moreover, in SAVE the need and feasibility of additional modelling enhancements have been further explored. These results provide a firm basis for the continued use and further development of the AERO-MS.

Chapter 3 Scope of the SAVE project

EASA's detailed requirements regarding the tasks to be performed and the products to be delivered have been specified In the Invitation to Tender of the SAVE project. The main requirements include:

- An updated, stand-alone PC-based version of the AERO-MS and related databases.
- A demonstration of the updated model performance and validation of model results
- Documentation of the AERO-MS update and products to support its use and dissemination
- Explorations on the enhancement of AERO-MS modelling capabilities and the use of its results by other (environmental) models.

A total of 13 work packages were defined as a practical basis for project execution and division of tasks among Consortium members. Each work package was assigned a lead member of the Consortium, having the prime responsibility for its execution and the delivery of the associated results. The main work packages considered relate to:

- The update of all relevant model inputs and associated databases
- The calibration of the updated AERO-MS
- The testing and validation of scenario and policy options
- Software technical support and enhancements
- Possible enhancements of fleet and flight forecasting for environmental assessment
- Reporting and dissemination of project results.

Important assumptions regarding project execution were formulated in the project proposal and the inception phase of the project, in agreement with EASA. Following these agreements there would be no re-structuring of the model system and no significant (re-)coding of individual models. Within this presumption, major enhancements to be achieved included:

- Re-defining regions to account for geo-political changes since 1992
- Operating at the level of individual airports (rather than cities)
- The use of geographically disaggregated data (all individual airport pairs) in the Unified Database
- Distinguishing between low-cost and relatively long-established carrier types
- Migration to an up-to-date software platform
- Establishing a data access layer on top of the AERO-MS databases.

Other important assumptions regarding project execution were formulated as follows:

- The Base Year for the update of the AERO-MS will be 2006
- Use of the WISDOM Operations Database as a basis for developing the Unified Database and use of the EUROCONTROL BADA data (version 3.7) for specification of aircraft operational characteristics in FLEM to the extent possible
- Update of commercial movements and associated demand in the Unified Database to be based on the same sources as originally employed
- General and military aviation not to be considered in the update
- Aircraft operating cost data to be sourced from published material
- Fare levels to be related to operating costs.

Chapter 4 Model and data structure enhancements

The following model and data structure enhancements have been implemented in the updated version of the AERO-MS.

- Consideration of airport pairs instead of city pairs

- Consideration of Low Cost Carriers (LCCs)
- Update of the regionalisation of countries
- Update of AERO-MS dimensions.

The 1992 AERO-MS Unified Database contained a description of direct (non-stop) aircraft movements between each pair of cities in the base year (1992). As part of the update of the AERO-MS, the already-detailed spatial capability of the model has been enhanced, by redefinition of the model "zones" from city level to airport level. As a result of this change, and because the updated AERO-MS does not contain aggregations of flight stages, the number of zones (airports) contained in the Unified Database increased from 1990 to 6104.

When the original AERO-MS was constructed, scheduled low-cost operations comprised a very small part of the global market, and were therefore not treated separately from other scheduled operations. However, in the last 2 decades, the supply of (and demand for) low-cost flights has led to a rapid expansion in the size of the LCC market. Given the very different demand profiles and cost structures of LCCs in comparison with scheduled carriers, it was felt necessary to treat LCC differently from the network carrier operations in the updated AERO-MS.

In the updated AERO-MS LCC operations are combined with charter movements, because of the similar characteristics of LCC and charter operations. As such, in the updated AERO-MS scheduled low-cost operations are treated separately from scheduled operations of network carriers.

Because the global political map has changed substantially since 1992, it was necessary to update the regionalisation in the AERO-MS, including the mapping of countries to regions. The update of the regionalisation has resulted in a re-definition of the 14 world regions in the AERO-MS. The 14 regions give rise to 196 region-pairs considered in the AERO-MS. The main purposes for defining regions and region-pairs in AERO-MS are:

- i) a large number of inputs and outputs are defined by region or region-pair
- ii) scenario and policy specifications can be defined by region or region-pair.

In the updated regionalisation Europe is split into EU27 and non-EU ECAC with also Russia and Belarus as a separate region. North America, Central America / Caribbean and South America are also 3 separate regions. North Africa is separated from the rest of Africa. Middle East is a separate region. Asia is split into 4 regions (Indian Subcontinent and Central Asia; China and Mongolia; Japan and Korea and South East Asia). The final region defined is Australia and Oceania. The 14 AERO-MS regions can be mapped to the 6 regions used by the Economic Analyses and Database (EAD) Division of ICAO.

AERO-MS model variables can be defined by a maximum of five dimensions. In the AERO-MS information for the about 100 dimensions is centrally defined in a data file which contains information on the number of elements in a dimension and the labels of dimension elements. As part of the SAVE project all dimensions have been reviewed and an assessment is made as to which of the dimensions needed to be updated. It was found that 19 dimensions needed to be changed as part of the update of the AERO-MS. The required changes were implemented.

Chapter 5 Update of the Unified Database

The Unified Database is the foundation upon which the Aviation Emissions Reduction Options Modelling System (AERO-MS) is built. It contains a detailed record of aviation movements in the model base year (2006), providing information on the volume of global aviation movements and corresponding passenger numbers and weight of cargo transported.

The new Unified Database constructed as part of the SAVE project updates the base year of the model from 1992 to 2006, and expands the level of spatial capabilities of the model by including information for each pair of airports for which direct (non-stop) aircraft movements were recorded in the new base year.

Data are represented as annual quantities. For 2006, the Unified Database records:

- 123,025 airport-pairs
- 33.1 m civil flights
- 2.6 bn passenger trips
- 4,658 bn passenger-km
- 44.8 m tonnes of cargo transported
- 158 bn cargo tonne-km

The updated Unified Database was compiled using a number of input data sources:

- 2006 WISDOM Operations Database of aircraft movement data – 6 week sample, global aviation movements, with factors for expansion to the annual level;
- 2006 ICAO Traffic by Flight Stage (TFS) scheduled air movement and demand data – annual, international;
- 2006 U.S. Department of Transport (DOT) T-100 scheduled air movement and demand data – annual, domestic U.S.;
- 2006 IATA Route Tracker passenger class split data – annual, international.

Creating the Unified Database required the datasets above to be combined. The demand and movement data available in the TFS and T-100 were employed to estimate load factors for application to the aircraft movement data provided by the WISDOM database. The passenger class split data was utilised to divide the demand data into distinct classes for use in AERO-MS.

Chapter 6 Update cost and fare input data

The AERO-MS variables comprising aircraft operating costs are owned by the ACOS model. The main function of ACOS is to estimate the operating costs on each flight stage for each (generic) aircraft type that could feasibly operate the flight stage. The costs by aircraft type are then fed into the aircraft choice mechanism that is shared with the ADEM model.

In turn, the main function of the aircraft choice mechanism is to modify the mix of aircraft forecast to operate on a stage as a consequence of the costs of operating different aircraft types being affected to different degrees by policy options. In response to these cost impacts the more fuel-efficient aircraft types will be less affected and thus become more attractive to operate. However, they may well have higher ownership costs, and the aircraft choice mechanism trades off these (and any other) differences in costs.

It follows that a crucial requirement of the input cost data is to be able to distinguish the individual components of operating costs between aircraft types on a systematic basis. Fare data was also updated using IATA and ICAO data. During this update, a conscious effort was made to ensure that inputs are at the same level of detail and disaggregation as those originally in the model. Where this has not been possible (due to data non-availability) this is clearly stated in the Report.

As part of the AERO-MS update, the definitions of the generic aircraft types have been revised. Consequently, the named aircraft that are allocated to those types differ from the 1992 based model.

Chapter 7 Update aircraft type input data

Chapter 7 describes the data gathering and processing to update aircraft type input data in ATEC to the new Base Year of 2006. The update is based on the fleet inventory properties from the EUROCONTROL PRISME Fleet 2, OAG Fleet Databases, ICAO emissions databank as well as the FESG retirement curves. The data includes historic technology scenarios and fleet sales over the years, and the geographical distribution of the fleet.

PRISME Fleet 2 is the EUROCONTROL aircraft database that holds the relevant information on a tail-number basis. This database has been used as the prime source of information to classify aircraft for this project. The information extracted from PRISME reflects the world fleet build-up for mid 2006. Aircraft are developed for certain markets with a payload and range in mind, leading to typical aircraft sizes and weights. Based on the properties of the individual aircraft, each aircraft is assigned to an aircraft purpose (passenger or cargo), a seat and range band (closely matching those of the FESG), a technology level (dependent upon the year of certification of the engine type), and AERO-MS region (operator region).

For each of the seat and range bands, technology scenarios, that describe fuel consumption and emissions as a function of engine certification) year, are extracted from the underlying aircraft data.

The retirement curve specifies the fraction (or percentage) of aircraft that are still in service as a function of how much of the average aircraft lifetime that has passed since the aircraft came into service. For the SAVE project, the FESG retirement curve is adopted. Because analyses have shown the average lifetime of aircraft to vary considerably between generic aircraft types, within the SAVE project, the original FESG curve has been modified to allow for the use of different maximum retirement ages, which introduces an additional degree of freedom in the modelling process.

Finally, the resulting data is made harmonized, compiled and made consistent for the ATEC model.

Chapter 8 - Flight and emissions modelling

The Flight and Emission Model (FLEM) within the AERO-MS serves to generate accurate information on the flight tracks, emissions and fuel consumption for 2006 and for a future situation optionally including operational policy measures. To accomplish this, FLEM combines the fuel flow and emission properties of a future fleet resulting from the ATEC model, with detailed characteristics of specific reference aircraft types.

The data currently supporting FLEM is based on detailed aircraft characteristics. However this source of data is no longer available and is therefore not considered a viable long term solution. As such, within the SAVE project, a feasibility study was performed to investigate to what extent EUROCONTROL's Base of Aircraft Data (BADA) version 3.7 could be used to update FLEM input variables. Complementary to BADA, the ICAO emissions database 16A and Jane's All the World Aircraft was used for specific information on engine characteristics.

Using BADA 3.7 and the other sources in combination, most of the variables used in FLEM could be populated appropriately, but there were seven critical variables that could not be. The main reasons for this is that BADA 3.7 does not contain the level of detail in aircraft characteristics required by FLEM, because of a difference in design philosophy between BADA 3.7 and FLEM. Unfortunately the discrepancies between FLEM and BADA proved to be too great to resolve within the SAVE project.

Though the reference aircraft in FLEM cannot be fully updated, they have been recalibrated to correspond with the updated 2006 fleet. Long term solutions for the Flight and Emissions model are discussed in Chapter 13.

The detour factors for 2006 in the updated AERO-MS are based on IEOGG (Independent Expert Operational Goals Group) data with respect to the estimated efficiency of the ATM system in 2006. For each of the 196 region pairs in the AERO-MS a detour value has been determined by taking the average of the ATM efficiency of the origin and destination region.

Chapter 9 Software and technical enhancements

The AERO-MS includes a software shell which manages the access to the central database, the interaction between the various models and the interaction between the user and the AERO-MS. In the SAVE project a number of software-technical enhancements to the shell and the models have been implemented in the AERO-MS.

In order to implement future model changes more easily, the first software enhancement involved the conversion of the code to new software platforms. The 1992 AERO-MS models were developed in C, and some parts of the framework (the Data Manager and Run Time library) in C++, using Borland C++ 5.01. The code was converted to Microsoft Visual Studio C++ 2008 being the modern-day equivalent. The AERO-MS user interface was originally developed in Delphi 7, and was converted to its successor Embarcadero Delphi 2010. It has been verified that, apart from very small, insignificant changes, the converted code yields the same results compared with the non-converted code.

The AERO-MS has a proprietary Application Programming Interface (API) to access the data in the AERO-MS databases. As part of the SAVE project a data access layer has been built on top of the AERO-MS databases. The data access layer publishes the content of the database of any run in SQL format.

A number of further software technical changes to the AERO-MS user interface and models were made as part of the SAVE project. These relate to:

- i) changes to the folder structure of the AERO-MS
- ii) dimensions displayed in the user interface
- iii) the data inspector function in the user interface
- iv) references in the user interface to atmospheric models and MECI (previously included in the AERO-MS but not in the updated version)
- v) relatively minor changes to the model code to ensure correct functioning with new data and dimension values.

Chapter 10 Calibration of updated AERO-MS

The calibration aimed to ensure the updated AERO-MS produces the correct outputs for the Base Year, compared to independent sources of data, by tuning the model inputs. The two main steps taken in the calibration were:

- collect reference data from external sources
- actual calibration of the new Base Year results.

It was agreed for the calibration of the updated Base Year to adopt the procedure which was also followed for the calibration of the original AERO-MS Base Year (1992). It was also agreed that no calibration of the number of aircraft movements was required because these directly follow from the WISDOM Operations Database which has already been reviewed extensively. The calibration of the AERO-MS focused on the following Base Year output categories:

- air transport demand (passengers, cargo, RTK’s)
- airline operating costs, revenues and operating result
- airline employment
- aviation fuel burn and emissions
- aircraft fleet size and composition.

Reference data were gathered from various external sources. For the calibration of air transport demand, airline operating costs, revenues and overall operating result, use was made of statistical data collected by ICAO from its Contracting States. Data on airline employment are published by the Air Transport Action Group (ATAG). With respect to aviation fuel burn and emissions, use was made of UNFCCC and IEA data, but also comparisons were made between the computational result of the AERO-MS for 2006 and fuel burn and emissions computed by other models. For the aircraft fleet size and composition CAEP/FESG data were used as a reference source.

The AERO-MS outputs were calibrated at various geographical levels. The main distinction was made between the calibration of results at a global level and the level of various world regions. The overall conclusion was that the revised AERO-MS calibrates generally very well against empirical estimates and the outputs of other models. Where there were differences between the results of the updated AERO-MS and the reference information, this was often explained by a difference in flight coverage between the updated AERO-MS Unified Database and the reference source. Generally it was possible to achieve a better calibration compared with the 1992 calibration, also because a more complete set of reference information was available for 2006.

Chapter 11 Testing of scenario options

The main purpose of the AERO-MS is to test the effects of potential policy options to reduce aviation emissions. The AERO-MS computes the effects of policy options relative to a baseline future development without policy options in place (scenario). In the AERO-MS a scenario is defined in terms of a coherent set of scenario variables. A scenario in the AERO-MS should be internally consistent, cover the total range of potential future developments of relevance for the air transport sector and must be formulated in such a way that it can be made operational by means of the available AERO-MS scenario variables.

The main scenario considered in the SAVE project is the CAEP/8 Medium Growth scenario. The main scenario year is 2026, but a scenario specification is also made for the years 2016 and 2036. The scenarios are referred to as the CAEP8-M 2016, CAEP8-M 2026 and CAEP8-M 2036 scenarios. The implementation of the CAEP/8 Medium Growth scenario in the AERO-MS allows for:

- i) the computation of a wide range of effects of the scenario
- ii) providing the main reference situation for the testing of the effects of policy options.

Developments included in the CAEP8-M scenario implementation in the AERO-MS relate to:

- Air transport demand growth
- Load factors
- Aircraft technology improvements
- Operational improvements
- Aircraft utilization and fleet size
- Operating costs, fares and airline profitability.

The effects of the CAEP8-M scenario as computed by the AERO-MS are compared with the computational results of various other models used in the CAEP process (i.e. AEDT/SAGE, AEM, AERO2k, FAST). Generally it was found that results of the AERO-MS and the other models are reasonably in line, but it was also found that the percentage growth in the number of flights in the AERO-MS is somewhat higher compared with what other models forecast. Since the same demand growth forecast and development of load factors underlie the various model computations, it seems that the change over time in the mix of operations across aircraft seat bands in the other models is different from what the AERO-MS assumes. As a result of the higher growth in the number of movements, the growth in fuel burn and related CO_2 emissions are also higher according to the AERO-MS. However, the regional pattern is similar in the AERO-MS to that of the other models.

With respect to global NO_x emissions, the AERO-MS computes an increase over time which is higher than the increase in fuel burn. This thus results in an increase of the global fleet average Emission Index (EI) for NO_x. Other CAEO models yield different results in this respect. The difference can likely be explained by different data used in relation to the technology developments before 2006 (i.e. this affects the EI NOx of the older aircraft which are replaced by newer aircraft and hence also the development of the fleet average EI NO_x over time).

A number of variations to the main CAEP8-M scenario are considered. These are

- i) optimistic technology and operational improvement (instead of moderate technology and operational improvement in the main scenario)
- ii) possible effect of oil price increase from Base (2006) to Datum (2026) on demand growth
- iii) taking into account the observed growth in aviation demand over the period 2007-2009.

The variations have been defined in order to test various different scenario user options in the AERO-MS and to show some of the potential scenario analyses to be carried out with the AERO-MS.

The overall conclusion from the testing of scenario options was that all scenario user facilities in the updated AERO-MS still function correctly. Another conclusion is that the AERO-MS is able to broadly take on board the latest scenarios developed within CAEP, and show the consequences in terms of aviation emissions and the economic situation of the global airline industry. This can be a starting point for the analysis of the effects of policy options for the reduction of emissions.

Chapter 12 Testing of policy options

The testing of policy options is aimed at the verification of the proper functioning of the updated AERO-MS and the illustration of its analysis capabilities. Within the policy testing the following steps have been considered:

- Testing of main global policies
- Selective testing on the specific behaviour of policies under different conditions and for different regional applications
- Testing of a number of illustrative sample cases.

The testing of global policies involves a representative set of policies that reflect the core functionality of the AERO-MS. Policies were tested by comparing the policy effects of the updated version with the old version of the AERO-MS. However, there are many reasons why the absolute results between the old and new AERO-MS versions are not directly comparable. Therefore it was only meaningful to make relative comparisons of the nature and extent of the behaviour and responses of the policies considered.

Policy impacts were compared based on a subset of relevant impacts related to air transport demand, flight operation, effects on airlines (costs and revenues), impacts on other actors and fuel use. The results of the comparisons have shown that the general patterns of policy responses across the various types of policies are comparable between the old and new version of the AERO-MS. Differences observed can be explained well, given the updates in input data, dimensions and schematisation. The results of the global policy tests thus provide strong reassurance that the SAVE project has been successful in achieving the intended updating, as well as in not introducing unintended consequences.

With respect to the various types of global policies considered some main observations are:

- Conclusions on the financial measures (taxation and charges) remain largely unchanged: fuel taxation and route charges remain to be most efficient, followed by the airport charge. Ticket taxation and especially value added taxation still seem least attractive.
- The prospect of measures such as scrapping (phasing out old aircraft) and tax credits seems to have become relatively less favourable because technology differences between the older and more current parts of the fleet, and thereby potential fuel savings, have become less significant.
- The prospect of measures such as accelerated fuel technology and ATM improvement seems to have become relatively more favourable because of the increase in the cost reductions associated with potential fuel savings.

The selective testing of specific policy applications was required:

- Investigation of selective policy responses
- Policy testing for different scenarios
- Regional effects of data update.

Selective policy responses investigated pertain to airline behaviour related to passing on costs to airline clients (driving the demand effects of measures) and aircraft choice (driving the technology effects of measures). For both types of responses, control options are provided within the AERO-MS allowing for the analysis of different types of airline behaviour that may occur depending on specific policy conditions. The example analyses demonstrate both the importance and use options of these important mechanisms within the AERO-MS.

A subset of global policies were tested under different scenarios, i.e. a CAEP/8 medium scenario for 2016, 2026 and 2036 and for a specific 2026 scenario with 'optimistic' baseline technology improvements. The policies considered were a fuel taxation (FT50), a scrapping measure (CScrap25) and an additional fuel technology improvement of 1% per year during the period 2007-2026. From the comparison of policy effects for the different scenario years it was concluded that the policies show a different behaviour in time that can be well explained. Comparing the effects under the regular and optimistic technology scenario for 2026 it was concluded that the relevant effects of the measures are quite robust against the changes between the two scenarios.

Following the update of air transport demand and air transport quantities it was shown that certain logical shifts have occurred in the ranking of countries and the shares of regions with respect to their contributions to the total volume of air transport. These differences also become manifest in the global impacts of regional policies as well as the regional impacts of global policies, as was demonstrated by considering a number of variations of the fuel taxation policy. On a more aggregate level the relative differences are rather limited.

Within the testing of sample cases, the following examples were considered:

- Possibilities for achieving a fuel efficiency improvement target
- Effects of specific technology developments (open rotor)
- Variations on the EU emission trading system (EU-ETS).

From these sample test cases the following outcomes are observed and specifically demonstrate the flexibility in the types of analysis and valuable insights that the AERO-MS can provide.

Fuel Efficiency

A comparison was made of the potential for fuel efficiency improvement (in terms of reducing fuel per RTK) for a number of measures including scrapping old aircraft, fuel technology and ATM improvement. The scrapping measure was found to be least effective. Both fuel technology and ATM improvement seem potentially favourable. The results suggest that, under favourable conditions, a combination of these measures might achieve a fuel efficiency improvement target of between 10% to 15% in the next 20 years.

Technology Developments

If it were assumed that open rotor technology could achieve a fuel use reduction of 15% for aircraft being certified from 2020 onwards, reductions in global fuel use brought about by the application of this technology would be quite modest when considered for individual aircraft types. This follows from the fact that the improved technology would only gradually enter into the fleet beyond 2020. Even if the open rotor technology would be applicable to all aircraft types, the overall reduction in global fuel use would still be only about 7% by the year 2036.

EU Emission Trading System

The EC proposal for the EU-ETS considers all flights departing from and arriving in an EU country. The cap to these emissions is set to 95% of average emissions in the period 1994-1996. A total of 18% of the emissions under the cap will be auctioned. The remaining 82% is benchmarked and made available to airlines free of charge. An option presently debated is the so-called "de minimis" provision for smaller air transport countries, implying that flights to, from and within the EU operated by carriers from these countries would be excluded from the EU-ETS. These two options were considered under two different assumptions. Under the first assumption the total cost of allowances (including the opportunity costs of benchmarked allowances) would be passed on to airline clients. Under the second assumption, only the costs of allowances actually purchased would be passed on.

The maximum effect on fuel use and CO_2 emissions is achieved for the EC-proposal with the total cost of allowances passed on, where the aviation sector would annually save less than 9 megatons of CO_2 (under the M 2026 scenario). This would be reduced to less than 7 megatons under the de-minimis option. In both cases these reductions would amount to only about 3.5% of the CO_2 emissions in 2026 beyond the cap, meaning that more than 96% of the required reduction would have to be from allowances to be bought from other sectors. If only the cost of allowances to be purchased would be passed on, the CO_2 reduction by the aviation sector would be further reduced (due to the decrease in the demand effect). In this case, the contribution of the aviation sector would be less than 2.5% of the total CO_2 reduction to be achieved in 2026.

Chapter 13: Proposals for further improvements to the AERO-MS

This chapter sets out the Consortium's findings in carrying out Work Package 9 (WP9): "Improved fleet and flight forecasting for environmental assessment". The purpose of WP9 was to contribute to EASA's objective of having an improved forecasting module to develop future fleets and operations with sufficient granularity for environmental assessments. Actual implementation of the proposed enhancements, however, would be beyond the scope of the current project.

The following topics have been considered:

- Resolving How BADA Might Support FLEM or use of AEM
- Enhancing Aircraft Retirement Functions
- Suggestions for Improvements to WISDOM
- Refining Aircraft Technology Characteristics Within Existing Model Structure
- Effect on Growth of Airport Capacity Constraints
- Forecasting Fuel Price Impacts in the Datum Case
- Differentiating Carrier Business Models and Allowing for Carrier Competition
- Forecasting Horizons for Transition Effects
- Refine Aircraft Technology Characteristics
- Detour Factors
- Additional Mappings and Interface Issues
- Levying Taxes/Charges at Individual Airports
- Intermediate Stops to Reduce Exposure to Emissions Trading Scheme
- Take-up of Alternative Fuels

Chapter 14: Interface with other models

In order to assess the environmental benefits and potential trade-offs within cost effectiveness / cost benefit assessments, it would be helpful if interfaces exist between AERO-MS and EUROCONTROL environmental models. EASA requested the SAVE consortium to investigate the necessary structure and data protocols required to be able to establish such interfaces. The investigation has taken into account past work performed within the EASA project called EEMA. The main EUROCONTROL models involved are AEM, STAPES, and ALAQS. Also other models such as GHG climate models CTMK and Sausen have been taken into account in the investigation. By establishing interfaces between AERO-MS and other models, the capabilities for performing (local) environmental and economic assessments in a standardized way are further increased.

Several options are available for establishing an interface between AERO-MS and the environmental models. EASA has expressed a clear preference for the Data Warehouse approach. For such an approach it is necessary to map the AERO-MS data, the data needed for the EUROCONTROL Environmental models (AEM, STAPES, ALAQS) and data in the climate models to the Data Warehouse contents.

A practical and relevant approach to bringing together Europe's aviation environmental modelling capability was developed in the EEMA project in the form of a Data Warehouse concept. This has demonstrated the feasibility and value of collecting and controlling the model input data [EEMA, 2007]. It is expected that the development of the Data Warehouse concept will progress both under SESAR WP16, to support current and future aviation and environmental assessment modelling, and under TEAM_Play, which focuses mainly on policy modelling issues.

In Chapter 14 the interface facilitating export of AERO-MS data is considered. This encompasses traffic and aircraft properties relevant to post processing (local air quality, noise, capacity, etc.). The interface with the Unified Database to accommodate traffic from the EEMA Data Warehouse has also been examined. At the same time, the compatibility and interfacing issues of AERO-MS with the prototype EEMA/EUROCONTROL input data structure and with the EUROCONTROL environmental toolset has been investigated by mapping data from these tools to the Data Warehouse contents. These matters can feed into implementation of an interface between the AERO-MS and EUROCONTROL models and other models, though this has not been within the scope of the SAVE project. Finally interface implementation issues, with e.g. transport protocols have been investigated.

1 Introduction

1.1 Main objective of the SAVE project

1.1.1 In 1994, the Dutch government's Civil Aviation Department commissioned the UK transpomment sis to develop a modelling system to compute and project aircraft engine emissions on a global level and to assess the economic and environmental impacts of policy options to reduce these emissions. That assignment was the start of the development of the ***Aviation Emissions and evaluation of Reduction Options Modelling System***: the ***AERO-MS***.

1.1.2 The value of the AERO-MS has been demonstrated by its successful application in a considerable number of high-profile international studies. In the period 1998 – 2004, studies with respect to Market Based Options and Voluntary Agreements in order to reduce emissions of the global aviation industry have been conducted for various ICAO CAEP cycles (i.e. CAEP/4, CAEP/5 and CAEP/6). Also the AERO-MS has been applied in various assignments for the EC to assess effects of potential European measures for the reduction of aviation emissions (e.g. kerosene taxation, en route emission charges and emission trading).

1.1.3 To maintain and enhance the value of the AERO-MS, in July 2009 EASA initiated the project ***SAVE (Study on Aviation Economic modelling)***. SAVE's objectives have been:

- To deliver an updated, stand-alone, PC based working version of the AERO-MS;
- To update its economic modelling capability;
- To update all relevant input data;
- To enhance the capability of the AERO-MS to assess European and global effects associated with the implementation of environmental regulatory measures on aviation including technology stringencies, operational limitations and financial measures.

1.1.4 In essence, the project is to provide an update of the AERO-MS, renewing its data inputs and modernising its usability, without engaging in any significant change to its modelling structure. Central to this update are the potential applications of the updated AERO-MS and their contribution to fulfilling EASA's remit in the field of aviation environmental protection.

1.2 Assignment of SAVE and parties involved in project execution

1.2.1 In November 2009 the project was assigned to a consortium consisting of:

- MVA Consultancy – Lead Consultant.
- National Aerospace Laboratory (NLR).
- Transport Analysis and Knowledge Systems (TAKS)
- DLR – German Aerospace Center
- QinetiQ.

1.2.2 MVA, NLR and the founding directors of TAKS comprised the original core AERO-MS team. The addition of DLR and QinetiQ has broadened the expertise of the team to deliver additional benefits for EASA.

MVA Consultancy – Lead Consultant

1.2.3 MVA Consultancy is a management and technical consultancy with over 40 years of experience in all modes of transportation. Regarding the original AERO-MS development, MVA was responsible for the global database on air transport activity (the Unified Database), the aviation demand module (ADEM) and the associated supply cost model (ACOS). MVA also provided the expertise to ensure that the economics of measures were applied to give a plausible reaction from the airline industry.

National Aerospace Laboratory (NLR)

1.2.4 The National Aerospace Laboratory is a non-profit organization established in 1919. It is the central institute in the Netherlands for aerospace research and developments. With respect to the AERO-MS, NLR led the development of the model for fleet replacement and aircraft technology (ATEC) and the flight and emissions model (FLEM). NLR has also supported the other parties in developing the Direct Operating Costs datasets and was responsible for the development of the NLR-runtime library to provide inputs to other models in the AERO-MS.

Transport Analysis and Knowledge Systems (TAKS)

1.2.5 TAKS was established in 2008. Through their previous employer Resource Analysis, the 4 founding directors of TAKS have been involved with the overall design of the AERO-MS from the very start of the AERO project, being responsible for the software technical integration of the modelling system and the development of the user interface. They were also responsible for the development of the direct economic impact model (DECI). In the period 1998 - 2008, the directors of TAKS have applied the AERO-MS in a great many studies for various clients including ICAO/CAEP, the EC, IATA and the Dutch national government.

German Aerospace Center (DLR)

1.2.6 DLR's expertise covers a wide range of aviation specific competence. DLR has coordinated the CONSAVE 2050 project (with other partners: NLR, MVA, IIASA and QinetiQ) and elaborated the CONSAVE scenarios, which were quantified with the AERO-MS. For the SAVE project DLR will bring in specific expertise on model calibration and scenario specification in support of policy assessments, also based on DLR's participation within ICAO CAEP Forecast and Economic Sub Group (FESG) and Market Based Measures Task Force (MBMTF).

QinetiQ

1.2.7 QinetiQ have worked closely with NLR, MVA and DLR in the CONSAVE project. The project combined QinetiQ aviation technical and policy expertise with AERO-MS modelling capabilities to produce the CONSAVE scenario results. QinetiQ's expertise was also employed in the EFEMTA and EASA EEMA projects which set out a European aviation policy modelling system applicable to global (CAEP) and European policy modelling. In SAVE this expertise will be used to support the collection and interpretation of technical data on aircraft technology, fleet development and flight operation.

Involvement of other parties

1.2.8 The execution of the SAVE project has taken place in close cooperation with the client (EASA) and a number of other parties, including the Civil Aviation Department of the Dutch Ministry of Transport, EUROCONTROL and a UK DfT consultant. The Dutch Civil Aviation Department (holding the IPR of the original AERO-MS) have supported the update of the AERO-MS. EUROCONTROL has provided important contributions by making available data and expertise related to a number of key datasets, notably the WISDOM (World Interconnected Sources Database of Operational Movements) database used in CAEP; the PRISME database on the global fleet; and BADA data on aircraft operation characteristics. The participation of the UK DfT consultant was requested by EASA in order to provide general advice to the project given his experience and knowledge of the CAEP process.

1.3 Project documentation and overview of final report

1.3.1 The SAVE project was executed in the period December 2009 to November 2010. The project documentation includes:

- Memos on specific key issues
- An Interim Report
- This Final Report
- An updated AERO-MS User Manual
- Updates of the existing system documentation

1.3.2 The Interim Report was delivered at the end of the inception phase (in February 2010). In consultation with EASA, the Interim Report was set up as a series of separate documents to set out each part of the AERO-MS update procedure as established or foreseen at that time. The documents covered the following topics:

1a Investigation into using WISDOM data in the AERO-MS Unified Database.

1b Demand data preparation.

2a Cost data preparation.

2b Fares estimation.

3 Update aircraft type input data.

4 Flight and emissions modelling.

5 Region and country dimensions and mapping of countries to regions.

6 Consideration of specific treatment of low cost carriers.

7a SAVE SharePoint site.

7b Update of development platform for models and user interface and data access layer.

8 Project deliverables and acceptance criteria.

9 Overview of issues to explore in Work Package 9 (which would be concerned with further development of the AERO-MS beyond the current scope of the SAVE project).

10 Interface with other models.

11 Project execution and client interaction.

1.3.3 The Final Report is contained in the present document, providing a full description of the update procedure and the results achieved in the SAVE project (including the calibration and validation results). In its Invitation to Tender, EASA set out a number of detailed requirements to meet the study objectives and provide the desired deliverables. In structuring the project approach and execution, the Consortium defined a number of concrete 'work packages' to address the EASA requirements. The structure of this Final Report is built upon these work packages. Following the present Introduction, Chapter 2 provides a brief overview of the history and main characteristics of the AERO-MS. Chapter 3 outlines the scope of the SAVE project and introduces the different work packages. The following chapters describe the activities within the various work packages and the results obtained. The chapters are:

4. Model and data structure enhancements (WP5)
5. Update of Unified Database (WP1)
6. Update cost and fare input data (WP2)
7. Update aircraft type input data (WP3)
8. Flight and emissions modelling (WP4)
9. Software-technical enhancements (WP8)
10. Calibration of updated AERO-MS (WP6)
11. Testing of scenario options (WP7)
12. Testing of policy options (WP7)
13. Proposals for further improvements to the AERO-MS (WP9)
14. Interface of AERO-MS with other models (WP10)

1.3.4 The updated AERO-MS User Manual consists of a separate document. Because there has essentially been no re-coding of the existing model system, the changes to the existing model system documentation are very limited. These are therefore not described in a separate document but included in the Final report.

2 Overview and history of the AERO-MS

2.1 Purpose and applications of the AERO-MS

2.1.1 In recent decades, emissions from the civil aviation sector and their possible effects on climate change have become a growing concern. In 1994, the Dutch government's Civil Aviation Department commissioned the development of the AERO-MS (Aviation Emissions and evaluation of Reduction Options Modelling System). The AERO-MS was developed as a policy-testing tool for quantifying the environmental and economic consequences of a wide range of measures to reduce global aircraft engine emissions, including regulatory, financial and operational measures.

2.1.2 More specifically, the AERO-MS was designed to meet the following analysis requirements:

- to provide a quantitative description of the air transport system aimed at the assessment of aircraft engine emissions;
- to adequately reflect the economic and technological developments in air transport;
- to assess the effects of a range of possible measures to reduce aircraft engine emissions taking into account the responses of and effects on all relevant actors (airlines, consumers, governments and manufacturers).

2.1.3 During and after its main development period (1994-1998), the AERO-MS has formed a key part of many international studies where the results from model tests have provided a quantified basis for policy judgement. Major applications of the AERO-MS include:

- Global analysis of emission charges and taxes for the "Focal Point on Charges" (CAEP/4) in the period 1997-1998.
- Assignment for the European Commission to analyse the effects of a taxation of kerosene in the period 1998-1999.
- Analysis of Market Based Options (MBO) for the reduction of global air transport related CO_2 emissions, assigned by the Netherlands' Directorate General of Civil Aviation, on behalf of CAEP's Forecast and Economic Support Group (FESG - CAEP/6) in the year 2000.
- Study to compare the differences between AERO-MS and the Stratus model (developed by the FAA) in assessing aviation effects of emission reduction measures in the period 2002-2003.
- Analysis of Voluntary Agreements and Open Emission Trading systems for the limitation of CO_2 emissions from aviation. Study for FESG (CAEP/6) in the period 2002-2004.
- Comparison of UNFCCC data on emissions from domestic and international aviation to support discussion on commitments of national governments between UNFCCC and ICAO in 2003.
- Study for IATA to inform the development of an IATA position on climate change and emission trading (2005).

- Several studies on the effects of including aviation in the European Emission Trading System (EU ETS) in the period 2004-2007.

2.2 Overview of the AERO-MS

2.2.1 The AERO-MS allows the user a large degree of flexibility in analyzing the effects of specific developments and measures in a "what-if" fashion. This was implemented by creating a great many user options to change key assumptions, schematization aspects, scenario developments and possible measures (policy options).

2.2.2 The economic and technical modelling of air transport within the AERO-MS consists of five interacting core models, as follows:

- The aircraft technology model (ATEC) to determine aircraft technology characteristics based on fleet development.
- The air transport demand model (ADEM) to forecast demand for air services and aircraft flights.
- The aviation cost model (ACOS) to estimate the overall aircraft operating costs.
- The flights and emissions model (FLEM) to calculate aircraft fuel use and engine emissions.
- The direct economic impacts model (DECI) to provide a comprehensive overview of the cost and revenues of air transport and a number of other economic impacts.

2.2.3 Apart from the models, the AERO-MS contains a User Interface which is involved with the interaction between the five AERO models and the interaction between the user and the system. A user of the AERO-MS is thus interfacing with the integrated ***system*** rather than with the individual models.

2.2.4 The five models are briefly described below. Figure 2.1 provides an overview of the core models in the AERO-MS.[1]

Aircraft technology model (ATEC)

2.2.5 The model ATEC is involved with the computation of technical characteristics by aircraft type and technology level based on a modelling of fleet development over time. Aircraft technology particularly applies to the fuel use and emission characteristics of different aircraft types. The technology characteristics are expressed as a function of aircraft 'technology age' which is defined by the year in which the aircraft (type) is certified. The technology age distribution is determined by the fleet build-up which depends on the development in time of aircraft sales (following air transport demand) and aircraft retirement.

[1] The AERO-MS as originally developed also includes models involved with the computation of: (a) emissions from other sources than aviation; (b) specific environmental effects of emissions; and (c) indirect economic effects for the Netherlands only. EASA has not required these models to be considered in the update of the AERO-MS in the SAVE project.

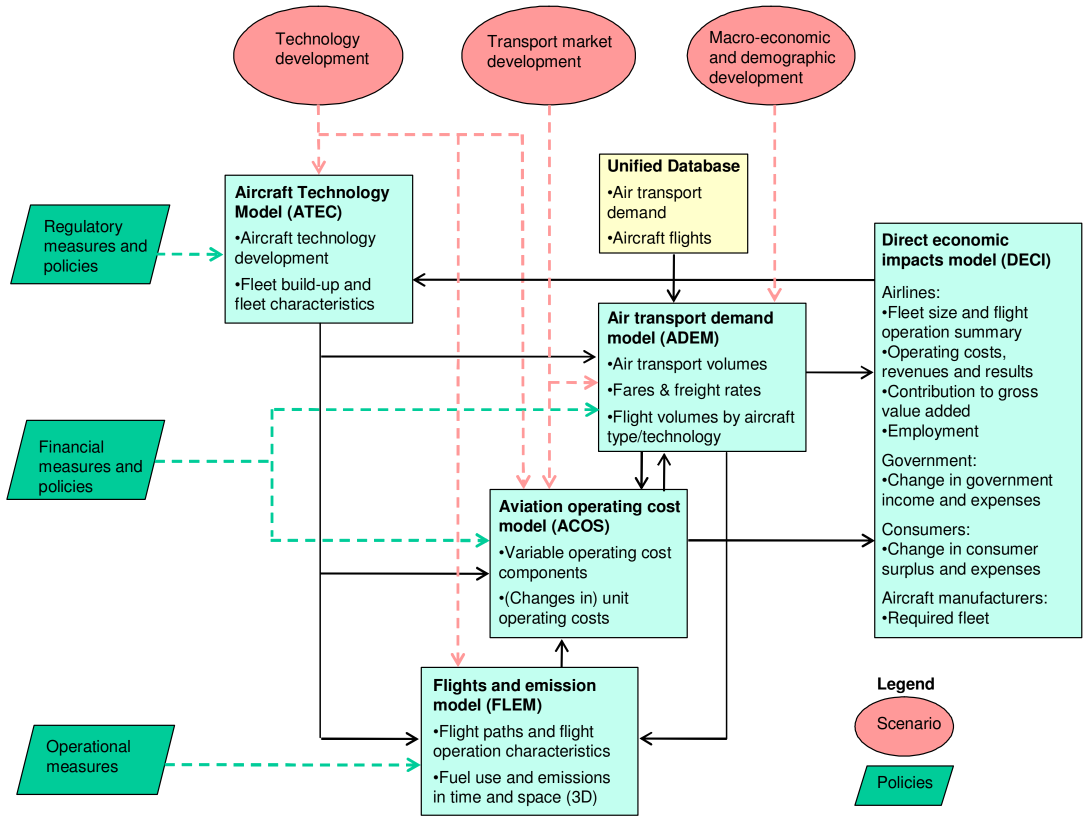

Figure 2.1 Overview of core models in the AERO-MS

Air transport demand model (ADEM)

2.2.6 The model ADEM matches the demand and supply side of air transport, i.e. air transport demand in terms of passengers and freight and the frequency and capacity of air transport services offered. Volumes of passengers and cargo transported, passenger fares and freight rates are determined in the process of balancing supply and demand. Aircraft flights are determined by origin-destination (flight stages) and expressed in terms of aircraft types and technology levels, in accordance with available fleets.

2.2.7 The starting point for the modelling of air transport demand and aircraft flights is provided by the **Unified Database** of the AERO-MS, which is a computerised description of the volume and pattern of global air transport activity in the base year (this is the year 1992 for the original AERO-MS). The original 1992 Unified Database was compiled from a number of major already-available databases and contains a detailed description (on the level of individual flight stage) of passenger and cargo demand and actual flights by aircraft type and technology level.

Aviation cost model (ACOS)

2.2.8 The model ACOS computes all relevant variable aircraft operating cost components and total operating costs. Variable operating costs are associated with flights by aircraft type and technology level and include: fuel costs; route and landing (airport) charges; flight and cabin crew costs; maintenance costs; capital costs (depreciation) and finance costs. In addition, total operating costs include a number of other, volume-related, costs such as the costs of ground-handling, sales, ground facilities (buildings) and overhead. Based on the total operating costs, ACOS determines the unit costs (per passenger and kg of cargo transported) of air transport by aircraft type, technology level and IATA region-pair. In particular, the model ACOS converts the costs of possible measures in the air transport sector to changes in unit operating costs.

Flights and emissions model (FLEM)

2.2.9 The model FLEM provides a detailed description of the actual flight profiles of individual aircraft flights. Fuel-burn and emissions for each flight are computed in three-dimensional space, taking into account the geographical flight specification and the technical characteristics by aircraft type and technology level. The emissions considered include CO_2, NO_x, SO_2, C_xH_y, CO and H_2O. In addition to the computation of fuel-burn and emissions there are a number of other important functions of FLEM. The detailed description of flight paths in FLEM allows for the simulation of a number of specific policy options related to flight operation. Also there is a direct connection between ATEC and FLEM allowing FLEM to take into account developments in aircraft technical and environmental performance as forecasted from scenarios and policies. And finally FLEM provides the information on fuel-burn as a basis for the cost computations in the AERO-MS.

Direct economic impacts model (DECI)

2.2.10 The model DECI is essentially a post-processing model. One of its main functions is to provide a comprehensive overview of the results of the other models in the AERO-MS, in particular the information related to air transport volumes; operating costs, revenues and results; fleet size and flight operation. Another main function of DECI is to compute a number of direct impacts to the relevant actors involved in air transport such as: the contribution of airlines to gross value added; changes in government income and expenses; changes in consumer surplus and expenses; and changes in the required fleet.

Model interactions

2.2.11 Based on the core models described above, the AERO-MS represents an integrated system of *interacting* models. The model ATEC provides inputs on aircraft technology characteristics by aircraft type and technology level to each of the models ADEM, ACOS and FLEM. The models ADEM and ACOS closely interact, whereby ADEM provides information on flight volumes by aircraft type and technology level to ACOS as a basis for computing operating costs, while ACOS provides information on changes in unit costs (following from measures) to assess the impacts of measures on flight volumes in ADEM. The resulting information on flight volumes by aircraft type and technology level from ADEM is used by the model FLEM for the computations of fuel-burn and emissions. In turn, information on fuel-burn resulting from FLEM computations is used in ACOS to allow for the computation of fuel cost. Finally, the information on fleet size and flight operation as compiled in DECI can be fed back into ATEC to ensure consistency with the fleet build-up used in ATEC to determine fleet technology characteristics. In order to facilitate the above interactions between and among different models, the design of the AERO-MS includes a number of iteration procedures and specific provisions.

Scenario developments and policies

2.2.12 The AERO-MS is capable of handling a wide variety of scenario developments and policy options. Scenarios reflect different expectations of autonomous developments affecting air transport activities and related impacts. The AERO-MS contains a large number of scenario variables that can be specified by the user, within the following three main categories:

- Technology development (providing inputs to ATEC, ACOS and FLEM).
- Transport market developments (providing inputs to ADEM and ACOS).
- Macro-economic and demographic developments (providing inputs to ADEM).

2.2.13 Policy options to be considered also fall in three different main categories, as follows:

- Aircraft fleet technology measures and policies (providing inputs to ATEC).
- Financial measures and policies (providing inputs to ADEM and ACOS).
- Operational measures (providing inputs to FLEM).

Outputs of the AERO-MS

2.2.14 The various models in the AERO-MS provide a wealth of different outputs. Provisions made in the User Interface of the AERO-MS allow for a detailed inspection of all individual model results. In addition, facilities have been provided to generate output reports according to the user's own specifications. A standard 'scorecard' facility is available for the comparison of model runs reflecting different scenario and/or policy situations. Main categories of model outputs in the scorecard representation are:

- ***Air transport and aircraft operations***: passenger and cargo demand by type; revenue ton-km; number of flights; aircraft-km.
- ***Effects on airlines***: operating costs, revenues and results; contribution to gross value added; airlines related employment.
- ***Economic effects on other actors***: (change in) government income/expenses; consumer surplus and expenses; required fleet.
- ***Fuel consumption and emissions***.
- ***Operating efficiency indicators*** (such as: operating cost/RTK; fuel/ATK; load factors).

2.3 Analysis principle

2.3.1 Policy options are evaluated in the context of alternative future "business-as-usual" economic and technological scenarios for the aviation sector. The AERO-MS comprehensively integrates the relevant economic, commercial and technological responses of alternative policy options within the scenario contexts considered. In this respect, the AERO-MS distinguishes between three different modelling situations:

- The Base situation representing the best possible knowledge of the air transport system in today's world.

- Projections of future scenario's containing alternative, autonomous economic and technological developments without policy options (referred to as the Datum situation).
- Projections of alternative (sets of) policy options within a specified scenario context (referred to as the Forecast situation).

2.3.2 This basic analysis principle is illustrated in Figure 2.2.

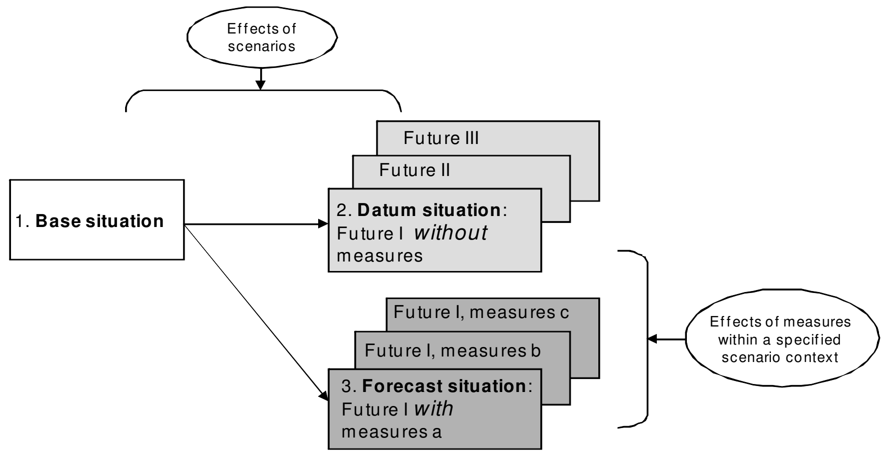

Figure 2.2 Basic analysis principles of the AERO-MS

2.3.3 The primary Base year used in the original AERO-MS was 1992 (which was subsequently updated to the interim Base year 1997). Driven by different sets of assumptions on autonomous developments, the effects of alternative futures (Datum situations) can be analyzed by comparing the modelling results with the Base situation. Within a selected future (Datum situation) reflecting a specific scenario context, the effects of alternative sets of measures (Forecast situations) can be analyzed by comparing the modelling results with the selected Datum situation.

2.3.4 Following the above analysis principle, the effects of alternative policy options are quantified in relation to a common benchmark represented by the selected Datum situation. This produces a "snapshot" of each policy option against the same scenario in the same year, allowing a comparative evaluation of policy options on a consistent basis. In order for this 'snapshot' evaluation procedure to be valid, it must be ensured that the measures were introduced sufficiently long before the selected forecast year so that, by that year, a more or less complete adaptation to the measure(s) will have been achieved.

2.3.5 The AERO-MS is global in coverage, but functions at a highly disaggregate level in several "dimensions", including:

- Spatial dimensions ranging from individual flight stages (based on city-pairs[2]) to a country and (IATA) region level.
- Air service demand for different classes of passenger traffic and air cargo.

[2] In the updated version of the AERO-MS airport-pairs are considered instead of city-pairs.

- Air service supply represented by ten generic aircraft types differentiated by combinations of seating (or cargo) capacity and range capability.
- Aircraft technology related to fuel efficiency and emissions based on different technology age classes within generic aircraft types.

2.3.6 Each explicit flight stage is described in the Unified Database in terms of its passenger and cargo demand, and the number of flights performed by each generic aircraft type, split according to technology age class and region of carrier registration. Other relevant input data include fares, freight rates and costs for different carriers, routes and aircraft types, as well as data on aircraft engine characteristics for the modelling of fuel-burn and emissions. The economic modelling in the AERO-MS is applied to commercial aviation. Non-commercial general aviation and military aviation have been included only in the fuel-burn and emission calculations (as part of FLEM). It was agreed with EASA that within SAVE, the fuel-burn and emissions related to the non-commercial and military aviation types will not be considered. This is because the policy context for reducing non-commercial and military aviation emissions is different from the context of reducing emissions from commercial civil aviation. For example the Kyoto Protocol requires industrialised countries to pursue the limitation or reduction of GHG emissions from international **civil** aviation through ICAO.

2.4 Maintaining and enhancing the value of the AERO-MS

2.4.1 The AERO-MS has proved to be a very powerful tool in the evaluation of policy options to reduce the environmental impact of aircraft engine emissions. However, its primary input data on world-wide aircraft movements, air-service demand and aircraft technology characteristics was based on 1992. Therefore, for the continued use of the AERO-MS, an update of these data was becoming increasingly necessary. Moreover, there have been other developments in the aviation sector as well as a broadening of the interest in aviation's environmental impacts and possible policy options to mitigate these. Following these developments, in 2007, the Dutch government's Civil Aviation Department has explored the requirements and possibilities of updating and redesigning the AERO-MS in order to enhance its modelling capabilities. The enhanced modelling system envisaged is referred to as AEROplus. Among the main requirements identified are:

- Broadening the AERO-MS potential in analyzing environmental policy options related to noise and local air quality.
- Extending the definition of aircraft types to allow for a finer granularity and increase the analysis potential with respect to environmental regulation and stringency measures.
- Consideration of different carrier business models with respect to aircraft choice and fleet investment decisions and to better represent carrier competition.
- Improvement of forecast procedures to be based on a stepwise projection in time.
- Establishing structural links between the AERO-MS and other models for (local) environmental and economic assessments.

2.4.2 The present SAVE project provides a complete update of data used in the AERO-MS, together with a selective number of enhancements related to modelling schematization. Moreover, in SAVE the need and feasibility of additional modelling enhancements have been further explored. The results of the SAVE project will provide a firm basis for the continued use of the AERO-MS in support of regional and global studies aimed at mitigating the environmental effects of aviation. Additional enhancements have also been identified to further develop AERO-MS capabilities via subsequent EASA projects or as part of other European aviation projects.

3 Scope of the SAVE project

3.1 EASA requirements

3.1.1 In the Invitation to Tender (ITT) of the SAVE project, EASA specified their detailed requirements regarding the tasks to be performed and the products to be delivered. These requirements can be summarised in the following main categories:

1) An updated, stand-alone PC-based version of the AERO-MS and related databases.

2) A demonstration of the updated model performance and validation of model behaviour based on the consideration of a number of plausible policy scenarios.

3) Documentation of AERO-MS update, incl. user manual and system documentation.

4) Products to support the use and dissemination of the updated AERO-MS.

5) Explorations on need and possibilities to enhance AERO-MS modelling capabilities and to support the use of AERO-MS results by other (environmental) models.

1) Updated version of the AERO-MS and related databases

3.1.2 From the ITT it followed that the updated version of the AERO-MS and its databases was to be the key deliverable of the SAVE project. More detailed requirements by EASA regarding this main product were specified as follows:

- A full update of all relevant input data to accurately describe the characteristics of the current aviation industry.
- A capability to assess all relevant aviation environmental policy options, including but not limited to, certification standards, operating restrictions and market based measures.
- Sufficient modelling granularity, functionality and flexibility to adapt to the needs of the relevant policy assessments.
- The use of best design practices and software development techniques which permit the model to be responsive and flexible and to ensure its capabilities for broad application.

2) Demonstration of updated model performance and validation of model behaviour

3.1.3 The behaviour of the updated AERO-MS was to be validated based on its performance in a variety of plausible policy scenarios to be defined in consultation with the client. In addition, a comprehensive testing was required of all relevant policy options involving all basic functional parts of the models. In the testing and validation process, results of the updated modelling system would be compared against other model results, available information from observed practices, or other generally accepted expert knowledge and information sources.

3) Documentation of AERO-MS update, including user manual and system documentation

3.1.4 A full and detailed documentation would be required of the model and database update procedures and results. In addition, an update would be required of the user manual and system documentation. However, since there was to be essentially no restructuring of the model system nor a re-coding of individual models, changes to the existing model documentation would be very limited.

4) Products to support the use and dissemination of the updated AERO-MS

3.1.5 In this respect, the requirements explicitly specified by EASA included a training course on the use of the AERO-MS and a PowerPoint presentation of the final results of the SAVE project, to be made to EASA and ICAO CAEP.

5) Explorations to enhance AERO-MS capabilities and its use by other models

3.1.6 Under this category, EASA identified two specific requirements. The first was involved with the possible improvement of the AERO-MS forecasting capabilities regarding the projection of future fleets and flight operations with sufficient granularity for environmental assessments. The second related to the investigation of the necessary structure and data protocols in order to interface with existing EUROCONTROL environmental models (such as AEM, STAPES and ALAQS), taking into account past work performed on these aspects (e.g. related to the data warehouse concept).

3.2 Work packages in SAVE project

3.2.1 As a practical basis for project execution and division of the tasks among Consortium members, a number of work packages were defined. Each work package was assigned a lead member of the Consortium, having the prime responsibility for its execution (including the formulation of required contributions from other Consortium members). An overview of work packages and lead Consortium members is presented in the table below.

Table 3.1 Overview of work packages and lead Consortium members

WP	Description	Lead Consortium member
WP1	Update of Unified Database	MVA
WP2	Update cost and fare input data	MVA
WP3	Update aircraft type input data	NLR
WP4	Flight and emissions modelling	NLR
WP5	Model and data structure enhancements	MVA
WP6	Calibration of updated AERO-MS	TAKS
WP7	Testing/validation scenario and policy options	TAKS
WP8	Software-technical support and enhancements	TAKS
WP9	Proposals to improve fleet and flight forecasting for environmental assessment	MVA
WP10	Interface with other models	NLR
WP11	Reporting	TAKS
WP12	Dissemination of project results	MVA
WP13	Project Management	MVA

3.2.2 In defining the contents of and approaches to these work packages it was ensured that all EASA requirements were adequately covered. Consequently, the work packages provide a full coverage of the project tasks to be executed and the results to be achieved. The following briefly describes the contents of the work packages.

WP1 – Update of Unified Database

3.2.3 The "Unified Database" is the basis and starting point of the AERO-MS forecasting capability. It contains an overview of global commercial aircraft movements and associated demand (passengers and freight) by individual flight stages, which in the original AERO-MS were based on city-pairs. The main tasks in this work package have been:

- Collect movement and demand data.
- Process data to re-populate Unified Database.
- Validate the updated Unified Database.

3.2.4 The data to re-populate the Unified Database have been collected from available sources for 2006, which is the new "Base Year". During the project it was decided in agreement with EASA that the WISDOM Operations Database held by EUROCONTROL would be used as the basis for the AERO-MS Unified Database (see also chapter 5 of this report).

3.2.5 The processing of the basic data has taken place in accordance with the assumptions on the relevant schematization aspects, subject to the model and data structure enhancements to be considered in WP5. The product of this work package is a complete and updated description of global flight operations according to the specifications required by the AERO-MS.

WP2 – Update cost and fare input data

3.2.6 Central to the forecasting by the AERO-MS of future flight operations is the assessment of the relative changes in aircraft operating costs through time and the related changes in fares. Detailed information on the present cost and fare structure is vital to that. The work package has updated aircraft ownership and day-to-day operating cost data; it has also synthesised and validated the required fares data.

3.2.7 Aircraft operating costs are broken down into ownership costs (capital costs including leasing and financing) and a number of variable operating costs including fuel costs; maintenance costs; landing and en-route charges; and cabin and flight crew costs. Cost data have been assembled for the computation of these costs by aircraft type and technology age, taking into account the regional differentiation in the cost components, where relevant. Fare data have been synthesized and processed to the level of individual flight stages. The product of this work package is a number of updated data files that will allow for the computation of costs and revenues on the required schematization levels, in accordance with the assumptions and results of work packages 1 and 3.

WP3 – Update aircraft type input data

3.2.8 In matching supply and demand in air transportation and the subsequent computation of operating costs, fuel use and emissions, the AERO-MS requires detailed information on fleet characteristics and specific aircraft type data. This information needs to be collected for generic aircraft types that are specified in terms of: capacity and range bands; cargo and passenger aircraft; and aircraft technology level (based on technology age). An update of the specification of these generic aircraft types was included in the work package. The information is derived from the processing of available information for the Base-Year world fleet and the mapping of this information onto the newly specified, generic aircraft types. The product of this work package is a number of updated and validated data files that will allow for the assessment of the relevant fleet and aircraft characteristics in the forecasting process, based on the projection of required fleet capacity.

WP4 – Flight and emissions modelling

3.2.9 The model FLEM determines the fuel use and emissions associated with forecasted volumes and patterns of global flight operations in three dimensional space. The modelling process in FLEM allows for the simulation of different operational measures affecting flight operation. Also, FLEM provides the estimates of fuel use required for the computation of fuel costs. It is essential that the aircraft characteristics related to flight performance, fuel burn and emission computations as used in FLEM are in agreement with the average aircraft type characteristics by generic aircraft type and their development in time in relation to fleet size and composition. The work package is involved with the matching of the aircraft characteristics used in FLEM with the average characteristics of the generic aircraft types used in the other models of the AERO-MS. This is achieved by synthesizing the data requirements for the reference aircraft types used to specify the detailed flight operations in FLEM. The resulting product consists of a number of updated and validated data files for the detailed assessment of flight operation, fuel use and emissions in FLEM.

WP5 – Model and data structure enhancements

3.2.10 The AERO-MS considers a great number of dimensions, both spatial and other, that allow it to function at a disaggregate level. Results are usually reported at more aggregate levels, in agreement with commonly used dimensions and report structures. In SAVE the modelling dimensions have been reviewed and revised to bring them up-to-date and to meet EASA's specific requirements, both from a presentation and modelling enhancement perspective. The most important revisions include:

- An update of the definition of regions, countries, cities and airports to adjust to changes in the geo-political map since 1992.
- A shift from flight stages on the level of city-pair to airport-pair.
- Explicit consideration of low-cost carriers alongside the traditional full service carriers.

3.2.11 The above type of changes and enhancements have considerable implications for the dimension and data structure involving all models of the AERO-MS, as well as the various tasks involved with the data update procedures (as included in WP1, WP2 and WP3). Work package 5 specified the required changes and their further processing in terms of model adjustments, data structures, input files and mapping procedures and the further testing of these changes.

WP6 – Calibration of updated AERO-MS

3.2.12 A calibration and validation of the entire updated AERO-MS has been carried out to ensure that the computational results match independent data. The calibration has tuned model inputs so that the model produces outputs for the new Base Year of 2006. All of the key results related to aviation activity, and its economic and environmental impacts, simultaneously match independent data sources.

3.2.13 The work package has involved collecting calibration and validation data from independent data sources and then calibrating the new Base Year results. The main output categories considered in the calibration process have included:

- aircraft movements;
- passenger and cargo carried;
- aircraft fleet;
- aviation fuel consumption and emissions;
- airline operating costs and revenues.

3.2.14 These outputs have been calibrated at various geographical levels. The product to be delivered is a calibration of the AERO-MS computational results for the new Base Year as well as a comprehensive description of the calibration process.

WP7 – Testing/validation scenario and policy options

3.2.15 The work package distinguished a number of steps in the testing procedure, including:

- A broad technical testing of all AERO-MS functionality
- Testing, validation and interpretation of scenario development options
- Testing, validation and interpretation of policy options.

3.2.16 The broad technical testing involved a quick testing of the whole spectrum of analysis options to ensure that all functionality of the previous version of the AERO-MS was still intact. The scenario testing evolves around the development of a Business as Usual (BaU) scenario to provide the default Datum run for the further testing and demonstration of policies. A number of scenario variations were defined to demonstrate the use and potential of scenario analyses, in relation to policy evaluation. Policy testing has been based on a representative range of global policy options and a more selective number of non-global policy options. Finally, a selection of policy combinations and special cases was considered to provide a number of illustrative testing examples related to policy issues and questions which are of particular interest to EASA and/or CAEP. The product resulting from this work package is a comprehensive description of the testing and analysis procedures of the examples considered, as well as an overview of testing results and related observations and interpretations.

WP8 – Software-technical support and enhancements

3.2.17 This work package comprised all tasks related to the update and enhancement of the software technical design of the final product, based on the present AERO-MS while applying the current best practices with respect to software development techniques. The main tasks and products included:

- The establishment of a Sharepoint site for communication and exchange of documents and data among Consortium members, the client and other parties.
- The migration of the AERO-MS to an up-to-date software platform (Visual Studio C++ 2008 for models and framework and Embarcadero Delphi 2010 for User Interface).
- The development and maintenance of an operational system for release management and version control to be used by all partners during the data update and modelling enhancement process.
- The development of a data access layer (compatible with MS SQL 2008) to provide access to AERO input data and modelling results for general purposes and to facilitate the use of these data in other, related models.
- An update and enhancement of the User Interface.
- General support of model integration, testing and debugging procedures, including all other software changes and improvements required to ensure the proper functioning of the updated system.

WP9 – Proposals to improve fleet and flight forecasting for environmental assessment

3.2.18 In addition to the update of the existing AERO-MS, and the selective modelling enhancements achieved in the previous work packages, WP9 has investigated more extensive improvements of interest to the client from the viewpoint of existing and anticipated analysis requirements. Possible approaches regarding these potential improvements have been explored. The question as to which improvements could be accomplished within the existing modelling structure, and which would require major changes to existing design principles, was of particular interest. The product of this work package includes an assessment of the feasibility, and required resources, for potential improvements as well as further recommendations regarding their potential implementation. The actual implementation of such improvements is outside the scope of the SAVE project.

WP10 –Interface with other models

3.2.19 It is foreseen by EASA that the AERO-MS will interface with environmental models in order to link economic and environmental assessments in the aviation sector. Such environmental models may include: the global aviation emissions model (AEM); the airport noise model (STAPES); the airport air quality model (ALAQS); and climate models such as CTMK and Sausen. This work package has investigated the required interface structure and data protocols to facilitate the exchange of data between the AERO-MS and these other models in accordance with the Data Warehouse approach that was specified in the context of the EASA EEMA study. The work package has provided an overview and further specification of the ways in which the interfacing with the AERO-MS could be established. The actual implementation of interface facilities is outside the scope of the SAVE project.

WP11 - Reporting

3.2.20 Following the inception period of the SAVE project an Interim Report was provided, as described in paragraph 1.3.2. The final documentation comprises the following parts:

- A Final Report – this document – describing the update procedure and the results achieved in the SAVE project (including the calibration and validation results).
- An updated AERO-MS User Manual.
- Updates of the existing system documentation.

3.2.21 Because there has essentially been no re-coding of the existing model system, the changes to the existing model documentation are very limited. These are therefore not described in a separate document but included in this Final Report.

WP12 – Dissemination of project results

3.2.22 This work package is involved with the delivery of the following products:

- A training course regarding the use of the AERO-MS for up to three EASA staff.
- A PowerPoint presentation on the results of the SAVE project to EASA and ICAO CAEP.

WP13 - Project Management

3.2.23 Project management has been an ongoing task during the project, concerned with:

- Meetings and other communication with EASA.
- Internal management of the Consortium.
- Overall delivery of project to time, agreed quality and budget.

3.2.24 Following chapters of this Final Report provide a detailed description of the activities and results within each work package, in particular the work packages 1 through 10. The results of WP5 (model and data structure enhancements) provide an important basis for the execution of the work packages WP1, WP2 and WP3. For this reason, the reporting on WP5 (chapter 4) precedes the reporting on the other work packages.

3.3 Core assumptions for execution of model update

Core assumptions in Consortium Proposal

3.3.1 Within the Consortium's proposal to undertake the SAVE project, a number of important assumptions for execution of the model update were formulated as follows.

3.3.2 The chief objective of the SAVE project was to update the AERO-MS so that it could better support future work in the field of assessing the economic impacts of measures and policies aimed at achieving environmental objectives. The main deliverable was therefore recognised to be the required update of the AERO-MS, covering the Unified Database and the core economic and technology modelling components: ATEC, ADEM, ACOS, FLEM and DECI.

3.3.3 There would be no re-structuring of the model system, and hence no significant (re-)coding of individual models. However, within this presumption the following enhancements would be achieved to the extent possible:

- Re-defining regions to account for geo-political changes (e.g. the much-expanded EU) since 1992.
- Operating at the level of individual airports (rather than cities), to allow more direct interfacing of AERO-MS outputs to local models.
- The use of disaggregated data in the Unified Database (considering all individual flight stages).
- Distinguishing between low-cost and traditional carrier types.
- Migration to an up-to-date software platform.
- Establishing a data access layer on top of the AERO-MS databases to open up modelling results and other AERO-MS data for use in other models.
- Further software technical changes to the AERO-MS user interface and models.

3.3.4 The update of commercial movements and associated demand of scheduled traffic in the Unified Database were anticipated to be based on the same data sources as employed in the preparation of the original Unified Database. The update would pertain to commercial aviation. General and military aviation would not be considered.

3.3.5 Aircraft operating cost data were expected to be sourced from published material, though it was recognised that less published information appears to be available than when the AERO-MS was first assembled. This might therefore require more synthetic treatment of costs to distinguish between aircraft types. Similarly, less published information on fares was available. For this reason, but also to improve model performance, it was proposed to relate fare levels to operating costs.

3.3.6 Since the internal structures and coding of the AERO-MS were not expected to change to any significant extent, the existing detailed technical documentation would continue to be the definitive source material. Any updates to this documentation will be provided separately.

Additional assumptions agreed during inception phase

3.3.7 Further specifications of core assumptions were made in consultation between EASA and the Consortium during the inception phase of the project. These have been specified in the various documents of the Interim Report (for overview see paragraph 1.3.2).

3.3.8 The following describes the main additional assumptions.

- The Base Year to be considered for the update of the AERO-MS is the year 2006.
- EASA has expressed their desire to use the WISDOM Operations Database as a basis for developing the Unified Database. Consequently, this was made available by EUROCONTROL and was used as the main source in compiling the AERO-MS Unified Database.
- The proposal to link fares to costs was replaced by a fare-estimation process which is similar to that for the original version of the AERO-MS, making use of published ICAO and IATA data.
- Generic aircraft types would continue to be specified in terms of capacity and range bands; cargo and passenger aircraft; and aircraft technology level. The number capacity and range bands considered in the original AERO-MS would also be retained, though the definitions of the seat bands would be adjusted to reflect the seat-range classification used by CAEP/FESG to the extent possible. The PRISME database of EUROCONTROL on the actual aircraft in the present fleet was made available and used as a basis to update the required aircraft type characteristics for the generic aircraft types considered.
- EASA also indicated that they would like to use the EUROCONTROL BADA data (version 3.7) as the basis for further specification of aircraft operational characteristics for the reference aircraft considered in FLEM.
- Additional assumptions for the re-definition of regions (see also paragraph 4.4.4).

4 Model and data structure enhancements

4.1 Introduction

4.1.1 Model and data structure enhancements were dealt with under SAVE Work Package 5. A number of enhancements have been implemented in the updated version of the AERO-MS. These enhancements pertain to:

- Re-definition of "Zones" in the Unified Database from cities to airports.
- Consideration of Low Cost Carriers (LCCs) as a distinct type of carrier in the Unified Database and in the AERO-MS forecasting capability.
- Update of the regionalisation of countries (for example due to EU enlargement) which requires the modification of AERO-MS dimensions relating to geographical information.
- An overall review of AERO-MS dimensions and identification of required changes.

4.2 Re-define "zones" from city-pairs to airport-pairs

4.2.1 The AERO-MS Unified Database forms a computerised description of the volume and pattern of global civil aviation activity in the base year of the model. While global in coverage, the primary spatial concept in the Unified Database has hitherto been the description of direct (non-stop) aircraft movements between each pair of cities in the base year.

4.2.2 It was proposed by the Consortium that this already-detailed spatial capability of the model should be enhanced in the creation of the updated Unified Database, by redefinition of the model "zones" from city level to airport level. This redefinition promotes an increased connectivity with other global aviation models.

4.2.3 A significant barrier to the implementation of this update to the zoning system was the level of detail contained in data which would be used in the creation of the Unified Database. The original Unified Database was constructed largely from the published datasets of ICAO, the United States Department of Transport (DOT) and the ABC (now OAG) flight schedules, not all of which contained information at airport-pair level.

4.2.4 However, for the creation of the updated Unified Database, a sample of the WISDOM Operations Database was made available to the Consortium. This provides a consolidated source of global aviation movement data, which is seen as best practice in the aviation industry. It was therefore used as the primary source of information on aircraft movements in the update of the Unified Database (supplanting the combination of datasets mentioned in paragraph 4.2.3).

4.2.5 A key feature of the WISDOM database is that the origins and destinations of all recorded movements are defined at *airport* level. This allowed the implementation of the proposed update of the AERO-MS zoning system from city-pair to airport-pair level. As a result of this change, and because the updated AERO-MS does not contain aggregations of flight stages, the number of zones (airports) contained in the Unified Database increased from 1990 to 6104.

4.2.6 While the WISDOM database provides rich information on aircraft movements, it offers no data on passenger or cargo demand. This data was instead obtained from the datasets mentioned in paragraph 4.2.3. One such dataset (ICAO Traffic by Flight Stage) reported only the city of arrival and departure for each record. It was therefore necessary to develop accurate correspondence between airport and city identifiers to ensure that demand data was correctly appended to movement information. More detailed discussion of this process is contained in Chapter 5 of this report.

4.3 Consideration of Low Cost Carriers as a distinct type of carrier

4.3.1 When the original AERO-MS was constructed, scheduled low-cost operations comprised a very small part of the global market. It was neither necessary nor practical for the model to identify and treat Low Cost Carriers (LCCs) any differently from other scheduled operations. However, in the interim period, the supply of (and demand for) low-cost flights has led to a rapid expansion in the size of the LCC market, with around half of European short-haul activity now performed by LCCs.

4.3.2 It was therefore necessary to consider how LCC movements and demand could be processed as a distinct component of scheduled traffic, and not treated identically to other scheduled flight stages operated by network carriers.

4.3.3 It was initially suggested that LCC operations could be added as a separate "level" within the "movement type" dimension, currently differentiated into two classes ("scheduled" and "charter"). If a third level could be included for LCC operations, it would allow variables such as operating costs and demand elasticities to be separately specified and processed in the model for LCC operations.

4.3.4 However, after examination of the model code and consideration of the effort associated with including a third level within the variable, it was decided that this approach was not possible within the scope of the SAVE project.

4.3.5 A solution to the treatment of Low Cost Carrier operations was identified through comparison of their characteristics with those of charter operations. Common features of LCC and charter operations include:

- Serving point-to-point demand;
- High fare elasticities;
- High load-factors;
- No belly-hold cargo;
- High aircraft utilisation, and hence lower depreciation per block-hour;
- Relatively low crew costs per RTK.

4.3.6 The common features of LCC and charter operations mitigated the impact that the combination of these movements to a single movement type might imply. In the absence of the possibility of including a dedicated LCC movement type and given the very different demand profiles and cost structures of LCCs in comparison to traditional scheduled carriers, it was deemed more appropriate for the LCC segment of the market to be grouped with charter operations than with scheduled network operations.

4.3.7 The Unified Database distinguishes between scheduled and charter activity by including separate traffic lines for each movement type. The consolidation of charter and LCC activity means that "charter" traffic lines in the updated Unified Database would be populated with the combined LCC and charter movements and demand for each flight stage.

4.3.8 A more detailed description of how LCCs were identified and processed during the construction of the Unified Database is contained in Chapter 5 of this report, and discussion of how costs, fares and elasticities were treated to take LCC activity into account can be found in Chapter 6.

4.4 Update of regionalization in the AERO-MS

4.4.1 Clearly the global political map has changed substantially since 1992 (the original base-year of the AERO-MS), particularly with the enlargement of the EU. Hence, it was necessary to update the regionalisation in the AERO-MS, including the mapping of countries to regions.

4.4.2 In the 1992 AERO-MS 14 World Regions were defined, based on definitions of IATA. These 14 regions give rise to 196 region-pairs. The main purposes for defining regions and region-pairs in AERO-MS are as follows:

- A significant number of inputs for the AERO-MS are specified by region or region-pair (such as cost inputs and elasticities of demand).
- Many of the outputs of the AERO-MS are computed and presented by region or region-pair. The economic effects on airlines are computed by the region in which they are based.
- Scenario and policy specifications can be defined by region or region-pair. For example an emissions related airport charge can be specified for all airports in one or more regions. It is noted that other policies (e.g. fuel taxation or emission trading) can also be specified for any set of flight stages or country pairs.
- Inputs and outputs of the AERO-MS which are specified by flight stage can be aggregated to region-pairs or origin/destination regions for presentation purposes.

4.4.3 As a first step in the update of the regionalisation, the country dimension in the AERO-MS was updated. The basis for this was the list of countries used in the recent CAEP/8 Environmental Goals analysis. This list contains 245 countries which includes all 192 UN Member States. Within this list, overseas territories and outer regions are considered as separate 'countries'.

4.4.4 The update of the regionalisation has resulted in a re-definition of the 14 world regions in the AERO-MS. These 14 regions are presented in Table 4.1 below. The table also shows how the 14 AERO-MS regions map to the 6 regions used by the Economic Analyses and Database (EAD) Division of ICAO and the 7 CAEP/FESG regions[4]. A geographical map of the 14 new

[4] In analyses carried out for CAEP/8 both the ICAO/EAD regions and the CAEP/FESG regions were used.

AERO-MS regions is presented in figure 4.1. With respect to the updated regionalisation the following points are noted:

- Europe is split into EU and non-EU ECAC with also Russia and Belarus as a separate region.
- North Africa is separated from the rest of Africa. This is because North Africa has a quite different traffic mix (business, tourism). In case future policies will be defined which have different impacts on different market segments, a separation can help to improve the policy assessment quality.
- Japan and Korea are separated from China (and Mongolia). This is because of the differences in expected air traffic growth rates.
- The 14 AERO-MS regions can exactly be mapped to the 6 ICAO/EAD regions. For this the CIS States in Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) are included in the region 'Indian Subcontinent and Central Asia". An alternative was to link up these 5 CIS States with Russia and Belarus in a single region. However, in that case there would be no full mapping to the 6 ICAO/EAD regions.
- A further split up of the Indian Subcontinent from Central Asia has been considered. However, the volume of air traffic to and from the Central Asian countries is limited, and does not justify defining Central Asia as a separate region. Moreover we have already split up the single ICAO/EAD region Asia/Pacific into 5 separate AERO-MS regions.
- The 14 AERO-MS regions can almost exactly be mapped to the 7 CAEP/FESG regions. The only exception is that within the CAEP/FESG regionalization Russia west of the Urals is included in the region Europe and Russia east of the Urals is included in the region Asia/Pacific. However if in the AERO-MS regionalisation we were to split Russia over two regions, this would create a number of problems. First of all, there is the option in the AERO-MS for modelling a domestic fuel tax (i.e. for all flights within a country). Splitting Russia over two regions would imply we would have to split Russia as a country. The domestic fuel tax would then not work correctly for flights between the two separate parts of Russia. Furthermore, the AERO-MS uses information on the "home region" of carriers. This is based on the home country of a carrier. A split of Russia into two "countries" would imply that we had to allocate carriers to either the Eastern or Western part of Russia (which was expected to be difficult to do).

Table 4.1. New AERO-MS Regions and mapping to ICAO/EAD and CAEP/FESG Regions.

New AERO-MS (or IATA) Regions	ICAO/EAD Regions	CAEP FESG Regions
1. North America	1. North America	1. North America
2. Central America and Caribbean	2. Latin America / Caribbean	2. Central America / Caribbean
3. South America		3. South America
4. ECAC (non-EU)	3. Europe	4. Europe
5. EU		
6. Russia and Belarus		Split over Europe and Asia/Pacific*
7. North Africa	4. Africa	5. Africa
8. Sub-Saharan Africa		
9. Middle East	5. Middle East	6. Middle East
10. Indian Subcontinent and Central Asia	6. Asia / Pacific	7. Asia / Pacific
11. China and Mongolia		
12. Japan and Korea		
13. South East Asia		
14. Australia and Oceania		

* Within the CAEP/FESG regions definition Russia west of Urals is included in Europe; Russia east of Urals is included in Asia/Pacific.

4.4.5 The EU in the updated AERO-MS relates to EU27. Though the AERO-MS Base Year is now 2006 and Bulgaria and Romania only entered the EU in 2007, EU27 is a suitable definition of the EU for forecasting. The outer regions Aland Islands and Gibraltar (both part of the EU) are also included in the new AERO-MS EU region.

4.4.6 ECAC presently has 44 Member States[5]. Apart from the 27 EU Member States these are: (1) Albania; (2) Armenia; (3) Azerbaijan; (4) Bosnia and Herzegovina; (5) Croatia; (6) Georgia; (7) Iceland; (8) Moldova; (9) Monaco; (10) Montenegro; (11) Norway; (12) San Marino; (13) Serbia; (14) Switzerland; (15) The former Yugoslav Republic of Macedonia; (16) Turkey and; (17) Ukraine. A number of smaller European States and outer regions (Andorra,

[5] http://www.eurocontrol.int/corporate/public/standard_page/org_membership.html

Liechtenstein, the Vatican, Faroe Islands, Greenland, Guernsey, Isle of Man, Jersey and Svalbard and Jan Mayen) are also included in the AERO-MS ECAC region.

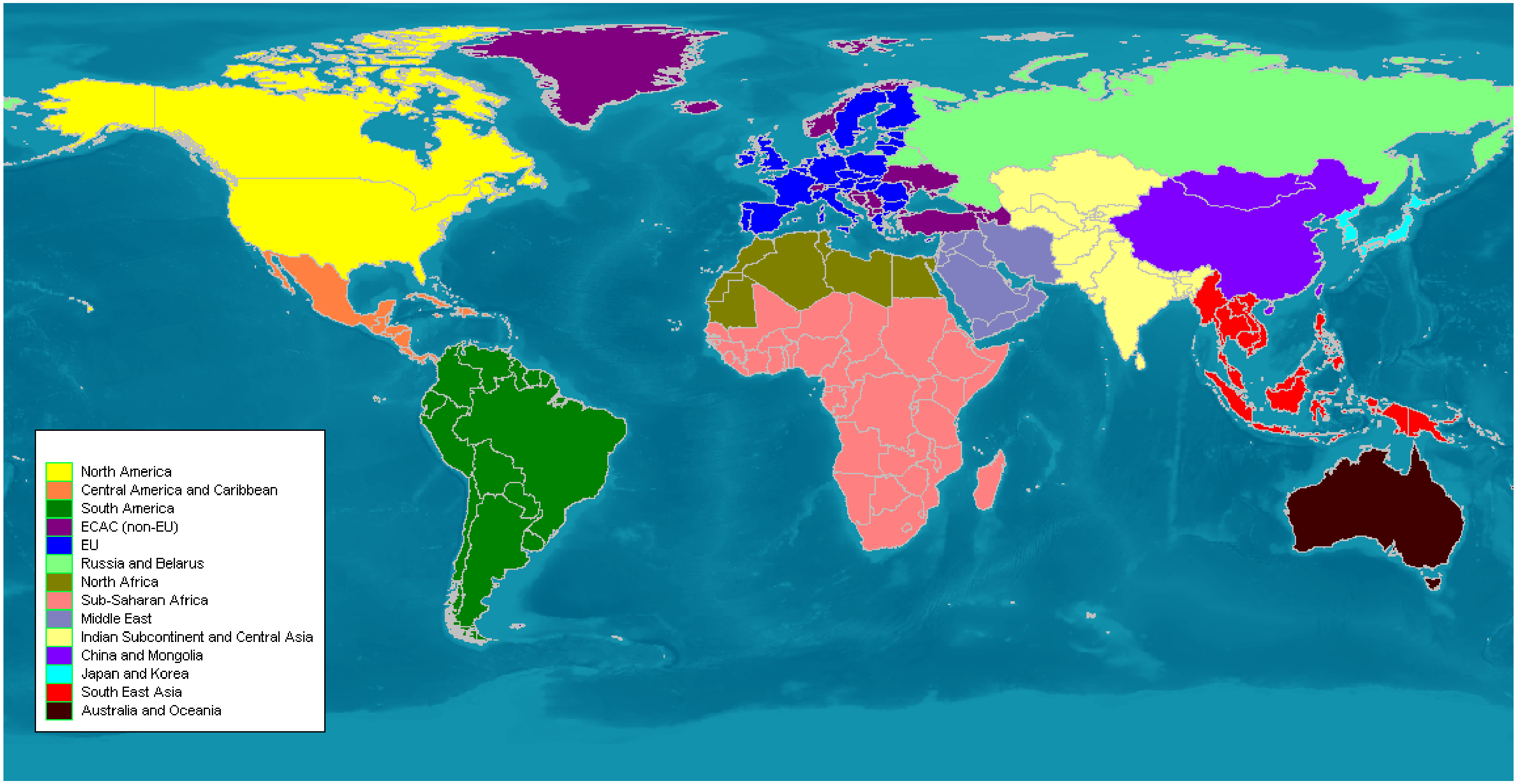

Figure 4.1. Regionalisation in the updated AERO-MS.

4.5 Review of dimensions used in the AERO-MS

4.5.1 AERO-MS model variables can be defined by a maximum of five dimensions. One of the features of the AERO-MS is that information on dimensions is centrally defined and stored in a framework data file. This data file contains information on the number of elements in a dimension and the labels of dimension elements.

4.5.2 As part of the SAVE project all dimensions have been reviewed and an assessment made as to which of the dimensions needed to be updated. In the 1992 AERO-MS 123 dimensions were defined. A number of these dimensions were used only in the atmospheric models, which are not being updated as part of the SAVE project. Also there are some dimensions which, though created during the development of the original 1992 AERO-MS, were not actually used in the AERO-MS models. In total 25 dimensions defined in the 1992 AERO-MS are redundant for the updated AERO-MS. One dimension (CAEP route group) has been added to the AERO-MS. In the 2006 AERO-MS there are thus 99 dimensions used by one or more of the models or the AERO-MS Interface.

4.5.3 It was found that 19 dimensions needed to be changed as part of the update of the AERO-MS:

- Geographical dimensions (14)
- Aircraft type dimensions (2)
- Movement type and flight type dimension (2)
- Year dimension (1).

Geographical dimensions

4.5.4 The dimensions of arrival city and departure city reflect the cities of destination and origin of flights in the 1992 Unified Database. As described in section 4.1, there has been a shift from city-pairs to airport-pairs. The dimensions are thus renamed to ***arrival airport*** and ***departure airport***. The updated AERO-MS now includes flights to/from 6104 airports, while the 1992 version of AERO-MS included only 1990 cities. The dimensions arrival airport and departure airport are used in the AERO-MS Interface to aggregate information by flight stage to the level of airport. Both dimensions are linked to the dimension ***zone*** (also reflecting 6104 airports) which is used by the AERO-MS models.

4.5.5 The 1992 AERO-MS had an aggregated Unified Database, in which "minor" flight stages were consolidated into representative flight stages[6]. In contrast, the updated AERO-MS contains a disaggregated database without such consolidation, though in order to avoid the need to change model code it was decided that the distinction between "major" and "minor" airports should remain. In the updated AERO-MS the dimension ***major origin*** classifies 354 airports as major.

4.5.6 The required update of a number of geographical dimensions was a result of the updated regionalization as described in section 4.3:

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[6] In the original 1992 AERO-MS minor flight stages were aggregated in order to limit the run time of the AERO-MS. Because of the strongly increased computing power of PCs over the last decade this aggregation is no longer required in the updated AERO-MS. The way minor flight stages were aggregated in the original AERO-MS is described in section 5.3 of the AERO Main Report from 2002.

- ***IATA Region***: 14 new regions (see table 4.1).
- ***IATA Region-pair***: Translates the new 14 regions into a revised list of 196 region-pairs.
- ***CPB[7] Region***: Equals the dimension IATA Region. Historically this dimension is used by a number of AERO-MS variables which drive the forecast of traffic growth (e.g. GDP growth; export growth; population growth).
- ***Country***: 245 countries (see also section 4.4).
- ***IATA Region and EU country***: The updated number of elements in this dimension is 42. These are the 27 EU countries plus 13 IATA regions (all regions excluding the EU). Note that the EU includes the Aland Islands and Gibraltar (see also section 4.4).
- ***Symmetrical IATA Region-pair***. This dimension is used in the AERO Interface only. It aggregates "opposite" region-pairs (e.g. North America to EU is aggregated with EU to North America). The number of elements in the dimension symmetrical IATA Region-pair continues to be 105 ([196-14]/2+14). The definition follows from the definition of IATA Region-pairs.
- The dimension ***Interface Region-pair*** is also used in the AERO Interface only. The dimension is an aggregation of IATA Region-pairs and is used for presentation purposes. The dimension continues to have 9 elements, whereby the mapping from the 196 IATA Region-pairs has been revised.

4.5.7 The dimension ***IATA Route Group*** is used by a number of input variables which relate to cargo/passenger fares per km. For the year 2006, average yield information was available for 17 route groups and the dimension IATA Route Group was changed accordingly.

4.5.8 The dimension ***Traffic*** contains all traffic lines. A traffic line is a combination of a ***Flight Stage***, aircraft purpose (pax/combi versus full freighter), and movement type (scheduled versus LCC/charter). In the updated AERO-MS flight stages relate to airport-pairs for which the Unified Database contains flights. The number of traffic lines and flight stages in the updated AERO-MS is respectively 153,134 and 123,026.

4.5.9 The dimension ***CAEP route group***, which was added to the updated AERO-MS, reflects the 23 route groups used in CAEP analyses. In the AERO-MS this dimension is an aggregation of the dimension flight stage. The information in any variable dimensioned by flight stage can thus be aggregated to CAEP route groups in order to facilitate the comparison with analyses carried out for CAEP.

Aircraft type dimensions

4.5.10 The dimension ***Aircraft Type*** reflects 10 generic aircraft types considered in the AERO-MS. An aircraft type is a combination of seat band and range capability. For the updated AERO-MS the specification of the 10 generic aircraft types (in terms of seat bands) has been changed (see for further details in Chapter 7). The dimensions ***Aircraft Seat Band*** (there are 7) and **Length of Haul** (there are 3) are also centrally defined in a framework data file. The dimension related to the 7 seat bands was changed in accordance with the changes made to the dimension aircraft type.

[7] CPB (Centraal Planbureau) is the Netherlands Bureau for Economic Policy Analysis. Originally the definition of world regions by CPB was different from IATA's definition of world regions for which reason 'CPB region' is a separate dimension in the AERO-MS.

Movement type and flight type dimension

4.5.11 The 1992 AERO-MS distinguishes two movement types: i) scheduled and ii) charter. As discussed in section 4.3, for the updated AERO-MS, LCCs are included in the second dimension element. This implies the definition of the elements under movement type has become:

0 Scheduled network carrier operations;
1 LCC and charter operations.

4.5.12 The dimension flight type combines the dimensions movement type and aircraft purpose. This implies the five elements under flight type are now defined as follows:

- Scheduled pax - network carriers;
- Scheduled freight;
- LCC and charter - pax;
- Charter - freight;
- Non-commercial.

Year dimension

4.5.13 Various variables in the ATEC model use the dimension year. The dimension is used in order to define the periods, for which the past and future development of fuel use and emission characteristics of new aircraft entering the market are specified. The dimension contains 10 elements. The dimension elements are not centrally defined, but are defined within ATEC (by a specific variable). As part of the update of ATEC, this variable has been updated by NLR. As a result the dimension year now allows developments of aircraft type characteristics to be specified for the following periods: 1967 – 1980, 1981 – 1992, 1993 – 2006 and 2007 – 2030.

5 Update of the Unified Database

5.1 Introduction

5.1.1 The Unified Database is the foundation upon which the Aviation Emissions Reduction Options Modelling System (AERO-MS) is built. It contains a detailed record of aviation movements in the model base year (2006), providing information on the volume of global aviation movements and corresponding passenger numbers and weight of cargo transported.

5.1.2 The new Unified Database constructed as part of the SAVE project updates the base year of the model from 1992 to 2006, and expands the level of spatial capabilities of the model by including information for each pair of airports for which direct (non-stop) aircraft movements were recorded in the new base year. The definition of flight stage is updated from city-pair in the 1992 version of the AERO-MS to airport-pair for the updated version.

5.1.3 The Unified Database segregates recorded movements into five distinct categories. The five movement categories (traffic groups) are:

- commercial, scheduled passenger (or combi) flights, excluding those of low cost carriers
- commercial, scheduled all-cargo (freighter) flights
- commercial, non-scheduled (charter) and low cost carrier passenger flights
- commercial, non-scheduled (charter) all-cargo (freighter) flights
- non-commercial movements by commercial carriers.

5.1.4 General aviation flights and movements operated with a military purpose were not included in the Unified Database of the 1992 version of the AERO-MS. So far as it has been possible to identify these categories of movement in the 2006 data, they are again excluded from the Unified Database.

5.1.5 Data are represented as annual quantities. For 2006, the Unified Database records[8]:

- 123,025 airport-pairs
- 33.1m civil flights
- 2.6bn passenger trips
- 4,658bn passenger-km
- 44.8m tonnes of cargo transported
- 158bn cargo tonne-km

5.2 Input Data Sources

5.2.1 The updated Unified Database was compiled using a number of input data sources:

[8] Where a billion is one thousand million.

- 2006 WISDOM Operations Database of aircraft movement data – 6 week sample, global aviation movements;
- 2006 ICAO Traffic by Flight Stage (TFS) scheduled air movement and demand data – annual, international;
- 2006 U.S. Department of Transport (DOT) T-100 scheduled air movement and demand data – annual, domestic U.S.;
- 2006 IATA Route Tracker passenger class split data – annual, international.

5.2.2 Creating the Unified Database required the datasets above to be combined. The demand and movement data available in the TFS and T-100 were employed to estimate load factors for application to the aircraft movement data provided by the WISDOM database. The passenger class split data was utilised to divide the demand data into distinct classes for use in AERO-MS.

WISDOM Operations Database

5.2.3 MVA received a sample of the WISDOM database from EUROCONTROL. This contained all reported aircraft movements for six separate weeks throughout 2006. EUROCONTROL also provided data by which this sample could be annualised. The annualised WISDOM data forms the spine of the Unified Database.

5.2.4 The WISDOM Operations Database provided point to point movement information for all aviation activity, but contained no information on numbers of passengers or volumes of cargo transported, nor any information on the purpose of the movement.

5.2.5 In the absence of this data, it was necessary to turn to the other datasets mentioned above in order to "infill" gaps in the requirements of the Unified Database.

ICAO Traffic by Flight Stage Data (TFS)

5.2.6 2006 Traffic by Flight Stage (TFS) data was obtained from ICAO.

5.2.7 The TFS contains information on international traffic between city-pairs as reported by participating carriers belonging to ICAO member states. The TFS comprises a separate record for each carrier on each city-pair, with data for the number of flights made by each aircraft type.

5.2.8 Capacity and passenger number/cargo volume information contained in the TFS was used to calculate passenger and cargo load factors for application to records in WISDOM, that shared the same combinations of carrier and city-pair. The TFS-derived load factor data were also employed to synthesise load factors for records where a direct correspondence was not available between the TFS and WISDOM. (WISDOM does not distinguish directly between scheduled, charter, general and military movements. There had to be the presumption that a movement in the WISDOM database should be treated as scheduled for the purpose of the Unified Database if it could not be otherwise classified. On this basis, about 60% of WISDOM "scheduled" movements had a correspondence with either the TFS data or the T-100 data next described.)

US Department of Transport T-100 Data

5.2.9 The T-100 dataset contains domestic non-stop segment data, when both origin and destination airports are located within the boundaries of the United States and its territories. Unlike the TFS which is reported at the city-pair level, the T-100 contains information on an airport to airport level.

5.2.10 Similarly to the TFS, capacity information and passenger numbers/cargo volumes in the T-100 were used to calculate load factors, which were appended to corresponding movement records contained in WISDOM. Since the T-100 contains only U.S. domestic movement data, load factors calculated from the T-100 dataset were only applicable to such movements.

IATA Class Split Data

5.2.11 Through supplementary use of the TFS and T-100 datasets, it was possible to append demand data to the movement data provided by the WISDOM Operations Database. However, the Unified Database requires that passenger volumes be segregated on each traffic line by class of travel (First/Business, Economy and Discount).

5.2.12 In the previous Unified Database, data was obtained recording proportions of passengers by class on a selection of scheduled services. This was used to calibrate a mathematical model of proportional class split by region-pair, which was applied to the demand data of the Unified Database.

5.2.13 We were not able to obtain corresponding flight stage class split data for 2006, and consequently the separation of passenger numbers into travel classes was carried out based on IATA Route Tracker analysis for the year November 2005 to November 2006.

5.2.14 Route Tracker data provided the growth rates over this year of two passenger classes (First/Business and Economy),and also for these classes combined, for Scheduled International Passengers for 27 route groups on a global level. It was then possible to infer the proportional split between the two classes for each route group. While the route groups used by IATA did not directly correspond with the regional aggregation used in the model, a generally close correspondence between IATA Route Group and AERO region-pairs was created.

Software

5.2.15 The processing of the Unified Database was carried out in Microsoft SQL Server, a relational model database server. The processing was broken down into a series of small steps which enabled close verification of each stage in the data processing, as well as allowing any amendments to be made if necessary.

5.2.16 Verification of the data sources during the processing stage was essential to ensure that the records passed to the Unified Database were being correctly classified for use in AERO-MS and that all computations were being carried out correctly. Flexibility in the processing stage allowed errors in the data to be recognised and corrected. The data processing stage of the Unified Database update is described in Section 5.5 below.

5.3 Construction of the Unified Database

5.3.1 The main tasks required to update the Unified Database are listed below:

- Compile correspondence lists to supplement WISDOM data (for example, to match different coding and naming conventions for airports);
- Check and process WISDOM data sample to create a single table of annual movements;
- Identify commercial movements and differentiate by carrier "nature" (scheduled network carrier or LCC/charter operations) and carrier "function" (passenger or cargo) to allocate movement information to traffic groups;
- Calculate load factors and attach to movement information to generate passenger/cargo demand data;
- Generate formatted tables of Unified Database variables (contained in zone, flight stage and traffic line files);
- Extract variables from SQL database and create each of the above files which comprise the Unified Database.

Compiling Correspondence Lists

5.3.2 It was necessary to add further context to the variables contained in WISDOM, and to create linkages between this data source and the supplementary sources mentioned above. Therefore, a number of correspondence lists were required. The files received are listed below along with the source of the data (e.g. TAKS provided the correspondence between Country and AERO Region):

- Airport Code to Airport Context (Name, City, Country etc); EUROCONTROL
- Country to AERO Region; TAKS
- Aircraft Type to Aircraft Name; EUROCONTROL
- Aircraft Type to Generic Aircraft Type; NLR
- Airline Carrier ID to Airline Name; EUROCONTROL
- List of recognised Low Cost Carriers; DLR/EUROCONTROL

5.3.3 The correspondence lists detailed above were checked and, where further detail was required by the Unified Database, amended to include this information. For example, it was necessary to update some of the information (especially city names) in the airport correspondence list in order to ensure consistency with the TFS and T-100 datasets, as well as including AERO specific variables such as region.

5.3.4 While the Unified Database does not function at the named carrier level, it does require that carriers be segregated into scheduled and LCC/charter operations (referred to as the carrier "nature") and passenger or cargo movements (referred to as the carrier "function"). This information was added to the airline correspondence list supplied by EUROCONTROL. Carrier natures and functions were defined using a combination of capacity information by carrier (where data was available in the TFS and T-100), in conjunction with internet research and industry knowledge. Where airlines could not be positively identified, a "default position" of scheduled/passenger was assumed. Lists of Low Cost Carriers (LCCs) were received from EUROCONTROL and DLR. Carriers known to be operating solely non-commercial movements (such as military organisations) were highlighted in the correspondence list, and such movements would not be carried forward to the Unified Database.

5.3.5 The classification of named aircraft types to the generic groupings used in AERO-MS utilised analysis of the PRISME fleet database. Aircraft were classified according to their range band (three classes) and seat band (seven classes), and also differentiated by technology level ("old" and "current"). The process and results of this classification are described in Chapter 7 (Sections 7.5 and 7.6) of this report. Where such information was not available in PRISME (many small aircraft types and cargo only types were not included in the database), named aircraft types were classified to a generic type using professional judgement and other information held by the study team. Around 10% of total commercial movements were allocated in this way.

5.3.6 Further correspondence lists were developed during the data processing stage, including relationships between major cities as defined in the 1992 Database and major airports in 2006, and a list containing a "home region" for each carrier.

Processing WISDOM sample

5.3.7 As explained in Paragraph 5.2.3, the sample of the WISDOM Operations Database received covered six weeks (42 days) spread over the 2006 base year. It was therefore necessary to "annualise" this sample in order to create a full base year of movements in the Unified Database. Annualisation factors were calculated using data received from EUROCONTROL which associated each day of 2006 with one of the sample days, and provided a ratio of movements of each day to the movements of the selected sample day. In effect, each sample day was annualised by summing the ratios applicable to that day, and using this sum as the annualisation factor for every movement recorded in the WISDOM database for that sample day. The annualised movements thus estimated were 38.3m.

5.3.8 Carriers are not specifically identified in WISDOM. For most commercial movements the carrier can be inferred from the CALLSIGN variable in WISDOM, but where the CALLSIGN was not recognisably that of a commercial carrier, other inferences had to be drawn. In particular, callsigns commencing with N followed by numeric digits were identified as FAA aircraft registration numbers rather than the callsigns of commercial operations. These "N-code" movements – amounting to 4.1m - were therefore categorised as general aviation movements and thereby partitioned from the movements that were to be carried forward to the Unified Database. The total number of retained annual movements came to 34.2m.

5.3.9 The next stage in the processing of the WISDOM data was to separate the annualised movement information into the five traffic groups contained within the Unified Database. Each record retained thus far must either be assigned to one of these traffic groups, or classified as a general aviation movement and not carried forward to the Unified Database.

5.3.10 Each WISDOM movement was assigned a traffic group identifier from 1 to 4, based upon the function and nature of the carrier as defined in the carrier correspondence list. Carriers which were not recognised in the carrier correspondence list, or were defined as General Aviation, were not assigned a value in this field. The final number of movements in each group is shown in Table 5.1 below.

Table 5.1 Numbers of Aircraft Movements by Traffic Group

Traffic Group	Group Description	Operations
GROUP 1	Scheduled Passenger	25,400,361
GROUP 2	Scheduled Cargo	1,396,467
GROUP 3	Charter/Low Cost Passenger	6,224,224
GROUP 4	Charter/Low Cost Cargo	71,384
TOTAL		**33,092,436**

5.3.11 Of the 34.2m movements contained in the annualised WISDOM database (once N-Code movements had been filtered out), 33.1m movements were identified as being operated by commercial carriers. The remaining movements (totalling approximately 1.1m) were either by those carriers not recognised in the carrier correspondence list, identified as General Aviation (military/helicopter/training movements), or were made by an aircraft type which was either identified as being non-commercial (specific military aircraft) or could not be allocated to a generic type[9].

5.3.12 Due to insufficient detail in the available data, it was not possible to identify non-commercial movements made by commercial carriers (positioning/training flights), which were intended to be housed in Traffic Group 5. Therefore, this flight group contains no movement information in the updated Unified Database. All movements by commercial carriers are contained in Traffic Groups 1 to 4.

5.3.13 The movement data provided by WISDOM was then separated into the four traffic groups required by AERO-MS. However, WISDOM contained no information on numbers of passengers and volumes of freight transported. It was therefore necessary to augment the WISDOM with the supplementary demand data sources introduced in section 5.2.

5.4 Demand Data

5.4.1 The demand and movement data available in the TFS and T-100 were employed to estimate load factors for application to the aircraft movement data provided by WISDOM, thereby allowing demand to be estimated for each movement identified as scheduled.

[9] There were 471 aircraft types in WISDOM which could not be allocated to an AERO generic class due to lack of corroborating secondary information. However, of these 471 aircraft types, none made more than 365 trips in the annualised WISDOM, and as such comprised a very small total of ASKs (available seat kilometres). These named aircraft types accounted for 28,000 movements, or 0.09% of total movements by recognised carriers.

Estimating demand data for Scheduled Operations

5.4.2 For scheduled flight stages contained in WISDOM which could be matched to those in the TFS and T-100 datasets, it was possible to directly apply calculated load factors in order to obtain numbers of passengers and volumes of cargo transported.

5.4.3 Records in the two datasets were given a unique identifier based upon their carrier and the city-pair of the flight stage. Despite the update of the new Unified Database to airport, rather than city level, it was necessary to work at the city-pair level as the TFS did not contain flight stage information by departure and arrival airport, instead only recording the city of departure/arrival.

5.4.4 Load factors were calculated for combinations of carrier and city-pairs in the T-100 using the total number of passengers carried divided by the total number of seats available (passenger load factor), and the total volume of freight and mail carried over the total available payload (cargo load factor).

5.4.5 There were instances in the T-100 data where the reported number of passengers or volume of cargo exceeded the reported seat or payload capacity, and the load factors were therefore greater than one. These records were manually constrained to have a load factor of 1 to prevent demand exceeding capacity on any flight stage. This was by no means a serious issue, however; seven flight stages were involved, accounting for only ten movements over the year, conveying a total of 114 seats.

5.4.6 In the TFS, the data were split into two parts for the calculation of load factors. Records with no revenue passengers were extracted and used to calculate load factors for scheduled cargo operations, as they were deemed to be freight specific city-pair movements. The remaining movements were used to calculate passenger and cargo (bellyhold) load factors for scheduled passenger movements.

5.4.7 As was evident in the T-100, there were a very small number of instances where the reported number of passengers or volume of cargo exceeded the reported seat or payload capacity on a flight stage, and the load factors were greater than 1. Again, these records were manually constrained to have a load factor of 1.

5.4.8 Each of the WISDOM records was assigned an identifier based upon the carrier of the movement and the city-pair it connected. These records were checked against corresponding carrier city-pairs with load factors as calculated using the TFS and T-100. Passenger and cargo demand was then calculated, where applicable, by firstly multiplying the total number of annual operations by an estimate of average aircraft capacity for each generic type to give total revenue seats/total payload capacity, and then multiplying by the corresponding TFS/T-100 derived load factor to provide passenger/cargo demand.

Estimating load factors for flight stages not covered by the TFS and T-100

5.4.9 Whilst the TFS and T-100 were able to provide coverage of much international and U.S. domestic aviation, there was still a section of the database for which demand is not directly computable. As in the creation of the 1992 Unified Database, demand for these movements was synthesised from statistical analysis of the TFS dataset to estimate load factors in relation to origin and destination regions, stage length, and whether "major" or "minor" cities were connected.

5.4.10 Where records did not have a corresponding carrier city-pair in the TFS and T-100 datasets, they were assigned passenger and cargo demand using the synthesised load factors, assigned according to the combination of explanatory variables for that record. Average aircraft capacity by generic type was again multiplied by the number of operations to give total capacity, and this value was then multiplied by the synthesised load factor.

5.4.11 Each record contained in WISDOM which had been classified as "scheduled" had now been provided with passenger numbers and/or cargo volume information, either directly from corresponding records in the observed data sources or from the load factors estimated based on the characteristics of the movement.

Estimating load factors for Charter Operations and Low Cost Carriers

5.4.12 In the creation of the 1992 Unified Database, a common load factor of 82% was assumed for charter operations. It was accepted through the Interim Report that this assumption be retained for charter passenger flights (this group now also including low cost airlines). Support for this assumption has subsequently been established, in that a study for the EU carried out by Cranfield University ("Analysis Of The EU Air Transport Industry", Final Report 2006) reports a load factor for European charter and low-cost carriers of 81.2% for 2006.

5.4.13 Charter cargo flights have been given a common load factor of 90%. There is little basis for establishing a load factor for charter cargo movements (for example, the US DOT does not require payload to be reported in relation to such flights), but assuming a high load factor better ensures that a forecast growth in demand for this category of movement is reflected in the AERO-MS in a corresponding increase in movements, as could be expected in practice.

5.4.14 The same methodology was used for charter movements as for scheduled operations; firstly total revenue seats/total payload capacity was calculated by multiplying operations by the generic aircraft capacity, and then this value was multiplied by the passenger or cargo load factor to provide demand information. Cargo demand (belly hold) on charter and low cost passenger flights was set to 0 for all movements.

5.5 Creating the Unified Database files

5.5.1 The Unified Database is comprised of three text files containing the variables which are used in the AERO-MS. After the processing of the WISDOM movement data and the introduction of passenger and cargo demand data, the final task in the creation of the Unified Database was the formatting of the variables and their extraction to the text files. Some Unified Database variables were still to be populated, and these were created following the calculation of the demand data.

5.5.2 IATA passenger class split data provided proportions of passengers travelling First/Business and Economy on a selection of route group[10]. Passengers on scheduled flights were split into First/Business and Economy classes using the IATA class-split estimates, and passengers on

[10] These IATA route groups did not directly correspond to the AERO region-pairs, so linkages were created between them manually. Each AERO region-pair was assigned a passenger class split proportion, and passengers on flight stages in these region-pairs were differentiated accordingly.

charter (and therefore low cost) flights would be classified as entirely Discount. Fare information was adapted to reflect this pricing structure.

5.5.3 A list of 23 region-pairs was identified for which surface competition was a viable alternative to air travel, using the same specification as in the construction of the 1992 Unified Database. Different classes of surface competition indicators were attached to the WISDOM flight stages, differentiating; i) no available surface competition, and ii) surface competition already present.

5.5.4 A list containing a "home region" for each carrier was constructed based upon their traffic activity patterns, allowing proportions of capacity on a route satisfied by carriers from the EU, from the origin region (if not the EU), and from the destination region (if neither the EU nor the origin region). Total capacity information was calculated for each route based upon the number of operations, the (great circle) distance of the flight stage and an estimate of average capacity for the given generic aircraft type, calculated using generic aircraft type information provided by NLR.

5.5.5 A number of processing scripts were run on the final traffic table (containing all movements) in order to create the required variables which would populate the zone, flight stage and traffic line files which comprise the Unified Database.

5.6 Processing Summary

5.6.1 The Unified Database was updated to a 2006 base year using movement information contained in the 42 day sample of the EUROCONTROL WISDOM Operations Database; in conjunction with demand data calculated using the ICAO Traffic by Flight Stage (TFS) and U.S. Department of Transport T-100 datasets.

5.6.2 Additional context was added to the WISDOM sample using a selection of correspondence lists both provided by external sources and generated by MVA.

5.6.3 The WISDOM database was annualised using factors calculated from data provided by EUROCONTROL, and a specific subset of movements corresponding to general aviation made by small aircraft in the U.S. was removed.

5.6.4 The remaining movements (34.2m) were partitioned according to whether they were scheduled or LCC/charter, passenger or cargo, and allocated to one of the four AERO traffic groups. After the removal of all non-commercial movements, movements by non-commercial aircraft types, and by aircraft types which were not classified to a generic type, 33.1m movements were passed to the Unified Database.

5.6.5 Demand data was attached to scheduled movements in WISDOM using the TFS (international movements) and T-100 (U.S. domestic movements) datasets, with load factors being directly attached to movements where direct correspondence of carriers and city-pairs was available. Where this was not the case, load factors were synthesised based on a combination of explanatory variables, as in the original Unified Database. Again following previous practice, charter and low cost movements were given common load factors which were applied for all passenger and cargo movements.

5.6.6 The remaining variables required by the Unified Database were populated, and the final traffic table was manipulated into tables corresponding directly to the format of the zone, flight stage and traffic line files which comprise the Unified Database. Data was exported and the files collated.

6 Update cost and fare input data

6.1 Update of the AERO-MS cost data

6.1.1 This section sets out the analysis carried out by MVA used to populate the updated cost data for the SAVE project. This section covers:

- data sources used
- data analysis
- updated variables and values.

Context

6.1.2 The AERO-MS variables comprising aircraft operating costs are owned by the ACOS model. The main function of ACOS is to estimate the operating costs on each flight stage for each (generic) aircraft type that could feasibly operate the flight stage. The costs by aircraft type are then fed into the aircraft choice mechanism that is shared with the ADEM model.

6.1.3 In turn, the main function of the aircraft choice mechanism is to modify the mix of aircraft forecast to operate on a stage as a consequence of the costs of operating different aircraft types being affected to different degrees by policy scenario developments such as emissions trading. In response to these cost impacts the more fuel-efficient aircraft types will be less affected and thus become more attractive to operate. However, they may well have higher ownership costs, and the aircraft choice mechanism trades off these (and any other) differences in costs.

6.1.4 It follows that a crucial requirement of the input cost data is to be able to distinguish the individual components of operating costs between aircraft types on a systematic basis. During this update, a conscious effort has been made to ensure that inputs were, at the very least, at the same level of detail and aggregation as those originally in the model. Where this has not been possible (due to data availability etc) this is clearly stated.

6.1.5 As part of the AERO model update, the definitions of the generic aircraft types have been revised. Consequently, the named aircraft that are allocated to those types differ from the 1992 based model.

6.2 ACOS Variables Updated

6.2.1 Many variables are calculated by the model and so do not need to be directly updated. The variables that are not automatically calculated by the model and so required updating are listed below:

Table 6.1 ACOS Variables Updated

Name	Caption	Unit	Dimensions*	Description
MV_ACOS_AcDeprRate	Aircraft depreciation rate	proportion	AircraftType; AircraftAgeBand	Real annual aircraft depreciation rate
MV_ACOS_YearlyAcDeprRate	Yearly Ac depreciation rate	proportion	AircraftType; YearBand	Yearly real annual aircraft depreciation rate
MV_ACOS_AverageStageLength	Average stage length	km	IATARegionPair	Reference average stage length of IATA region-pairs
MV_ACOS_FuelPriceFactor	Fuel price factor	proportion	IATARegion	Fuel price factor
MV_ACOS_AcUtil_B,_D,_F	Annual aircraft utilisation	hours pa	MovementType; AircraftType; AircraftPurpose; TechnologyLevel	Average annual aircraft utilisation
MV_ACOS_CabinCrewNeeded_B,_D,_F	Cabin crew needed	employees	MovementType; AircraftType; TechnologyLevel; AircraftPurpose; IATARegion	Cabin crew needed
MV_ACOS_CabinCrewSal_B,_D,_F	Cabin crew salary	2006US$/hour	MovementType; IATARegion	Cabin crew salary, subsistence and bonuses per flight hour
MV_ACOS_CrudeOilPrice_B,_D,_F	Crude oil price	2006US$/kg	IATARegion	Crude oil price per IATA (AERO) region
MV_ACOS_FlightCrewNeeded_B,_D,_F	Flight crew needed	employees	MovementType; AircraftType; TechnologyLevel	Flight crew needed
MV_ACOS_FlightCrewSal_B,_D,_F	Flight crew salary	2006US$/hour	MovementType; IATARegion; AircraftType; TechnologyLevel	Flight crew salary, subsistence and bonuses per flight hour

MV_ACOS_MaintCostPerHour_B,_D,_F	Maintenance costs per maint. hr	2006US$/hour	AircraftType; TechnologyLevel; IATARegion	Maintenance costs per hour of maintenance
MV_ACOS_InterestRateRegion_B,_D,_F	Finance charge interest rate	proportion	IATARegion	Real interest rate used in calculation of finance charges
MV_ACOS_LandingCharges_B,_D,_F	Landing charges	2006US$/cycle	AircraftType; TechnologyLevel; IATARegion	Landing charges
MV_ACOS_RouteCharges_B,_D,_F	Route charges	2006US$/km	AircraftType; IATARegionPair; TechnologyLevel	En route navigation charges per kilometre

6.2.2 The following data sources have been used to update the ACOS variables:

- **ICAO data** – ICAO supplied six datasets containing data for 2006 and covers 74% of movements in the Unified Database, 99% of aircraft km and 97% of ATKs. The data sets included:
  - **Financials** – Financial data for each carrier that reports to ICAO. This includes a line of data on revenue, expenses, profit/loss, debt, tax and assets/liabilities for each carrier.
  - **Traffic** – Movement data given for each carrier including aircraft km, aircraft hours, passengers/freight carried and average load factors. The data contains a line of data for each carrier and flight type (domestic/international and scheduled/non-scheduled) for each month of 2006.
  - **Traffic by Flight Stage (TFS)** – Movements at the city-pair level for each carrier and aircraft type. Data includes demand (passengers and freight), capacity and load factors for each city-pair, operator and aircraft type for international movements.
  - **Personnel** – Number of pilots, cabin crew, maintenance and ticketing personnel employed by each airline including expenditure.
  - **Fleet Numbers** – Number of different aircraft types operated by each airline including number of seats, payload capacity and maximum take of mass
  - **Fleet Utilisation** – Total departures and hours flown for each airline by aircraft type.
- **EUROCONTROL WISDOM Operations Database 2006 –** supplied by EUROCONTROL and included the following variables for each aircraft movement in 2006: Callsign, Departure time, Departure Airport, Arrival Airport, Aircraft Type and Data Source.
- **US Energy Information Administration** - Spot Prices for Kerosene Jet Type Fuel, (http://tonto.eia.doe.gov/dnav/pet/pet_pri_spt_s1_a.htm)

- **ICAO Regional Differences in International Airline Operating Economics** (2004 and 2005) – Includes a breakdown by region of scheduled passenger revenues and related costs.
- **Avmark data** – aircraft values and prices
- **"Buying the big jets",** Paul Clark, Ashgate, 2001
- **OPEC** - http://www.opec.org/opec_web/en/data_graphs/40.htm
- **Form 41 data –** contains dataset US P-52 Data (data by aircraft type for the North American fleet)
- **IATA Economics Briefing "Airline Cost Performance", March 2007** – shows relativities of costs between network carriers and Low Cost Airlines
- **OAG Solution Fleet Database** – data covering flight crew required for each aircraft type

6.3 Aircraft Value Depreciation Rates

6.3.1 Variables updated:

- MV_ACOS_AcDeprRate
- MV_ACOS_YearlyAcDeprRate

6.3.2 Populating the above variables has adopted the same process as in earlier versions of the AERO-MS. The variables contain the annual rates of depreciation of aircraft. In the AERO-MS the annual depreciation rate is taken to be the proportion of an aircraft's current market value that is lost during each successive year of ownership. The values of the variables are empirically estimated, as described below.

6.3.3 The input data required are the dates when particular (named) aircraft types were first and last produced, and the fair market values at some given date of the oldest and newest aircraft of each type. These data have been taken from the January 2005 issue of the "Avmark Newsletter", which gives "Estimated Jet Transport Values" as at that date. This source provided data in the form needed to carry out the depreciation analysis. While no comparable data based in 2006 was found, this was not felt to be critical since the essence of the method is the ***relativity*** between the values of the oldest and newest aircraft of particular types.

6.3.4 Thus comparing the values of the oldest and newest aircraft of each type indicates the overall rate of depreciation over the implied span of aircraft age. These overall depreciation rates can be thought of as the result of a sequence of annual depreciation rates that may depend upon the age of the aircraft. Regression analysis was employed to investigate whether the average annual rate of depreciation did in fact vary with aircraft age, as had been found in developing the previous version of the AERO-MS. In the present case, however, the empirical analysis did not justify variation of annual depreciation rates with aircraft age. A single rate of 6.6% per year was estimated for all ages of aircraft.

6.4 Average Stage Length

6.4.1 Variables updated:

- MV_ACOS_AverageStageLength

6.4.2 This variable requires an average stage distance (km) for each of the 196 region-pairs. It is used in ACOS as an input to the NLR run-time library function to calculate aircraft weights and subsequently the ACOS approximations of fuel consumption and block time (both at an average region pair level)

6.4.3 To obtain the average stage distance, the Unified Database was used in the following steps:

- Distances between each airport-pair were calculated using the great circle distance
- Airport-pairs were collapsed into region-pairs with total km flown between each region-pair summed
- Total movements between each region-pair were obtained by summing all the movements between airports in their respective region-pairs

6.4.4 To obtain an average km flown for each region-pair:

Average Stage Length = Total region-pair km flown/Total movements

6.4.5 This methodology weights the stage length by the number of movements at the airport-pair level to give a more accurate answer. There were region-pairs where no movements were recorded in the WISDOM data. For these region-pairs the city with the most arrivals and departures was selected and a representative great circle distance calculated between the two regions.

6.5 Fuel Price Factor

6.5.1 This is the factor used to convert oil price into kerosene fuel price.

6.5.2 Variables updated:

- MV_ACOS_FuelPriceFactor

6.5.3 Inputs are required for each of the 14 regions.

6.5.4 The US Energy Information Administration provides kerosene spot prices (2006 US$) in 2006 for five areas:

- New York Harbour
- U.S. Gulf Coast
- Los Angeles
- Amsterdam-Rotterdam-Antwerp (ARA)
- Singapore.

6.5.5 Spot prices are routinely published only for the locations shown above. It has therefore been necessary to adopt these as the spot prices for other regions also. New York Harbour, US Gulf Coast and Los Angeles were used to calculate an average price for North America. Amsterdam-Rotterdam-Antwerp was used for the EU and Singapore used for South East Asia. This gave values for 3 of the 14 regions. The table below shows which of these values were used as a proxy for the other regions.

Table 6.2 Origin of proxy kerosene price and mapping to AERO regions

AERO Region	Origin of proxy kerosene price
North America	New York Harbour, US Gulf Coast and LA
Central America and Caribbean	New York Harbour, US Gulf Coast and LA
South America	New York Harbour, US Gulf Coast and LA
ECAC (non-EU)	Amsterdam-Rotterdam-Antwerp (ARA)
EU	Amsterdam-Rotterdam-Antwerp (ARA)
Russia and Belarus	Amsterdam-Rotterdam-Antwerp (ARA)
North Africa	Amsterdam-Rotterdam-Antwerp (ARA)
Sub-Saharan Africa	Amsterdam-Rotterdam-Antwerp (ARA)
Middle East	Singapore
Indian Subcontinent and Central Asia	Singapore
China and Mongolia	Singapore
Japan and Korea	Singapore
South East Asia	Singapore
Australia and Oceania	Singapore

6.5.6 The factor on oil price was calculated by dividing the kerosene spot prices by the average oil price in 2006. The factor is dimensioned by AERO Region and varies between 1.13 and 1.16.

6.6 Aircraft Utilisation

6.6.1 Variables updated:

- MV_ACOS_AcUtil_B

6.6.2 The variable contains the annual average aircraft utilisation, in terms of average total block hours per annum of aircraft operation. This allows "ownership" costs (depreciation and financing) to be mapped from an annual to a block-hour basis, for inclusion in the operating cost function for each generic aircraft type and technology level on a flight stage. Thus to represent utilisation, inputs are required for each generic aircraft type separately for passenger/freighter, old/current technology level and scheduled/charter creating 80 aircraft cells to populate.

6.6.3 The ICAO Fleet Utilisation dataset and Fleet Numbers dataset were used to update this variable. The steps taken to update this variable were:

- Aircraft types in the Fleet Utilisation data were matched to a generic type and technology level (Old/Current)

- A lookup column containing information on the old/current, passenger/cargo and generic aircraft type was created
- Total hours flown by each aircraft in each category were summed
- Using the Fleet Numbers dataset, the total number of aircraft in the fleet for each of the aircraft categories was calculated
- Average utilisation (hours per aircraft) was calculated by dividing the total aircraft hours by the total number of aircraft for each aircraft category

6.6.4 This process left a number of aircraft categories with no data. For these values it was necessary to synthesise the data using the data available in the other categories:

- Due to there being no aircraft over 500 seats in the fleet database in 2006, it was necessary to synthesise this category. It was decided to use the same relativity between the largest and second largest generic aircraft type as used in the original version of the AERO-MS. In the case of this variable the values for the largest aircraft type were the same as the second largest. We have no reason to suggest this relationship should change and have adopted this again.
- The scheduled/old/freighter category for each generic aircraft type was populated using the data but there were too few aircraft to populate the equivalent columns for charter/old/freighter, scheduled/current/freighter and charter/current/freighter in a reliable manner. In these cases the values for charter/old/freighter have been allocated the same values as scheduled/old/freighter (as in the original AERO model). The values for scheduled/current/freighter and charter/current/freighter were synthesised using the same relativities between scheduled/old/freighter and scheduled/current/freighter in the original AERO model. While this implies the same utilisation rates for scheduled and charter freighters, this was felt to be reasonable in the absence of sufficient direct evidence to obtain distinct values. (As noted above, the main function of utilisation rates in the AERO-MS is to map annual ownership costs to block-hour costs. Since ownership costs account for only 10-20% of total operating costs, substantial changes in the assumed utilisation rates would not have a large impact on total operating costs.)

6.7 Cabin Crew Needed

6.7.1 Variables updated:

- MV_ACOS_CabinCrewNeeded_B

6.7.2 Inputs are required for each generic aircraft type by scheduled/charter and old/current creating 40 different cells to populate. The variable is also segmented by aircraft purpose (passenger/freighter) and it is assumed that freighter movements have no cabin crew.

6.7.3 The mandatory maximum number of passengers per member of cabin crew is 50 but many scheduled airlines decide to have more cabin crew to give a better level of service. Using the publication "Buying the big jets" by Paul Clarke a value for the number of passengers per cabin crew member for scheduled carriers was 33. In the absence of detailed data, for charter and low cost carriers we have assumed the legal minimum number of cabin crew are deployed at 50 passengers per cabin crew member. The process for populating this variable was as follows:

- The average capacity was obtained for each generic aircraft type and for old/current movements
- To calculate the cabin crew per flight the aircraft capacity was divided by the number of cabin crew required (33 or 50 for scheduled/charter respectively)

6.7.4 For the largest aircraft type, an average capacity of 550 seats was assumed to calculate the cabin crew required.

6.8 Cabin Crew Salary

6.8.1 Variables updated:

- MV_ACOS_CabinCrewSal_B

6.8.2 For each carrier home region, and by scheduled/charter, wage rates (2006 US$) per hour were required. The ICAO Personnel and ICAO Traffic datasets from 2006 were used to complete this variable.

6.8.3 Wage rates per hour were calculated as follows:

- Total expenditure (2006 US$) on cabin crew by each airline was compiled from the ICAO Personnel dataset
- Total aircraft hours by carrier were compiled using the ICAO Traffic dataset
- Total expenditure on cabin crew and total hours by carrier were aggregated by the home carrier region of each carrier to give a cabin crew cost per aircraft hour for scheduled and charter carriers based in each region
- Average number of cabin crew per movement was calculated for each region using the value calculated for MV_ACOS_CabinCrewNeeded_B weighted by the number of movements carried out by each generic aircraft type from each carrier region
- Cabin crew costs (2006 US$) per aircraft hour were divided by the average number of cabin crew to calculate the cost per cabin crew member per hour

6.8.4 For Charter movements, because the ICAO has very little data on LCC and charter movements, the relativity between the crew costs of network airlines and EasyJet was applied to the scheduled cabin crew costs. The values shown in the IATA Economics briefing (March 2007) have been used. The relationship between network airlines in Europe and EasyJet was used the best data available for showing the relationship between scheduled and charter/LCC movements. Although the data refers to crew costs which may include cabin crew costs, it is the relativities between the different carrier types that is important for this variable.

6.9 Crude Oil Price

6.9.1 Variables updated:

- MV_ACOS_CrudeOilPrice_B

6.9.2 A single value is required in US dollars (2006 US$) per kg. Though the model allows for different crude oil prices for each region, a single world-wide value is consistent with treating crude oil as a Heckscher-Ohlin good; that is, as a commodity for which there are several competing sources but which also has to be imported by all significant economies, with little scope for import substitution, thereby tending to a single world price. The original model also assumed a single global crude oil price.

- The average oil price for 2006 (2006 US$) was calculated using daily price per barrel data from OPEC. The average for 2006 was 65 US$ per barrel.
- The price per barrel was converted into price per kg by dividing by the mass of oil in kg that can fit into in a barrel of oil (130 kg).

6.10 Flight Crew Needed

6.10.1 Variables updated:

- MV_ACOS_FlightCrewNeeded_B

6.10.2 Different values are required for each generic aircraft type, old/current technology level and by scheduled/charter movement types. Values are required in terms of flight crew per flight.

6.10.3 The required flight crew needed was obtained through the OAG Aviation Solution Fleet Database (one of the two main sources to determine the 2006 aircraft fleet characteristics). The minimum number of flight crew members required to fly the aircraft was given for each aircraft in this database. With the 2006 aircraft fleet classified in seat and range bands, old/current technology and movement type, the average flight crew was determined.

6.11 Flight Crew Salary

6.11.1 Variables updated:

- MV_ACOS_FlightCrewSal_B

6.11.2 Cost (2006 US$) per hour is required by home region of carrier, old/current technology level, scheduled/charter and by generic aircraft type.

6.11.3 The methodology adopted was:

- Calculate an average flight crew cost per aircraft hour for scheduled movements for each generic aircraft type using the Form 41 data which covers North American carriers
- Use the average flight crew cost to create a factors representing the difference between the generic aircraft types. For example, the first generic aircraft receives a

factor of 1 and then all the other factors work from there so if the second generic aircraft type has a cost twice the first then this receives a factor of 2 etc.

- For each home region, the total expenditure on flight crew and the total aircraft hours flown were calculated from the ICAO Financials data and used to calculate a cost per aircraft hour for each region
- The total expenditure on flight crew was then known for each region but this needed to be split by aircraft type keeping the costs by aircraft type in proportion with the factors calculated in point 2 calculated from the Form 41 (US P-52) data – this was done using the Excel solver function by controlling the average cost per aircraft hour across generic aircraft types for each region to the average cost per aircraft hour expected from the ICAO data
- For charter/LCC flight crew costs the same relativity used for the cabin crew salaries has been used.

6.12 Maintenance Costs

6.12.1 Variables updated:

- MV_ACOS_MaintCostPerHour_B

6.12.2 The values required are for the cost of maintenance per hour of maintenance, in dollars per hour. Different values are required for each carrier home region, aircraft type and by old/current technology level.

6.12.3 The ICAO Financials data provides expenditure on maintenance personnel by home carrier region but does not allow this to be differentiated by aircraft type as required. The Form 41 (P-52) data gives maintenance costs for North America by aircraft type and was used to break down the costs by aircraft type:

- Maintenance cost per flight hour were extracted from the US P-52 data by generic aircraft type for old and current technology levels
- For generic aircraft types 0 and 9 (<20 seats and >500 seats) no data was available so the relativities from the original AERO model were used to synthesise these values (Generic type 0 expenditure on maintenance was calculated as being 2.5 times less than generic aircraft type 1; Generic aircraft type 9 expenditure on maintenance as calculated as being 20% higher than generic aircraft type 8)
- A value of 0.1 maintenance hours per aircraft "block" hour was used to convert maintenance cost per flight hour into cost per hour of maintenance. This value of 0.1 maintenance hours per aircraft "block" hour (see MV_ACOS_MaintHoursPerFlHour_B) was assumed in the original AERO model. No data have been identified to improve on this assumption, and so it has been retained for the AERO update.
- These stages calculate a set of values for old/current technology level and for each generic aircraft type for North America
- Separately, using the ICAO Personnel data, expenditure on maintenance personnel was extracted for each region and expenditure on maintenance per aircraft "block"

hour calculated using the total aircraft "block" hours by carrier home region. This gives the relativity of maintenance costs per aircraft "block" hour between the regions

- Using the North America region as the starting point (from the P-52 data), and the relativities of maintenance costs per aircraft "block" hour between regions calculated from the ICAO data, the maintenance cost per hour of maintenance was calculated for the other regions.

6.13 Interest Rates

6.13.1 Variables updated:

- MV_ACOS_InterestRateRegion_B

6.13.2 Interest rates in real terms are required for each home carrier region to reflect the cost of raising money.

6.13.3 The ICAO Financials data provides information on overall debt levels and interest payments for each carrier that reports to ICAO. The process used was:

- For each carrier total debt and total annual interest paid was extracted from the ICAO Financials dataset
- Carriers that received large interest payments were not included in the analysis as they are unlikely to have reported their debt in a consistent way or hold large cash reserves
- Total debt and interest was aggregated by home carrier region
- Interest rates paid in each region were calculated by dividing the interest paid by the total debt. These were transferred into real interest rates.

6.13.4 Four regions did not have any reporting carriers so for these regions values needed to be synthesised as follows using their nearest neighbour geographically:

- Russia and Belarus used the value for ECAC
- North Africa used the value for Sub-Saharan Africa
- Middle East used the value for the EU
- Australia and Oceania used the value for South East Asia.

6.14 Landing Charges

6.14.1 Variables updated:

- MV_ACOS_LandingCharges_B

6.14.2 The dimensions of this variable allow for landing charges in dollars per cycle to be distinguished between world regions and generic aircraft types.

6.14.3 The ICAO publication "Regional differences in International Airline Operating Economics 2004 and 2005" (the most recent available) Table 4-3 provides dollars charged per departed tonne for world regions. Values were available for North America, Central America/Caribbean, South America, Europe, Middle East, Africa and Asia/Pacific. To provide values for all the AERO regions a mapping between the available data was necessary as shown in Table 6.3.

Table 6.3 Mapping between AERO Region and world region in ICAO report

AERO Region	Allocated Region from ICAO report
North America	North America
Central America and Caribbean	Central America/Caribbean
South America	South America
ECAC (non-EU)	Europe
EU	Europe
Russia and Belarus	Europe
North Africa	Africa
Sub-Saharan Africa	Africa
Middle East	Middle East
Indian Subcontinent and Central Asia	Asia/Pacific
China and Mongolia	Asia/Pacific
Japan and Korea	Asia/Pacific
South East Asia	Asia/Pacific
Australia and Oceania	Asia/Pacific

6.14.4 Values were compiled in the following steps:

- Dollars per departed tonne from the ICAO publication were mapped to AERO regions
- MTOW was extracted for each generic aircraft type
- MTOW was multiplied by each region's dollars per departed tonne to give the landing charges for each region for each generic aircraft type

6.15 Route Charges

6.15.1 Variables updated:

- MV_ACOS_RouteCharges_B

6.15.2 Navigation charges in dollars per km are required for each region-pair by aircraft type and old/current technology level.

6.15.3 The ICAO publication "Regional differences in International Airline Operating Economics 2004 and 2005" Table 3-2 provides air navigation costs in cents per passenger km for the main route groups. The process used was:

- For each route group convert values from cents per passenger km to cents per km using average load factors and average seats for each route group shown in the same ICAO report
- Route groups were mapped to AERO region-pairs so that each region-pair has an average route charge per km averaged across generic aircraft types

- To split values by generic aircraft type MTOW was used as a basis for establishing proportional differences between them
- While maintaining the proportional differences between generic aircraft types established using MTOW, the overall average across generic aircraft types was controlled to the values established in point 1 using the Excel solver function

6.16 Updating the AERO Fare Data

6.16.1 The variables that require populating with fare data is shown below:

Table 6.4 Updated Fare Variables

Name	Caption	Unit	Dimensions	Description
MV_ADEM_PaxRouteFare	Pax fare for route per km	2006US$/km	Class; IATA Route Group; Distance Limit	Scheduled Passenger fare for route per kilometre
MV_ADEM_ChPaxRouteFare	Charter Pax fare for route per km	2006US$/km	IATA Route Group Distance Limit	Charter Passenger fare for route per kilometre
MV_ADEM_CgoRouteFare	Cargo fare for route per km	2006US$/km	IATA Route Group	Cargo fare for route per kilometre

6.16.2 For scheduled passengers, fare data is required by the following dimensions:

- **Class** (First Business, Economy and Discount)
- **Route group** (17 IATA route groups have been identified to be used for the AERO update which has been constrained by the data available from ICAO in Para. 6.2.2. Route groups are defined as:
  - Between North America and Central America/Caribbean
  - Between and within Central America and the Caribbean
  - Between Canada, Mexico and the United States
  - Between North America/Central America/Caribbean and South America
  - Local South America
  - Local Europe
  - Local Middle East
  - Local Africa
  - Between Europe and Middle East
  - Between Europe/Middle East and Africa
  - North Atlantic

- Mid-Atlantic
- South Atlantic
- Local Asia/Pacific
- Between Europe/Middle East/Africa and Asia/Pacific
- North and Mid-Pacific
- South Pacific

■ **Distance Limit** – fares expressed in per-km terms have been shown to decrease with journey distance. This dimension sets the upper limits on distance bands. These have been retained from the original AERO model, and define distance bands for fare calculation as <250km, 250 to 500km, 500 to 1000km, 1000km to 2500km, 2500km to 4500km, and >4500km.

6.16.3 For charter/low cost carrier movements the same dimensions are required but only for one class type (discount). Cargo route fares are required by route group per km for each 100kg of cargo. This is not split by distance band.

Data Sources

6.16.4 The following data sources have been used to update the ACOS variables:

■ **ICAO data** – ICAO supplied six datasets containing data for 2006. The data sets used for the fare data analysis were:

- **Financials** – Financial data for each carrier that report to ICAO which includes, revenue, expenses, profit/loss, debt, tax and assets/liabilities. The data contains a line of data for each carrier.
- **Traffic** – Movement data given for each carrier including aircraft km, aircraft hours, passengers/freight carried and average load factors. The data contains a line of data for each carrier and flight type (domestic/international and scheduled/non-scheduled) for each month of 2006.
- **Traffic by Flight Stage (TFS)** – Movements at the city-pair level for each carrier and aircraft type. Data includes demand (passengers and freight), capacity and load factors for each city-pair, operator and aircraft type for international movements.

■ Regional differences in International Airline Operating Economics (ICAO): 2004 and 2005

■ IATA Fare Development Report WATS53 – provides relativity between First/Business and Economy fares

■ IATA Route Tracker – provides passenger class split data for 27 route groups.

6.17 Methodology for estimating passenger fares

6.17.1 To enable us to populate the dimensions defined in 6.16.2, it has been necessary to set up a process for combining datasets in a structured way. The key steps were:

- **Step 1:** Control route group fares to match the route group average yields (cents/RPK) from the document "Regional differences in International Airline Operating Economics" and revenue of carriers as defined in the ICAO Financials data
- **Step 2**: Split the average yields into distance bands using the relativities from the original AERO model
- **Step 3:** Define fares by class

6.17.2 The next sections look at each step in turn and the outline processes required.

Step1 – Controlling fares to route group average yields and revenue of carriers

6.17.3 Route group average yields (cents/RPK) from ICAO "Regional differences in International Airline Operating Economics 2004 and 2005" were applied to all flight stages by route group in the ICAO TFS data.

6.17.4 Then using these average yields, the revenue thus implied for each carrier on each flight stage was calculated by multiplying the relevant route-group yield by the carrier's RPKs for the flight-stage in the TFS data. These implied revenues were summed for each carrier. So that they matched the carrier's actual revenue reported in the ICAO Financials, a control factor was calculated for each carrier..

6.17.5 These factors were then used to adjust the implied revenue for each carrier on a flight stage in the TFS. The yields for each route group were then revised, using these flight stage revenues summed across carriers divided by the RPKs on each flight stage, also summed over carriers. In effect, this resulted in a yield for each route group adjusted to the revenue of carriers on that route group.

Step 2 - Split the average yields into distance bands

6.17.6 Data that had enabled yields to be related to distance bands in 1992 were not available for 2006. Consequently, to introduce a distance relationship into the route-group yields thus far computed for 2006, it was decided to apply the 1992 relativities of yields between distance bands.

6.17.7 For this, the 1992 yields by distance band were applied to the 2006 RPKs by distance band within each route group. Then the resulting total revenue for the route group based on 1992 yields was factored to the 2006 total revenue previously calculated. The factors thus derived were applied to the 1992 distance-band yields to give corresponding distance-band yields for 2006.

Step 3: Define fares by class

6.17.8 The original AERO-MS required fares for First/Business, Economy and Discount classes. It has only been possible to source data for the relativities of fares and demand for First/Business and Economy. Therefore, the discount category has not been used in the updated version of MV_ADEM_PaxRouteFare.

6.17.9 The discount category is still used in the charter fare variable (MV_ADEM_ChPaxRouteFare) and these fares have been calculated using the relativities of the economy and discount fares in the original AERO-MS.

6.17.10 There are three key inputs into the process of defining the scheduled fares by class:

- Average yields split by distance band from Step 2
- Fares split by class from IATA Fare Development Report (First Business/Economy) for each route group (this is total fare not fare per km)
- Demand split from IATA Route Tracker for First Business/Economy

6.17.11 The second and third inputs permitted the relativity of First/Business and Economy revenues to be estimated by route group. This allowed the yield computed for each route group – and distance band within route group – to be partitioned into yields specific to the First/Business and Economy classes.

7 Update aircraft type input data

7.1 Introduction

7.1.1 The AERO-MS is designed for evaluation of the effectiveness of measures that are implemented in the context of scenarios (Datum cases) that have evolved from a Base Year which reflects a calibrated, observed situation (Base case) in a recent year. The evaluation of measures is dependent on a forecast (a snapshot) of aviation demand and capacity, and hence also of the future fleet and its relevant properties, e.g. fuel flows, costs and emissions. Because of the long lifespan of aircraft, the resulting fleet is, in many cases, strongly tied to the historic fleet build-up in the Base case.

7.1.2 The future fleet, in terms of its properties as well as the capacity it will provide, is also heavily dependent on (future) fleet growth, technology advances and cost developments. Therefore, the fleet composition and the fleet properties also depend on the properties of (future) aircraft types not yet on the market or even under development. Data on these future aircraft types are generally not available. On the other hand, because of the differences in existing aircraft types and brands, there are apparent significant markets for different aircraft types with different sizes, ranges and operational characteristics. In addition, social and economic developments may also contribute to variations in the transport requirements, e.g. small commuter aircraft operating from small airports are developed for different market requirements from 'super jumbos'.

7.1.3 Therefore, the AERO-MS reverts to a description of a future fleet in terms of generic aircraft types. Each type represents a group of aircraft that are similar in range, seating (or cargo) capacity and technology (level). It is implicitly assumed that the costs for operating aircraft within each group are similar. Each group of aircraft is represented by a **generic aircraft** having group-averaged properties (fuel consumption, range, seating, emissions, costs etc.). Some of these properties (fuel, emissions, costs) of a generic aircraft are a function of the scenario, the Datum year and the measures applied. The process of grouping is called classification.

7.1.4 Generic aircraft in the predicted future fleet are differentiated according to the following four criteria:

- Aircraft purpose (passenger/combi or freighter aircraft)
- Maximum range
- Seating capacity
- Technology level ('old' or 'current')

7.1.5 For the Base case, the ATEC model within the AERO-MS determines the various properties of the global fleet that has evolved from a historic build-up of the existing fleet until the 2006 Base Year. For the Datum and Policy cases, the fleet build-up is extended into the future, aided by user specified scenarios and subject to potential policy option measures in a future year. These fleet properties concern fuel consumption, emissions (NO_x, CO, HC, SO_2 CO_2 and H_2O), and aircraft new prices. These properties vary by AERO-MS regions. Because of the long aircraft life cycles, the properties of a future fleet are usually rooted in history.

7.1.6 This chapter describes the data gathering and processing to update the ATEC variables to the new Base Year of 2006. The update is based on the fleet inventory properties from the EUROCONTROL PRISME Fleet 2 and OAG Fleet Databases, as well as the FESG retirement curves. The data includes historic technology scenarios and fleet sales over the years, and the geographical distribution of the fleet.

7.2 Data sources

7.2.1 There are three major sources of information to describe the fleet properties and the embedded historic parts of technology scenarios.

- The PRISME Fleet 2 database, supplied by EUROCONTROL, provides data on the fleet as operated in mid-2006. This database holds information at an aircraft tail-number level.
- OAG Aviation Solutions Fleet Database, and Avmark, are commercial databases licensed to NLR. These databases also hold relevant data on a tail-number basis and were used to supplement the PRISME database where PRISME has incomplete or insufficient information.
- Engine specific data (LTO emissions coefficients and fuel flows) were extracted from the ICAO Aircraft Engine Emissions Databank (Issue 16A). For each tail-number, the engine type that powers the aircraft is known within the PRISME database.
- The retirement curves specify the percentage of aircraft retired as a function of years in operation and is adopted from FESG. For the purpose of SAVE, the shape of the FESG curves are retained. However, the age after which all aircraft have retired as determined for each seat and range band, and aircraft purpose (freighter and passenger transport), is dependent on the generic aircraft type to allow for a best match with the historic fleet build-up.

7.3 Classification of aircraft

7.3.1 PRISME Fleet 2 is the EUROCONTROL aircraft database that holds the relevant information on a tail-number basis. This database is the prime source of information to classify aircraft for this project. The information extracted from PRISME reflects the world fleet build-up for mid 2006. For each aircraft (tail-number) the following data is determined:

- Aircraft type and year of production of this tail-number
- First year of production of the aircraft type
- Engine type and the engine first year of production
- Aircraft (certified) maximum take-off weight MTOW
- Aircraft purpose: cargo or passenger transport
- Operator country (where the aircraft is based)

7.3.2 Where the required data was not complete, the OAG and Avmark databases have been used to complete the information. From OAG and Avmark, the following was extracted:

- Current value estimated by insurance companies
- Range at maximum structural payload together defining the harmonic flight distance.
- Aircraft typical weights: maximum payload and operating empty weight (OEW), where OEW is defined (by OAG) as the MTOW of the aircraft minus the maximum structural payload and usable consumables (fuel, oil, etc.). These values are determined per tail number if available in the databases; if the applicable fields are empty expert judgment is used to fill in the blanks.
- Belly hold cargo capacity for passenger aircraft. This is defined as the available cargo capacity after taking into account passengers and their baggage. It is the difference between the maximum payload and the number of seats times 100kg (default weight of a passenger including baggage).

7.3.3 Based on the properties of the individual aircraft, each aircraft is assigned an aircraft purpose, a seat and range band, a technology level, and AERO-MS region (operator region). These properties will be discussed in the next paragraphs.

7.4 Aircraft purpose

7.4.1 The passenger air transport business, and its fleet and operations, differ significantly from the cargo air transport business. Within the AERO-MS, these two types of air transport are treated differently. Therefore, each aircraft is classified as either a passenger or cargo transport aircraft.

7.5 Seat and Range band

7.5.1 Aircraft are developed for certain markets with a payload and range in mind, leading to typical aircraft sizes and weights. Fuel consumption, emissions, costs, as well as operational characteristics such as flight and cabin crew, speeds and observed routings, vary accordingly. The aircraft cabin layout is recorded in the PRISME database; the aircraft range in the OAG Fleet.

7.5.2 During the SAVE project, it was agreed that the range splits (at 4000 and 8000 km) in the AERO-MS would remain unchanged. It was also agreed that the number and properties of the generic aircraft types should closely match those of the FESG (which has defined seat bands, but does not feature range bands that are a main requirement for the functioning of the AERO-MS). The resulting classification is given in the table below:

- Short haul, less than 20 seats
- Short haul, 20 to 100 seats
- Short haul, 101 to 150 seats
- Short haul, 151 to 210 seats
- Medium haul, 101 to 150 seats
- Medium haul, 151 to 210 seats
- Medium haul, 211 to 300 seats

- Long haul, 211 to 300 seats
- Long haul, 301 to 500 seats
- Long haul, more than 500 seats

7.5.3 Note that different seating arrangements may show the same aircraft type in different seat and range bands because the seating arrangement and range in PRISME and OAG is defined at tail-number level.

7.5.4 For the purpose of the AERO-MS, freighter cargo is converted into equivalent seats using 130kg of cargo as the equivalent of 1 seat. This conversion holds the contributions of passengers with baggage and weight items specific to passenger transport such as seats, lavatories, galleys, cabin panels, as well as differences in floor structures and cargo handling equipment.

7.5.5 The 500+ long range seat and range band is exclusively reserved for new large aircraft. While the A380 would be thus classified, it was not yet in service in 2006. (The few high density B747 and freighter variants that could be allocated to this seat and range band are allocated to the 301-500 long range generic aircraft class.)

7.6 Technology level

7.6.1 Within a seat and range band, aircraft technology (in terms of e.g. fuel consumption or emission characteristics) still may vary considerably according to the technology year (or certification year) of the aircraft. Aircraft technology evolves in time. Aircraft production life spans easily exceed 20 years, while production runs of aircraft without significant changes in technology (e.g. an engine upgrade) may last in the order of a decade.

7.6.2 In the original AERO-MS, the distinction between 'current' and 'old' technology depended upon the year of certification of the ***aircraft*** type. However, during the production life span of a single aircraft type, aircraft may be technologically upgraded or a new aircraft type may have been derived from an older technology aircraft, without incorporating the latest developments in fuel consumption. Typical examples are:

- Some aircraft have been in production for a long time already e.g. the A320 since 1986. The A320 has previously been classified as 'old', however evolutionary improvements to this aircraft type over the years would not be visible if the technology level is based on aircraft type certification year alone.
- Some 'current' newer aircraft are variants of 'old' aircraft technology, such as the B767-400 that was derived from the B767-300. This aircraft would be classified as 'current' technology if based on the aircraft certification year although both its engine and airframe probably better reflect the B767-300 technology level.

7.6.3 To distinguish between these differences, and to allow for a proper handling of technology developments in time, each aircraft tail-number in the PRISME database is assigned a technology level: 'old' or 'current'. This classification is now based on the ***engine*** type rather than the aircraft type.

7.6.4 The Engine Technology Year (now used as the basis for the old-current classification) is the year prior to the first engine production year. The Engine Technology Year serves to put the technological properties of the aircraft in a historic time perspective as a placeholder for scenario development.

7.6.5 Figure 7.1 shows the number of aircraft as a function of Aircraft Production Year (upper plot). The lower plot shows the number of aircraft as a function of Engine Technology Year (the basis for aircraft technology classification). This latter plot reveals a low point in the introduction of new aircraft-engine type designs around the year 1990, 16 years before the Base Year of 2006. Taking this low point as a break between old and current technology maximises distinction between these categories. Based on these data, EASA has endorsed taking 16 years as the break point between 'old' and 'current' technology.

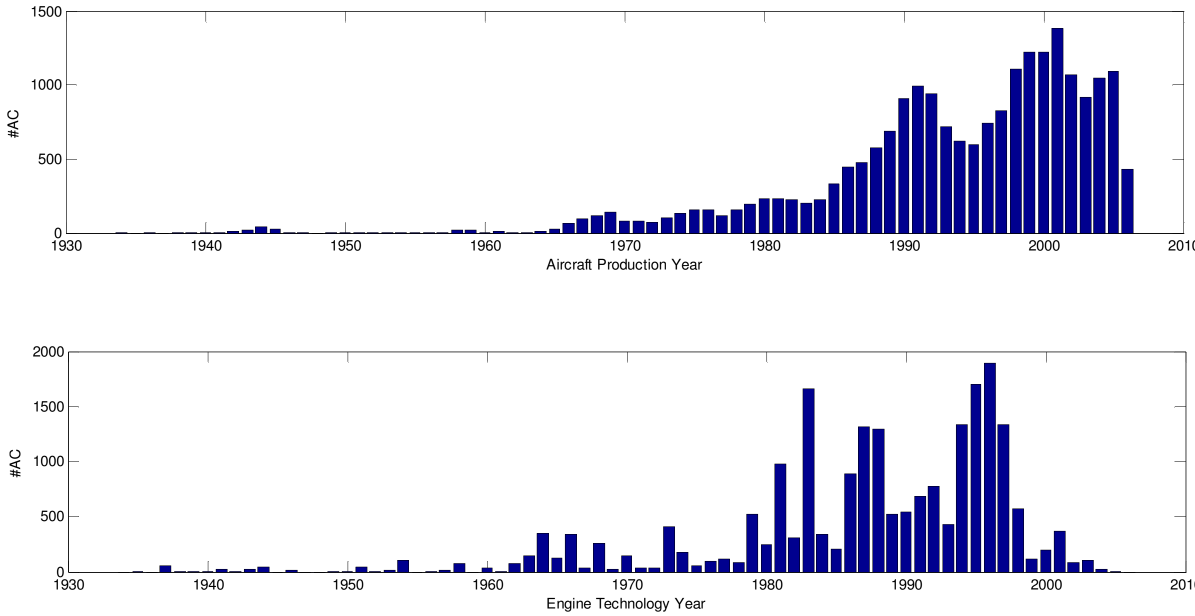

Figure 7.1 Number of aircraft by aircraft production and engine technology year

7.6.6 Aircraft types are classified 'old' if the Engine Technology Year is 1990 or older, which is equivalent to the first engine production year being 1991 or earlier. Aircraft types are classified 'current' if the Engine Technology Year is 1991 or later, equivalent to the first engine production year being 1992 or later. Hence, the first year of engine production might be earlier than that of first production of the particular aircraft.

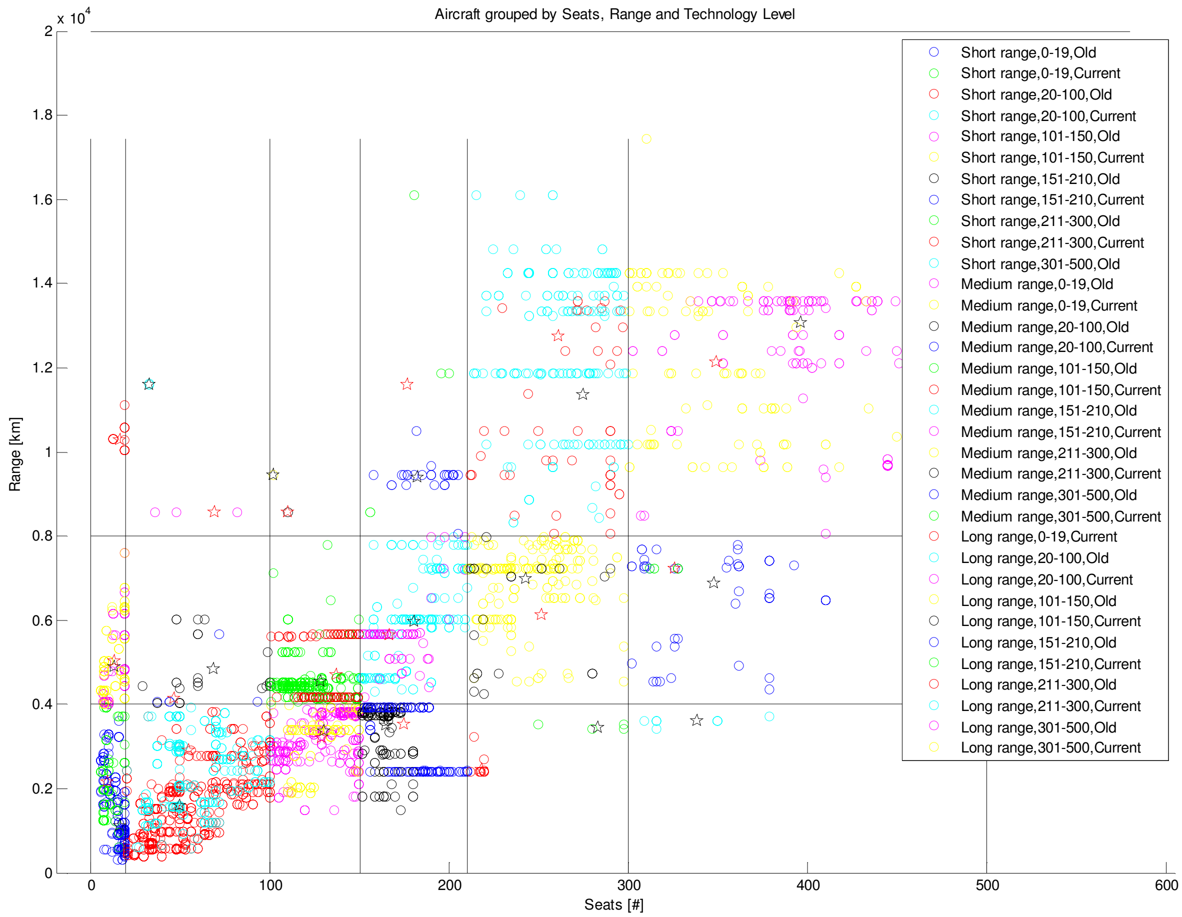

Figure 7.2 Distribution of aircraft over the seat and range bands

7.6.7 Figure 7.2 shows the distribution of aircraft types over the seat and range bands as adopted in the AERO-MS. Table 7.1 provides an overview of the technical attributes by seat and range band in terms of technology level, fuel use, belly capacity, payload and count (numbers in 2006 global fleet), as well as the old/current ratios related to fuel use and numbers. From the graph in Figure 7.1 it follows that small proportions of aircraft drop out of the AERO-MS classification (do not fall within the 10 seat and range bands that were actually considered). The seat and range bands and the corresponding numbers of aircraft dropping out are also indicated in the grey shaded parts in table 7.1. To avoid these aircraft actually dropping out, they have been added to the nearest range band.

Table 7.1 Seat and range band attributes

Range	Seats	Technology	Fuel use (kg/ tonkm)	old/ current	Bellycap .(kg)	Payload (kg)	Count (#)	old/ current
Short	0-19	Old	0.625	0.72	384	1977	1218	2.26
Short	0-19	Current	0.874		364	1353	540	
Short	20-100	Old	0.367	1.74	1036	5903	2445	0.86
Short	20-100	Current	0.212		1227	6727	2858	
Short	101-150	Old	0.208	1.18	4246	17196	1428	1.40
Short	101-150	Current	0.176		3871	16747	1019	
Short	151-210	Old	0.299	1.50	2047	18273	565	0.48
Short	151-210	Current	0.199		3744	21227	1183	
Short	211-300	Old	0.148		10128	38428	8	
Short	211-300	Current	0.309		1609	22958	47	
Short	301-500	Old	0.286		11761	45634	30	
Medium	0-19	Old	0.878		545	1842	183	
Medium	0-19	Current	0.787		408	1588	489	
Medium	20-100	Old	0.133		9941	14805	38	
Medium	20-100	Current	0.548		7410	3697	27	
Medium	101-150	Old	0.167	1.13	3226	15839	2110	1.88
Medium	101-150	Current	0.148		3507	17246	1122	
Medium	151-210	Old	0.161	1.22	7943	25992	1138	1.63
Medium	151-210	Current	0.132		2682	19331	699	
Medium	211-300	Old	0.160	0.97	13808	35798	685	7.61
Medium	211-300	Current	0.165		14155	39180	90	
Medium	301-500	Old	0.160		18363	52826	116	
Medium	301-500	Current	0.165		10775	43385	29	
Long	0-19	Current	0.600		1034	2711	78	
Long	20-100	Old	0.176		28325	31625	3	
Long	20-100	Current	0.098		8818	15751	9	
Long	101-150	Old	0.171		23366	33566	2	
Long	101-150	Current	0.126		4751	15751	1	
Long	151-210	Old	0.127		17983	36217	88	
Long	151-210	Current	0.099		20105	37770	20	
Long	211-300	Old	0.134	1.19	24696	52173	91	0.11
Long	211-300	Current	0.112		26683	52818	808	
Long	301-500	Old	0.147	1.46	30170	69819	509	1.13
Long	301-500	Current	0.100		24572	59108	451	

7.7 Aircraft new prices

7.7.1 The Aircraft new prices are derived from Avmark 2005 and Ascend 2009 databases. These databases contain the actual value of aircraft as estimated by insurance companies by aircraft type and production year. These values are a result of the new price (at the date of purchase), depreciation (due to the accumulation of flying hours and time) and inflation rates.

7.7.2 Airlines usually negotiate considerable discounts on the quoted, advertised manufacturer's prices. Hence, aircraft market values are considered a better basis to derive the 'true' aircraft new prices. To establish the aircraft new price in 2006, the prices are extrapolated (if production has stopped before 2006) or interpolated (if production has continued) to arrive at a 2006 value. Based on the Ascend data for 2009, the new price is derived from the

2009 value by correcting for inflation (approximately 3% per year) to obtain the 2006 new price

7.8 ATEC fleet build-up

7.8.1 The global fleet composition is a result of airline fleet management strategies lasting over a long period, up to half a century. Because of the long life span of aircraft, ATEC holds historical information on the fleet build-up based on the modelling of the operational life, (the time span between the aircraft first flight and the withdrawal from airline operations) fleet expansion and fleet replacement due to retirements. ATEC models the aircraft fleet as a combination of a fleet purchase scheme combined with a retirement scheme. The following paragraphs discuss these aspects. (Purchase year in the context of ATEC means the year the aircraft is actually put into operational service, not the time of signing contracts.)

7.9 Operational life and retirement

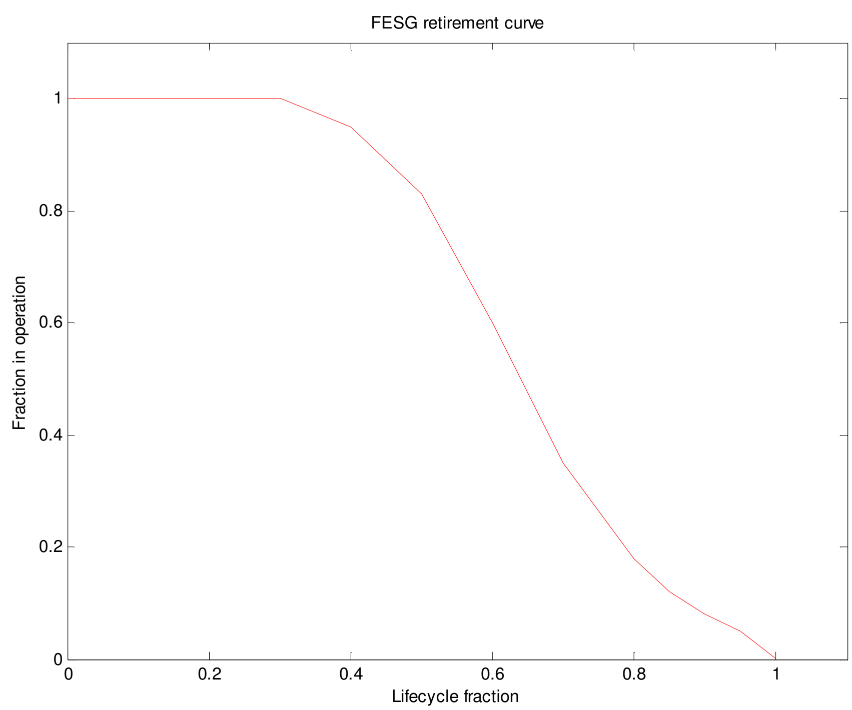

Figure 7.3 FESG Retirement Curve

7.9.1 The retirement curve specifies the fraction (or percentage) of aircraft that are still in service as a function of how much of the average aircraft lifetime that has passed since the aircraft came into service. For the SAVE project, the general FESG retirement curve is adopted. Because analysis has shown the average lifetime of aircraft to vary considerably between generic aircraft types, within the SAVE project, the original FESG curve has been modified to allow for the use of different maximum retirement ages, which introduces an additional degree of freedom in the modelling process. Aircraft proportions in service are now expressed in terms of a fraction of maximum retirement age (called life cycle fraction) with varying maximum retirement ages. For each seat and range band and passenger/freighter aircraft, this maximum retirement age has been determined using the aircraft numbers by purchase year in the PRISME database for 2006.

7.9.2 It must be noted that the shape of the FESG retirement curve is invariant between aircraft seat and range bands. In reality (i.e. in the PRISME database) the retirement curves are likely to vary by aircraft type, and seat and range band, and depending on whether the aircraft is a passenger or freighter plane.

7.10 Purchase behaviour

7.10.1 Airlines continually add new aircraft to their fleets. In the case of fleet expansion, a portion of these new aircraft replaces the older aircraft that have been retired, and the remaining portion is in effect a fleet expansion. If certain parts of the fleet size shrink, the number of aircraft being retired is larger than the number of new aircraft coming into operation. Within the AERO-MS the demand for new aircraft, and the retirement of old ones, varies between the seat and range bands. If no further information is available these demands might be based on extrapolation of trends in sales growth (the default if no further information on the demand for transport or aircraft is available). Alternatively, in the process of setting the fleet, the demand for air transport (passenger and cargo), being the result from the ADEM model is translated into the demand for transport in terms of aircraft by seat and range band. The required fleet is a result of the historic fleet built up, retirement of the oldest aircraft and policies that affect aircraft production and price. Based on the required fleet, ATEC estimates the sales of aircraft beyond the Base year 2006

7.11 Technology penetration

7.11.1 Aircraft that are purchased each year (the equivalent of the year taken into service) are developed in a series of preceding years. Hence the technology that is present in the newly bought aircraft stems from different time positions in terms of a technology timeline. The technology penetration defines the variation in engine technology years that can occur in a single purchase year. An aircraft production run can last several years without a relevant significant change in technology (e.g. an engine upgrade). Hence, aircraft that are produced and taken into operation in a particular year can originate from different technology years. Within the AERO-MS it is assumed the engine technology year is up to eight years older than its production year. It is noted that this technology penetration parameter also serves to model the speed of penetration of measures into aircraft purchases.

7.12 Fleet size: observed fleet and matching procedure

7.12.1 An important step in the data update procedure has been to match the observed historic fleet with the ATEC model variables. In this matching process, the pre-defined seat and range bands, technology levels, and some other aspects have served as boundary conditions. The following paragraphs describe this process.

7.12.2 The process starts with allocating each aircraft tail-number to the appropriate seat and range band, and determining its purpose (passenger transport or freighter). Aircraft having a maximum takeoff weight of 5760 kg or below are considered General Aviation and are not included in subsequent analysis. All other aircraft are associated with the best fitting seat and range band. Freighters are allocated to a seat band by converting the maximum payload into a number of seats, assuming a 130 kg per passenger seat equivalence.

7.12.3 Each tail-number is assigned to an AERO-MS geographical region based on the aircraft operator's country of registration.

7.12.4 Fleet age, and hence the technological properties, are not homogeneously distributed over the world. In some AERO-MS regions the fleet is, on average, older than in others. Hence, the relevant properties of the fleet, even within a seat and range band, vary from region to region. Within the AERO-MS the differences between regions are modelled based on the differences in average fleet age. For each region, the average age of the aircraft in the fleet, and the number of aircraft in the fleet by seat and range band and aircraft purpose, are determined using the information in the PRISME database.

7.12.5 For each seat and range band and aircraft purpose, the historic fleet build-up in terms of aircraft entering into the fleet by purchase year is retrieved from PRISME (containing information about the year each aircraft is taken into operational service). An example for a single seat and range band (151-210 seats / medium range) is shown in the first graph of Figure 7.4 below (the green line). Note that the PRISME database is a snapshot of mid-2006. This implies that the observed 2006 purchase volume is probably only about half of what could be expected by the end of the year.

7.12.6 In approximating the modelled fleet in ATEC, for each seat and range band a maximum life span has to be specified to fully define the FESG retirement curve. This curve is then inversely applied to obtain the (synthesized) sales over the purchase years from the observed sales in the PRISME fleet. From these sales an average annual sales growth rate is determined using the last 10 years prior to 2006. Combining the information on annual sales with the FESG retirement curve and the assumed maximum life span now determines the modelled aircraft entering the fleet by purchase year. By varying the relevant assumptions, a best matching between the observed and modelled fleet build-up is accomplished interactively. An example is shown in Figure 7.4 (first graph) where the modelled aircraft type entering into the fleet in ATEC (blue line) are shown together with the historic fleet build-up based on PRISME (green line). The resulting modelled aircraft fleet in ATEC should be a smoothed representation of the observed aircraft type tail-numbers in the PRISME database.

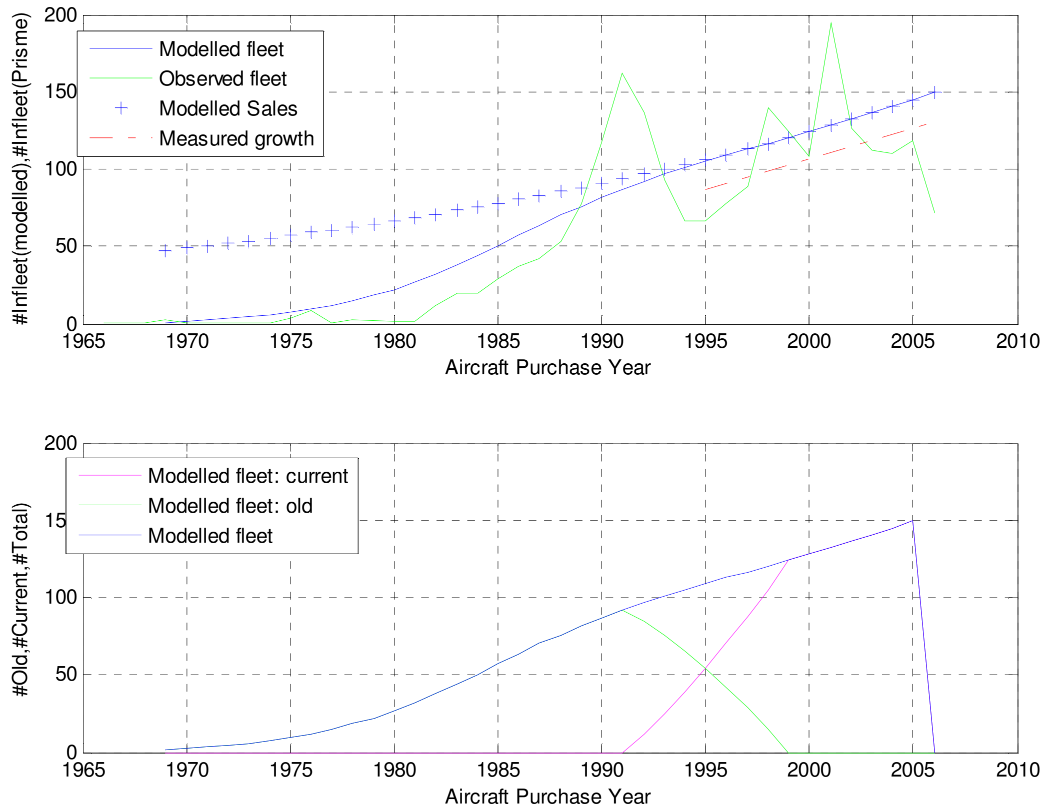

Figure 7.4 Example of the historic fleet build up

7.12.7 Once the matching of observed and modelled fleet build-up has finished, the numbers of old and current aircraft in the fleet are determined. For each purchase year, the aircraft purchase volume is split into technology years using the technology penetration variable. The assignment of each aircraft to the old and current portion of the fleet follows from the technology year of that aircraft. Finally a count of old and current number of aircraft is done. An example is provided in the second graph of Figure 7.4, where the total modelled curve of aircraft entering into the fleet is split up by the contributions of old and current aircraft (with reference to the Base Year 2006). Note that the X-axis in this second graph shows the development of technology over the years. Hence, in this case the timeline represents the Engine Technology Year.

7.13 Some observations

7.13.1 The matching between modelled and observed fleet build-up is strongly dependent on the quality of the parameters involved and the volatility of aircraft purchases between years (as Figure 7.4 demonstrated). The parameter space for accommodating this process is deliberately limited so as to maintain consistency with other uses of certain parameters, notably the Technology Penetration and 'old-current' Transition Period, in the AERO-MS. Other limitations exist in the quality and extent of the available data (available from PRISME only).

7.13.2 The adopted procedure for calibrating the modelled fleet to the observed fleet is to match the 'current' number of (modelled and observed) aircraft while simultaneously finding a balance between the number of 'old' aircraft and the general purchase behaviour over the years. This is accomplished by selecting a reasonable maximum retirement age.

7.13.3 In this process, a number of (very) old aircraft types may drop out of the modelled fleet (partly as a result of the limitations imposed by the shape of the retirement curve). It might be expected that these 'drop-outs' have low utilisation rates and do not significantly contribute to the transport volume and emissions.

7.13.4 Considering the purchase timeline resulting from the fleet matching procedure it is observed that actual purchases (and thereby technology advances) show a large variability. This implies expert judgement when applying certain technological measures, e.g. the scrapping of older aircraft.

7.14 Technology scenarios

7.14.1 ATEC technology scenarios describe the changes in fuel use and emissions (CO_2, H_2O, SO_2, HC, CO and NO_x) as a function of time. These scenarios are defined for each generic aircraft type in terms of seat and range band. The scenarios have the form of a percent change per year over a number of adjacent years, reflecting the development of (state-of-the-art) technology. The time aspect of a technology scenario is set by the Engine Technology Year which is determined by the first year the engine appears in the fleet minus one year.

7.14.2 The specification of technology development is based on a timeline that includes the entire build-up period of the present fleet, preceding the Base Year. From the Base Year onwards, technology developments are then further projected into the future. Hence, the timeline for the specification of technology development consists of a historic part (before the Base Year and a future part (after the Base Year). Within both parts of this timeline a number of discrete time intervals have been defined. Scenario developments have been specified as annual changes that are constant within these time intervals.

7.14.3 Note that the technology scenario specification is solely a function of technology advances, and not its penetration into the fleet. The technology characteristics of the actual fleet in service, taking into account the effects of fleet build-up and distribution of technology within the fleet, are an output of ATEC and by definition not part of the technology scenarios.

7.14.4 The historical development of technological properties until 2006 is extracted from PRISME data in combination with the ICAO database. In PRISME, data on engine type and year of purchase are available for each aircraft tail-number. The value of the Engine Technology Year is set to the purchase year before the first purchase year of the engine type (independent of the aircraft type). Thereby it is implicitly assumed that the engine holds the key technology in terms of fuel consumption and emissions properties.

7.14.5 The future development of technological properties from 2006 onwards follows from expected autonomous developments. For the BaU (Business as Usual) scenario, QinetiQ has proposed a set of developments that are in accordance with other studies including the CAEP/8 Environmental Goals studies. These will be further addressed in Chapter 11 of this report.

7.15 Assessment of historic fuel consumption properties

7.15.1 The fuel consumption considered in the technology scenario is based on the fuel consumed per payload kilometre at maximum flight distance (range) that can be achieved at maximum payload. This is a typical design condition for an aircraft, based on a number of well defined properties, as recorded in the PRISME database. The fuel consumption is calculated as:

$$FuelUsePerTonkm = \frac{MTOW - OEW - MaxPayload}{Range * MaxPayload}$$

The relevant fuel weight equals the maximum takeoff weight ($MTOW$) minus operational empty weight (OEW) and minus maximum payload ($MaxPayLoad$). Dividing the fuel weight by maximum flight distance ($Range$) and maximum payload yields the fuel consumption per tonne payload-km. In this context it is important that the range, payload and fuel weight refer to the same operational flight specification.

7.15.2 The resulting values for all aircraft can then be put in a historical (time) perspective by adding the Engine Technology year. The results can then be graphically displayed (see Figure 7.5 for an example of such a graphical presentation).

7.16 Assessment of historic emission properties

7.16.1 The LTO total emission values (Em) of HC, CO and NO_x have been derived from the data in the ICAO Aircraft Engine Emissions Databank. For each engine in this database, the LTO (Landing and Take-Off) cycle value of the relevant emission is calculated. The LTO cycle is the engine certification reference procedure, and this cycle is generally assumed to be a conservative representation of the actual aircraft LTO NO_x emissions. The LTO cycle is effectively a time-weighted average of the fuel use and emissions values for the 100%, 85% 30% and the 7% thrust settings at static ambient conditions, given by:

$$Em_{LTO} = \frac{\sum_{100,85,30,7} FF \cdot EI \cdot Tim}{\sum_{100,85,30,7} FF \cdot Tim}$$

In this calculation Em is the emission value, FF the fuel flow, EI the emission index and Tim the time in each thrust setting mode. Like the fuel flow characteristics, the resulting values for all aircraft can then be put in a historical perspective by adding the Engine Technology year.

7.17 Building the historic part of the technology scenarios

7.17.1 Once the fuel and emissions properties for each aircraft (by tail-number) are determined, the next step is to actually build the historic part of the technology scenarios. For this purpose, all aircraft are first assigned to their seat and range band and to Engine Technology Year, using the PRISME database information.

7.17.2 Note that different seating arrangements may show the same aircraft type in different seat and range bands because the seating arrangement and range in PRISME is defined at tail-number level. Furthermore, a single aircraft type may have several, different Engine Technology Years if equipped with different engine types. The fuel use per (payload) ton-km is determined at tail-number level and further grouped by aircraft type (name).

7.17.3 The historical part of the technology scenario is split into two intervals: 1967 to 1980 and 1980 to 2006. The default starting point 1967 is currently inherited from the original AERO-MS: the technology scenario starts at 1967, and now runs up to 2006, with a trend break at 1980. Splitting the scenario timeline into more intervals will increase the degrees of freedom in the specification of historic developments, but will also result in more volatile trends. The opposite holds if the number of intervals is reduced. Another interval starts at 2006 and runs into the future, where the technology development will be based on the BaU scenario assumptions. This is only relevant for the period after the Base Year. The software implementation of ATEC requires one common interval definition (the same year where kinks in trends are allowed) of the scenario timeline for all generic aircraft (seat and range bands) and scenario aspects (fuel and emission types).

7.17.4 As a last step, a trend line using a robust regression method is drafted through the data points on each interval. "Robust" here means that outliers are automatically identified and their importance reduced in setting the trend line.

7.17.5 A sample result is shown in Figure 7.5. In the upper sub-graph, the fuel technology development as used within the AERO-MS is shown by a red line that denotes the trend in the observed historical fuel consumption of the aircraft type. Because trends show different values over the years, the trend line is broken into two time intervals. The oldest interval starts at the year where according to the FESG retirement curve aircraft are within the ATEC fleet. It ends at 1980 where the next interval starts up to 2006. The first sub-graph also shows for each aircraft type (fuel use and Engine Technology Year) the number of tails (by the size of the circle). This indicates the importance of a certain aircraft type in the determination of the scenario. The second sub-graph shows the associated named aircraft types.

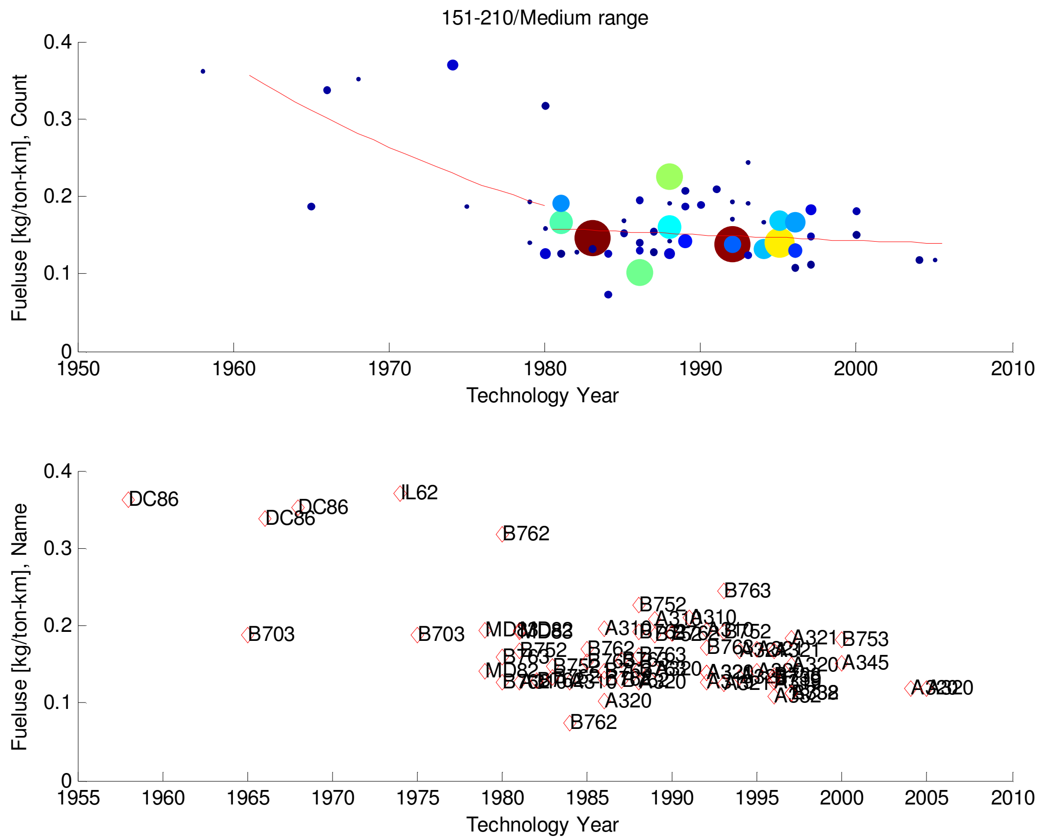

Figure 7.5 Sample result of historic technology development

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7.17.6 Although in general the fuel consumption per tonne-km of new aircraft entering the fleet reduces over time, it is observed that a number of generic aircraft types (types Short haul, less than 20 seats, short haul, 101 to 150 seats and Medium haul, 211 to 300 seats, with the second type shown in figure 7.6 below) show a slight increase in fuel consumption per tonne-km in the period 1980 - 2006.

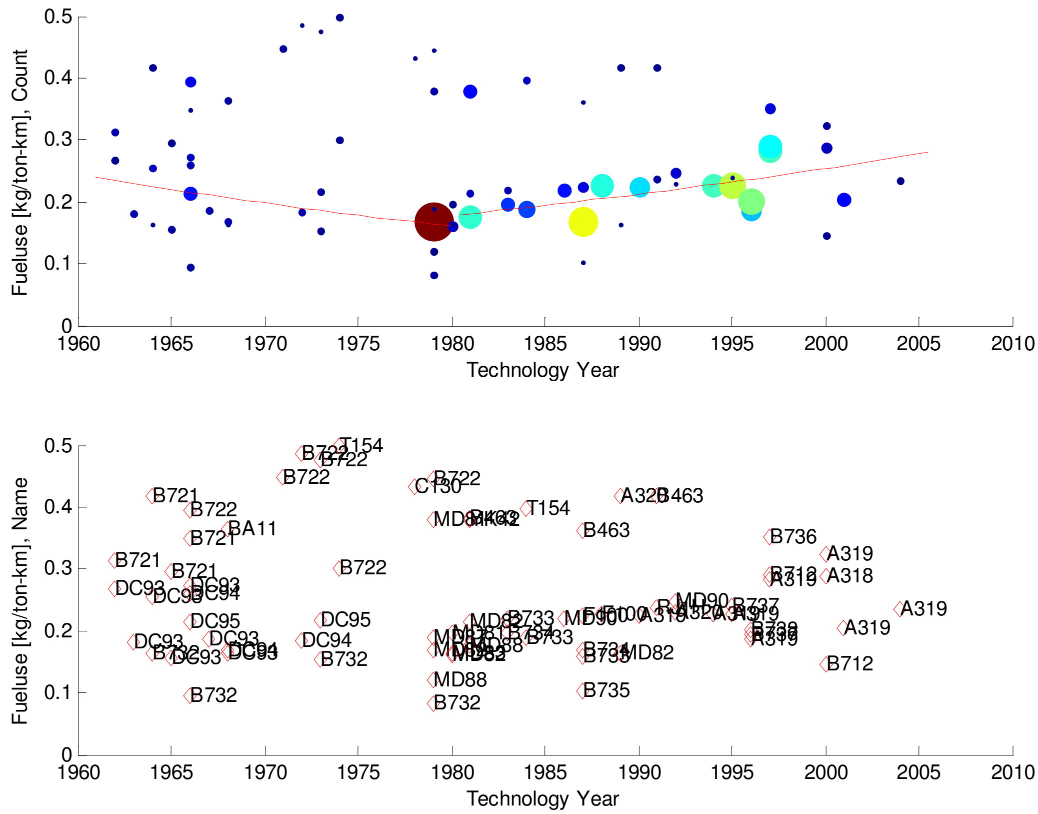

Figure 7.6 Historic technology development for aircraft type 2

7.17.7 Looking at these generic aircraft types, it can be seen that this trend appears to be correlated with some other trends:

- Reductions in older commuter type, turboprop aircraft and increases in modern longer range jet powered business jets,
- Recent low capacity and high range, or high capacity and short range, aircraft types derived from older base line "parent" aircraft types.

7.17.8 It was shown above that, for most seat and range bands, the fuel consumption per tonne-km of new aircraft entering the fleet has been falling over time. This necessarily implies that the fleet-wide average of fuel consumption per tonne-km has also been falling. It is of interest to consider NO_x production in a similar manner.

7.17.9 The following graph shows the development of NO_x production on the timeline of engine certification for individual aircraft types now in service. It shows very clearly that there has been a significant increase in NO_x production for the more current aircraft relative to the oldest aircraft in the fleet. This increase is observed for all seat and range bands, and may well be a consequence of the manufacturers' quest for improved fuel efficiency with higher engine temperatures and pressures, as well as the introduction of larger aircraft types with higher rated engines.

7.17.10 It implies, of course, that the fleet-wide average of NO_x production is increasing. That will continue as the older aircraft are retired. The ATEC model builds this historical effect into the AERO-MS fleet forecasts, though in creating Datum scenarios the model-user can set assumptions as to NO_x production for future aircraft types.

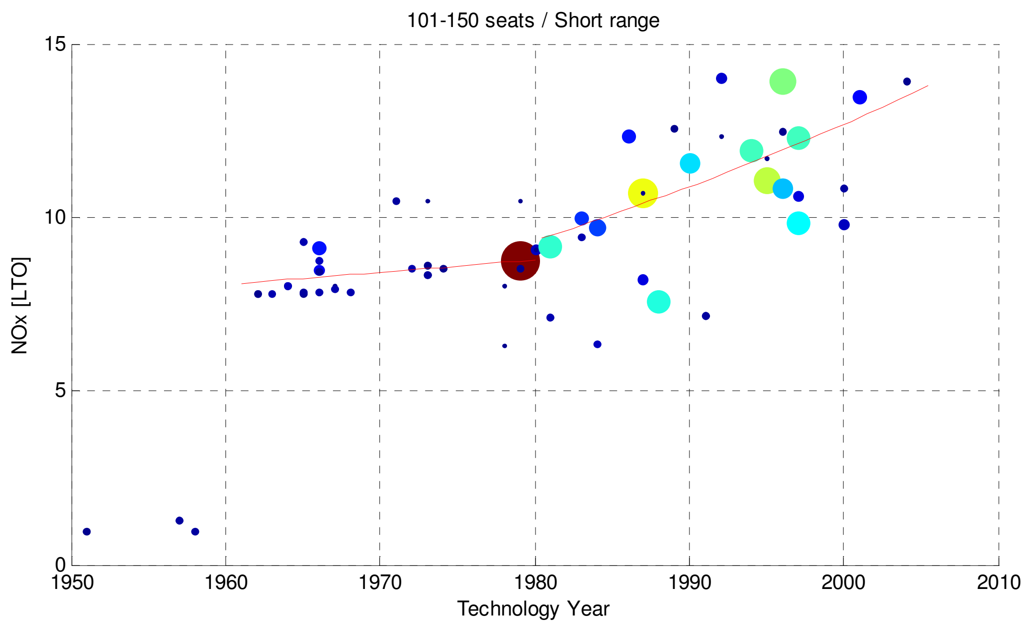

Figure 7.7 A typical NOx scenario development

7.17.11 Finally, in this project, only kerosene powered aircraft turboprops and turbofans are considered. Given the current status of engine combustion process, the SO_2, H_2O and CO_2 emissions properties are then primarily a fuel property.

8 Flight and emissions modelling

8.1 Background of FLEM

8.1.1 The FLight and Emission Model (FLEM) within the AERO-MS serves to generate accurate information on the flight tracks, emissions and fuel consumption, for a future situation, optionally including operational policy measures. To accomplish this, FLEM combines the fuel and emission properties of a future fleet resulting from the ATEC model, with detailed characteristics of specific reference aircraft types.

8.1.2 FLEM takes into account developments in aircraft technical, environmental and operational performance as forecasted from scenarios and policies.

8.1.3 The resulting fuel-burn and emissions are allocated into three dimensional space in the global atmosphere ready for further processing in connection with e.g. climate effects or emissions trading scheme analysis.

8.1.4 The Flight and Emission Model will provide the AERO-MS with estimates of fuel-burn at a higher accuracy than the NLR Runtime Library (NLRRT) supporting ACOS. FLEM contains reference aircraft with their characteristics in order to generate realistic flight paths between two airports and consequently calculate fuel consumption and emissions along these flight paths.

8.2 Feasibility study: BADA3.7 as primary update source for FLEM

Overview and outcome of BADA3.7 investigation

8.2.1 The data currently supporting FLEM is based on detailed aircraft characteristics, however this source of data is no longer available and is therefore not considered a viable long term solution. As such, within the SAVE project, a feasibility study was performed to investigate to what extent EUROCONTROL's Base of Aircraft Data (BADA) could be used to update FLEM input variables. The main reason for using BADA is that it has been extensively reviewed and validated by various stakeholders, including industry, and is widely used and supported by a user group to facilitate future development and enhancements.

8.2.2 If BADA data could be used for the update of FLEM, the primary data source would be EUROCONTROL's BADA 3.7. BADA 3.7 is a kinematic model designed for use in trajectory simulation and prediction algorithms within the domain of Air Traffic Management (ATM) (ref EEC Technical/Scientific Report No. 2009-003). As such, BADA 3.7 is primarily focused on the trajectory generation and ATM requirements. BADA 3.7 contains performance and operating procedure coefficients for 294 different aircraft types. These coefficients include those used to calculate thrust, drag and fuel flow and those used to specify nominal cruise, climb and descent speeds.

8.2.3 BADA 3.7 is designed to accurately represent the kinematic behaviour of aircraft (in particular speed, climb and descent rates). FLEM, by design, is a kinetic model requiring an accurate description of forces acting on the aircraft, i.e. drag and lift. Because of the different approach in modelling, NLR has investigated to what extent BADA data could be used within FLEM, and what expert judgement would be required to allow FLEM to work with BADA input.

8.2.4 Complementary to BADA, the ICAO Aircraft Engine Emissions Databank 16A is used for specific information on engine characteristics. This includes emission indices for a number of emissions and fuel flow. Also Jane's All the World Aircraft would be used to supplement BADA in some cases with additional aircraft information, for example certain aircraft weights.

8.2.5 Using BADA 3.7 and these sources in combination, most of the variables used in FLEM could be populated appropriately, but there were seven critical variables that could not be. There were three main reasons for this:

- BADA does not contain all information required for FLEM (e.g. detailed engine characteristics),
- BADA does not contain the level of detail in aircraft characteristics required by FLEM, e.g. lack of Mach number or weight dependency for some variables, notably thrust (settings) and drag.
- Where other sources of information have been used alongside BADA issues arise to make the data consistent to allow FLEM to generate credible results.

8.2.6 With BADA not having the level of detail required by FLEM, the flights paths generated by FLEM become unrealistic: modelled aircraft fly too high or too low, resulting in unrealistic fuel-burn and unrealistic distribution of emissions in three-dimensional space. Unfortunately the discrepancies between FLEM and BADA proved to be too great to resolve within the current SAVE project.

8.2.7 The issues encountered using BADA have been discussed with EUROCONTROL. It was recognised that the aircraft performance model design philosophy was different in BADA from that of FLEM. The BADA approach reduced the need for detailed input data while maintaining accuracy for the targeted purposes of BADA. For one of the seven critical FLEM variables EUROCONTROL saw possibilities to derive the information from BADA 3.7, while it is thought that the remaining six variables will be derivable based on BADA 4.0 (the successor to BADA 3.7) and additional modelling.

8.2.8 Further information on long term solutions can be found in chapter 13 on proposals for further improvements to the AERO-MS.

8.2.9 The following paragraphs detail the BADA 3.7 investigation.

Selecting reference aircraft

8.2.10 Throughout the AERO-MS the concept of seat and range bands is applied to distinguish the segmentation in the aircraft fleet. As stated before, with each seat and range band, a reference aircraft is selected to complement the information to determine a flight trajectory between two airports and to calculate fuel use and emissions. As part of the AERO-MS update, reference aircraft must be selected that represent/support/match the generic, fleet averaged, aircraft types (from ATEC and the Unified Database).

8.2.11 The choice of reference aircraft for each fleet segment (seat/range band) for which a generic aircraft is derived is driven by the market share within the seat and range band, the 'state-of-the-art' of the aircraft and quality of aircraft characteristics.

8.2.12 The market share by aircraft type can be found within fleet databases (e.g. PRISME). It is deemed logical that the most common aircraft within a certain seat and range band will be the reference aircraft for that band. Because the reference aircraft should also cover a future fleet, a recent and representative design is preferred. From the data gathering aspects, BADA contains two types of aircraft: aircraft that are directly modelled, and aircraft that are represented by another type. Logically, only directly modelled aircraft are eligible as representative aircraft.

8.2.13 The granularity, consistency and completeness of data from the FLEM perspective (i.e. thrust and drag are modelled with sufficient sensitivity to various operating conditions) as stored within BADA will determine whether or not the aircraft can be modelled accurately enough in FLEM.

8.2.14 The starting point for selecting the reference aircraft are the aircraft types in each of the AERO-MS seat and range bands as observed within the PRISME database. The most favourable reference aircraft is that aircraft type that is most common in a seat and range band. Therefore for each seat and range band the most common aircraft are selected.

8.2.15 Then, an appropriate reference aircraft must be modelled using BADA, which requires that this aircraft is in fact available in BADA. In particular, the smaller aircraft (0-19 seats) are not well represented in BADA at present. The best candidate reference aircraft are presented in Table 8.1.

Table 8.1 Reference aircraft and engine type for seat/range bands

Reference A/C	Aircraft type	Engine type	Seat band	Range band
0	C750	AE3007C	0-19	Short
1	CRJ2	GE CF-34-3B1	20-100	Short
2	A319	CFM56-5B5/P	101-150	Short
3	B738	CFM56-7B26	151-210	Short
4	B737	CFM56-7B22	101-150	Medium
5	A320	CFM56_5_A3	151-210	Medium
6	B764	CF6-80C2B7F	211-300	Medium
7	B772	PW4090	211-300	Long
8	B772	PW4090	301-500	Long
9	A380	TRENT 970-84	>500	Long

Updating FLEM variables

8.2.16 Within FLEM, three kinds of data can be distinguished. The first kind of data is related to operational flying procedures, and is aircraft-type dependent. The typical operational data are: speed, operating altitude, range, climb rates, descent rates, associated thrust settings, and resulting fuel flow rates that vary by aircraft and operational condition (altitude, speed, climb, descent, level flight and aircraft configuration).

8.2.17 The second kind of data is specific to an aircraft type. This data comprises specific weights e.g. maximum takeoff weights, maximum fuel weight, maximum landing weight, maximum payload weight, drag and lift characteristics.

8.2.18 The third kind of data are variables not specific to aircraft or operations. Usually they define various dimensions such as grid cell sizes and altitude bands. These are usually not critical but require review whether the chosen values are still applicable.

8.2.19 An inventory of FLEM variables that require update was made and can be found in Table 8.2. The potential update method is given for each variable that could be updated. If it could not be updated, the reason is given.

8.2.20 There are five update methods mentioned in Table 8.2 which are classified as follows:

- "BADA": Data are extracted/derived from EUROCONTROL BADA version 3.7. Data are given in table form in BADA model files or implementing the BADA model delivers the required information.
- "ICAO": Data are extracted/derived from ICAO emissions database 16A. Most of the required information is directly given in the database. Information mainly involves LTO emission indices, fuel flow and pressure ratios.
- "Jane's": Data are extracted/derived from Jane's All the World Aircraft. Mainly used to supplement BADA with aircraft weight, range and Mach number information.
- "EXPJUD": Needs expert judgement, required further investigation or interpretation of data. As FLEM was not designed around BADA data, this includes expert judgement on the use of BADA for some variables.
- "Calibration": A calibration between reference aircraft and aircraft fleet is required (calibration between AERO models). With this calibration a reference aircraft can accurately represent aircraft within the corresponding seat and range band.

Table 8.2: FLEM variables that require update

FLEM variable (description)	Updated	Update method
Aviation type related to aircraft	√	EXPJUD
Constants in formula for atmospheric corrections to fuel flow	√	EXPJUD
Factor on flight time to make specific aircraft type representative for all aircraft within the aircraft class	√	Calibration
Maximum scale factor on aircraft reference type	√	EXPJUD

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FLEM variable (description)	Updated	Update method
Maximum payload weight	√	BADA and Jane's
Maximum take-off weight	√	BADA and Jane's
Maximum landing weight	√	Jane's
Maximum fuel weight	√	BADA and Jane's
Empty weight of aircraft	√	BADA and Jane's
Weight of reserve fuel	√	EXPJUD, BADA and Jane's
Load factor at the design range	√	Jane's and EXPJUD
Aircraft range at design load factor	√	Jane's
Range correction to account for climb and descent	√	EXPJUD
Non-scalable weight of aircraft	√	EXPJUD
Engine Pressure ratio for 100% thrust at sea level	√	ICAO
Aircraft reference flight level	√	BADA
Mach number at initial cruise	√	Jane's
Wing surface	√	BADA
Minimum rate of climb	√	BADA and EXPJUD
Minimum flight path angle	√	BADA and EXPJUD
Descent performance table: flight path angle	√	BADA and EXPJUD
Performance table: height values	√	EXPJUD
Descent performance table: speed schedule	√	BADA and EXPJUD
Climb performance table: climb speed schedule	√	BADA and EXPJUD
Performance table: Mach number values	√	EXPJUD
Performance table: power setting values	√	EXPJUD
Performance table: thrust values	√	EXPJUD
Engine LTO time values	√	ICAO
Engine ICAO fuel flow values	√	ICAO
Engine ICAO emission index values	√	ICAO
Performance table: weight values	√	EXPJUD
Factor on fuel flow to make specific aircraft type representative for all aircraft within the aircraft class	√	Calibration
Factor on emission index to make specific aircraft type representative for all aircraft within the aircraft class	√	Calibration
List of cities selected for the city LTO map	√	EXPJUD
Maximum flight level for IATA region-pair	√	EXPJUD
Distance change factor for IATA region-pair and aircraft type	√	EUROCONTROL data (CANSO)
Distance step of the profile segments	√	EXPJUD

FLEM variable (description)	Updated	Update method
in the various flight phases		
Off-cruise fuel flow correction factor	√	Calibration
Engine effective jet radii ratio R1/R2 *	X	No information available within BADA 3.7
Engine Isentropic inlet efficiency *	X	No information available within BADA 3.7
Engine Isentropic compression efficiency *	X	No information available within BADA 3.7
Constants used in the calculation of the drag coefficient	X	No information available within BADA 3.7. Climb and descent unrealistic.
Constants used in the calculation of the lift coefficient	X	In insufficient detail in BADA 3.7: no Mach number dependency.
Engine 100% Power setting *	X	No information available within BADA 3.7.
Performance table: high pressure compressor power setting *	X	No information available within BADA 3.7.
Performance table: low pressure compressor power setting *	X	No information available within BADA 3.7.
Maximum Mach number per major flight phase	X	In insufficient detail in BADA 3.7: no max Mach number in climb known.
Climb performance table: climb maximum thrust	X	In insufficient detail in BADA 3.7: no Mach number dependency.
Performance table: fuel flow values	X	In insufficient detail in BADA 3.7: Fuel flow determined using BADA formulas using only cruise fuel flow correction factor. Therefore exact operational fuel flow is not known.
Engine LTO engine power values *	X	No information available within BADA 3.7.
Cruise performance table: cruise Mach number schedule	X	In insufficient detail in BADA 3.7: no weight dependency.
Weight step table, a maximum weight at 1000 ft intervals	X	In insufficient detail in BADA 3.7: It states max. weights estimated using two values: maximum altitude at MTOW and maximum operating values. Detailed best altitude-weight relationships for cruise altitude not known.

* involves NLR P3T3 method, non-critical part of FLEM

8.2.21 As noted earlier and can be seen from Table 8.2, a large number of FLEM variables (38) could be updated using BADA 3.7 as the primary data source with some additional data sources and methods. A total of 14 variables could not be updated because of insufficient information. Seven out of these 14 variables, labelled with an asterisk (*), are non-critical to the functioning of FLEM because they involve a non-default P3T3 method used for calculating NO_x. Thus, seven critical FLEM variables remained which could not be updated.

8.3 Re-calibration of reference aircraft

8.3.1 With the feasibility study showing that some critical FLEM variables could not be updated using BADA3.7, and there being currently no other data sources available that contain enough detailed information for the update of FLEM reference aircraft, the reference aircraft from the original AERO model were used. Though they cannot be fully updated, they have been recalibrated to correspond with the updated 2006 fleet.

8.3.2 The re-calibration of FLEM reference aircraft in order to correspond to the updated 2006 fleet relates to the update of two fuel and emission calibration factors in FLEM. In order to have accurate fuel and emission results from the current FLEM model, the reference aircraft in FLEM are re-calibrated for the new 2006 aircraft fleet fuel and emission characteristics. This re-calibration allows a reference aircraft in FLEM to deliver representative fuel and emission results for the corresponding seat and range band.

8.3.3 First the characteristics in terms of fuel use and emissions of the reference aircraft are determined for the LTO thrust settings from the ICAO emissions databank. Next, the average fuel use and emissions characteristics of the 2006 aircraft fleet within each seat and range band are determined, using the same LTO thrust settings from the ICAO emissions databank. Finally, for each of the thrust settings, the fuel and emission LTO values are determined by using a scaling factor which turns the fuel and emission characteristics from the reference aircraft to the average aircraft for the seat and range band concerned.

8.4 Detour factors

8.4.1 Hitherto in the AERO-MS the default values for detour have been 1.1 for flights between IATA regions and 1.15 for flights within an IATA region. The detour factors for 2006 in the updated AERO-MS are based on IEOGG[11] data with respect to the estimated efficiency of the ATM system in 2006. These data were made available to the SAVE project by EUROCONTROL. A 100% efficiency represents aircraft flying point to point via the optimum trajectory such as the great circle ground track route at the most fuel efficient altitude and speed. A flight that uses 2% more fuel than the optimum trajectory is considered 98% efficient. The report recognizes that 100% ATM efficiency is not achievable as some efficiency is reserved for the interdependencies such as safety, capacity, weather and noise.

8.4.2 The IEOGG data contain an estimated ATM efficiency by region (with a lower and upper bound estimation):

- Africa 90% - 93%
- Asia/Pacific 91% - 94%
- Europe 89% - 93%
- Central America / Caribbean 93% - 96%
- Middle East 92% - 94%

[11] IEOGG stands for Independent Expert Operational Goals Group. The IEOGG was established by CAEP to examine and make recommendations for noise, NO_x and fuel burn with respect to air traffic operational goals.

- North America 92% - 93%
- South America 93% - 96%

8.4.3 The IEOGG data have formed the basis for the updated detour factors to be included in the AERO-MS. For each of the 196 region pairs a detour value has been determined by taking the average of the ATM efficiency of the origin and destination region (whereby per region the average of the IEOGG lower and upper bound estimation is considered). In this process an efficiency of e.g. 90% according to the IEOGG data is translated into an AERO-MS detour factor of 1.10. As part of the calibration further limited changes to the detour factors in the updated AERO-MS have been made (see also chapter 10).

9 Software technical enhancements

9.1 General

9.1.1 The AERO-MS is a software tool that includes a number of models and a software shell which manages the access to the database with inputs and computational results, the interaction between the various models and the interaction between the user and the AERO-MS. As part of Work Package 8 (WP8) of the SAVE project a number of software-technical enhancements have been implemented in the AERO-MS. These enhancements relate to the conversion to new software platforms, the inclusion of a data access layer to the AERO-MS and further software technical changes to the AERO-MS user interface and models. These enhancements are reported respectively in section 9.2, 9.3 and 9.4 of this chapter.

9.1.2 Apart from the software-technical enhancements, WP8 was also involved with other software issues like the set-up and use of a SAVE Sharepoint site and the use of a model version management system facilitated by Assembla. These were software support actions to facilitate the project execution which have not affected the actual design and contents of the AERO-MS, and are therefore not further addressed in this report.

9.2 Conversion to new software platforms

Steps taken in conversion process

9.2.1 The 1992 AERO-MS was developed on platforms that are currently outdated, several release versions behind their modern-day equivalents and hence unsupported. At the start of the SAVE project it was examined whether the development platforms could be updated to current versions. The main advantages of converting the AERO-MS models, framework and user interface to more modern platforms is that modern platforms enable programmers to work more efficiently. Moreover it is hard to find programmers who have the skills to use the outdated platforms used in the 1992 AERO-MS. By using modern platforms, the minor code changes made during the SAVE project could be implemented more efficiently. Also possible future changes to the models and user interface outside the scope of the SAVE project and future maintenance of the AERO-MS can be done more efficiently with the code converted to more modern platforms.

9.2.2 The 1992 AERO models were developed in C, and some parts of the framework (the Data Manager and Run Time library) in C++, using Borland C++ 5.01. As a modern-day equivalent Microsoft Visual Studio C++ 2008 is available, which is most widely used on Windows Platforms. For the 2006 AERO-MS it was therefore agreed to work with Microsoft Visual Studio C++ 2008. The AERO user interface was originally developed in Delphi 7, for which Embarcadero Delphi 2010 is the natural successor.

9.2.3 The first task in the conversion process was to port the modeling framework (the Data Manager) to Visual C++ 2008. Most of the required changes had to be made because of a difference in non-standard C/C++ syntax and method names related to the Windows environment. Other affected areas included code that used Borland-specific DOS functions;

these were ported to the standard Windows equivalents. Some small bugs have been fixed and error detection has been improved. These bugs did not affect model results. The functionally of the framework has remained the same.

9.2.4 The AERO models (ATEC, ACOS, ADEM, DECI and FLEM) also have been ported to Visual C++ 2008. Most of the changes in the code of the models reflect changes in the framework, such as new macro definitions. A few changes relate to better syntax checking in the new platform: incorrect assignments that worked in the old environment but are now flagged as errors. None of these changes affect the functionality of the models.

9.2.5 The new environment offers better debugging and testing support. Testing the models in the new environment (still with 1992 input data) showed deviations of the result for selected policies in the so-called ReviseFleet function in the model ADEM. It turned out that the old environment (Borland C++) did not compile the ADEM code as expected. As a result, some code that ran perfectly in the old environment did not work correctly in the new environment and had to be fixed.

9.2.6 In a next step, the user interface of the AERO-MS was ported from Delphi 7 to Embarcadero Delphi 2010. The integration with the Visual C/C++ platform required some work, but most of the code did not have to be revised. Some changes to the functionality of the user interface were made to ensure the non-updated AERO models cannot be included by accident in the model runs.

9.2.7 Finally, the directory structure of the AERO-MS source files, executables and data files was changed in preparation of the new version management system. The source files are now separated from the files required for model runs. The configuration file was split into several files, separating the settings that should not be changed by the end user, local settings, model run queue and statistics.

Testing of converted AERO-MS

9.2.8 The converted AERO-MS was tested by comparing the results with the non-converted version of the system. All test runs used Base Year 1992 input data. From a comparison of results it turned out that for Base and Datum (scenario) runs the results are identical. However, Forecast (policy) runs results between the converted and non-converted AERO-MS were slightly different, as Table 9.1 shows for the effects of a fuel taxation policy of 0.20 US$ per kg (FT20) relative to a scenario run.

Table 9.1 Selective number of results for converted and non-converted AERO-MS.

Indicators	Effects of policy (FT20) relative to scenario results	
	Converted AERO-MS	**Non-converted (original) AERO-MS**
Number of flights	-6.60%	-6.60%
Aircraft-km	-6.28%	-6.34%
Revenue Tonne-Km	-6.41%	-6.58%
Fuel consumption	-8.30%	-8.42%

9.2.9 It was important to understand why these differences, small as they are, were computed. Because during the conversion to the new platform model a code fix was made in the ReviseFleet function in the model ADEM, the analysis focused on this function. In a Forecast run the ADEM ReviseFleet function is also used in the model ACOS. From the analysis it turned out that in the original (non-converted) AERO-MS for a number of traffic lines the ReviseFleet function used in ACOS does not handle the inclusion of New Large Aircraft (NLAs) correctly because of an anomaly in the old development environment. The converted AERO-MS does not suffer from this problem.

9.2.10 To be absolutely sure that the NLA-related fix in the ReviseFleet function was responsible for the differences presented in Table 9.1, a scenario was defined with no introduction of NLAs[12]. With both the converted and non-converted AERO-MS the effects, including the effects of the FT20 policy under the revised scenario were recomputed. As expected, under the revised scenario no differences were found between the converted and non-converted AERO-MS. This proved that the fix in the ReviseFleet function is responsible for the limited differences in computational results between the converted and non-converted AERO-MS as presented in Table 9.1.

9.2.11 The overall conclusion from the testing was that the AERO-MS had been successfully converted to the new, more modern, development platforms (Microsoft Visual Studio C++ 2008 and Embarcadero Delphi 2010).

9.3 Data access layer in SQL

9.3.1 The AERO-MS has a proprietary Application Programming Interface (API) to access the data in the AERO-MS databases. A user can extract data either manually using the AERO-MS user

[12] During the development of the original AERO-MS with Base Year 1992 it was not yet clear whether New Large Aircraft would be introduced. Therefore the variable MV_ADEM_NLAAvailable_D was introduced. A value of 0 for this variable implies it is assumed that as part of a future scenario no NLA's will be introduced. A value of 1 implies that NLA's will be introduced. In the updated version of the AERO-MS, with Base Year 2006, in all scenarios we have specified a value of 1 for the NLA variable because of the introduction of the A380 with its first commercial flight in October 2007.

interface, or use the API (which requires solid programming skills). Modern systems use either an off-the-shelf database for which many data access tools are available, or provide data access based on open standards.

9.3.2 As part of the SAVE project a data access layer has been built on top of the AERO-MS databases. The data access layer publishes the content of the database of any run in SQL format so that it can be read by other tools.

9.3.3 EASA has requested the data access layer to be compatible with Microsoft Server SQL 2008. In the SAVE project a conversion tool, written in C#/.NET 3.5 with Visual Studio 2008, has been developed. The tool reads the AERO-MS database of one or more AERO runs, and stores the data in a SQL database. As requested by EASA, the SQL storage process can be switched-off by the user.

9.3.4 The SQL database can be accessed by various other programs like MS Excel and MS Access. The variable values are available as queries. There is a query for the original variable dimensions and for every available aggregation dimension. Similar to the AERO-MS User Interface, variables dimensioned by for example flight stage can thus be aggregated to various aggregation dimensions.

9.3.5 The conversion tool works with all editions of SQL Server 2008, including the free SQL Server Express edition (that is limited to 10Gb storage). When deployed on the local machine, the tool can create the required databases, provided that the user has sufficient privileges. It is also possible to use a centrally deployed database, in which case the tool will create the required database schema.

9.3.6 The default setting in the AERO-MS is to collect the data from multiple AERO-MS runs into a single SQL database, but the setting can be changed so that the results of separate runs are stored in separate SQL databases. The model run is also a dimension, so the user can analyze the results from multiple runs in one go. This works well in for example MS Excel (at least in the 2007 office version), where the user can refresh data imported in tables and pivot tables after a new run so that MS Excel re-retrieves the data and displays the new model run results.

9.3.7 The user can specify export specification files. These files can be made in a code editor (for example Notepad) and basically contain a list of AERO variables to be exported to SQL. An example of an export specification file is available as part of the delivery of the updated version of the AERO-MS.

9.3.8 When the AERO user makes a run, an export specification file can be chosen. The variables listed in the selected file are then exported to SQL. When a certain run is redone, the data of the original run is removed from the SQL database. More information on how to export to a SQL database is included in the updated version of the AERO-MS User Manual

9.3.9 It is noted that exporting a full AERO-MS database takes quite some time (10-15 minutes) and results in a 2Gb database (where the data limit for SQL Express is 10Gb – so the full AERO-MS database of only 5 AERO runs can be stored).

9.4 Further software technical changes to the AERO-MS user interface and models

9.4.1 Further software technical changes to the AERO-MS user interface and models made as part of the SAVE project relate to:

- Changes to the folder structure of the AERO-MS;
- Dimensions showed in the user interface;
- Data inspector function in the user interface;
- References to atmospheric models and MECI in the user interface;
- Changes to the model code.

9.4.2 Some of these changes affect the user interface and how it is operated. The result of these changes is also included in the updated version of the AERO-MS User Manual.

1. Changes to the folder structure of the AERO-MS

9.4.3 The AERO-MS is managed in a series of folders. There is a separate folder for the executables of the models and framework components, the input data files and the databases containing the results of a model run. As part of the SAVE project some revisions have been made to the folder structure. For example for each of the models a separate folder with input files is now available in the updated version of the AERO-MS. Also the import files with definitions of cases to be run (Base, Datum or Forecast runs) are now included in a separate folder. The folder structure was revised to facilitate the transferability of the AERO-MS to EASA staff members.

2. Dimensions showed in the user interface

9.4.4 At the request of EASA the dimension CAEP route group (with 17 international and 6 domestic route groups) was added to the AERO-MS. All AERO-MS variables dimensioned by flight stage (i.e. airport-pair) can be aggregated to the dimension CAEP route group. Including the dimension in the AERO-MS allows for the comparison of the AERO-MS outputs with CAEP outputs. Furthermore a number of aggregation dimensions were renamed. Because of the change from city-pair to airport-pair, outputs can now be aggregated to 'airport of departure' or 'airport of arrival' (instead of city of departure and city of arrival).

3. Data inspector function in the user interface

9.4.5 The data inspection function in the AERO-MS can be used to inspect both the input and output data of any run made with the AERO-MS. Using the updated data input files, it turned out there were a number of problems with the data inspector. The first problem was that it was not possible anymore to inspect variables dimensioned by flight stage or traffic line because of the increased size of the dimensions. Also problems were encountered with inspecting variables with five dimensions. As part of the SAVE project, revisions to the data inspector function were made to solve the problems.

4. References to atmospheric models and MECI in the user interface

9.4.6 The 1992 AERO-MS User Interface contains various references to the atmospheric models and to the model with respect to the macro economic impacts for the Netherlands (MECI). Because these models were not being updated as part of the SAVE project, the references to these models are hidden. (If at a later stage one or more of these models is restored to the AERO-MS, relevant parts of the user interface can be revitalized very easily.)

5. Changes to the model code

9.4.7 Apart from the changes to the code made as part of the process to convert to more modern software platforms (see section 9.2), some further limited changes to the software code of some of the models were made. These changes relate to:

- Change the units of financial output variables from 1992 US$ to 2006 US$. Note that the output variables and its units are defined by the model code (whereas input variables are defined in the data input files).
- Limited changes were made to the model ADEM. In order to reduce computing time in the 1992 AERO-MS the Base fares by flight stage were created in a one time pre-processing exercise and then included in an ADEM input file. To facilitate the calibration process, and making use of the increased computing power of PCs, in the updated version of the AERO-MS the Base fares by flight stage are computed in an ADEM Base run based on the input variables described in section 6.16.

10 Calibration of updated AERO-MS

10.1 Calibration of Base Year 2006

10.1.1 In general model calibration aims to have the AERO-MS produce the correct outputs for the Base Year, compared to independent sources of data, by tuning the model inputs. The aim, and challenge, of the calibration of the updated version of the AERO-MS was to achieve a situation where all of the key results related to aviation activity and its economic and environmental impacts simultaneously match the available external data sources, within the boundary conditions imposed by internal model consistency and available input data.

10.1.2 As reflected by Figure 2.2 in section 2.6 of this report, the AERO-MS computation for the Base situation is the starting point for any computation with respect to a future situation with or without policy measures in place. It is therefore of great importance that the results of the Base run adequately reflect the situation of the aviation industry in Base Year 2006.

10.1.3 The two main steps taken in the calibration are:

- collect reference data from external sources;
- actual calibration of the new Base Year results.

10.1.4 These two steps are reported below, in sections 10.2 and 10.3.

10.1.5 During the Inception Meeting of the SAVE project it was agreed for the calibration of the updated Base Year to adopt the procedure which was also followed for the calibration of the original AERO-MS Base Year (1992)[13]. It was also agreed that no calibration of the number of aircraft movements was required because these directly follow from the WISDOM Operations Database which has already been reviewed extensively. The calibration of the AERO-MS focused on the following Base Year output categories:

- air transport demand (passengers, cargo, RTK's);
- airline operating costs, revenues and operating result;
- airline employment;
- aviation fuel burn and emissions;
- aircraft fleet size and composition.

10.1.6 Calibration of each of these outputs of the updated AERO-MS is addressed in section 10.3 below. They have been calibrated at various geographical levels. The main distinction was made between the calibration of results at a world level and the level of various world regions.

[13] This procedure is described in chapter 13 of the AERO-MS Main Report published in July 2002.

10.1.7 It will be seen that the revised AERO-MS calibrates generally very well against empirical estimates and – where comparable – the outputs of other models. In comparison with the calibration of the 1992 version of the AERO-MS more detailed reference information was available to support the calibration process for the updated AERO-MS. This is especially true for data with respect to operating costs, revenues and operating result. For 1992 only limited financial information per region of carrier registration was available, whereas for 2006 we have financial reference data for all 6 EAD carrier regions considered by ICAO. The availability of more reference data allowed for a more complete and detailed calibration of the updated AERO-MS in comparison with the 1992 version of the AERO-MS.

10.2 Reference data from external sources

10.2.1 Calibration data have been collected from various external sources. An overview of the information from external data sources used for the calibration of the AERO-MS output categories is provided in Table 10.1. The level of detail of external data sources by which comparisons are made with AERO-MS outputs is included in the table.

Table 10.1 Overview of data from external data sources used for calibration of AERO-MS outputs for Base Year 2006.

Output category / outputs	Level of detail in external data source	External data source
1. Air transport demand		
Revenue Tonne Km (RTK)	Region of carrier registration	ICAO
Available Tonne Km (ATK)	Region of carrier registration	
Load factors	Region of carrier registration	
2. Airline operating costs, revenues and operating result		
Operating revenues	Region of carrier registration	ICAO
Operating costs	Region of carrier registration	
Operating result	Region of carrier registration	
3. Airline employment		
Airline employment	Region of carrier registration	ATAG
4. Aviation fuel burn and emissions		
Fuel burn	Region of flight origin	AEDT/SAGE; AEM; AERO2k; FAST
Fuel burn per RTK	Region of flight origin	
CO_2 emissions	Country[14]	UNFCCC / EU
CO_2 emissions	World	IEA
NO_x emissions	Region of flight origin	AEDT/SAGE; AERO2k
5. Aircraft fleet size		
Aircraft fleet size	Aircraft seat band; aircraft purpose	FESG (CAEP/8)

10.2.2 Information from ICAO [ICAO,2010] for the year 2006 includes:

[14] UNFCCC CO_2 emissions by country are based on fuel bunker data.

- Revenue Tonne Km (RTK), Available Tonne Km (ATK) and load factors for the 6 ICAO/EAD regions (based on region of carrier registration). As illustrated in table 4.1 the 14 AERO-MS regions can be aggregated to these 6 regions.
- Total operating revenues, operating costs and operating result for the 6 ICAO/EAD regions (also based on region of carrier registration). The operating result (profitability) is expressed as a percentage of operating revenues.
- Split of operating costs in various cost categories (e.g. fuel costs, flight crew costs; maintenance costs; route and landing costs etc).

10.2.3 The ICAO data only relate to what is called "scheduled airlines". Both scheduled and non-scheduled operations of "scheduled airlines" are included in the ICAO data. The ICAO data are based on reported data of around 400 airlines. This group of airlines includes network carriers, LCCs (e.g. Ryan Air; EasyJet) and cargo airlines. The Unified Database of the AERO-MS contains flights related to over 2500 different airlines. This includes a lot of airlines with only a limited number of flight operations in 2006. The top 400 airlines in the AERO-MS (in terms of number of flights in 2006) take account of around 90% of the flights in the AERO-MS.

10.2.4 The ICAO data also contain information on the number of aircraft departures (movements) and aircraft km. Though it was agreed we would not calibrate the number of movements in the AERO-MS Unified Database (UD), we have made comparisons between ICAO and AERO-MS in order to have an idea of the knock-on effect of a difference in flight coverage for the comparison of the other metrics. The ICAO data covers about 26.7 million aircraft departures in 2006, whereas the UD of the AERO-MS for 2006 covers over 33 million flights (+24% compared with ICAO). The difference between the two data sets is very probably mainly related to small aircraft and short haul flights as was established to be the case with a similar difference in the creation of the original UD. The relative differences in most metrics between ICAO and AERO-MS, such as RTK, total revenues etc, can therefore be expected to be much smaller. Furthermore we have made comparisons between ICAO and AERO-MS for metrics like load factors (RTK/ATK), costs per ATK and revenues per RTK which are not (or hardly) affected by a difference in flight coverage.

10.2.5 Global direct airline employment in 2006 is available in an ATAG report by region of carrier registration for the 6 ICAO/EAD regions [ATAG, 2008]. The information from the ATAG report is used as a reference for the AERO-MS computation of the direct airline employment for the 14 AERO-MS regions (whereby the outputs for the 14 regions are aggregated to the 6 ICAO/EAD regions).

10.2.6 With respect to global aviation fuel burn and emissions in 2006, as part of the CAEP/8 cycle computations have been made by various models (AEDT/SAGE; AEM; AERO2k and FAST). The results of these computations are presented in the CAEP's Environmental Goals Assessment document [CAEP, 2009]. In this document results are split by region of origin of a flight whereby again the 6 ICAO/EAD regions are considered. The CAEP document also covers information on the number of flights underlying the fuel and emission calculations by the various models. AEDT/SAGE and AEM calculations are based on 31.0 million flights, AERO2k is based on 29.9 million flights and FAST on 31.7 million flights. It may be noted that all these estimates of movements – though lower than the new UD of the AERO-MS (33.1 million) in the order of 5% to 10% - are appreciably higher than reported by ICAO.

The CAEP document also contains information on the fuel per RTK computed by the various reference models (a metric which is not greatly affected by the difference in flight coverage).

10.2.7 Information on aviation CO_2 emissions has been taken from IEA [IEA, 2008], UNFCCC [UNFCCC, 2010] and EU [EU, 2010] sources. The UNFCCC and EU CO_2 emissions are exactly the same and are based on fuel bunker data for 40 Annex I countries[15]. The UNFCCC fuel bunker data can be compared with AERO-MS computational results for individual countries (i.e. fuel burn on all flights departing from a country). The IEA has made an estimation of global aviation CO_2 emissions for 2006 wherein emissions from military traffic are also included.

10.2.8 As part of CAEP/8, FESG has made a forecast of the future fleet mix for both passenger and freighter aircraft [FESG, 2008]. The FESG fleet forecast started from a Base fleet for 2006. This Base fleet is specified in terms of the number of aircraft by FESG seat category for both the passenger and the freighter fleet, and was based on the Campbell-Hill fleet database (with extensions to include turboprops and business jets).

10.3 Calibration results for Base Year 2006

10.3.1 As a first step some verification checks of the number of flights and flight km in the Unified Database have been made. Because the Unified Database of the updated AERO-MS contains flights in terms of airport pairs instead of city pairs, it is now possible to look at the number of movements (i.e. departures and arrivals) at the level of individual airports. We have done that for 10 major European airports whereby we compare the number of movements per airport in the 2006 Unified Database with the number of aircraft movements in 2006 published in the annual reports of airports.

10.3.2 Figure 10.1 shows there is a close match between the AERO-MS Unified Database and the reported airport data. Interestingly the AERO-MS Unified Database for 2006 contains somewhat more movements for all 10 airports (i.e. on average 3.5% more movements). This might have to do with small inaccuracies in the factors which have been applied to "annualise" the sample of the WISDOM operations database for 42 days into the Unified Database containing the full number of Base Year movements (see also Chapter 5). Another option is that the annual reports do not contain all the movements which actually did take place in 2006.

[15] Annex I countries include the industrialized countries that were members of the OECD in 1992, plus countries with economies in transition (the EIT Parties). The Annex I countries which have ratified the Kyoto Protocol have committed to reduce their emission levels of greenhouse gasses.

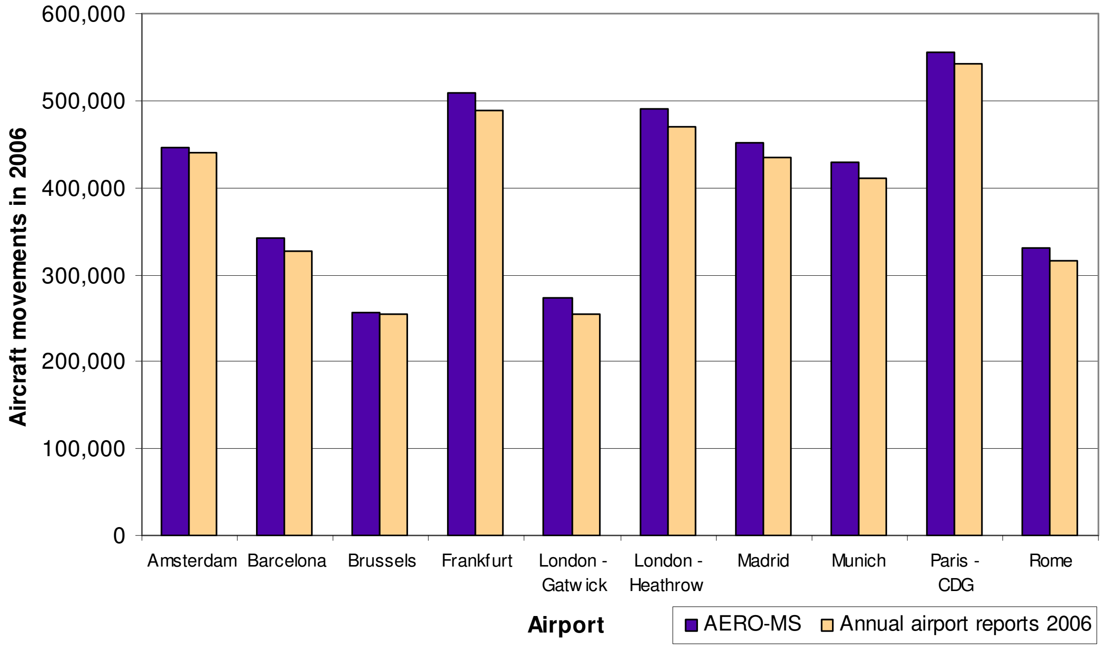


Figure 10.1 Aircraft movements in 2006 for 10 major European airports - AERO-MS compared with annual airport reports.

10.3.3 In the remainder of this section the calibration results for the 5 output categories listed in Table 10.1 are presented and discussed.

Air transport demand

10.3.4 For 2006 the global air transport demand in terms of Revenue Tonne Km in the AERO-MS Unified Database is 577,826 million RTK (see Table 10.2). The number of RTK's for 2006 in the AERO-MS is about 4% higher compared with the ICAO data, whereas the number of aircraft departures and aircraft km is respectively 24% and 19% higher in the AERO-MS. This confirms the expectation that the flights included in the AERO-MS but not in the ICAO data are generally smaller aircraft used for short distance flights.

10.3.5 The global average load factor for 2006 in both the AERO-MS and the ICAO data is 63%. Hereby it is noted that the global passenger load factor in the AERO-MS is 75% (in the ICAO data it is 76%) whereas the global cargo load factor in the AERO-MS is 45% (in the ICAO data it is 46%). For some carrier regions (e.g. Africa, Europe) the load factors in the AERO-MS are somewhat lower in comparison with ICAO data, whereas for other regions of carrier registration load factors in the AERO-MS are somewhat higher (see also table 10.2). Regional load factors for both passenger and cargo demand have been examined separately in order to better understand regional differences between the AERO-MS and the ICAO data. It turned out that for some regions especially the cargo load factors differ between the AERO-MS and ICAO. However, no inaccuracies in the AERO-MS data underlying the cargo load factors have been identified.

Table 10.2 RTK, ATK and load factors by region of carrier registration in 2006 - AERO-MS compared with ICAO data.

Region of carrier registration	AERO-MS			ICAO data[16]		
	million RTK[17]	million ATK	Load factor	million RTK[18]	million ATK	Load factor
Africa	12,718	23,859	53%	11,897	20,552	58%
Asia/Pacific	155,404	254,197	61%	150,570	240,113	63%
Europe	170,148	263,635	65%	161,913	233,978	69%
Latin America/Caribbean	21,564	36,346	59%	19,909	35,665	56%
Middle East	32,285	49,990	65%	28,342	48,211	59%
North America	185,706	288,571	64%	181,959	298,124	61%
World	**577,826**	**916,597**	**63%**	**554,589**	**876,644**	**63%**

10.3.6 The regional distribution of RTKs across the 6 ICAO/EAD regions is also presented in figure 10.2. The figure illustrates that for 2006 the regional distribution of aviation demand in the AERO-MS matches the ICAO data very well.

10.3.7 We have also compared the international versus domestic air traffic quantities in the AERO-MS with ICAO data (see figure 10.3). The AERO-MS and the ICAO data clearly show very similar patterns in terms of the ratios between international and domestic traffic for subsequently the number of flights, flight km and RTKs. In figure 10.4 we present the regional distribution of RTKs across the 14 regions considered in the updated AERO-MS. The figure illustrates that 26% of global aviation demand in terms of RTK was met by carriers registered in the EU and a further 32% by North America-registered carriers.

[16] Data for scheduled airlines of ICAO Contracting States (covering both scheduled and non-scheduled operations).

[17] In the AERO-MS, for the computation of RTK's an average weight of a passenger (including baggage) of 90 kg is assumed.

[18] In the ICAO data, for the computation of RTK's an average weight of a passenger (including baggage) of about 91 kg is assumed (where ICAO recommends a value of 90 kg).

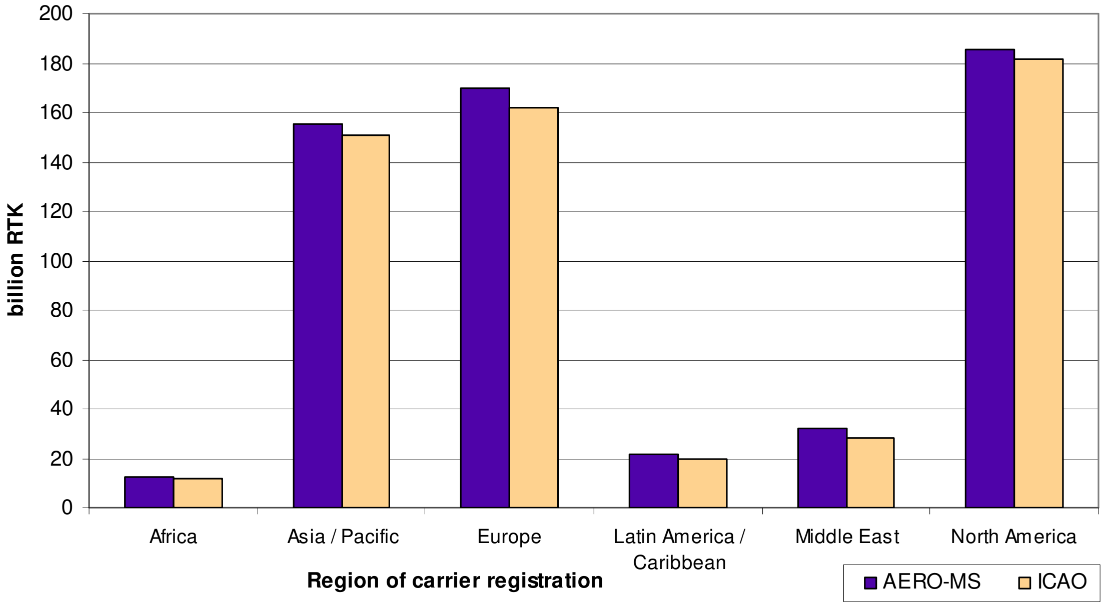


Figure 10.2 Revenue Tonne Km (RTK) in 2006 by region of carrier registration – AERO-MS compared with ICAO data

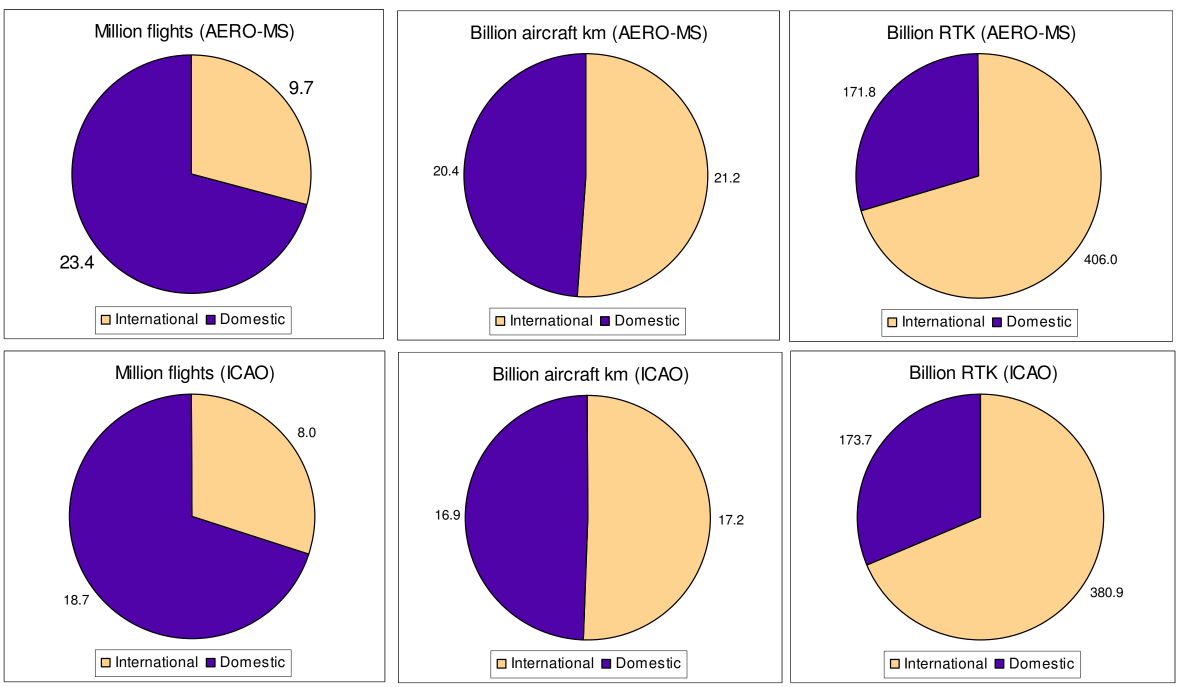


Figure 10.3 International and domestic air traffic quantities in 2006 - AERO-MS compared with ICAO data

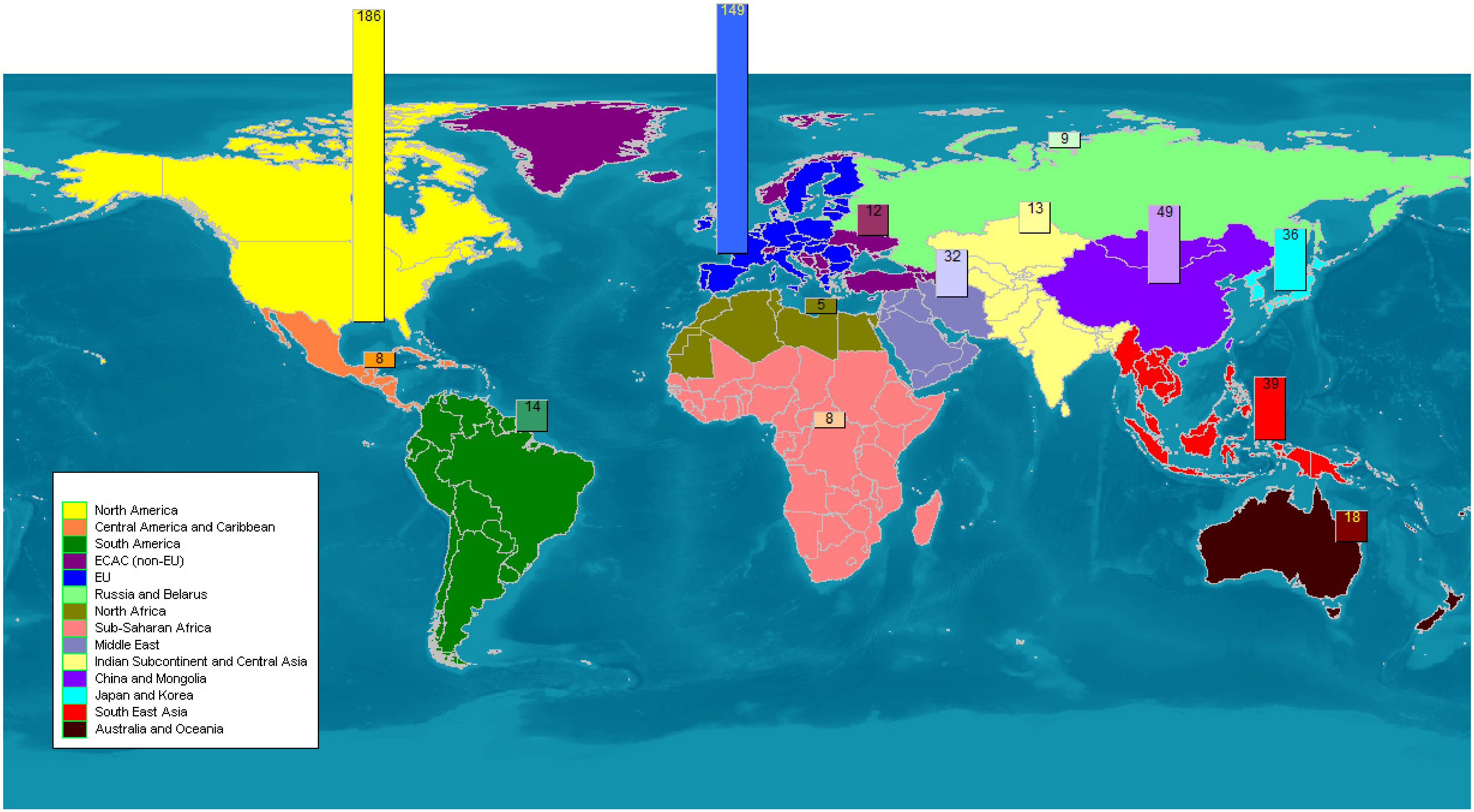


Figure 10.4 Revenue Tonne Km (in billion RTK) in 2006 by region of carrier registration for the 14 AERO-MS regions.

10.4 Airline operating costs, revenues and operating result

10.4.1 Total operating costs, revenues and result by ICAO/EAD carrier region are presented in Table 10.3 whereby again the AERO-MS computational results are compared with ICAO data. From the table it can be observed that the distribution of total operating costs and revenues of the global airline industry across carrier regions, as computed by the AERO-MS, is well in line with reported ICAO data.

10.4.2 The AERO-MS computes 501.9 and 486.3 billion US$ for respectively the total operating revenues and total operating costs of the global airline industry in 2006. This is about 8% higher compared to the numbers reported by ICAO, reflecting the wider coverage of the number of flights in the AERO-MS compared with the number of flights underlying the revenue and cost data of ICAO.

10.4.3 For both AERO-MS and the ICAO data, the operating result is presented as a percentage of operating revenues. The table illustrates that the AERO-MS results are fairly good in line with the data reported by ICAO. The variation in the profitability of airline operations across the 6 carrier regions as computed by the AERO-MS is somewhat less compared with what is reported by ICAO. The profitability for some of the smaller carrier regions (like Africa) can differ a few percent between the AERO-MS and ICAO. However for the larger carrier regions in terms of aviation activity (i.e. North America and the EU) the profitability between the AERO-MS and ICAO data matches fairly close.

Table 10.3 Operating revenues, costs and result by region of carrier registration in 2006 - AERO-MS compared with ICAO data (in million US$).

Region of carrier registration	AERO-MS			ICAO data[19]		
	Operating revenues	Operating costs	Operating result[20]	Operating revenues	Operating costs	Operating result[2]
Africa	11,341	10,911	3.79%	10,259	10,157	0.99%
Asia/Pacific	115,730	113,392	2.02%	110,197	108,443	1.59%
Europe	156,947	151,377	3.55%	142,639	137,466	3.63%
Latin America/Caribbean	20,140	19,432	3.52%	17,991	17,496	2.75%
Middle East	24,263	23,969	1.21%	20,254	20,276	-0.11%
North America	173,471	167,171	3.63%	163,824	156,373	4.55%
World	**501,891**	**486,252**	**3.12%**	**465,164**	**450,211**	**3.21%**

10.4.4 In the ICAO data, operating revenues and costs are also presented in terms of revenues per RTK and costs per ATK. We have done the same for the AERO-MS (see Table 10.4).

[19] Data for scheduled airlines of ICAO Contracting States (covering both scheduled and non-scheduled operations)

[20] Operating result presented as a % of operating revenues.

Table 10.4 Unit revenues and costs by region of carrier registration in 2006 - AERO-MS compared with ICAO data (in US$c).

Region of carrier registration	AERO-MS		ICAO data[21]	
	Revenues/RTK	Costs/ATK	Revenues/RTK	Costs/ATK
Africa	89.2	45.7	88.4	50.5
Asia/Pacific	74.5	44.6	72.4	44.7
Europe	92.2	57.4	88.5	58.9
Latin America/Caribbean	93.4	53.5	90.3	49.0
Middle East	75.2	47.9	71.4	42.0
North America	93.4	57.9	97.6	56.8
World	**86.9**	**53.0**	**86.0**	**52.6**

10.4.5 Table 10.4 shows that at a world level the Base Year results of the AERO-MS very closely resemble the ICAO data. Also at the level of the various regions there is a fairly good match between the AERO-MS and the ICAO data. For some regions (e.g. Latin America/Caribbean and Middle East) both the unit revenues and unit costs in the AERO-MS are somewhat higher compared to ICAO. For Africa costs levels in the AERO-MS seem somewhat low for which reason the profitability of African airlines may be computed to be somewhat too high (see also Table 10.3). For Europe the unit revenues are a bit higher compared with ICAO data, whereas for North America the unit revenues in the AERO-MS are a bit lower. We have not made any further changes to fare inputs however. This is because, as shown in table 10.3, the profitability for both the European and North American carriers is fairly very well in line with ICAO data. In fact the limited disparities in unit revenues between the AERO-MS and ICAO data are counterbalanced by small disparities between the AERO-MS and ICAO for the regional load factors (see Table 10.2). The calibration procedure has ensured that for aggregated route groups and for separate regions of carrier registration there is a reasonable level of profitability.

10.4.6 Table 10.5 compares the total costs for various airline cost categories computed by the AERO-MS versus data reported by ICAO (i.e. all numbers relate to the global aviation industry). Table 10.5 shows that the AERO-MS considers 9 cost components which vary with the number of aircraft operations, and these are referred to as variable costs components. The remainder of airline operating costs are referred to as volume related costs. The ICAO data distinguishes between 16 cost components. Table 10.5 links the cost categories of the AERO-MS to the ICAO categories so far as possible.

10.4.7 The main observations which follow from Table 10.5 are:

- The total flight crew costs, fuel costs and maintenance costs computed by the AERO-MS match fairly well with the equivalent cost categories in the ICAO data.

[21] Data for scheduled airlines of ICAO Contracting States (covering both scheduled and non-scheduled operations)

- The summation of the capital costs (depreciation) and finance costs for the global airline industry computed by the AERO-MS (50.1 million US$) is about 9% less compared with the related costs in the ICAO data. This is very likely explained by the differences between the AERO-MS and ICAO cost categories. ICAO data for example explicitly reports the costs for the rental of flight equipment. In the AERO-MS the rental of aircraft is not explicitly considered, but capital and finance costs are based on aircraft new prices, depreciation rates and interest rates.
- The global en route and landing cost computed by the AERO-MS are respectively 10% and 15% higher compared with what ICAO reports. The difference can be explained by the larger number of flights and flight km considered in the AERO-MS (see also section 10.1).
- Cabin crew costs computed in the AERO-MS cannot be compared directly with one of the ICAO cost categories. The ICAO cost category "Passenger services" includes both cabin crew costs and the costs for ground personnel. A comparison of the cabin crew costs computed by the AERO-MS (21.5 million US$) and the costs for passenger services reported by ICAO (40.1 million US$) suggests about half of the costs for passenger services is involved with ground personnel and the other half with the costs for cabin crew.
- Volume related costs in the AERO-MS relate to a number of cost categories considered by ICAO (in Table 10.5 nrs. 12-16 and probably about half of the costs under cost category nr 11). Different from the 8 variable costs components considered AERO, which are based on detailed unit cost inputs (see Chapter 6), the total volume related costs in the AERO-MS is a closing entry to end up with both a reasonable total operating cost and profitability level for the global airline industry.

Table 10.5 Global airline operating costs in 2006 for various cost categories - AERO-MS compared with ICAO data (in million US$).

AERO-MS		ICAO data[22]	
Variable costs components			
1. Flight crew costs	34,845	1. Flight crew salaries, expenses and training	34,220
		2. Flight crew training	450
Subtotal	34,845	Subtotal	34,670
2. Fuel costs	107,419	3. Aircraft fuel and oil	106,931
3. Maintenance costs	45,392	4. Maintenance and overhaul	45,010
4. Capital costs	27,664	5. Depreciation of flight equipment	21,160
5. Finance costs	22,416	6. Amortization	1,350
		7. Rental of flight equipment	30,160
		8. Flight equipment insurance & uninsured losses	1140
Subtotal	50,079	Subtotal	53,810
6. En route costs	11,809	9. Route facility charges	10,800
7. Landing costs	21,182	10. Landing and airport charges	18,460
8. Cabin crew costs	21,481	11. Passenger services[23]	40,070
Other costs			
9. Volume related costs	194,044	12. Station expenses	43,660
		13. Ticketing, sales and promotion	39,620
		14. General and administrative	25,769
		15. Depreciation ground property & equipment	4,050
		16. Other operating expenses	27,360
Subtotal	194,044	Subtotal	140,459
Total	**486,252**	**Total**	**450,210**

10.5 Airline employment

10.5.1 Figure 10.5 compares the number of employees of airlines in 2006 as computed by the AERO-MS with data reported by ATAG. The numbers only contain direct employment of airlines and do not include indirect employment related to the purchases of goods and services from companies in the supply chain of airlines. The following employment categories are considered in the AERO-MS:

- Flight crew (pilots, co-pilots and other flight deck personnel);
- Cabin crew;
- Maintenance labour;
- Volume related labour (all other airline personnel).

10.5.2 The global airline employment computed by the AERO-MS for 2006 is about 2 million employees. This is very similar to what is reported by ATAG. Figure 10.5 illustrates that also at a regional level there is a close match between the AERO-MS and ATAG data.

[22] Data for scheduled airlines of ICAO Contracting States (covering both scheduled and non-scheduled operations)

[23] ICAO passenger services includes the costs for both cabin crew and ground personnel

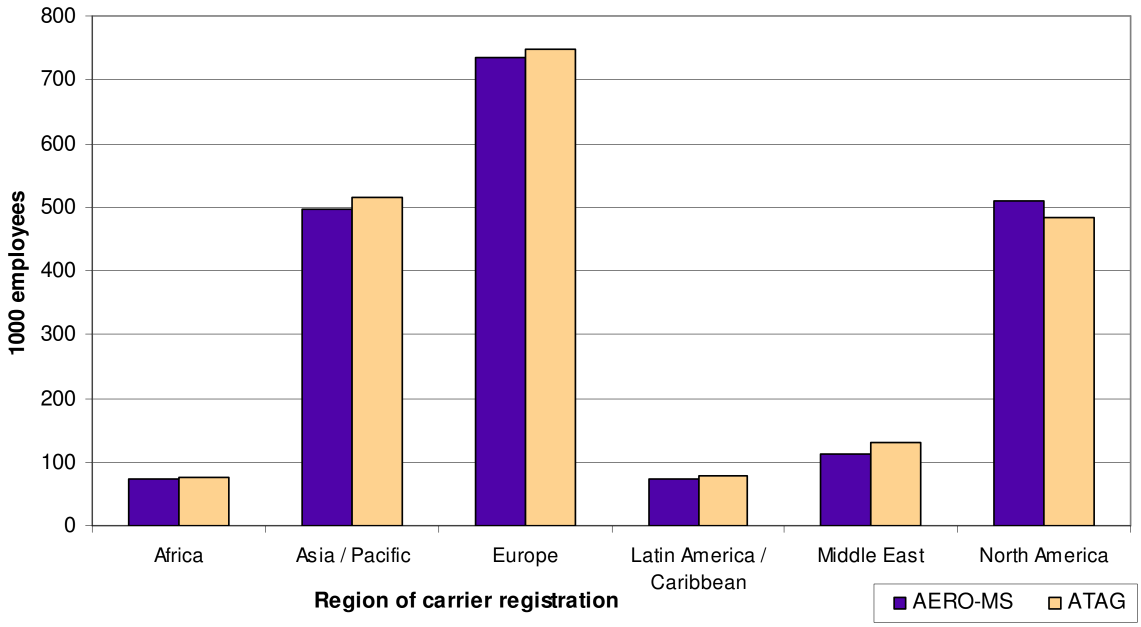


Figure 10.5 Airline employment by region of carrier registration in 2006 - AERO-MS compared with ATAG data

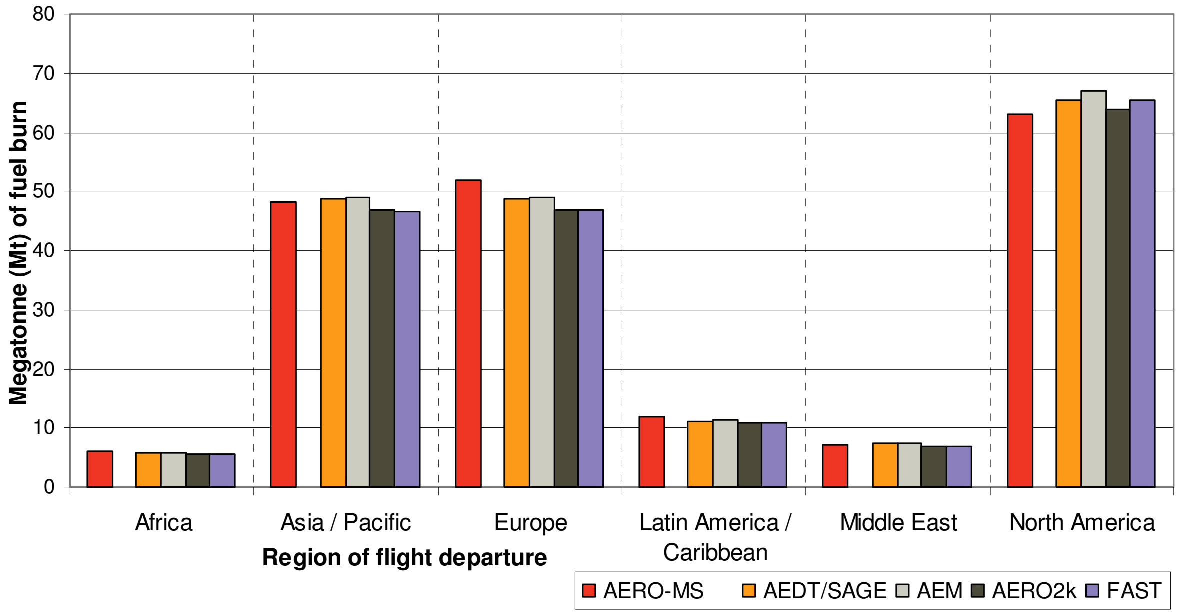
10.6 Aviation fuel burn and emissions

10.6.1 Aviation fuel burn and emissions are computed by the AERO-MS model FLEM. The results of FLEM have been compared with various other sources.

10.6.2 As part of the calibration of the fuel burn computed by the AERO-MS the following steps have been taken:

- First calibration of fuel use (and emission) factors whereby the reference aircraft in FLEM are recalibrated in order to represent the fuel use characteristics of the 2006 aircraft fleet (see also section 8.3). The first calibration step was based on PRISME fleet data.
- Fine tuning of the fuel burn calculation by making limited changes to the detour factors and the FLEM representative flight time factors (which is one of the calibration factors that allow the reference aircraft to accurately represent the generic aircraft types). Adjustments to the representative flight time factors were made for the generic aircraft in the smaller seat bands only.

10.6.3 We have compared aviation fuel burn in 2006 as computed by the AERO-MS with the computational results of other models. This comparison, by region of departure of flights, is presented in Figure 10.6. The figure shows the result of the AERO-MS is closely in line with the results of the other models presented in the CAEP/8 Environmental Goals Assessment document (CAEP/8-IP/8).



Source AEDT/SAGE, AEM, AERO2k and FAST: CAEP Environmental Goals Assessment document (CAEP/8-IP/8) - tables p19 to p22.

Figure 10.6 Comparison of AERO-MS aviation fuel burn by region in 2006 with CAEP environmental goal assessment results

10.6.4 As indicated in section 10.2, the number of flights underlying the fuel burn computations of the other models is in the order of 5% to 10% lower relative to the number of flights in the new UD of the AERO-MS. Therefore we have also compared fuel use per RTK between the AERO-MS and the other models (see table 10.6). The table shows that also in terms of fuel per RTK there is a close match between the results of the AERO-MS compared with the other models. Only for the flights departing from Europe the AERO-MS result is somewhat higher. This might result from the relatively low efficiency of European flights according to the IEOGG data (see section 8.4). The detour factors assumed for European flights in the AERO-MS are thus relatively high implying a somewhat higher fuel burn.

Table 10.6 Comparison of AERO-MS aviation fuel burn per RTK by region in 2006 with various other sources

Region of flight departure	AERO-MS	Results environmental goal assessment CAEP[24]		
		AEDT/SAGE	AEM	AERO2k
Africa	0.355	0.334	0.339	0.324
Asia/Pacific	0.312	0.300	0.301	0.292
Europe	0.326	0.307	0.308	0.300
Latin America/Caribbean	0.347	0.366	0.374	0.365
Middle East	0.292	0.289	0.293	0.275
North America	0.337	0.336	0.345	0.335
World	**0.326**	**0.317**	**0.322**	**0.312**

10.6.5 Table 10.7 summarizes total global CO_2 aviation emissions in 2006 as computed by the AERO-MS and the models used for the CAEP/8 Environmental Goals Assessment. The table illustrates that, similar to the fuel burn comparison in Figure 10.6, the result of the AERO-MS is closely in line with the results of other models.

10.6.6 The table also includes aviation CO_2 emissions based on bunker fuel data provided to UNFCCC and an estimation for 2006 of the International Energy Agency (IEA). The UNFCCC fuel bunker data only relate to Annex I countries, and the total CO_2 emission is therefore lower relative to the computation results of models which all relate to global commercial aviation. For the top 10 countries in terms of the CO_2 emission on departing flights, aviation CO_2 emissions based on UNFCCC data and the AERO-MS are compared (see Figure 10.7). The figure shows that generally CO_2 emission levels computed by the AERO-MS are lower relative to the emission levels based on the UNFCCC fuel bunker data. The percentage difference varies between 18% lower emissions in the AERO-MS for the U.S. and Canada and 5% lower emissions for Australia. The AERO-MS computes 403.88 Mt of CO_2 emissions on flights departing from the 40 Annex I countries for which UNFCCC data are available. This is 16% lower compared with the 468.78 Mt of CO_2 emissions reported by UNFCCC.

10.6.7 The IEA has made its estimate of global aviation emissions by using the IEA energy balances and the default sector approach method and default emission factors from the Revised 1996 IPCC Guidelines. The IEA estimate includes both the CO_2 emissions of commercial and military aviation, whereby the military emissions are not reported separately in the data available to the SAVE Consortium.

10.6.8 AERO2k has computed and published CO_2 emissions of global military aviation for the year 2002 (61 Mt) [QinetiQ, 2004]. It was concluded that military aviation emissions represent about 11% of total aviation emissions. Assuming the relative CO_2 emission level for military aviation in 2006 is equal to the relative level in 2002 (11%), and also taking into account that the AERO-MS (and other models) do not taken into account CO_2 emission following from general aviation (about 2%) and the use of APUs (about 1%), the IEA CO_2 emissions for

[24] CAEP's Environmental Goals Assessment document (CAEP/8-IP/8) - tables P-23 through P-25.

global commercial aviation would be about 627 Mt (i.e. 86% of 729 Mt). This reduces the gap between IEA and the AERO-MS computational result to about 5%.

Table 10.7 Comparison of AERO-MS global CO_2 aviation emissions in 2006 with various other sources

Model/source	CO_2 emissions in Mt	Scope
AERO-MS	595.19	Global commercial aviation
AERO-MS	403.88	Only Annex I countries
CAEP/8 model results		
AEDT/SAGE	592.00	Global commercial aviation
AERO2k	571.11	Global commercial aviation
AEM	599.04	Global commercial aviation
FAST	574.95	Global commercial aviation
Other sources		
UNFCCC[25]	468.78	Only Annex I countries
IEA[26]	729.10	Global aviation including military traffic

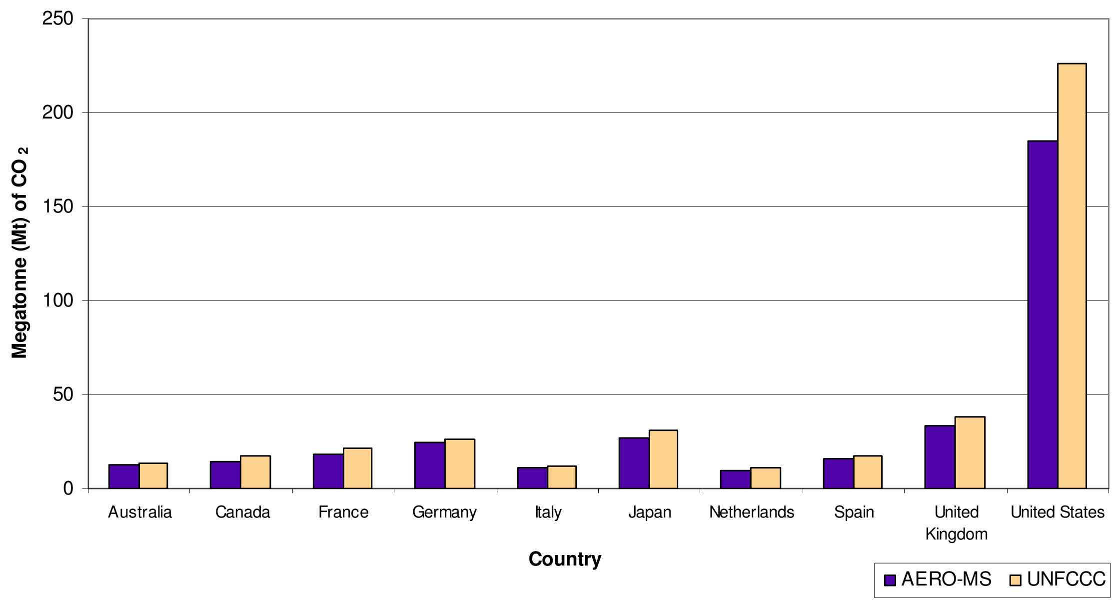


Figure 10.7 CO2 aviation emissions in 2006 by country - AERO-MS compared with UNFCCC data.

10.6.9 Both UNFCCC and IEA CO_2 estimations are higher compared with the CO_2 emissions of the global commercial aviation industry as computed by various models (i.e. both the AERO-MS and the models applied in CAEP/8). These findings are in line with an earlier conclusion based on a comparison of the 1992 CO_2 emissions computed by the 'old' version of the AERO-MS and UNFCCC data. In this respect it has to be borne in mind that the quality of UNFCCC data can be poor. For example the UNFCCC data might include the use of kerosene in other sectors (power generation, kerosene lamps and cooking in third world countries).

[25] Based on fuel bunker data provided to UNFCCC by countries.

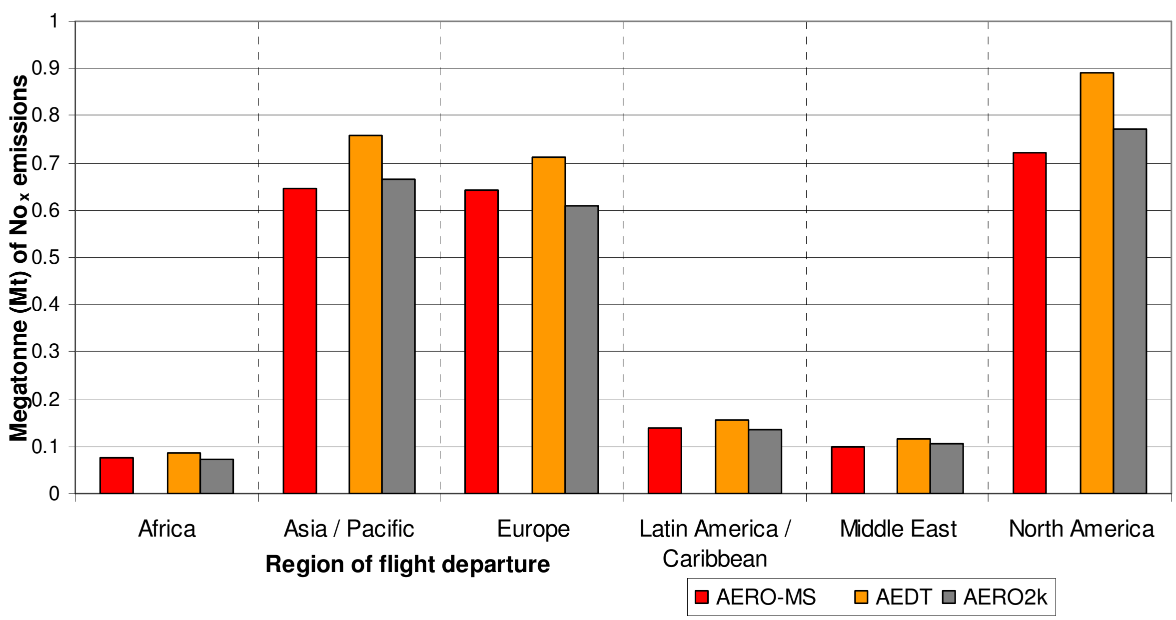
[26] "CO_2 Emissions from Fuel Combustion (2008 Edition) OECD/IEA, 2008"

With respect to the IEA data there is an uncertainty with respect to the contribution of military traffic to the reported CO_2 emission level in 2006.

10.6.10 All in all it was concluded that the global aviation fuel burn computed by the AERO-MS is of the right order of magnitude. This is confirmed by the fact that global aviation fuel costs as computed by the AERO-MS match very well with ICAO data (see table 10.5).

10.6.11 In relation to global NO_x emissions the AERO-MS contains two alternative computation methods: the Boeing method and the P3T3 method[27]. The Boeing method is the default because this method is widely accepted internationally and does not require detailed technical data inputs. The results on NO_x emission presented in Figure 10.8 and Table 10.8 are based on the Boeing method. Both the figure and the table show the NO_x emissions computed by the AERO-MS, AEDT and AERO2k. The NO_x emissions computed by the AERO-MS and AERO2k match very closely (whereby the AERO2k uses the DLR method for the computation of NO_x emissions). On a world level the NO_x emissions computed by the AEDT are 17% higher compared with the AERO-MS. Since the fuel use computed by the AERO-MS and AEDT closely match (see Table 10.7) the global average EI NO_x in the AERO-MS is also lower (see Table 10.8). The EI NO_x computed by AERO2k is in between the result of the 2 other models. The difference in the NO_x result between various models is likely to be explained by the sensitivity of NO_x emissions in relation to assumed flight operation characteristics. If for example the actual take off weight of an aircraft is relatively low (in case of a short haul flight) the required thrust settings are lower which can significantly affect NO_x emission levels.

Figure 10.8 Comparison of AERO-MS NO_x emissions in 2006 with various other sources.



[27] For more details: See chapter 10 of the AERO-MS Main Report published in July 2002

Table 10.8 Comparison of AERO-MS EI NOx in 2006 with various other sources.

Region	EI NO_x (gram / kg of fuel)		
	AERO-MS	AEDT	AERO2k
Africa	12.56	14.68	13.44
Asia/Pacific	13.39	15.55	14.25
Europe	12.34	14.58	12.95
Latin America/Caribbean	11.72	14.10	12.59
Middle East	13.75	15.92	15.27
North America	11.42	13.65	12.06
World	**12.33**	**14.54**	**13.06**

10.7 Aircraft fleet size.

10.7.1 The final calibration topic is the size and composition of the aircraft fleet as estimated in the AERO-MS. Chapter 7 discusses how the PRISME fleet and other data sources have been used for the model ATEC to define the properties of the generic aircraft that represent the 2006 fleet. These sources also imply the size of the fleet for each generic type for input to ATEC. In addition, the AERO-MS computes the 2006 fleet size independently based on:

- flights by flight stage, flight type and aircraft type (as contained in the Unified Database);
- computation of block hours flown (depending on flight distance, flight profile, detour factor);
- average annual utilization of different types of aircraft.

10.7.2 Whereas the fleet input to ATEC defines the fuel use and emission properties of generic aircraft types (and the development of these properties over time), the computed fleet size underlies the estimation of capital and finance costs. It has thus been important to verify that the size of the ATEC input fleet and the computed fleet closely match to ensure internal model consistency within the AERO-MS.

10.7.3 We have compared the AERO-MS computed fleet by seat band with the 2006 fleet considered in the FESG-CAEP/8 analysis. As stated in Chapter 7 the updated AERO-MS considers seven seat bands, where the lowest seat band (fewer than 20 seats) is not considered in the FESG fleet. The 9 FESG seat categories can be linked to the remaining 6 seat bands considered in the updated AERO-MS as follows:

AERO-MS seat bands	**FESG seat categories**[28]
1. 20 - 100 seats	20 - 50 seats and 51 - 100 seats.
2. 101 - 150 seats	101 - 150 seats
3. 151 - 210 seats	151 - 210 seats
4. 211 - 300 seats	211 - 300 seats
5. 301 - 500 seats	301 - 400 seats and 401 - 500 seats
6. > 500 seats	501 - 600 seats and 601 - 650 seats

[28] For the freighter fleet CAEP the smallest 'seat category' is < 50 seats (so including < 20 seats).

10.7.4 Figure 10.9 provides a comparison of the computed commercial fleet between the AERO-MS and FESG. It can be observed that there is a quite a close match between the two fleets, both for passenger aircraft and freighters.

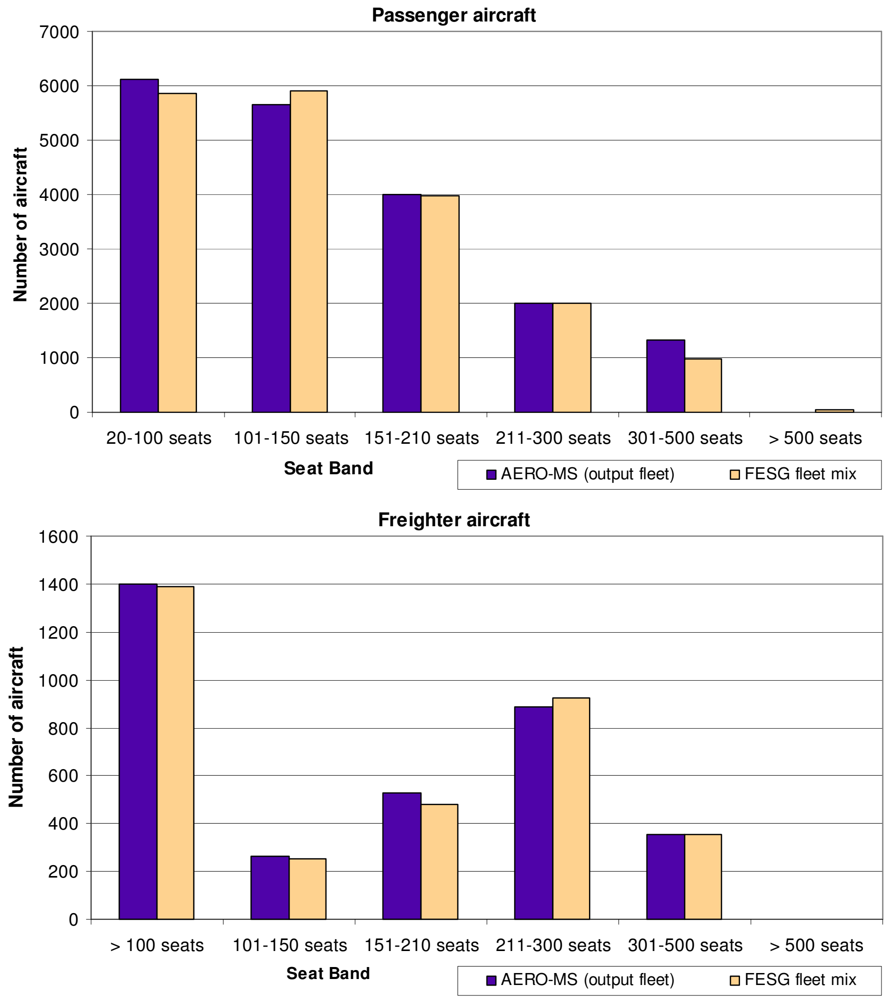


Figure 10.9 Passenger and freighter aircraft fleet by seat band in 2006 - AERO-MS compared with FESG

11 Testing of scenario options

11.1 Introduction

11.1.1 The main purpose of the AERO-MS is to test the effects of a wide range of potential policy options to reduce aviation emissions. The AERO-MS computes the effects of policy options relative to a base line future development without policy option in place (scenario).

11.1.2 A scenario is a statement of future circumstances that are exogenous to the policy options being tested, but which potentially affect the analysis of the impacts of policy options. In the AERO-MS a scenario is defined in terms of a coherent set of scenario variables. A scenario in the AERO-MS should satisfy the following requirements.

- A scenario should be consistent in itself. Developments in different fields are sometimes interdependent, which implies the need to link the predictions on individual variables in a scenario.
- A scenario should cover the total range of potential future developments of relevance for the air transport sector.
- A scenario description must be formulated in such a way that it can be made operational by means of the available AERO-MS scenario variables.

11.1.3 A scenario is defined for a future year to be selected by the AERO-MS user. This allows the AERO-MS to produce a “snapshot” of effects for the air transport sector for the selected forecast year (see also chapter 2). A scenario run for any forecast year requires a separate, scenario specification file. However procedures have been developed to construct a set of scenarios over time. For scenario variables values can be specified for all years between the base year 2006 and any future year up to the year 2056. The sets of time-dependent values for scenario variables can be used in the scenario input files for each of the scenario years to be considered. The time-dependent scenario development procedure ensures that scenarios for different years are consistent.

11.1.4 For the specification of a complete and consistent scenario in the AERO-MS a procedure has been developed that includes a number of steps. This procedure is described in the AERO-MS User Manual.

11.1.5 In consultation with EASA it was decided to consider the CAEP/8 Medium Growth scenario as the main scenario to be used in the SAVE project. Thereby the main scenario year is 2026, but a scenario specification is also made for the years 2016 and 2036. The scenarios are referred to as the CAEP8-M 2016, CAEP8-M 2026 and CAEP8-M 2036 scenarios. As part of the CAEP/8 Environmental Goals Assessment, a limited number of effects of the Medium Growth scenario have been computed using other models. The main effects computed relate to the number of flights, total fuel burn, fuel burn/RTK and NO_x emissions.

11.1.6 The implementation of the CAEP/8 Medium Growth scenario in the AERO-MS allows for:

- The computation of a wide range of effects of the scenario. Because the various AERO-MS models are integrated in a single system, these effects are computed on a consistent basis.

- This scenario being the main reference situation for the testing of the effects of policy options (see chapter 12).

11.1.7 A number of variations to the main CAEP8-M scenario are considered.

11.1.8 Sections 11.2 and 11.3 elaborates on respectively the specification of the CAEP8-M scenario and the scenario variations, in terms of AERO-MS scenario variables. The AERO-MS computational results for the scenarios are presented in sections 11.4 and 11.5. For the CAEP8-M scenario, the results are compared with the results of other models presented in the CAEP/8 Environmental Goals Assessment document.

11.2 Specification of CAEP8-M scenario

11.2.1 The CAEP8-M scenario not only contains the medium growth of aviation demand as forecasted by CAEP, but also other developments which affect the future situation of the global air transport industry. The developments included in the CAEP8-M scenario implementation in the AERO-MS relate to:

1. Air transport demand growth;
2. Load factors;
3. Aircraft technology improvements;
4. Operational improvements;
5. Aircraft utilization and fleet size;
6. Operating costs, fares and airline profitability.

11.2.2 The various developments included in the CAEP8-M scenario are described below.

Air transport demand growth

11.2.3 As part of the CAEP/8 cycle, the FESG has made a traffic and fleet forecast for the period 2006 to 2036[29] . Thereby a low, medium and high growth scenario has been defined. In consultation with EASA it has been agreed to use the Medium Growth scenario as the main scenario to be considered in the SAVE project.

11.2.4 For passenger demand, an annual percentage growth in passenger km is defined for 23 route groups by FESG/CAEP. These annual growth percentages are defined by FESG/CAEP for the periods 2006-2016, 2016-2026 and 2026-2036. The medium forecast assumes an average global growth in passenger traffic of 5.1%, 4.8% and 4.4% per annum for these 3 periods respectively (with variations in growth across route groups).

11.2.5 For the implementation of the medium growth in the CAEP8-M scenario in the AERO-MS, we used information provided by EUROCONTROL on the exact definition of the 23 route groups. Based on this we could link the 23 CAEP route groups to the 196 Region Pairs in the AERO-MS. The input to the AERO-MS is thus an annual growth rate (percentage) of passenger km per region pair for all years in the period 2006-2036. A growth rate for any region pair in any year applies to both scheduled and charter/LCC demand as there is only a single growth variable in the AERO-MS (MV_ADEM_PaxAutoGrowth).

[29] The FESG CAEP/8 traffic and fleet forecast is presented in a document with reference CAEP-SG/20082-IP/02 (dated August 2008).

11.2.6 The FESG traffic forecast document does not contain data with respect to the forecast of cargo demand over the period 2006-2036 (although the document *does* contain a forecast of the freighter fleet). DLR has made available the data on the growth of cargo demand underlying the CAEP/8 forecast of the freighter fleet. In these data the growth in cargo demand is presented for flights originating from the 6 ICAO/EAD regions. In the AERO-MS CAEP8-M scenario specification the annual growth rates for cargo demand are also specified by region pair (variable MV_ADEM_CgoAutoGrowth).

11.2.7 Because we decided to represent the FESG medium growth scenario as closely as possible in the AERO-MS, also for the first years in the forecast period (2007-2009) the growth in demand is based on the FESG forecast, even though, due to the global economic downturn, the observed growth in aviation demand over the period 2007-2009 has been quite different. However, in one of the scenario variations we have taken on board the observed growth rates in the years 2007-2009.

Load factors

11.2.8 Though not very explicitly reported, we have understood that assumptions have been made with respect to the load factor development in the CAEP/8 cycle. This load factor development is included in CAEP scenarios for which the results are presented in the CAEP/8 Environmental Goals Assessment document.

11.2.9 The global average passenger load factor in 2006 is 75% in both the AERO-MS (see chapter 10) and according to the CAEP/8 data. CAEP assumes that the average passenger load factor goes up to 78% in 2016 and 81% in 2026 and 2036. Hereby there is a fairly strong variation across the assumed passenger load factor developments for various route groups. In the AERO-MS CAEP8-M scenario specification we have taken on board CAEP's passenger load factor developments including the regional variation.

11.2.10 For cargo load factors it is understood CAEP/8 assumes these to remain unchanged in the period 2006-2036. However, in the AERO-MS the development of load factors for cargo transported in the belly hold of passenger aircraft cannot be specified separately from the passenger load factors. Therefore, part of the cargo demand load factors do go up according to the CAEP8-M scenario specification in the AERO-MS.

Aircraft technology improvements

11.2.11 The main issue here is the assumed autonomous fuel efficiency improvement of aircraft. In the AERO-MS the fuel efficiency improvement is specified in terms of the yearly fuel burn reduction of new aircraft: that is, the fuel burn of aircraft produced in year X relative to that of aircraft produced in year X-1. These improvements can be separately specified for the 10 generic aircraft types. For the CAEP8-M scenario in the AERO-MS it was agreed with EASA to adopt the moderate technology scenario assumed in CAEP's Environmental Goals Assessment (i.e. CAEP's technology/operational improvement scenario 3). This represents an annual improvement in fuel efficiency for new aircraft of 0.96% during the period 2006-2036. Furthermore, in line with CAEP's moderate technology scenario, it is assumed that there is no change in the NO_x, CO and HC emission indices of new aircraft during 2006-2036.

Operational improvements

11.2.12 Operational improvements lead to a higher ATM efficiency. As indicated in section 8.4, as part of the Base situation in 2006 the AERO-MS has taken on board IEOGG data on the ATM efficiency by region. These data are included in the detour factors for the Base year considered in the AERO-MS.

11.2.13 CAEP/8 assumes two operational improvement scenarios: a lower and upper bound scenario. These operational improvements are specified per region relative to the Base 2006 situation.

11.2.14 As part of the CAEP8-M scenario implemented in the AERO-MS we have taken on board the lower bound operational improvement scenario (also part of CAEP's scenario 3). It is understood from QinetiQ that in the computational results presented in the CAEP's Environmental Goals Assessment, the regional variation in operational improvements are not taken into account. Therefore, similar to these computations, we have simply assumed a global operational improvement of 1.0% and 1.4% for respectively 2016 and 2026/2036. In the AERO-MS scenario this is implemented by a reduction in the detour factors.

Aircraft utilization and fleet size

11.2.15 FESG has provided not only a traffic forecast but also a fleet forecast. As described for a Base run in section 10.7, also in a scenario (Datum) run, the AERO-MS computes the fleet based on the number of block hours (following from the number of flights and flight distances) and annual aircraft utilization rates. In the AERO-MS the aircraft utilization rates can be specified as part of a scenario. So that the AERO-MS estimate of fleet size development is similar to the FESG forecast, we have assumed aircraft utilization to change from the Base values. For the main scenario year 2026 aircraft utilization rates on average increase by about 10% relative to the 2006 levels. This assumption has an effect on unit capital and finance costs.

11.2.16 Furthermore we have made assumptions on the routes where New Large Aircraft (i.e. these are aircraft with over 500 seats) would be operated. We have assumed that New Large Aircraft (NLA's) would be mainly operated on routes between Europe, Middle East and Asia/Pacific, and would be operated by carriers registered in these regions.

Operating costs, fares and airline profitability

11.2.17 The main uncertainty with respect to the development of operating costs into the future seems to be related to the development of the oil price and hence the fuel costs for airlines. Despite the uncertainty, there are no specific assumptions with respect to the oil price development which underlie the FESG traffic forecast. However, as part of an AERO-MS scenario the development of the oil price has to be specified. In the CAEP8-M scenario in the AERO-MS, the future oil price is based on the reference scenario of the International Energy Agency (IEA). IEA assumes the oil price in real terms to reach US$100 per barrel by 2020 and US$115 per barrel by 2030. Note that in the Base Year 2006 the average oil price was US$ 65 per barrel. For the 3 scenario years considered in the scenario analysis, we have assumed the following oil prices:

- 2016 $90US per barrel

- 2026 $109US per barrel
- 2036 $115US per barrel

11.2.18 With respect to other direct operating cost categories in the AERO-MS (en route costs, landing costs, maintenance costs, cabin and flight crew costs) unit costs in real terms are assumed not to change.

11.2.19 The oil price increase implies a loss making situation for the airline industry if the cost increase was not assumed to be passed on to fares and freight charges. Therefore as part of the scenario we have assumed fare and freight charge adjustments. This is done on the level of region pair separately for scheduled passenger fares, LCC/charter passenger fares and cargo fares. Higher fares and freight charges reduce the rate of growth of demand. Hence in the scenario specification file we have slightly increased the input annual growth percentages per region pair (both for the variables MV_ADEM_PaxAutoGrowth and MV_ADEM_CgoAutoGrowth). It has been verified that the final demand computed by the AERO-MS for 2016, 2026 and 2036 is still in line with CAEP's medium growth forecast (see also Table 11.2 below).

11.2.20 As a final step in the scenario development procedure we have assumed changes in the levels of volume related costs in such a way that reasonable levels of profitability are computed (around 3%) for all carrier regions and all types of operations (i.e. scheduled passenger demand, charter/LCC demand and cargo demand).

11.3 Specification of scenario variations

11.3.1 A number of scenario variations have been specified. These variations are made relative to the main CAEP8-M scenario described in section 11.2. The scenario variations relate to:

- Optimistic technology and operational improvement (instead of moderate technology / operational improvement in the main scenario).
- Possible effect of oil price increase from Base (2006) to Datum (2026) on demand growth.
- The observed growth in aviation demand over the period 2007-2009.

11.3.2 A description of the various scenario variations is presented below.

Optimistic technology and operational improvement

11.3.3 As part of CAEP/8 various technology and operational improvement scenarios have been considered. The main CAEP8-M scenario includes the moderate scenario. As a variation we have replaced this moderate scenario by CAEP's Optimistic Technology and Operational Improvement (OTI) scenario. We have only specified this scenario for the year 2026. Relative to the main CAEP8-M scenario, the following adjustments are made:

- An annual improvement in fuel efficiency of 1.5% for all aircraft entering the fleet in the period 2006-2026 (whereas in the main scenario the annual improvement is 0.96% - see above).
- Use of the upper bound operational improvement specified by CAEP (instead of CAEP's lower bound operational improvement included in the main scenario - see above).

11.3.4 Furthermore the oil price for 2026 in this scenario variation is not based on the IEA forecast but on a forecast of the UK Department of Energy and Climate Change (DECC). In this forecast (high scenario) the oil price is assumed to reach 122.7 US$ per barrel in 2026. This is 12.5% higher compared to the oil price for 2026 in the main scenario.

11.3.5 The resulting scenario is referred to as 'CAEP8-M 2026 OTI'. As part of the testing of the effects of policies (see Chapter 12), we have analyzed to what extent this alternative scenario specifications alters the effects of various policy options.

Possible effect of oil price increase on demand

11.3.6 There is a lot of uncertainty about the development of future oil prices, and there is a possibility that future increases might be quite dramatic. This may have an impact on air transport demand growth.

11.3.7 As specified above in the main CAEP8-M scenario for 2026 it is assumed that CAEP's Medium Growth forecast of air transport demand goes together with the IEA oil price forecast (i.e. 109 US$ for 2026). Note that his assumption has been made in order to complete the CAEP8-M scenario in terms of AERO variables (i.e. the assumption does not follow from FESG/CAEP because they have not specified an assumption with respect to the oil price development in relation to the medium growth forecast).

11.3.8 We have made a 'what-if' type of analysis, whereby we have assumed that the original Medium Growth forecast specified by FESG/CAEP would have been based on a situation without a change of the real oil price between 2006-2026. In other words, the oil price in 2026 would still be US$ 65 per barrel (in US$ 2006). If it is then assumed that the IEA oil price forecast would become reality, the question is to what extent CAEP's Medium Growth forecast for 2026 would be reduced if the increased fuel prices were incorporated in the fares (implying less growth in demand).

11.3.9 In the present AERO-MS, changes in the Datum crude oil price are not automatically incorporated in fares (see also topic 14 addressed in Chapter 13). We therefore assessed the required increase in fares by comparing the Datum cost levels of scenario runs for 2026 with oil prices of respectively 65 and 109 US$ per barrel. If airlines would incorporate the additional costs (i.e. the difference between the 2 runs) in fares, an average fare increase of 12.5% would be required. This fare increase is taken on board in the scenario variation (referred to as 'CAEP8-M 2026 Ef_OPI1') to asses the effect on demand.

11.3.10 We have defined a second variation, whereby also the effects on global GNP growth, following from the oil price increase, are taken on board. The MIT Emissions Predictions and Policy Analysis (EPPA)[30] model estimates that a 50% increase in the oil price over the period 2006-2026 results in a reduction of global GNP by 7% in 2026 (i.e. reduction relative to what GNP would have been without the increase of the oil price). Though the oil price increase in our scenario is somewhat higher (i.e. from 65 US% to 109 US$ implies an increase of 67%), we have taken on board the 7% reduction of global GNP in our test run. Note that we only have used the EPPA information as an example of a relationship between the oil price and the global GNP which can be taken on board in the AERO-MS. The effect of a change in

[30] More information on the model can found at: http://globalchange.mit.edu/igsm/eppa.html

future GNP on future aviation demand can be computed by the AERO-MS (using the variable MV_ADEM_CPBGNPGrowth).

11.3.11 In summary the following variations are defined:

- CAEP8-M 2026 Ef_OPI1. Increase in oil price from 65 US$ in 2006 to US$ 109 in 2026 is incorporated in fares leading to a reduction of CAEP's Medium Growth forecast for 2026.
- CAEP8-M 2026 Ef_OPI2. As variation 1 whereby also the effects on CAEP's Medium Growth forecast resulting from a reduction of global GNP growth are taken into account. The reduction of global GNP growth is assumed to also follow from the oil price increase.

Observed growth in aviation demand over the period 2007-2009

11.3.12 The CAEP8 air transport growth forecast was published in August 2008. For the Medium Growth forecast a global average growth of passenger demand for the period 2006-2016 is forecast to be 5.1% per annum. For cargo demand this percentage is 6.2%. For the years after 2016 the growth rates are forecasted to be slightly reduced.

11.3.13 The recent global economic downturn, which more or less started in September 2008, has had a very significant effect on air transport demand growth. For example in 2009 there was a 3.5% decrease in global passenger demand. For carriers registered in the EU and North America the negative growth was even larger (-5% and -5.6% growth respectively). Moreover, the negative growth of global cargo demand in 2009 was even more significant (-10.1%).

11.3.14 In this scenario variation we have taken on board the observed growth in aviation demand for the years 2007-2009 as an alternative for the forecasted growth rates in CAEP's Medium Growth forecast[31]. In so far as available we have also taken on board published growth numbers for the first half of 2010, during which especially cargo growth has shown a strong recovery.

11.3.15 With this scenario variation we show the potential long term consequences of the recent economic downturn for aviation demand assuming that after 2010 the growth in demand will be according to CAEP's Medium Growth scenario.

11.4 Scenario results

Results for CAEP8-M scenario

11.4.1 The main effects of the CAEP8-M scenario, as computed by the AERO-MS are presented in table 11.1. Hereby we have presented results for the years 2016, 2026 and 2036. The effects are presented in both absolute terms and in terms of the % change relative to the Base year 2006. We have presented results related to:

[31] Air transport growth numbers (passenger and cargo demand) are published monthly by IATA. Hereby a distinction between regions of carrier registration (6 regions). Data can be found on: http://www.iata.org/pressroom/facts_figures/traffic_results/Pages/index.aspx

1. Air transport demand;
2. Flights and aircraft km;
3. Effects on airlines;
4. Fleet size; and
5. Fuel and emissions.

11.4.2 The various effects, as computed by the AERO-MS, are further discussed below. Hereby, where possible, we have compared the results of the AERO-MS computations with the results of other models presented in the CAEP/8 Environmental Goals Assessment document.

Air transport demand

11.4.3 According to CAEP's medium growth scenario, overall passenger demand is forecasted to be over 4 times as high in 2036 compared with 2006 (+309%). Cargo demand is forecast to increase by 470% over the same period. Table 11.2 compares the growth following from the AERO-MS scenario runs and the FESG CAEP/8 traffic forecast data (presented in document CAEP-SG/20082-IP/02/). It also shows that passenger demand in the AERO-MS starts from a higher level (+9% compared with the FESG CAEP/8 data). Most likely, this is because the AERO-MS is more complete in its flights coverage. According to the AERO-MS cargo demand in 2006 is less compared with the FESG CAEP/8 data (-14%).

11.4.4 As illustrated in Table 11.2 the ratio between the AERO-MS and FESG CAEP/8 for both passenger and cargo demand remains almost constant over time. Differences between the AERO-MS and FESG CAEP/8 in the absolute level of demand for the future scenario years are thus explained by differences in the Base 2006 level of demand. Overall the conclusion is that CAEP's medium growth scenario has been implemented correctly in the AERO-MS scenario input files. Thereby it has been verified that also at the level of the route groups considered by CAEP the growths in demand match very closely (see table 11.3). Note that, as shown in table 11.3, the absolute levels in demand for various route groups can differ between FEST/CAEP and AERO-MS. In the AERO-MS the demand on every leg of a flight is allocated separately to a route group. It is understood that the allocation of demand in the FESG/CAEP data is based on the origin and destination of a flight with the same flight number (without taking into account the location of possible stopovers).

11.4.5 Table 11.1 also shows that the growth for charter/LCC passenger demand following from the implementation of CAEP's medium growth scenario in the AERO-MS is less compared with the growth for scheduled demand. This follows from the AERO-MS scenario specification procedure. As indicated in paragraph 11.2.19. it is assumed that the increase in oil prices has been incorporated in higher fares separately for scheduled passenger fares, LCC/charter passenger fares and cargo fares. The effect of higher fares for LCC/Charter passenger demand is more significant in comparison with the effect for scheduled passenger demand because of the higher fare elasticity associated with LCC/Charter demand.

Table 11.1 AERO-MS results for CAEP8 Medium growth scenario (CAEP8-M) for the years 2016, 2026 and 2036.

Effect	Unit	Base 2006	Results (absolute)			Results (% change relative to Base)		
			CAEP8-M 2016	CAEP8-M 2026	CAEP8-M 2036	CAEP8-M 2016	CAEP8-M 2026	CAEP8-M 2036
Air transport demand								
Pax scheduled Network Carriers (NC)								
1 First/business	billion pax-km	357	603	976	1550	69%	174%	334%
2 Economy (+ discount)	billion pax-km	3470	5822	9419	15053	68%	171%	334%
3 Total pax scheduled - NC	billion pax-km	3827	6425	10395	16603	68%	172%	334%
4 Pax non-scheduled and LCC	billion pax-km	831	1170	1676	2449	41%	102%	195%
5 Total pax demand	billion pax-km	4658	7595	12072	19053	63%	159%	309%
6 Cargo demand	billion tonne-km	159	281	509	903	77%	221%	470%
7 Revenu Tonne-Km (RTK)	billion RTK	578	964	1595	2618	67%	176%	353%
Flights and aircraft km								
8 Flights - technology age > 16 years	million flights	17.1	23.6	34.5	48.6	38%	102%	184%
9 Flights - technology age <= 16 years	million flights	16.0	25.0	35.4	53.0	57%	121%	231%
10 Total flights	million flights	33.1	48.6	69.9	101.6	47%	111%	207%
11 Aircraft km - technology age > 16 years	billion ac-km	20.6	30.0	44.5	65.1	45%	116%	216%
12 Aircraft km - technology age <= 16 years	billion ac-km	21.0	32.6	48.1	77.6	56%	130%	270%
13 Total aircraft km	billion ac-km	41.6	62.6	92.6	142.7	50%	123%	243%
Fleet size								
14 Passenger fleet (> 20 seats)	nr. of aircraft	19091	25862	34984	48047	35%	83%	152%
15 Freighter fleet	nr. of aircraft	3435	4329	5990	8499	26%	74%	147%
Effects on airlines								
16 Direct operating costs	billion US$	242.1	425.1	697.3	1090.2	76%	188%	350%
17 Total operating costs	billion US$	486.3	839.8	1403.3	2338.0	73%	189%	381%
18 Total operating revenues	billion US$	501.9	863.9	1452.8	2419.9	72%	189%	382%
19 Total operating result	% of revenues	3.1%	2.8%	3.4%	3.4%	n.a.	n.a.	n.a.
Fuel and emissions								
20 Total fuel use	billion kg	188.5	274.1	397.4	583.7	45%	111%	210%
21 Fuel / RTK	kg/tonne-km	0.33	0.28	0.25	0.22	-13%	-24%	-32%
22 CO_2 emissions	billion kg	595.2	865.2	1254.6	1842.7	45%	111%	210%
23 NO_x emissions	million kg	2323.7	4211.1	6770.1	10214.6	81%	191%	340%

11.4.6 In a subsequent step we made the correction in the scenario input file which, as described in par. 11.2.19, restores the demand growth according to CAEP's Medium Growth scenario (using variable MV_ADEM_PaxAutoGrowth). If the assumption were to be that the two types of demand would grow at the same rate, the correction for LCC/charter should be larger as the effect of the assumed fare adjustment is larger. However, the AERO-MS does not allow us to separately specify growth for the two types of passenger demand[32]. In this respect it is also noted that CAEP's Medium Growth forecast does not present separate growth numbers for scheduled versus LCC/charter passenger demand, so it is assumed that the variation in growth for scheduled versus LCC/charter passenger demand as presently shown by the AERO-MS are in line with CAEP assumptions in this respect.

Table 11.2 Passenger and cargo demand development - AERO-MS versus FESG CAEP/8 traffic forecast.

Year	AERO-MS	FESG CAEP/8[33]	Ratio (AERO-MS / CAEP/8)
Passenger demand (billion pax km)			
2006	4658.2	4271.0	1.09
2016	7595.0	7025.6	1.08
2026	12071.6	11198.6	1.08
2036	19052.7	17249.8	1.10
Cargo demand (billion tonne km)			
2006	158.6	184.9	0.86
2016	280.7	340.0	0.83
2026	508.9	602.6	0.84
2036	903.4	1062.6	0.85

[32] In order to make this possible, an additional variable would be required which is only related to the growth of LCC/charter demand. It does not seem complicated to implement this in the AERO-MS (model ADEM) but was out of scope for the SAVE project.

[33] [FESG, 2010] for passenger demand. DLR provided cargo demand numbers

Table 11.3 Passenger demand by route group according to medium growth scenario in billion passenger km (FESG/CAEP versus AERO-MS).

CAEP route group		FESG/CAEP			AERO-MS (CAEP-M 2026 scenario)		
		2006	2026	% growth p.a.	2006	2026	% growth p.a.
1	North Atlantic	454	1097	4.5%	520	1255	4.5%
2	South Atlantic	83	252	5.7%	89	267	5.7%
3	Mid Atlantic	59	171	5.5%	95	276	5.5%
4	Transpacific	312	1003	6.0%	275	864	5.9%
5	Europe - Asia / Pacific	371	1083	5.5%	379	1105	5.5%
6	Europe - Africa	129	378	5.5%	167	487	5.5%
7	Europe - Middle East	73	235	6.0%	122	385	5.9%
8	North America - South America	50	133	5.0%	53	139	4.9%
9	North America - Central America / Caribbean	94	235	4.7%	127	319	4.7%
10	Middle East - Asia/Pacific	109	356	6.1%	120	388	6.0%
11	Intra Africa (domestic and international)	44	137	5.8%	30	94	5.8%
12	Intra Asia / Pacific (domestic and international)	701	2510	6.6%	764	2703	6.5%
13	Intra Europe (domestic and international)	665	1420	3.9%	686	1465	3.9%
14	Intra Latin America (domestic and international)	105	337	6.0%	98	315	6.0%
15	Intra Middle East (domestic and international)	39	105	5.0%	28	75	5.0%
16	Intra North America (domestic and international)	925	1589	2.7%	1063	1821	2.7%
17	Other International Routes	57	158	5.2%	42	115	5.2%
	Total	**4271**	**11199**	**4.9%**	**4658**	**12072**	**4.9%**

Flights and aircraft km

11.4.7 Table 11.1 contains the growth of the number of flights and aircraft km as computed by the AERO-MS. The growth of the number of flights and aircraft km with "old" and "current" aircraft (technology age > 16 years and <= 16 years respectively in the forecast year) is higher for "current" aircraft. This reflects that the fact the fleet size has to be expanded due to growing demand, which implies that relatively new aircraft have to be acquired at a faster rate than older aircraft are being retired.

11.4.8 Table 11.4 compares the number of flights as computed by the AERO-MS with numbers computed by other models as part of CAEP's environmental goal assessment. It is understood that the models applied in CAEP/8 used the same detailed future forecast provided by the US to ensure commonality. So there is no independence between the results of the models applied in CAEP/8. The table shows that the growth in the number of flights in the AERO-MS is higher compared with what other models forecast based on their common inputs. Since the same demand growth forecast and development of load factors underlie the various model computations, it seems that the change over time in the mix of operations across aircraft seat bands in the other models is different from what the AERO-MS assumes. However, for the other models we do not have data with respect to the number of operations by aircraft seat bands in order to make more detailed comparisons. Moreover, we do not have data with respect to the future number of aircraft km computed by the other models.

Table 11.4 Forecast of number of flights for medium growth scenario - AERO-MS versus various other model results.

Year / period	AERO-MS	Results environmental goal assessment CAEP[34]			
		AEDT/SAGE	AEM	AERO2k	FAST
Number of flights (million)					
2006	33.1	31.0	31.0	29.9	31.7
2016	48.6	44.5	44.5	42.5	44.5
2026	69.9	62.9	62.9	59.6	62.9
2036	101.6	88.3	88.3	83.2	88.4
Growth in number of flights (per 10 year period)					
2006-2016	47%	44%	44%	42%	40%
2016-2026	44%	41%	41%	40%	41%
2026-2036	45%	40%	40%	40%	40%

Effects on airlines

11.4.9 In line with growing demand, the turnover of the global airline industry will increase over time. Table 11.1 shows that both total operating revenues and total operating costs grow faster compared with the growth in RTK's, reflecting the assumed increase in fuel costs and the subsequently higher fares.

11.4.10 As described in section 11.2, cost and fare levels for the various scenario years have been set in such a way that the profitability of the airline industry is around 3%.

11.4.11 Other models have not computed the effects on airline operating costs, revenues and result following from CAEP's Medium Growth scenarios, so no comparisons with these AERO-MS outputs could be made.

Fleet size

11.4.12 The passenger fleet size presented in Table 11.1 relates to all aircraft with > 20 seats. This facilitates the comparison with the FESG fleet forecast presented by FESG CAEP (document CAEP-SG/20082-IP/02).

[34] CAEP's Environmental Goals Assessment document (CAEP/8-IP/8) - tables P-19 through P-22.

11.4.13 For the various scenario years, we have compared the AERO-MS output fleet by seat band (for both passenger aircraft and freighters) with the FESG fleet forecast. The comparison for 2026 is presented in Figure 11.1 Similar to the comparison of the 2006 fleet (see Chapter 10), we have linked the seat bands in the updated AERO-MS with the FESG seat categories.

11.4.14 It can be observed that there is a fairly close match between the two fleet forecasts for 2026, both for passenger aircraft and freighters. For the passenger fleet, only the 211-300 seat band in the AERO-MS computes a higher number of aircraft. For the freighter fleet, the AERO-MS does not compute any aircraft in the largest seat band (> 500 seats). Consequently the AERO-MS computes a larger number of freighters than the FESG CAEP fleet forecast in the 301-500 seat band.

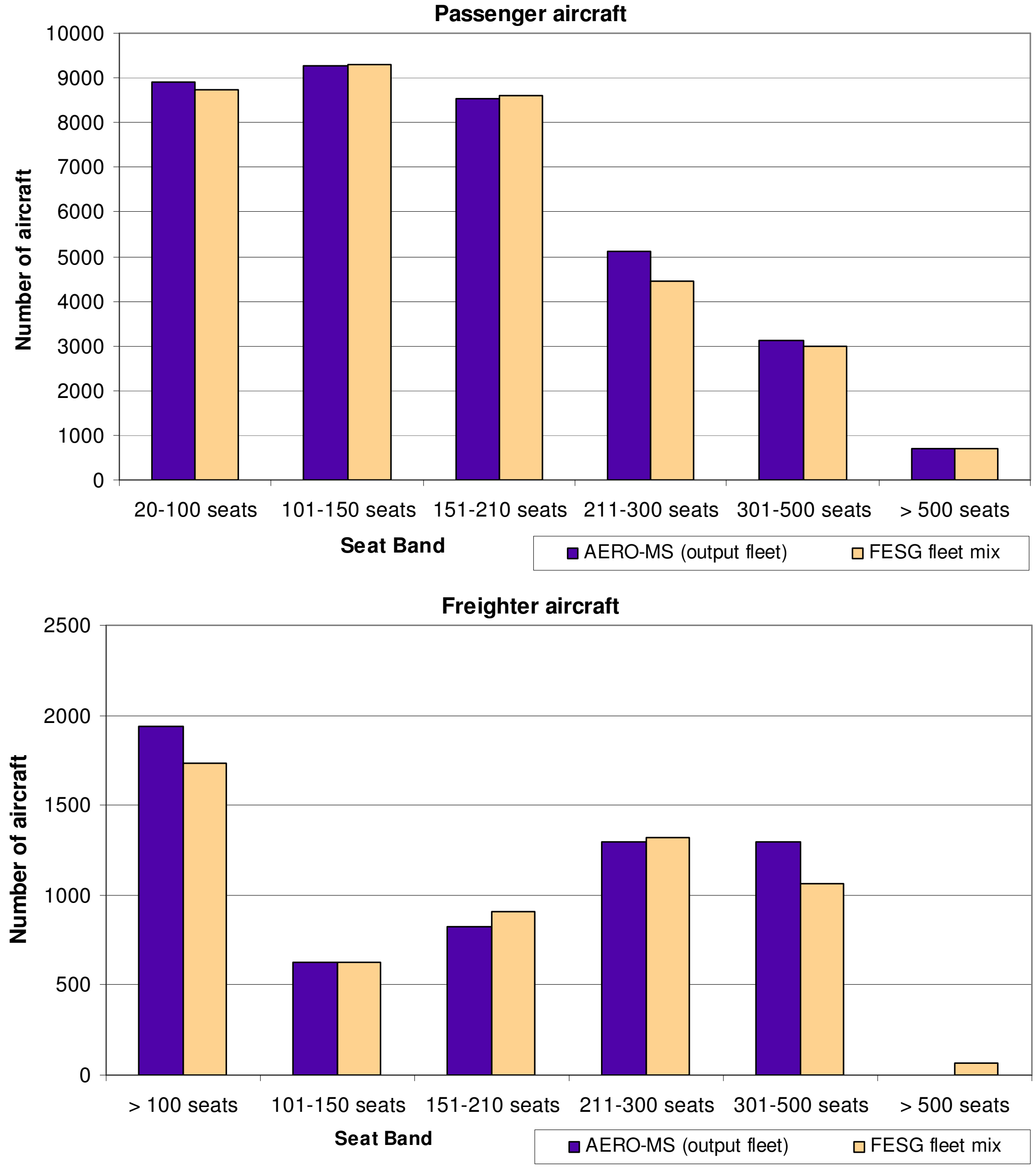


Figure 11.1 Passenger and freighter aircraft fleet forecast for medium growth scenario in 2026 - AERO-MS compared with FESG.

11.4.15 The number of New Large Aircraft (NLA) in the passenger fleet, as computed by the AERO-MS, is 703 in 2026. This is very similar to the number of 701 as forecasted by FESG. Table 11.5 includes the number of NLA in 2026 by region of carrier registration as computed by the AERO-MS. As part of the scenario specification it is assumed that the NLA are mainly operated on routes between Europe, Middle East and Asia/Pacific, on that basis that carriers operating on these routes will buy NLA. The distribution of NLA across carrier regions is fairly in line with the number of A380 ordered so far[35].

Table 11.5 Number of new large aircraft (> 500 seats) per region of carrier registration computed by the AERO-MS for 2026 (medium growth scenario).

AERO region of carrier registration	Number of new large aircraft
Middle East	152
South East Asia	147
EU	146
China and Mongolia	102
Japan and Korea	62
Australia and Oceania	41
Indian Subcontinent and Central Asia	41
North America	10
Other regions	2
Total	703

Fuel and emissions

11.4.16 For the Base Year 2006 the global fuel burn of the aviation industry computed by the AERO-MS is 188.5 Megatonne (Mt). As described in Chapter 10 the AERO-MS results match the results of other model computations fairly closely (see figure 10.6). For the future scenario years the AERO-MS computed fuel burn is somewhat higher compared with the results of other models. The AERO-MS computes an increase to 397.4 Mt in 2026 (+111% relative to 2006). The other models used in CAEP's Environmental Goal Assessment compute an increase in the global fuel burn between 101% and 103% over the period 2006-2026. The higher fuel burn computed by the AERO-MS can be can be explained by the larger number of flights which are computed by the AERO-MS (see table 11.4).

11.4.17 In figure 11.2 the fuel burn by region for 2026 as computed by the AERO-MS is compared with the results of other models. Allowing for the overall higher fuel burn estimated by the AERO-MS, the regional pattern is similar in the AERO-MS to that of the other models.

[35] By September 2010 234 NLA's have been ordered (plus 57 options) mainly by carriers from the Middle East, the EU and Asia/Pacific (see http://en.wikipedia.org/wiki/List_of_Airbus_A380_orders_and_deliveries)

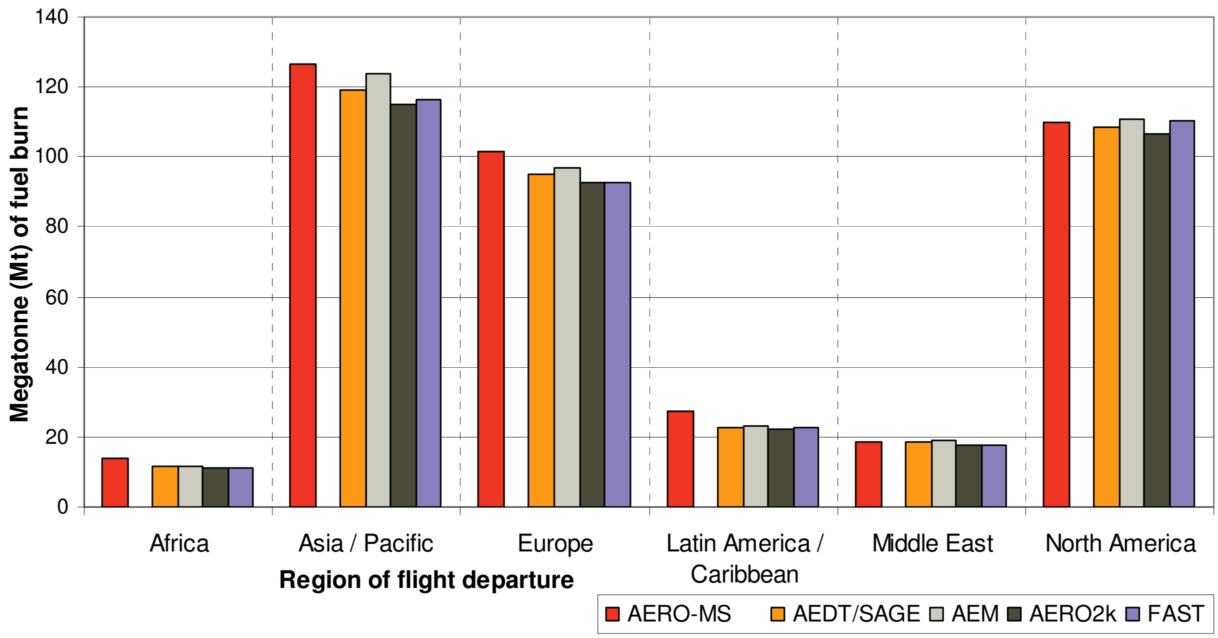


Figure 11.2 Comparison of AERO-MS aviation fuel burn by region in 2026 with CAEP environmental goal assessment results (medium growth scenario)[36]

11.4.18 We have also compared the change in fuel burn per RTK between the AERO-MS and other models (see table 11.6). In this respect it should be borne in mind that the change in fuel burn per RTK over time is affected by various scenario developments.

1 Assumed increase in passenger load factors.
2 Annual improvement of fuel efficiency of new aircraft entering the fleet of 0.96%.
3 Operational improvements.
4 Change in aircraft fleet mix (change in mix across seat bands; larger proportion of current aircraft).

[36] AEDT/SAGE, AEM, AERO2k and FAST: CAEP's Environmental Goals Assessment document (CAEP/8-IP/8) - tables P-19 through P-22 (scenario 3 - moderate technology / operational improvements).

Table 11.6 Forecast of fuel per RTK - AERO-MS versus various other model results (medium growth scenario).

Year /period	AERO-MS	Results environmental goal assessment CAEP[37]		
		AEDT/SAGE	AEM	AERO2k
Fuel burn per RTK (kg / tonne km)				
2006	0.326	0.317	0.322	0.312
2016	0.284	0.287	0.292	0.285
2026	0.249	0.258	0.265	0.257
2036	0.223	0.241	0.249	0.240
Percentage change of fuel burn per RTK (per 10 year period)				
2006-2016	-13%	-10%	-9%	-9%
2016-2026	-12%	-10%	-9%	-10%
2026-2036	-11%	-7%	-6%	-6%

11.4.19 Table 11.6 shows that the AERO-MS computes a **larger** overall improvement in fuel burn per RTK compared with the other models. This is very peculiar because the demand growth in the AERO-MS is almost exactly in line with the FESG forecast (see Table 11.2), but the increase in fuel burn computed by the AERO-MS is larger compared to the other models (see par 11.4.16). A larger increase in fuel burn would mean a **smaller** improvement in fuel per RTK for the AERO-MS.

11.4.20 When we analysed the results of the other models more closely it turned out that the results presented in CAEP's Environmental Goal Assessment (i.e. fuel burn and fuel burn per RTK results) do not seem consistent with the results presented in the FESG traffic forecast document (i.e. passenger and cargo demand). In other words the RTK demand growth following from the absolute fuel burn and fuel burn per RTK results seems not in line with the growth according to CAEP's medium growth scenario as presented in the FESG traffic forecast document. However, we may have misunderstood the results presented for the other models. In any case a proper comparison between the results of the AERO-MS and other models is difficult, but it is deemed not to be part of the SAVE project to completely understand and explain the model results presented as part of CAEP's Environmental Goal Assessment. Furthermore one could say that the apparent inconsistencies in the results of other models underline one of the strong features of the AERO-MS: because the AERO models are integrated in a single system, the results are internally consistent.

11.4.21 With respect to global NO_x emissions, the AERO-MS computes an increase over time which is considerably higher than the increase in fuel burn (see Table 11.1). The resulting fleet average Emission Index (EI) for NO_x thus increases over time according to the AERO-MS computational

[37] CAEP's Environmental Goals Assessment document (CAEP/8-IP/8) - tables P-23 through P-25 (scenario 3 - moderate technology / operational improvements).

results (see Table 11.7). The AEDT results presented as part of CAEP's Environmental Goals Assessment are clearly different from these.

Table 11.7 Comparison of AERO-MS global aviation NOx emissions with AEDT (medium growth scenario).

Region	NO_x (in Mt)		NO_x emission index (gram / kg of fuel)	
	AERO-MS	AEDT[38]	AERO-MS	AEDT
2006	2.32	2.72	12.33	14.54
2016	4.21	3.82	15.37	14.00
2026	6.77	5.01	17.04	13.35
2036	10.21	7.00	17.50	13.44

11.4.22 The reason for this increase in the EI NO_x, assuming that NO_x emission indices of new aircraft entering the market in the period 2006-2036 remain unchanged, follows from technology developments **before** 2006. As shown in Figure 7.7, the data included in the AERO-MS (based on ICAO NO_x certification data) show an increase in the EI NO_x of new aircraft over time for the period before 2006. The "old" aircraft in the Base fleet thus have relatively favourable NO_x characteristics, and over time these aircraft are replaced by aircraft with relatively unfavourable NO_x characteristics. It is not clear how in the AEDT computation the development of the EI NO_x of aircraft before 2006 has been taken into account, and whether the disparities in this respect are responsible for the difference in computational results for the future years.

11.5 Results for scenario variations

11.5.1 In this section the results of analysis of the scenario variations, as described in section 11.3, are presented and discussed.

Optimistic technology and operational improvement

11.5.2 Table 11.8 contains the results for the scenario variation whereby we have replaced the default moderate technology and operational improvement scenario by CAEP's Optimistic Technology and Operational Improvement scenario. The table also includes the results of the default scenario for 2026 (moderate technology scenario) to facilitate the comparison with the optimistic scenario variation.

11.5.3 The table shows that we have not made any changes to CAEP's medium growth scenario. Hence, demand growth and the number of flights for both scenarios are exactly the same. The number

[38] Source: CAEP's Environmental Goals Assessment document (CAEP/8-IP/8) - table P-7 (AEDT/EDMS for NO_x emissions < 3000 ft) and table P-15 (AEDT/SAGE for NO_X emissions > 3000 ft). Scenario 2 - moderate technology / operational improvements

of aircraft km in the optimistic scenario is lower following from the assumed additional operational improvements implemented in the AERO-MS by a reduction of the detour factors.

11.5.4 Total fuel burn in the optimistic scenario is 368.1 Mt, which is 7.4% lower compared with the default scenario. This percentage difference between the two technology scenarios is fairly similar to what is computed by other models as part of CAEP’s Environmental Goal Assessment. The models applied in CAEP/8 (AEDT, AEM, AERO2k and FAST) compute the optimistic scenario fuel burn to be between 7.8% and 8.1% lower than for the moderate technology scenario in 2026[39].

11.5.5 In the AERO-MS about half of the lower fuel use in the optimistic scenario follows from the assumed larger improvement of fuel efficiency of new aircraft entering the fleet (1.5% annual improvement in optimistic scenario instead of 0.96% improvement in moderate scenario). The other half follows from the additional operational improvements.

11.5.6 Overall the fuel costs in the optimistic scenario are higher compared with the moderate scenario. This is because the oil price is assumed to be 12.5% higher relative to the moderate scenario, and the fuel burn is ‘only’ 7.4% lower. The costs for a number of other operating costs categories go down in the case of the optimistic scenario because of the assumed additional operational improvements.

[39] See table P-19 of the CAEP’s Environmental Goal Assessment document.

Table 11.8 AERO results for CAEP8 Medium growth scenario (CAEP8-M) for 2026 - moderate and optimistic technology / operational improvement.

Effect	Unit	Base 2006	Results (absolute)			
			CAEP8-M 2026 (Moderate technology / operational improvement)	CAEP8-M 2026 OTI (Optimistic technology / operational improvement)	CAEP8-M 2026 (Moderate technology / operational improvement)	CAEP8-M 2026 OTI (Optimistic technology / operational improvement)
Air transport demand						
Pax scheduled Network Carriers (NC)						
1 First/business	billion pax-km	357	976	976	174%	174%
2 Economy (+ discount)	billion pax-km	3470	9419	9419	171%	171%
3 Total pax scheduled - NC	billion pax-km	3827	10395	10395	172%	172%
4 Pax non-scheduled and LCC	billion pax-km	831	1676	1676	102%	102%
5 Total pax demand	billion pax-km	4658	12072	12072	159%	159%
6 Cargo demand	billion tonne-km	159	509	509	221%	221%
7 Revenu Tonne-Km (RTK)	billion RTK	578	1595	1595	176%	176%
Flights and aircraft km						
8 Flights - technology age > 16 years	million flights	17.1	34.5	34.5	102%	102%
9 Flights - technology age <= 16 years	million flights	16.0	35.4	35.4	121%	121%
10 Total flights	million flights	33.1	69.9	69.9	111%	111%
11 Aircraft km - technology age > 16 years	billion ac-km	20.6	44.5	42.9	116%	108%
12 Aircraft km - technology age <= 16 years	billion ac-km	21.0	48.1	46.3	130%	121%
13 Total aircraft km	billion ac-km	41.6	92.6	89.2	123%	114%
Fleet size						
14 Passenger fleet (> 20 seats)	nr. of aircraft	19091	34984	34618	83%	81%
15 Freighter fleet	nr. of aircraft	3435	5990	5809	74%	69%
Effects on airlines						
16 Direct operating costs	billion US$	242.1	697.3	705.3	188%	191%
17 Total operating costs	billion US$	486.3	1403.3	1413.5	189%	191%
18 Total operating revenues	billion US$	501.9	1452.8	1452.8	189%	189%
19 Total operating result	% of revenues	3.1%	3.4%	2.7%	n.a.	n.a.
Fuel and emissions						
20 Total fuel use	billion kg	188.5	397.4	368.1	111%	95%
21 Fuel / RTK	kg/tonne-km	0.33	0.25	0.23	-24%	-29%
22 CO_2 emissions	billion kg	595.2	1254.6	1162.0	111%	95%
23 NO_x emissions	million kg	2323.7	6770.1	6237.5	191%	168%

Possible effect of oil price increase on demand

11.5.7 In scenario variation 1 with respect to the effects of an oil price increase (CAEP8-M 2026 Ef_OPI1) the oil price increase implies 12% higher fares (see also section 11.2). Given the price elasticities of demand which are considered in the AERO-MS, this fare increase results in a decrease in demand growth (in terms of RTK) by 7.4% (see Table 11.9). If it would thus be assumed that CAEP's medium growth scenario was based on an unchanged oil price between 2006 and 2026 and the assumption is there will be an increase in oil price from US$ 65 per barrel in 2006 to US$ 109 per barrel in 2026, the level of demand in 2026 is estimated to be 7 to 8% lower compared with what is projected by CAEP's medium growth scenario.

Table 11.9 Effects of scenario variations with respect to the effects of an increase of the oil price on future aviation demand.

Demand effect	Unit	CAEP8-M 2026 default	Effects relative to default scenario	
			CAEP8-M 2026 Ef_OPI1	CAEP8-M 2026 Ef_OPI2
Pax scheduled - Network carriers	billion pax-km	10,395	-6.9%	-15.5%
Pax non-scheduled and LCC	billion pax-km	1,676	-13.1%	-22.0%
Total pax demand	billion pax-km	12,072	-7.8%	-16.5%
Cargo demand	billion tonne-km	509	-6.7%	-17.8%
Revenue tonne-Km (RTK)	billion RTK	1,595	-7.4%	-16.9%

11.5.8 In scenario variation 2 (CAEP8-M 2026 Ef_OPI2) the GNP related effect of an increased oil price (i.e. the increase in the oil price implies a lower growth in global GNP which has a negative impact on aviation demand growth) is also taken into account. In this case the level of demand in 2026 in terms of RTK is estimated to be 16.9% lower compared with what is projected by CAEP's medium growth scenario. According to the AERO-MS result the assumed 7% lower growth of GNP over the period 2006-2026, following from the crude oil price increase, thus implies a reduction of demand growth by about 10%. This follows from the AERO-MS elasticities for air travel demand with respect to GNP (presently 1.5 for leisure and 0.8 for business purpose travel).

11.5.9 Apart from that we have seen that this part of the AERO-MS (i.e. scenario variables reflecting a change in GNP affecting aviation demand computed by the model) is still functioning as it should, the conclusion is that an increase in the oil price can have a significant effect on the future growth in aviation demand. Hereby the increase from US$ 65 per barrel in 2006 to US$ 109 in 2026 assumed in this analysis does not seem to be very extreme in the light of recent variations in oil prices.

Observed growth in aviation demand over the period 2007-2009

11.5.10 Using a set of time-dependent values for passenger and cargo demand growth between 2006 and 2036 (i.e. for all region pairs for all 30 years a growth percentage is specified), we have computed global aviation demand with the AERO-MS according to the default CAEP8-M scenario for all years between 2006-2036 (30 scenario runs). The results of these runs in terms of the development of global passenger and cargo demand are presented in Figure 11.3? (lines without dots).

11.5.11 In a next step we have defined a set of time-dependent values for passenger and cargo demand whereby we have replaced the demand growth for the period 2007-2009 by the observed growth. Again we have computed global aviation demand with the AERO-MS according to this growth 'scenario' for all years between 2006-2036 (again 30 scenario runs). The results of these runs in terms of the development of global passenger and cargo demand are presented in Figure 11.3 (lines with dots).

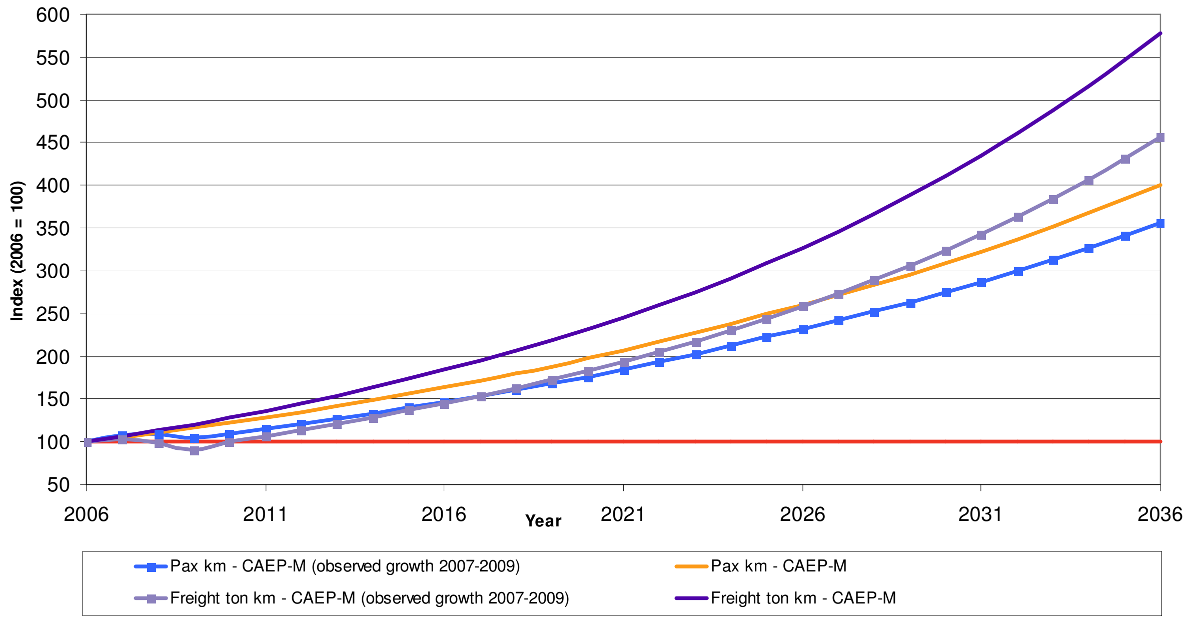


Figure 11.3 Growth in aviation demand according to CAEP8-M scenario (with and without observed growth in the years 2007-2009).

11.5.12 From Figure 11.3 it follows that the effects of the recent economic downturn are potentially significant for the future level of aviation demand. Clearly the big unknown in this respect is to what extent post-economic-downturn growth will be higher compared with what was originally forecasted by CAEP8-M, so that part of the 'lost' growth over the last years will be compensated. A scenario specification in the AERO-MS is able to take on board any possible re-bound effect of the industry which might take place over the coming years.

11.5.13 In the light of an expected increase in oil price, and the effects of the recent economic downturn, it is questionable to conclude that demand levels as forecasted by the CAEP/8 medium growth scenario will be realised in the associated timescales.

12 Testing of policy options

12.1 Overview of policy testing

12.1.1 The testing of policy options is aimed at the verification of the proper functioning of the updated AERO-MS and the illustration of its analysis capabilities. Moreover, based on the various tests and illustrations, further insights will be provided on the effects and improvements achieved as a result of the update.

12.1.2 The starting point for the policy testing is the updated version of the AERO-MS, converted to the new software platform and including all new data files and related adjustments to modelling dimensions and mapping procedures. In developing the updated AERO-MS a number of subsequent model versions were considered reflecting the relevant steps in the update procedure, including: the conversion to the new software platform; the changes in the modelling dimension structure; the update and replacement of the key data files; the calibration of input data and modelling results for the new Base Case 2006; and the development of a number of representative scenarios. During all stages of development, a broad and general technical testing has taken place in order to verify the core functionality and plausibility of results of the entire modelling system (including the user interface). The broad technical testing was based on the whole spectrum of analysis options as applied during previous AERO analyses and has led to the correction of a number of errors and shortcomings that occurred during the conversion and update process. In a few instances, minor corrections were also made to the code of the old AERO-MS, whereby it was verified that these corrections had no significant effects on the results of previous analyses.

12.1.3 Within the policy testing a number of different steps have been considered, as follows:

- Testing of main global policies.
- Selective testing on the specific behaviour of policies under different conditions and for a number of different regional applications.
- Testing of a number of illustrative sample cases.

Testing of main global policies

12.1.4 The testing of global policies involves a representative set of policies that reflect the core functionality of the AERO-MS. These include the relevant policies within the main categories economic/financial and regulation/operation. In considering the effects of these policies, a comparison is made with the policy effects that were found with the old version of the AERO-MS (i.e. version with Base year 1992). This comparison provides a basis for judging that the updates included in the revised model are functioning correctly in respect of policy-testing. Of course, there are differences in the results, but the tests show that these can be explained reasonably, given the updates in input data, dimensions and schematisation. There is also need to allow for the forecast year being different. It has been agreed with EASA that 2026 should be used for reporting results from the revised AERO-MS (to align with CAEP scenarios); the nearest forecast year to this for which runs of the old model are available is 2020.

12.1.5 Clearly, with the Base Year having advanced from 1992 to 2006, the absolute levels of demand, movements, revenues, costs, fuel consumption and emissions are very different between the old and revised models. Thus there is little merit in comparing policy effects based on ***absolute*** numbers, but there is much to be learned from comparisons of the effects of policies in terms of ***relative*** changes to a selection of key quantities.

Selective testing of specific policy behaviour

12.1.6 The selective policy testing considers three different parts:

- More detailed investigation of selective global policies.
- Policy testing for different scenarios.
- Regional effects of data update.

12.1.7 The more detailed investigation of selective global policies is involved with the effects of a number of specific conditions that affect policy behaviour and that may be varied by the user as part of the policy specifications. Variations of such policy settings are considered for a number of main policy options including fuel technology improvement, scrapping and fuel taxation.

12.1.8 The future effects of policies may be different depending on the specific scenario conditions and target years considered. Examples of such effects are illustrated by considering a number of key policies for a number of different time horizons of the CAEP8 medium scenario and for a clearly different set of scenario specifications related to fuel technology development and related fuel price.

12.1.9 As a result of the data update, air transport quantities, geographical distributions and schematizations have changed significantly. This part of the policy testing provides an insight in some of the main data changes resulting from the update and the consequences for the effects of a number of regional policies. The regional policies considered are based on a fuel taxation and include an application for domestic and international flights only; an application for some selective geographical regions; and an application for a specific carrier region (all carriers based in the EU).

Testing of illustrative sample cases

12.1.10 In addition to the testing of specific individual policies and policy specifications, a number of illustrative cases have been considered to demonstrate the use of the AERO-MS in addressing a number of specific analysis questions. For this purpose, a number of topics were selected that relate to issues or questions of particular interest to EASA and/or CAEP. The specific sample cases considered include:

- Possibilities for achieving a fuel efficiency improvement target.
- Effects of specific technology developments (open rotor).
- Variations on the EU emission trading system (EU-ETS).

12.1.11 From these sample test cases the following outcomes are observed and specifically demonstrate the flexibility in the types of analysis and valuable insights that the AERO-MS can provide.

12.2 Testing of main global policies

12.2.1 Global policies to be tested have been considered within two main groups:

- Economic and financial policies.
- Regulation and operation policies.

Economic and financial policies

12.2.2 The economic and financial policies include:

- Fuel taxation.
- Route Charge.
- Airport Charge.
- Ticket taxation applied to airlines (though potentially passed on as a fare increase to air-service users).
- Value added taxation applied directly to air-service users.

12.2.3 When originally conducted with the old AERO-MS, the value of the route charge was made "equivalent" to the level of fuel taxation that was tested by specifying a distance-related charge by aircraft type and technology level to coincide with the fuel taxation. Similar equivalencing to the fuel taxation was performed to set the values of the airport charge, ticket taxation and value added taxation.

12.2.4 ' A global fuel taxation is implemented in the AERO-MS by increasing the fuel price (in US$/kg) by an amount to be specified by the model-user, the increased fuel price being applied to all flights across the globe. In our policy testing example we have considered a fuel taxation of US$ 0.50 per kg of fuel. For the route charge and airport charge policies, equivalent taxation levels have been applied.

12.2.5 The route charge is applied as a charge per aircraft-km distinguishing between generic aircraft types and technology level. The fuel tax equivalent route charge in US$ per aircraft-km was determined by computing the average amount of fuel used by aircraft type and technology level (in kg/aircraft-km) and applying a taxation level of US$ 0.50/kg to these amounts.

12.2.6 The airport charge is applied as a charge for a single visit (landing + take-off) to an airport. The fuel tax equivalent airport charge in US$ per aircraft-movement was determined by computing the average amount of fuel (kg) used for a single movement by aircraft type and technology level and applying a taxation level of US$ 0.50/kg to these amounts. In this way, the resulting charges will be higher for older, less fuel efficient aircraft, inducing a shift towards more fuel efficient aircraft.

12.2.7 Both a ticket taxation and a value added taxation are involved with a direct increase in ticket price per passenger (or the freight rate per kg in case of cargo). The difference between the two is in the way the increases in fares and freight rates are applied. In the case of a ticket taxation, the taxation is imposed on the airlines, which may then pass on the additional costs to their clients to maintain profitability. In the case of a value added taxation, the increase in fares and freight rates is directly imposed by the government to the air transport clients in a way comparable to imposing or raising the VAT.

12.2.8 The price increase to be imposed for the ticket tax is 'matched' to the fuel taxation by ensuring that the resulting cost increase (measured in terms of total operating cost per RTK) is equal to the fuel taxation case. The same increase is used for the value added taxation. Increases are expressed as a relative (%) increase in the fares and freight rates applied in the Datum situation.

12.2.9 According to the above specifications, the global financial policies considered are:

- FT50: fuel taxation of US$ 0.50 per kg of fuel.
- RCFT50: route charge in US$ per aircraft-km by aircraft type and technology level equivalent (as explained earlier) to the (FT50) fuel taxation.
- ACFT50: FT50 equivalent airport charge in US$ per aircraft movement by aircraft type and technology level.
- TTFT50: FT50 equivalent ticket taxation to airlines by applying a global increase (%) in fares and freight rates.
- VTFT50: FT50 equivalent value added taxation to air transport clients lines by applying a global increase (%) in fares and freight rates.

12.2.10 The results of these tests are presented and discussed later in this chapter.

Regulation and operation policies

12.2.11 The regulation and operation policies include:

- Removing older aircraft from the global operational fleet beyond a certain age based on technology (certification) year. In the scenario year, the part of the fleet older than the specified technology year would be considered to be phased-out'. In the old AERO-MS terminology, this policy is referred to as 'scrapping'.
- Removing older aircraft by 'scrapping' aircraft beyond a certain age based on purchase year.
- Additional fuel technology improvement by imposing a fuel use stringency.
- Providing a tax credit of as a percentage of the purchase price of new aircraft.
- Reduction of air traffic detour and delays by improving air traffic management (ATM).

12.2.12 In the AERO-MS accelerated fleet renewal by removing older aircraft from the global operational fleet (by 'scrapping' old aircraft) can be modelled in two ways: (1) by removing aircraft beyond a certain technology age (based on certification year); and (2) by removing aircraft purchased before a certain purchase year. For the policy testing the scrapping age considered is 25 years for both situations. Since new aircraft purchased already have a certain 'technology age', the first type of scrapping condition is stricter than the second leading to more aircraft being scrapped. In view of the present AERO-MS assumption regarding the 'introduction' of new technology, where new aircraft purchased may have a technology age up to a maximum of 8 years, the average difference between purchase and technology age is of the order of 4 years.

12.2.13 Additional fuel technology improvement is achieved by imposing an aircraft fuel burn certification requirement on the technology characteristics of newly certified aircraft. This is implemented in terms of a stringency limit resulting in an overall fuel use reduction (in %) for new aircraft becoming available in the marked as a function of technology year. This would be accomplished from a specified measure year onwards and/or a gradual forced annual improvement (% per year) during a specified period. As a consequence of the technological improvement there will be an effect on the price of new aircraft falling under the stringency. This is accounted for by specifying a relative increase in the price of newly purchased aircraft in terms of a percentage increase for each 1% of fuel efficiency improvement. For the policy testing, an additional fuel technology improvement of 1% per year during a period of 20 years was considered, assuming a 2% increase in new aircraft price for each 1% of fuel improvement.

12.2.14 A new aircraft purchased may have a technology age ranging from a minimum of 1 to a maximum of 8 years. The technology time span from which newly bought aircraft are to be selected is the so-called technology penetration parameter (presently set to 8 years). Newly purchased aircraft are equally distributed across this time span. The tax credit measure is involved with the specification of a relative reduction (%) of the purchase price of a new aircraft, purchased from a certain measure year onwards, providing that the technology age is no more than x years older than the purchase year, i.e. aircraft having a technology 'vintage depth' less than or equal to x. For the policy testing a tax credit of 50% was assumed for a period of 10 years prior to the Scenario Year (leading to Measure Year 2010 for the old and Measure Year 2016 for the new AERO-MS) and for a technology 'vintage depth' equal to or less than 2 years. Consequently, the tax credit only applies to aircraft with technology ages of 2 years or less at the moment of purchase.

12.2.15 A reduction in air traffic detour and delays by improving ATM is simulated by proportionally reducing the detour factors that are specified for each flight stage. Detour factors are expressed in terms of a factor greater than 1 to be applied to the great circle distance between an origin and destination. The costs of improving ATM, which are highly uncertain, are accounted for by proportionally increasing the operating costs related to the route charge. The measure considered in policy testing assumes a reduction of 50% of the part of the detour factor in excess of 1 and a 100% increase in route charges.

12.2.16 According to the above specifications, the global regulation and operation policies considered are:

- CScrap25: all aircraft with certification year older than 25 years to be scrapped.
- PScrap25: all aircraft with purchase year older than 25 years to be scrapped.
- FTI-1% 01-20 AP2% (old AERO-MS) and FTI-1% 07-26 AP2% (updated AERO-MS): additional fuel technology improvement of 1% per year during a 20-year period for the period 2001-2020 (old AERO-MS) and 2007-2026 (updated AERO-MS), respectively. Price increase of new aircraft: 2% for each 1% additional fuel improvement.
- TC50% MY2010 VD2 (old AERO-MS) and TC50% MY2016 VD2 (new AERO-MS): tax credit of 50% to new aircraft purchased from 2010 (old AERO-MS) or 2016 (new AERO-MS) onwards with vintage depth (difference between purchase year and technology year) less than or equal to 2 years.

- RDF50% RC+100%: 50% reduction of part of detour factor in excess of 1 and 100% increase in route charges.

Computation of global policies and presentation of results

12.2.17 For all above global policies, computations were made for both the updated AERO-MS and the old AERO-MS. The computations with the updated AERO-MS were made for the medium CAEP8 scenario and the year 2026 (CAEP8-M 2026). The computations with the old AERO-MS were based on the scenario M-2020. This scenario for 2020 is defined for the old AERO-MS version and was used for the original analyses underlying the AERO-MS Main Report published in July 2002. The computations with the old AERO-MS were made with the version that was transferred to the new platform. As described in Section 9.2, the results of this version are identical to the results of the latest available version of the old AERO-MS, with the exception of some minor changes caused by a code correction involving the handling of New Large Aircraft.

12.2.18 A summary of the results of the policy computations for the old and new versions of the AERO-MS is provided in Table 12.1 and Table 12.2 (for the economic/financial and regulation/operation policies, respectively). From within these tables, an explanation of a subset of the most relevant results is presented as follows:

Air transport demand

- Passengers scheduled (Network Carriers) for three classes (first/business, economy, discount) and total in billion (10^9) pax-km (effects 1-4). Between the old and new AERO versions there is a difference in the classes considered. The old AERO version distinguishes between first/business, economy and discount. Given the available demand data, for the new AERO-MS version a distinction between economy and discount could not be made. Hence these latter categories were combined.
- Passengers non-scheduled (or Charter and Low Cost Carriers (LCC) for new AERO-MS version) in billion pax-km (effect 5). In the new AERO-MS, the originally considered movement type 'non-scheduled' was redefined to include the operation of Low Cost Carriers. As a result, this category now includes a large part of the demand that would fall under the discount class in the old AERO-MS.
- Total passengers in billion pax-km (effect 6).
- Cargo demand in billion tonne-km (effect 7).
- Revenue Tonne-Km (RTK) in billion tonne-km. The number of RTK expresses the total demand. In the new AERO-MS, in line with the ICAO data that were used for the calibration for the Base Year (2006), an average weight of 90 kg is assumed for 1 passenger including baggage (effect 8). In the old AERO-MS an average passenger weight of 100 kg is assumed. It is understood that the current ICAO standard has also been set to 100 kg.

Aircraft km (in billion ac-km)

- Aircraft km performed with aircraft of technology age larger than 12 years in old AERO and 16 years in new AERO (effect 9).

- Aircraft km performed with aircraft of technology age smaller or equal than 12 years in old AERO and 16 years in new AERO (effect 10).
- Total aircraft km (effect 11).
- The technology age of 12 years marks the difference between aircraft that were considered of 'current' and 'old' technology in the old AERO-MS. In the new AERO-MS the age-break between current and old was shifted from 12 to 1o 16 years, based on the observed characteristics of the PRISME fleet.

Effects on airlines

- Direct operating costs including all variable operating costs with the exception of capital costs and finance charges (i.e.: fuel costs, maintenance costs, cabin and flight crew cost, landing and en route charges) in billion US$ (effect 12).
- Total operating cost of air transport in billion US$ (i.e. direct operating costs, capital costs and finance charges, and volume related costs) (effect 13).
- Total operating revenues: total revenues of air transport in billion US$ (effect 14).
- Total operating result: the difference between total operating revenues and costs (expressed as a percentage of total operating revenues) (effect 15).
- It is noted that in the old AERO-MS all monetary values are expressed in 1992 US$. For the new AERO-MS all monetary values are expressed in 2006 US$.

Impacts on other actors

- Change in consumer surplus (effect 16): consumer surplus corresponds to the difference between the willingness to pay and the actual fares for air transport clients. The computation of the change in consumer surplus is based on the shift in air transport demand brought about by the increase in fares and freight rates, following from the price elasticities of demand. By far the major part of the change of the consumer surplus (expressed in billion US$) follows from the increase in the cost of air transportation (and hence fare increases) for those clients who still make use of aviation services if a policy is in place (but, because of higher fares, the difference between the willingness to pay and the fares is reduced). Another part of the reduction in consumer surplus relates to the clients who have decided not to make their air journeys because the increased fare exceeds their willingness to pay. (The loss of consumer surplus for these "priced off" clients is half the increase in fare.)
- Revenue from taxation/charges: in the case of a taxation or charge to be collected by a third party (usually the government) a substantial amount of revenues may be generated, which represent an important monetary benefit (expressed in billion US$) of the policy measure (effect 17).

Fuel impacts

- Total fuel use: total amount of annual fuel use for commercial air transport in billion kg (effect 18).
- Fuel/RTK: the average amount of fuel use in kg/tonne-km (effect 19).
- Relative contribution of demand reduction to reduction in fuel use in % (effect 20).

- Relative contribution of technology and efficiency improvement to reduction in fuel use in % (effect 21).

12.2.19 The decrease in fuel use achieved by the various policy options is one of the key impacts to be considered. Reductions in fuel use follow from two major phenomena:

- A reduction in demand which is triggered by the cost increases following from policy implementation.
- Improvements to aircraft technology and efficiency of aircraft operation that is due to or incentivised by the policy measure.

12.2.20 Essentially all financial and aircraft technology and operation related measures will lead to an increase in aircraft operating cost, usually to be first incurred by the airlines. As a general modelling principle, airlines are assumed to reduce the cost impacts by adjusting fleet and flight operation. These airline responses aimed at reducing costs (supply side responses) typically lead to a reduction in fuel use by inducing shifts to more modern technology and to improvements in operating efficiency. (It should be borne in mind that the AERO-MS represents the final steady-state position of the response by airlines and other aviation-sector actors to policy measures.) Remaining cost increases will then be passed on to air transport clients in order to maintain profitability. This leads to increases in fares and freight rates which in turn lead to a decrease in demand, depending on the price elasticities of demand that are considered in the AERO-MS for the various demand categories. Demand reductions lead to a reduction in fuel use following from the decrease in the volume of flight operation.

12.2.21 The relative contribution of the demand effect to total fuel reduction directly follows from the reduction in total RTK. The relative contribution of the technology and efficiency effect follows from the changes in fuel use per RTK. The summation of these two effects fully accounts for the resulting reduction in fuel use. The relative contributions (in %) are computed as the relative share of each effect to the summation of the effects.

12.2.22 In both Table 12.1 and Table 12.2 absolute values for the above quantities are presented for the Scenario Year considered in the old and new version of the AERO-MS (indicated as A-old and A-new). These results serve as a reference for the comparison of the policy effects. The Scenario Years considered are 2020 and 2026. As noted earlier, these absolute results of the old and new AERO-MS are not directly comparable (because of differences in: years; input data; scenario specifications; and monetary values). Yet, the absolute results for the Scenario Years give rise to a number of relevant observations:

- Total RTK for 2026 (new version) is somewhat larger than total RTK for 2020 (old version) and seems to be reasonably in line with the trend in former projections.
- The relative share of first/business passengers is appreciably higher in the new AERO-MS version.
- Due to differences in price/cost developments and monetary values, as well as the higher activity levels in terms of RTK, the absolute totals of operating costs and revenues are quite a bit higher in the new versus the old AERO-MS.
- In view of the assumptions underlying the calibration and scenario development procedures, total operating results expressed as a percentage of operating revenues are very much comparable.

12.3 Results of economic and financial policies

12.3.1 Table 12.1 shows the results of the global financial policies described above for both the old and new AERO-MS. All policy results are expressed as relative changes (%) to the quantities computed for the (same) Scenario Year but without the policy in place. This facilitates a comparison of the relative policy effects between the old and new versions of the AERO-MS. The following paragraphs briefly discuss the various types of main effects.

Air transport demand

12.3.2 Considering the total demand effect on total RTK of the global fuel taxation FT50, the demand effect is significantly smaller for the new version of the AERO-MS (8.9% versus 12.5%, which is almost 30% less - see effect 8). The demand effect is driven by the relative change in total operating costs brought about by the policy. For the new AERO-MS, the reference level of total operating costs in the scenario year is much higher than for the old AERO-MS (as can be observed in the scenario values for total operating costs in Table 12.1 - effect 13). There are a number of reasons why the operating cost level is higher for the new AERO-MS. One obvious reason is the difference in monetary values (2006 US$ in the new versus 1992 US$ in the old version of the AERO-MS). Another is the change in assumed price levels according to the scenario specification. This is particularly true for the level of fuel prices. Where the M-2020 scenario of the old AERO assumes a fuel price of the order of 1992 US$ 0.24/kg (there is some regional variation in fuel price), this is of the order of 2006 US$ 0.96/kg for the CAEP8 M-2026 scenario of the new AERO-MS. The increase in the absolute level of total operating costs causes the relative cost change resulting from the taxation measure FT50 (involving a fixed increase in fuel price of $0.50 per kg of fuel for both model versions) to be significantly lower in the case of the new AERO-MS. From a more detailed comparison of cost changes for the two model versions it was verified that this difference in relative cost change is of the order of 25%, which largely explains the difference in the demand response.

12.3.3 Other, much smaller differences follow from changes in the distribution of transport activity across passenger demand categories and the related price elasticities of demand. One of these smaller effects is e.g. that the number of first/business passengers, with a relatively low price elasticity of demand, has increased significantly in the new AERO-MS. Comparing the pattern of demand responses across the detailed demand categories between the old and new versions of the AERO-MS, the results are consistent (see effects 1-7).

12.3.4 The same is true for the changes between the various taxation measures. The responses of the fuel equivalent route charge (RCFT50) are almost identical to the FT50 policy, which is true for both versions of the AERO-MS. Also for both versions of the AERO-MS, the demand responses of the other financial policies are somewhat different from the first two, with, the fuel equivalent airport charge (ACFT50) having the smallest total demand response and the value added taxation (VTFT50) the largest (see effect 8).

Aircraft km by technology level

12.3.5 The fuel taxation, route charge and airport charge measures (FT50, RCFT50 and ACFT50) lead to an increase in the direct operating costs of aircraft, in particular for the older, less fuel efficient aircraft. The differences in cost effects induce a shift in the use of 'old' versus 'current' aircraft in the future fleet. This becomes clearly manifest in the change in the number of aircraft-km performed, where for both versions of the AERO-MS the share of aircraft-km 'current' is significantly larger (although, due to the sizable overall demand effect, there is still a small reduction in the aircraft-km current).

12.3.6 The total extent of the technology shift in the old AERO-MS is larger than in the new AERO-MS (see effects 9 and 10). The main reason is that in the new version of the AERO-MS the differences in the technology characteristics between the older and current parts of the fleet, following from the processing of the properties of the PRISME fleet, are less pronounced than in the old version of the AERO-MS. The overall behaviour of the technology changes are quite comparable, however.

12.3.7 In case of the ticket and value added taxation policy (TTFT50 and VTFT50) there is no direct relation between taxation level and fuel use. Hence these policies do not introduce any cost differences between aircraft of 'old' and 'current' technology. As a result there is no differential effect on the volume of old and current aircraft-km. From Table 12.1 it can be observed that the relative effects on the old and current aircraft-km are indeed identical, both for the old and new version of the AERO-MS (see effects 9 and 10).

Effects on airlines

12.3.8 The fuel taxation measure FT50 leads to a very significant relative increase in ***direct*** operating costs, of which the fuel costs represent a very important part (see effect 12). The relative increase in ***total*** operating costs is substantially less, since fuel costs represent a much smaller part of total operating costs (see effect 13). It should be borne in mind that these changes reflect the result of two effects. One is the increase in fuel costs following from the taxation; the other is a decrease in all operating cost components due to the reduction in demand and the subsequent reduction in the volume of flight operation (compared to the levels of activity in the without-measures case). Total operating revenues also increase in a way that is comparable to the increase in total operating costs (see effect 14). This is the net result of an increase in fares (driven by the increase in operating costs) and a reduction in transport volume following from the demand reduction. In adjusting fares the airlines strive to maintain profitability.

12.3.9 Considering the total operating result, expressed as a percentage of total operating revenues, it can be observed that in FT50 some reduction occurs (see effect 15). In this respect, it should be noted that the mechanisms to maintain profitability in the AERO-MS are applied at a very detailed level (of individual flight stages). Consequently, certain deviations may occur at the aggregate level of the total operating result. If deemed necessary, for individual policy measures, the process of maintaining airline profitability can be fine-tuned to some extent by making use of the so-called 'profit adjustment factor'. This is a model parameter to control the extent to which increases in operating costs incurred by airlines are passed on to airline clients. In the comparison across different policies, this factor was always set to its default value (equal to 1) which should in principle lead to maintaining the profitability that would occur without the policy in place. Section 12.6 provides a further demonstration of the possible use and consequences of this profit adjustment factor.

12.3.10 It can be observed that, with respect to the measure FT50, the behaviour of the old and new AERO/MS is very similar. Note that the relative increase in direct operating costs is somewhat less for the new AERO-MS, as the relative impact of the fixed FT50 taxation level on direct operating cost is less, due to the higher absolute cost level (see effect 12). The behaviour across the measures RCFT50, ACFT50 and TTFT50 is largely similar to FT50, for both the old and new AERO-MS. The behaviour of the measure VTFT50 (the value added taxation) is quite different, however. In contrast with the other measures, taxation charges for this measure are not imposed on the airlines but directly on air transport clients. Therefore, the cost increases related to the taxation do not appear in the airline accounts and we only see the cost and revenue reductions that follow from the demand reduction.

12.3.11 Looking at the effects on total operating result, it appears that more or less significant reductions still occur in the old AERO-MS, especially in case of the airport charge (ACFT50) and the ticket taxation (TTFT50). This is due to limitations in the modelling approach to actually achieve a stable operating result for different types of policies at the aggregate level, given the details of the computational procedures applied at the flight stage level. In this respect it should also be realised that the operating result is computed as the difference of two large numbers, i.e. the total operating costs and the total revenues. Note that deviations in the operating result are directly connected to the fare increases to airline clients and the resulting demand effects. If the operating result becomes lower, fares should actually have been increased a bit more. If the operating results becomes higher, the increase in fares should have been a bit lower. These deviations should be considered as a limitation of the present modelling process. As explained above, for individual measures a further fine-tuning could be carried out by using the profit adjustment factor required to actually maintain airline profitability at the aggregate level. In the new version of AERO-MS we can observe that without this fine-tuning, profitability across the various measures is better maintained (all operating results remain in the range of 2.5 to 4.1% - see effect 15). Changes and refinements to the input data brought about by the update process have improved the robustness of this behaviour.

Impacts on other actors

12.3.12 All the taxation and financial measures considered lead to a very significant increase in the cost of air travel experienced by the air transport clients. This cost increase is reflected in the large negative changes in consumer surplus (see effect 16). For the various measures considered, the effects are quite similar. However, the effects are largest for the value added taxation (VTFT50) because the cost of this measure is not imposed on the airlines and therefore does not provide any incentive to cut down on aircraft operating costs. We also see a somewhat higher value for the ticket taxation TTFT50. Although the cost of this measure is imposed on the airlines, this measure does not differentiate between aircraft technology which reduces its effectiveness in achieving cost reductions from technology improvement, compared to the measures FT50, RCFT50 and ACFT50 which are differentiated by aircraft technology.

12.3.13 The patterns of the old and new versions of the AERO-MS are very similar for the effects on consumer surplus and revenue from taxation and charges. For the new AERO-MS, the impacts on consumer surplus are structurally higher (see effect 16) because of the somewhat larger transport volume in the Scenario Year that is subjected to the measures. The revenues from taxation/charges collected by the government are of the same order of magnitude as the cost increases incurred by the consumers, counterbalancing this negative effect (see effect 17). This simply follows from the principle that airlines maintain their profitability to the greatest extent possible. Consequently, in the case of a taxation measure, the additional cost of air transport as incurred by the airline clients is basically equal to the revenues collected by the government.

Fuel impacts

12.3.14 For the measure FT50 the total reduction in fuel use for the old AERO-MS is of the order of 15%. For the new AERO-MS this is about 4% less (see effect 18). The difference is explained by two reasons. The most important one is the reduction in the demand effect as explained in para. 12.3.2. Another reason is the reduction in the effects of technology and efficiency improvement as can be observed in the reduction in fuel/RTK (effect 19). This effect is less for the new AERO-MS because of a somewhat reduced shift in technology (aircraft-km of old versus current) and the less pronounced differences in the technology characteristics of old versus current. Since both the effects of demand reduction and technology improvement go down, we find that the relative contributions of demand reduction and technology improvement to total fuel reduction (effects 20 and 21) remain the same.

12.3.15 The effects on fuel impacts for the measures FT50 and RCFT50 are almost exactly equal for both the old and new AERO-MS. However, for the measures ACFT50, TTFT50 and VTFT50 we observe a difference in the behaviour of the old versus the new AERO-MS with respect to the changes in fuel use per RTK. Comparing the reduction in demand (effect 8) with the reduction in aircraft-km (effect 11), in the case of the old AERO-MS for the measures ACFT50, TTFT50 and VTFT50 we observe that demand goes down more than the number of aircraft-km. This indicates a shift towards the use of smaller aircraft and/or a loss of efficiency in the number of RTK per aircraft. For the measure ACFT50 this effect almost counterbalances the favourable effect of technology improvement on fuel/RTK. For the measures TTFT50 and VTFT50 there is no incentive for technology improvement, so in the old AERO-MS we only see an upward effect on fuel use per RTK (see effect 19).

12.3.16 In the results for the new AERO-MS, there is hardly a difference in the reductions in total RTK demand (effect 8) and aircraft-km (effect 11) for measures ACFT50, TTFT50 and VTFT50. Consequently, there is no significant upward effect on fuel/RTK. Therefore, the favourable effect on fuel/RTK (due to technology improvement) for the measure ACFT50 is more or less comparable to the measures FT50 and RCFT50. For the measures TTFT50 and VTFT50 (no incentive for technology improvement) the resulting effect on fuel/RTK now is close to 0 (effect 19).

12.3.17 In spite of these differences in the detailed responses between the old and new AERO versions, the fundamental behaviour remains the same. The detailed differences observed may be related to various changes made in the update process (e.g. the definition of aircraft types, distribution of demand categories across aircraft types, numbers and lengths of flight stages, cost differences between aircraft types, load factors, etc.) and cannot be simply pinpointed to a particular change.

12.3.18 The overall effects and policy conclusions of the old and new versions AERO-MS are very similar. Differences between the effectiveness of the measures ACFT50, TTFT50 and VTFT50 versus FT50 and RCFT50 have become slightly less but the measures FT50 and RCFT50 are still most efficient in terms of fuel use reduction (with ACFT50 now getting closer). Measures TTFT50 and VTFT50 still do not lead to improvements in technology or efficiency, as can be verified from the relative contributions to the fuel effect (effects 20 and 21). This reinforces the finding that, as would be expected, measures that discriminate by aircraft technology incentivise fuel efficiency improvements, while measures that do not so discriminate have no such incentive effect.

12.4 Results of regulation and operation policies

12.4.1 Table 12.2 shows the results of the regulation and operation policies considered for both the old and new AERO-MS. The following briefly discusses the comparison of the main relative effects.

Air transport demand

12.4.2 From comparing the total demand effect on total RTK of the scrapping measures (CScrap25 and PSScrap25) for the old and new versions of the AERO-MS, it follows that the demand effect is considerably smaller for the new AERO-MS (see effect 8). There are a number of explanations. The demand effect is caused by the cost increases following from accelerated fleet renewal which removes the older aircraft from the fleet and replaces these with new ones. This leads to an increase in some cost components, such as capital costs and finance charges, but at the same time to a reduction of other operating cost components, such as fuel costs. In the scenario underlying the new AERO-MS, the fuel price is of the order of four times higher than in the scenario for the old AERO-MS. Consequently, the favourable effects brought about by a reduction in fuel costs are much higher for the new AERO-MS.

12.4.3 Another effect that reduces the cost of scrapping in the new AERO-MS has to do with the number of aircraft affected. Following from the processing of the PRISME fleet and the further projection of this fleet into the future, it turns out that the number of older aircraft eligible for scrapping is appreciably lower in the new AERO-MS compared to the old AERO-MS, which also has a strong impact on the costs. And finally, there is the effect that the relative effect of the same absolute cost increase is noticeably lower in the new AERO-MS due to the significantly higher absolute cost level, as observed in para. 12.3.2. This results in a very substantial reduction in the relative change in total operating costs, which directly corresponds to the change in demand. The overall impact of the measure PScrap25 is substantially smaller than the measure CScrap25 (which is much 'stricter' in removing old aircraft). The pattern of differences in demand effects between CScrap25 and PScrap25 is very similar for the old and new AERO-MS.

12.4.4 For the measures on technology improvement (FTI-1% 01-20 (07-26) ACP2%) and reduction in detour factor (RD50%+RC100%) we also observe a significantly smaller demand effect with the new AERO-MS (see effect 8). Two of the explanations given above are also valid for these cases. Again, the overall cost increases are reduced because of the larger (favourable) effect of fuel savings, given the much higher fuel prices in the new AERO-MS; and the relative cost changes are reduced because of the higher absolute cost level.

12.4.5 For the detour reduction there is an additional explanation. The cost effects of this measure have been approximated by assuming a doubling (+100%) of the route costs. As it turns out, the route costs in the new AERO-MS are considerably lower than in the old AERO-MS (a direct result of the updated cost calibration). This further reinforces the differences observed in the relative overall cost changes between the old and new AERO-MS for this measure.

12.4.6 The tax credit measure (TC50% MY2010 (2016) VD2) has no demand effects as this measure leads to a reduction in total operating costs. Any favourable effect on total operating costs is assumed to be not passed on to the air transport clients. Therefore demand effects are zero. This holds for both the old and new AERO-MS.

Aircraft km by technology level

12.4.7 The scrapping measures lead to a very considerable shift in aircraft-km from the old to the current part of the fleet. It can be observed that the effect for the measure CScrap25 is about twice as big as for PSCrap25 (see effects 9 and 10). This is true for both the old and new AERO-MS. But also, it can be observed that the effects for the old AERO-MS are about twice as big as the effects for the new AERO-MS. The reason is that the number of old aircraft eligible for scrapping is substantially lower for the new AERO-MS.

12.4.8 Considering the fuel improvement measure we see a shift between old and current aircraft-km that works the other way around. The explanation is that new aircraft, because of the imposed fuel improvement stringency, become quite a bit more expensive relative to the older aircraft. This is driven by the present assumption that each 1% additional fuel improvement would lead to an additional increase in the aircraft new price of 2%. The effect on the shift from current to old is substantial and even larger in the new versus the old AERO-MS as the % price increase applies to higher absolute price levels. It is noted that this shift from current to old counteracts the intended effects of the measure, which is aimed at speeding up the introduction of more fuel efficient aircraft. A shift from current to old technology aircraft estimated by the AERO-MS is relative to the situation without the policy measure. In practice, this would manifest itself as a slower take-up over time of newer technology aircraft designs in the situation with the policy measure in place.

12.4.9 The reduction of detour measure (RD50% RC+100%) does not distinguish between aircraft of different technology level. Consequently, we do not see any significant difference between the changes in old and current aircraft-km. This is true for both the old and new AERO-MS.

12.4.10 The tax credit measure provides a strong incentive to accelerate the replacement of older aircraft with the latest available technology, inducing a strong shift of old to current aircraft-km. The effects are quite comparable for the old and new AERO-MS.

Effects on airlines

12.4.11 The scrapping measures lead to an increase in both the direct and total operating costs (see effects 12 and 13). In line with earlier observations these are substantially less for PScrap25 versus CScrap25 and for the new versus the old AERO-MS. Operating revenues are increased following from the price increases required to maintain airline profitability (see effect 14). Total operating result is roughly maintained (see effect 15) but still somewhat reduced (and a little bit more in the case of the old AERO-MS).

12.4.12 Considering the fuel technology improvement measure, in the old AERO-MS direct operating costs go down, but total operating costs go up (see effects 12 and 13). Direct operating cost do not include the increase in capital costs and finance charges because of the purchase of more expensive aircraft, but do contain the reduced costs of fuel use. Apparently this cost reduction outweighs the cost increases in the other direct cost components. In the new AERO-MS, both direct and total operating costs go down. In this case, the very much larger reduction in fuel costs is able to outweigh the increase in capital costs and finance charges, at least for a part of the total air transport activity (a part of the flight stages). For certain parts of the air transport activity this is not the case, since we also observe a demand reduction which can only occur if there are flight stages where total operating costs increase. This shows that for the new AERO-MS, the measure is close to the breakeven point, where for some parts of the air transport activity the total operating costs increase and for other parts they decrease. The increase in total operating revenues (see effect 14) only occurs for the flight stages where total operating costs increase (to maintain airline profitability). For the other flight stages, the net cost decrease is incurred by the airlines and not passed on to the airline clients. This also becomes manifest in the slight improvement of the total operating result (see effect 15).

12.4.13 In the case of the reduction of the detour factor, for the old AERO-MS, the direct operating costs (including the route charges) increase (effect 12). Total operating costs are at a breakeven point (effect 13), but still for a significant part of the flight activity the total costs are higher, which explains the demand effect (effect 8). Where this occurs, fares will be raised leading to an increase in total operating revenues. Where costs decrease, this leads to an improvement of the total operating result. An almost similar pattern is observed for the new AERO-MS. But in this case the increase in direct operating costs is much smaller (effect 12), while the total operating costs are slightly reduced (effect 13). Therefore only a small part of flight activity requires a fare increase, leading to only a small increase in total operating revenue (effect 14) and a small improvement of total operating result (effect 15).

12.4.14 The tax credit measure leads to a reduction in both direct operating costs and total operating costs as fuel costs, capital costs and finance charges are reduced (see effects 12 and 13). The financial support provided to the airlines is not passed on to the airline clients, thus leading to an improvement of total operating result (effect 15). The behaviour of the old and new AERO-MS is very comparable, but effects in the new AERO-MS are smaller because of the higher absolute cost levels to which the changes apply.

Impacts on other actors

12.4.15 The changes in consumer surplus are more or less proportional to the demand effects and the underlying cost increases (see effect 16). In the new AERO-MS these effects are somewhat stronger, in the sense that the same relative demand effect leads to a larger effect on consumer surplus (because of higher absolute cost levels).

12.4.16 In the case of a reduction of the detour factor the costs of implementing the measure are approximated by a doubling of the route charges. The additional route charges appear as revenue from charges to the government (see effect 17). From these amounts it can be observed that route charges in the new AERO-MS are in fact lower than in the old AERO-MS. Also it can be observed that the revenues from these charges outweigh the reduction in consumer surplus. The reduction in detour factor has a favourable effect on various cost components that in fact ‘pay’ for a substantial part of the revenues from charges that are generated. Therefore the cost increases charged to the airline clients only have to cover a part of the revenues generated. In the new AERO this part is substantially less than in the old AERO-MS.

12.4.17 In the case of a tax credit, the airlines would benefit by improving their operating result. The present assumption is that the tax credit would be provided by the government. The annual costs of the tax credit measure to the government is shown as a negative ‘revenue’ from taxation (see effect 17). The annual costs follow from the amortization of the annual tax credit expenditure (based on average aircraft life time) and summed across the period to which the tax credit measure applies. In the new AERO-MS these costs are quite a bit higher, because of the higher new aircraft prices and shorter average life times for which the amortised costs of the tax credit are computed.

Fuel impacts

12.4.18 For the scrapping measures CScrap25 and PScrap25 the total effects on fuel use for the new AERO-MS are reduced drastically, compared to the old AERO-MS (to less than a third - see effect 18). This follows from the strong reduction of both the effects on demand and the technology improvement effect (effects 8 and 19). The most important reason is found in the reduction of the number of old aircraft eligible for scrapping, reducing both the cost impacts (and thereby the demand effect) and the technology effect. Cost and demand effects are further reduced because of the increase in fuel savings following from the much higher fuel prices in the new AERO-MS. Technology effects are further reduced because of the less pronounced differences in fuel use between old and current.

12.4.19 It is noted that the reduction of the numbers of old aircraft eligible for scrapping basically follows from the matching of the fleet build-up as supplied by the PRISME fleet. As reported in Sections 7.12 and 7.13 of Chapter 7, in view of the presently available ATEC variables, there are certain limitations in this matching process. Consequently, this was identified as an area of future modelling improvement.

12.4.20 For the fuel technology improvement measure, the contribution of the demand effect to the reduction in fuel use in the old AERO-MS is larger than in the new AERO-MS (effect 8). As it turns out, in the new AERO-MS there is even a net saving in total operating costs (the difference between the cost increases of purchasing the more expensive new aircraft and the cost reduction because of the fuel savings - see effect 13). This causes the demand effect to only apply to a part of the flight operation (where the net cost increase is positive). The technology effects on fuel/RTK (effect 19) are quite comparable. As a result, the total effect on fuel use is somewhat less in the new AERO-MS and the contribution of the technology effect is somewhat higher (effects 20 and 21).

12.4.21 Also for the detour reduction measure, the reduction in fuel use is quite a bit higher in the old AERO-MS. This holds for both the demand effect and the technology effect. The demand effect in the new AERO-MS is less because of the very much reduced effect on total operating costs (where the various cost savings just outweigh the assumed costs of the measure - see effect 13). The much higher savings in fuel costs; the higher fuel prices are largely responsible for this. The technology effect in this case reflects the savings achieved in the distances flown. In the new AERO-MS, the original detour factors specified as part of the scenario are smaller than the detour factors applied in the old AERO-MS. This explains why the effects of the same relative reduction in detour factors come out smaller.

12.4.22 In the case of the tax credit measure the effect on fuel use only follows from technology improvement (effect 18). The results for the old and new AERO-MS are more or less comparable, although the effect is somewhat less in the new AERO-MS. These differences relate to various smaller effects caused by the restructuring of the transportation and aircraft data.

12.5 Main conclusions

12.5.1 The overall conclusion is that the general patterns of policy responses across the various types of policies considered are comparable between the old and new version of the AERO-MS. There are important differences between the results, but these can be fully explained by the changes in input data and other aspects of the AERO-MS update. The results of the policy tests thus provide strong reassurance that the SAVE project has been successful not only in achieving the intended updating but also in not introducing unintended consequences.

12.5.2 The causes of the main differences in results of the new AERO-MS compared to the old can be summarised as follows:

- Demand effects of the same financial measures (expressed in absolute terms) may be quite a bit smaller because of the smaller relative cost effects (given the increase in absolute cost levels).
- Technology effects in terms of reducing the use of the older part of the fleet have become smaller because of the less pronounced differences in fuel use technology between old and current.
- Technology effects of scrapping have become quite a bit smaller because of a smaller number of older aircraft eligible for scrapping in the present fleet build-up.
- The financial effects of the savings in fuel use have considerably increased because of the assumed much higher future fuel prices in the new versus the old AERO version. The most relevant effects on the policy measures are:
  - Demand effects of fuel burn technology improvement measures (such as fuel stringencies and ATM improvements) go down because of the reduction in net measure costs.
  - Benefit/cost ratios are favourably affected and technology improvement measures are brought closer to the point where they may be cost-effective.
- Due to the update and restructuring of the data on transport flows and flight operation the new AERO-MS seems to show a somewhat more robust behaviour in maintaining airline profitability and transportation efficiency.

12.5.3 The consequences of the above observations for the interpretation of the various measures may be different. Broadly speaking, these can be headlined as follows:

- Conclusions on the financial measures remain largely unchanged: fuel taxation and route charges remain to be most efficient, followed by the airport charge; ticket taxation and especially value added taxation seem least attractive.
- The prospect of measures such as scrapping and tax credits seems to have become relatively less favourable because technology differences between the older and more current parts of the fleet, and thereby potential fuel savings, have become less.
- The prospect of measures such as accelerated fuel technology and ATM improvement seems to have become relatively more favourable because of the increase in the cost reductions of potential fuel savings.

Table 12.1 Effects of economic and financial policies in old and new version of AERO-MS

Effect	Unit	Scenario Year		FT50		RCFT50		ACFT50		TTFT50		VTFT50	
		M-2020	CAEP8 M 2026										
		A-old	A-new	A-old	A-new	A-old	A-new	A-old	A-new	A-old	A-new	A-old	A-new
Air transport demand													
Pax sched. Network Carriers													
1 First/business	billion pax-km	273	976	-3.6%	-2.1%	-3.6%	-2.1%	-3.1%	-1.4%	-3.6%	-2.3%	-4.5%	-3.0%
2 Economy (+ discount)	billion pax-km	1053	9419	-6.6%	-7.0%	-6.6%	-7.0%	-5.5%	-6.1%	-7.4%	-7.6%	-9.0%	-9.5%
3 Discount	billion pax-km	7161		-12.1%		-12.2%		-10.0%		-12.2%		-14.7%	
4 Total pax sched. NC	billion pax-km	8487	10395	-11.1%	-6.6%	-11.2%	-6.6%	-9.2%	-5.7%	-11.3%	-7.1%	-13.7%	-8.9%
5 Pax non-sched. (and LCC)	billion pax-km	1154	1676	-19.7%	-21.7%	-20.4%	-22.1%	-13.1%	-18.0%	-22.4%	-16.6%	-22.7%	-16.6%
6 Total pax demand	billion pax-km	9641	12072	-12.2%	-8.7%	-12.3%	-8.7%	-9.7%	-7.4%	-12.7%	-8.4%	-14.7%	-10.0%
7 Cargo demand	billion tonne-km	451	509	-13.3%	-9.3%	-13.3%	-9.3%	-12.2%	-8.1%	-11.2%	-7.9%	-16.0%	-11.6%
8 Revenu Tonne-Km (RTK)	billion RTK	1415	1595	-12.5%	-8.9%	-12.7%	-8.9%	-10.5%	-7.6%	-12.2%	-8.3%	-15.1%	-10.5%
Aircraft km													
9 Techn.age > 12 (16) years	billion ac-km	42.0	44.5	-22.5%	-18.1%	-23.5%	-18.9%	-13.4%	-12.9%	-10.9%	-8.4%	-13.0%	-9.8%
10 Techn.age <= 12 (16) years	billion ac-km	40.4	48.1	-2.5%	-3.1%	-2.9%	-3.1%	-3.8%	-2.9%	-11.0%	-8.5%	-13.0%	-9.9%
11 Total aircraft km	billion ac-km	82.4	92.6	-12.7%	-10.3%	-13.4%	-10.7%	-8.7%	-7.7%	-10.9%	-8.4%	-13.0%	-9.9%
Effects on airlines													
12 Direct operating costs	billion US$	436.8	697.3	20.6%	16.0%	20.8%	16.0%	21.6%	15.7%	25.7%	18.7%	-13.9%	-10.0%
13 Total operating costs	billion US$	911.0	1403.3	4.7%	4.6%	4.8%	4.6%	4.9%	4.8%	6.1%	5.4%	-14.2%	-9.9%
14 Total operating revenues	billion US$	938.7	1452.8	3.8%	4.1%	4.0%	4.2%	3.3%	3.8%	3.8%	4.5%	-14.6%	-9.3%
15 Total operating result	% of revenues	2.9%	3.4%	2.1%	2.9%	2.1%	3.0%	1.4%	2.5%	0.8%	2.7%	2.6%	4.1%
Impacts on other actors													
16 Change in consumer surplus	billion US$			-148.5	-175.7	-149.3	-176.0	-140.5	-171.7	-160.1	-182.8	-197.6	-232.0
17 Revenue from taxation/charges	billion US$			147.6	177.8	147.3	176.5	142.8	168.5	171.2	225.1	166.9	220.7
Fuel impacts													
18 Total fuel use	billion kg	368.0	397.4	**-14.8%**	**-10.5%**	**-14.8%**	**-10.6%**	**-10.6%**	**-9.5%**	**-11.2%**	**-8.4%**	**-13.6%**	**-10.3%**
19 Fuel / RTK	kg/tonne-km	0.26	0.25	-2.6%	-1.8%	-2.5%	-1.8%	-0.2%	-2.0%	1.2%	-0.1%	1.8%	0.3%
20 Contr. of demand reduction	%			83%	83%	84%	83%	98%	79%	110%	99%	113%	103%
21 Contr.of techn&eff improvement	%			17%	17%	16%	17%	2%	21%	-10%	1%	-13%	-3%

Table 12.2 Effects of regulation and operation policies in old and new version of AERO-MS

Effect	Unit	Scenario Year M-2020	CAEP8 M 2026	CScrap25		PScrap25		FTI1% 01-20 AP2%	FTI-1% 07-26 AP2%	RD50% RC+100%		TC50% MY2010 VD2	TC50% MY2016 VD2
		A-old	A-new	A-old	A-new	A-old	A-new	A-old	A-new	A-old	A-new	A-old	A-new
Air transport demand													
Pax sched. Network Carriers													
1 First/business	billion pax-km	273	976	-1.1%	-0.2%	-0.5%	-0.1%	-0.7%	-0.3%	-0.3%	-0.1%	0.0%	0.0%
2 Economy (+ discount)	billion pax-km	1053	9419	-1.8%	-0.7%	-0.9%	-0.3%	-1.4%	-1.1%	-1.4%	-0.4%	0.0%	0.0%
3 Discount	billion pax-km	7161		-3.3%		-1.6%		-2.5%		-1.6%		0.0%	
4 Total pax sched. NC	billion pax-km	8487	10395	-3.0%	-0.7%	-1.5%	-0.3%	-2.3%	-1.1%	-1.6%	-0.4%	0.0%	0.0%
5 Pax non-sched. (and LCC)	billion pax-km	1154	1676	-5.0%	-3.2%	-2.3%	-1.3%	-3.2%	-2.4%	-9.4%	-1.2%	0.0%	0.0%
6 Total pax demand	billion pax-km	9641	12072	-3.3%	-1.0%	-1.6%	-0.4%	-2.4%	-1.2%	-2.5%	-0.5%	0.0%	0.0%
7 Cargo demand	billion tonne-km	451	509	-3.9%	-1.7%	-2.1%	-1.0%	-2.9%	-2.1%	-1.9%	-0.5%	0.0%	0.0%
8 Revenu Tonne-Km (RTK)	billion RTK	1415	1595	-3.5%	-1.3%	-1.8%	-0.6%	-2.6%	-1.5%	-2.3%	-0.5%	0.0%	0.0%
Aircraft km													
9 Techn.age > 12 (16) years	billion ac-km	42.0	44.5	-31.5%	-17.3%	-14.6%	-7.4%	17.5%	26.0%	-8.3%	-4.2%	-18.7%	-20.4%
10 Techn.age <= 12 (16) years	billion ac-km	40.4	48.1	23.4%	12.3%	10.6%	4.9%	-22.4%	-28.0%	-7.0%	-3.3%	18.6%	19.9%
11 Total aircraft km	billion ac-km	82.4	92.6	-4.6%	-1.9%	-2.3%	-1.0%	-2.0%	-2.1%	-7.7%	-3.8%	-0.4%	0.5%
Effects on airlines													
12 Direct operating costs	billion US$	436.8	697.3	2.2%	0.8%	0.9%	0.2%	-1.2%	-2.2%	4.3%	0.6%	-1.3%	-0.7%
13 Total operating costs	billion US$	911.0	1403.3	1.9%	0.9%	0.9%	0.4%	0.7%	-0.6%	0.0%	-0.3%	-3.3%	-1.4%
14 Total operating revenues	billion US$	938.7	1452.8	1.0%	0.4%	0.5%	0.1%	0.7%	0.6%	0.5%	0.2%	0.0%	0.0%
15 Total operating result	% of revenues	2.9%	3.4%	2.0%	2.9%	2.6%	3.2%	3.0%	4.6%	3.4%	3.9%	6.1%	4.8%
Impacts on other actors													
16 Change in consumer surplus	billion US$			-45.5	-24.2	-22.0	-10.2	-28.9	-28.5	-29.0	-7.9	0.0	0.0
17 Revenue from taxation/charges	billion US$			0.0	0.0	0.0	0.0	0.0	0.0	48.7	30.0	-20.9	-40.5
Fuel impacts													
18 Total fuel use	billion kg	368.0	397.4	**-8.6%**	**-2.7%**	**-5.0%**	**-1.3%**	**-6.2%**	**-5.5%**	**-7.4%**	**-4.5%**	**-2.5%**	**-1.8%**
19 Fuel / RTK	kg/tonne-km	0.26	0.25	-5.3%	-1.5%	-3.3%	-0.7%	-3.7%	-3.8%	-5.2%	-4.1%	-2.5%	-1.8%
20 Contr. of demand reduction	%			39%	46%	34%	44%	41%	29%	31%	11%	0%	0%
21 Contr.of techn&eff improvement	%			61%	54%	66%	56%	59%	71%	69%	89%	100%	100%

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12.6 Additional testing of selective policies

12.6.1 The additional testing of selective policies is involved with:

- Investigation of selective policy responses.
- Policy testing for different scenarios.
- Regional effects of data update.

Investigation of selective policy responses

12.6.2 In this section, a number of selective policy responses are further explored. The investigations include:

- Functioning and control of main policy responses.
- Variations of the fuel technology improvement measure.

12.6.3 The main policy responses considered are the demand and technology responses. The first is driven by the assumption that net cost increases resulting from measures adopted by or imposed on airlines will in principle be passed on to the airline clients, leading to an increase in passenger fares and freight rates. Taking into account the price elasticities of demand, this will then lead to a reduction in transportation demand and related volumes transported (relative to the scenario without measures). The technology response basically follows from a change in fleet and flight operation brought about by the differential cost effects of measures, leading to a shift in preferences for aircraft types and technology levels. The estimation of such responses is facilitated by the aircraft choice model.

12.6.4 For both above policy responses, control options are provided within the AERO-MS allowing for the analysis of different types of airline behaviour that may occur depending on the analysis conditions and policy specification. The demand response can be controlled by a global variable specifying the extent to which cost increases incurred by airlines are passed on to the airline clients. In the default situation the variable has a value of 1, meaning that all additional costs are passed on to the airline clients, while all cost reductions will be subsumed by the airlines. If this variable is given a value of 0, all cost increases will be absorbed by the airlines, while cost reductions will be passed on to the airline clients. Between these extremes, the policy variable can take all possible values from 0 to 1, operating as a factor (the so-called 'profit adjustment factor') that can seamlessly mimic all intermediate positions.

12.6.5 A similar type of variable (factor) is available for controlling the operation of the aircraft choice model. If given a value of 1, the aircraft choice model will be in its full (default) operation mode. If given a value close to zero, the function of the aircraft choice model will be eliminated (whereby it is noted that, in view of the algorithms involved, a value of 0 is not allowed; instead, a very small, positive number can be specified, e.g. 0.001). Again there is the possibility for seamless control by specifying any fraction between 0 and 1. If the function of the aircraft choice model is switched off, the choice of aircraft would remain unchanged from the situation without the policy in place.

12.6.6 Table 12.3 provides a demonstration of the functioning of these policy response control variables. Based on a fuel taxation of US$ 0.50 (FT50), with default settings of the profitability adjustment and aircraft choice factors of 1, the following cases are considered:

- FT50 NoDR: no demand response (profit adjustment factor set to 0).
- FT50 50%DR: 50% demand response (profit adjustment factor set to 0.5).
- FT50 NoAC: no aircraft choice function (aircraft choice factor set to 0.001).
- FT50 50%AC: 50% aircraft choice function (aircraft choice factor set to 0.5).

12.6.7 The effects of the policies are computed for the scenario CAEP8-M 2026. Effects shown are equal to the effects considered in Table 12.1 and Table 12.2. When demand effects are eliminated (FT50 NoDR), we only see a net shift in the use of old and current aircraft, decreasing the old aircraft-km and increasing the current aircraft-km (effects 9 and 10). Note that the balance of these effects is not necessarily zero (effect 11) because of changes in the types and sizes of aircraft used. Direct and total operating costs significantly increase (effects 12 and 13) while revenues do not change (effect 14) leading to a dramatic total operating result (effect 15). There is no change in consumer surplus as the airline clients do not experience any cost increase (effect 16). Revenues of taxation increase, as no reduction in volumes transported occur (effect 17). The reduction in fuel use only follows from the technology effect (compare effects 18 and 19). If the demand effects are reduced by 50% (FT50 50%DR) all effects end up right in between the effects for FT50 and FT NoDR, as can be verified from Table 12.3.

Table 12.3 Illustration of variations in policy responses

Effect	Unit	CAEP8 M 2026	FT50	FT50 NoDR	FT50 50%DR	FT50 NoAC	FT50 50%AC
Air transport demand							
Pax sched. Network Carriers							
1 First/business	billion pax-km	976	-2.1%	0.0%	-1.1%	-2.1%	-2.1%
2 Economy (+ discount)	billion pax-km	9419	-7.0%	0.0%	-3.7%	-7.1%	-7.0%
3 Discount	billion pax-km						
4 Total pax sched. NC	billion pax-km	10395	-6.6%	0.0%	-3.4%	-6.6%	-6.6%
5 Pax non-sched. (and LCC)	billion pax-km	1676	-21.7%	0.0%	-12.2%	-21.8%	-21.8%
6 Total pax demand	billion pax-km	12072	-8.7%	0.0%	-4.7%	-8.7%	-8.7%
7 Cargo demand	billion tonne-km	509	-9.3%	0.0%	-5.0%	-9.4%	-9.4%
8 Revenu Tonne-Km (RTK)	billion RTK	1595	-8.9%	0.0%	-4.8%	-8.9%	-8.9%
Aircraft km							
9 Techn.age > 12 (16) years	billion ac-km	44.5	-18.1%	-9.7%	-14.3%	-9.2%	-13.9%
10 Techn.age <= 12 (16) years	billion ac-km	48.1	-3.1%	6.9%	1.5%	-9.4%	-6.4%
11 Total aircraft km	billion ac-km	92.6	-10.3%	-1.1%	-6.1%	-9.3%	-10.0%
Effects on airlines							
12 Direct operating costs	billion US$	697.3	16.0%	27.3%	21.2%	17.0%	16.4%
13 Total operating costs	billion US$	1403.3	4.6%	14.0%	9.0%	4.7%	4.6%
14 Total operating revenues	billion US$	1452.8	4.1%	0.0%	2.1%	4.2%	4.2%
15 Total operating result	% of revenues	3.4%	2.9%	-10.1%	-3.1%	2.9%	3.0%
Impacts on other actors							
16 Change in consumer surplus	billion US$		-175.7	0.0	-89.7	-176.9	-176.4
17 Revenue from taxation/charges	billion US$		177.8	195.4	185.8	180.1	178.9
Fuel impacts							
18 Total fuel use	billion kg	397.4	**-10.5%**	**-1.6%**	**-6.4%**	**-9.2%**	**-9.9%**
19 Fuel / RTK	kg/tonne-km	0.25	-1.8%	-1.6%	-1.7%	-0.2%	-1.1%
20 Contr. of demand reduction	%		83%	0%	73%	97%	89%
21 Contr.of techn&eff improvement	%		17%	100%	27%	3%	11%

12.6.8 Eliminating the aircraft choice mechanism (FT50 NoAC) will leave the demand response intact. From the effects 9 through 11 it can be verified that aircraft-km for the old and current parts of the fleet are reduced equally. Compared to FT50, there are only small changes to the effects on airlines (effects 12 through 15). We see direct operating and total operating costs and revenues slightly increase as the (small) cost effects of technology improvement are no longer achieved. The impacts on other actors (effect 16 and 17) remain almost the same. The technology effect on the reduction in fuel use is essentially eliminated (effects 18 through 21) except for some minor change in efficiency improvement. If 50% of the aircraft choice mechanism is maintained (FT50 50%AC) all effects are in between the effects for FT50 and FT NoAC.

12.6.9 From the above results it becomes unambiguously clear why airlines will seek to pass on the cost increases following from measures to their clients. Yet, in certain situations strong competition may not allow airlines to fully pass on the cost increases, and this can be represented by the facility (demonstrated above) to moderate the extent of cost pass-through.

12.6.10 The possibility to adjust aircraft choice behaviour provides a useful facility for the simulation of certain specific measures, as the following example will show.

12.6.11 Table 12.4 shows the effects of a number of variations in the fuel technology improvement measure. The measure considered in the global policy testing (FTI-1% 07-26 AP2%) assumes a forced additional fuel use reduction (stringency) for newly certified aircraft, improving fuel use by 1% per year during a period of 20 years prior to the Scenario Year (from 2007 to 2026). It is noted that this fuel use improvement is associated with the *certification* and not the *purchase* of new aircraft. If a new aircraft is purchased, the certification year (technology age) may be from 1 to 8 years older than the purchase year. This causes the introduction of improved technology into the actual fleet to be delayed by about 4 years on average. The costs of the additional improvements are expressed as a percentage increase in the price of new aircraft for each 1% of additional improvement in fuel efficiency. The assumption on the price increase represents a major uncertainty. For this reason, a certain range of new aircraft price increases was considered in the testing example (from 1% to 3% price increase per 1% of fuel improvement). Another important assumption relates to the aircraft choice behaviour that would follow from the introduction of the more fuel efficient, but also more expensive new aircraft. In the global policy testing it was observed that, according to the regular aircraft choice behaviour, airlines would move away from purchasing the more expensive new aircraft. This would lead to a shift from the use of current (more expensive) to older (less expensive) aircraft, which would counteract the intended effects of the fuel technology improvement. Depending on how the policy would be defined and implemented, the regular aircraft choice mechanism may or may not apply.

12.6.12 In order to further explore these mechanisms, Table 12.4 considers the following variations:

1. FTI-1% 07-26 AP1%: an additional fuel improvement of newly certified aircraft of 1% per year during the period 2007-2026 with a 1% increase in aircraft new price for each 1% of fuel improvement.
2. FTI-1% 07-26 AP1% NoAC: as measure 1 with the aircraft choice mechanism eliminated.
3. FTI-1% 07-26 AP2%.
4. FTI-1% 07-26 AP2% NoAC.
5. FTI-1% 07-26 AP3%.
6. FTI-1% 07-26 AP3% NoAC.

12.6.13 Measure 3, 4 and 5, 6 are identical to measures 1, 2 with a price increase of new aircraft of 2% and 3%, respectively.

Table 12.4 Illustration of variations of fuel technology improvement measure

Effect	Unit	CAEP8 M 2026	FTI-1% 07-26 AP1%	FTI-1% 07-26 AP1% NoAC	FTI-1% 07-26 AP2%	FTI-1% 07-26 AP2% NoAC	FTI-1% 07-26 AP3%	FTI-1% 07-26 AP3% NoAC
Air transport demand								
Pax sched. Network Carriers								
1 First/business	billion pax-km	976	0.0%	0.0%	-0.3%	-0.4%	-0.6%	-1.1%
2 Economy (+ discount)	billion pax-km	9419	0.0%	0.0%	-1.1%	-1.5%	-2.2%	-3.9%
3 Discount	billion pax-km							
4 Total pax sched. NC	billion pax-km	10395	0.0%	0.0%	-1.1%	-1.4%	-2.1%	-3.6%
5 Pax non-sched. (and LCC)	billion pax-km	1676	0.0%	0.0%	-2.4%	-3.1%	-5.0%	-8.6%
6 Total pax demand	billion pax-km	12072	0.0%	0.0%	-1.2%	-1.6%	-2.5%	-4.3%
7 Cargo demand	billion tonne-km	509	-0.2%	-0.2%	-2.1%	-2.9%	-3.7%	-6.6%
8 Revenu Tonne-Km (RTK)	billion RTK	1595	-0.1%	-0.1%	-1.5%	-2.1%	-2.9%	-5.0%
Aircraft km								
9 Techn.age > 12 (16) years	billion ac-km	44.5	-4.8%	-0.2%	26.0%	-2.2%	46.4%	-5.1%
10 Techn.age <= 12 (16) years	billion ac-km	48.1	4.0%	-0.2%	-28.0%	-2.5%	-48.7%	-5.8%
11 Total aircraft km	billion ac-km	92.6	-0.2%	-0.2%	-2.1%	-2.4%	-3.0%	-5.5%
Effects on airlines								
12 Direct operating costs	billion US$	697.3	-4.1%	-3.8%	-2.2%	-5.8%	0.5%	-8.5%
13 Total operating costs	billion US$	1403.3	-0.8%	-0.7%	-0.6%	0.7%	-0.5%	2.2%
14 Total operating revenues	billion US$	1452.8	0.0%	0.0%	0.6%	0.8%	1.2%	2.2%
15 Total operating result	% of revenues	3.4%	4.2%	4.1%	4.6%	3.5%	5.1%	3.4%
Impacts on other actors								
16 Change in consumer surplus	billion US$		-1.3	-1.4	-28.5	-37.8	-55.5	-97.9
17 Revenue from taxation/charges	billion US$		0.0	0.0	0.0	0.0	0.0	0.0
Fuel impacts								
18 Total fuel use	billion kg	397.4	**-7.7%**	**-7.3%**	**-5.5%**	**-9.3%**	**-4.3%**	**-12.2%**
19 Fuel / RTK	kg/tonne-km	0.25	-7.7%	-7.2%	-4.1%	-7.4%	-1.4%	-7.5%
20 Contr. of demand reduction	%		1%	1%	27%	22%	67%	40%
21 Contr.of techn&eff improvement	%		99%	99%	73%	78%	33%	60%

12.6.14 The demand effect of the first measure (FTI-1% 07-26 AP1%) is negligible (effect 8). The reason is that for essentially the whole flight operation there is a net reduction of total operating costs (effect 10), as the savings on fuel cost outweighs the increase in capital cost and finance charges following from the increase in the price of new aircraft. This also leads to a positive effect on total operating result (effect 15). We see a limited shift towards the use of current aircraft following from the favourable effect on net operating costs for these aircraft. Fuel use is reduced by 7.7% (effect 18) which is almost entirely caused by the improvement in fuel efficiency (effects 20 and 21).

12.6.15 Measure 2 is the same as measure 1 with the aircraft choice mechanism eliminated, which can be verified by considering the effects 9 and 10. The demand effects are the same (effect 8). The effect on operating costs and total operating results (effects 12, 13 and 15) are a little bit reduced. The fuel reduction (effect 18) is somewhat reduced (7.3%) and still almost entirely due to fuel efficiency improvement. In this case we see that the elimination of the aircraft choice behaviour reduces the use of current (more fuel efficient) aircraft thereby leading to a small reduction in fuel savings and operating result for the airlines.

12.6.16 For measures 3 and 4 (FTI-1% 07-26 AP2% with and without aircraft choice) the cost of the measure will be doubled. In this case, for a considerable part of the flight operation there would be a net increase in total operating costs. With the aircraft choice mechanism in operation (measure 3), this leads to a shift from the use of the more expensive current to older aircraft (effects 9 and 10). We now see a more significant effect on demand (effect 8) that follows from the parts of the flight operation where increases in total operating costs cannot be avoided. At the same time, benefits are incurred of decreases in total operating costs for other parts of the flight operation leading to a positive effect on total operating result (effect 15). As a result of this behaviour, the effects on fuel use are significantly reduced (effect 18). The reduction follows from a strong decrease in the fuel efficiency effect (effect 19) which is somewhat compensated by the introduction of the demand effect. If the aircraft choice mechanism is eliminated (measure 4) the 'undesired' shift from the use of current to older aircraft is prevented. We see the demand effect (effect 8) and total operating cost (effect 13) increase, while profitability (operating result) is maintained (effect 15). Fuel use is now reduced to 9.3% (effect 19) which follows from the 'restored' fuel efficiency effect (effect 20) in combination with the increased demand effect.

12.6.17 Considering the measures 5 and 6 (FTI-1% 07-26 AP3% with and without aircraft choice) we see the above pattern of behaviour reinforced due to the further increase in the measure costs. With the aircraft choice mechanism in place (measure 5), the evasion of the measure by avoiding and postponing the use of the more expensive new aircraft becomes much stronger, eliminating most of the fuel efficiency improvement effect (effect 19). Without the aircraft choice mechanism (measure 6), the maximum fuel technology improvement effect is retained (effect 19) while total fuel use reduction is reinforced by a stronger demand effect (effects 18 and 8). Along with the increase in the demand effects we see an increasing (negative) change in consumer surplus (effect 16) showing that airline clients are picking up the bill of the net costs of the technology improvement.

12.6.18 From these examples it becomes clear that the combination of fuel use stringency measures in combination with 'default' aircraft choice behaviour would obstruct the intended effects of the measure. In practice this could presumably be avoided, e.g. by voluntary agreement of airlines to maintain their regular fleet replacement behaviour or by additional regulation on the use of new technology aircraft. Therefore, in investigating the potential of technology improvement measures it may be quite reasonable to assume that the regular aircraft choice behaviour would not apply.

12.7 Policy testing for different scenarios

12.7.1 A small selection of polices were tested under different scenarios, as follows:

- Comparison of policy effects in time (for scenarios CAEP8-M 2016, M 2026 and M 2036).
- Comparison of policy effects for scenarios CAEP8-M 2026 and M 2026 OTI: effects of optimistic technology improvements in addition to the policy induced technology improvements.

12.7.2 The policies considered are:

- FT50: global fuel taxation of US$ 0.50 per kg of fuel.
- CScrap25: all aircraft with certification year older than 25 years to be scrapped.
- FTI-1% 07-26 AP2% NoAC: additional fuel technology improvement of 1% per year during the period 2007-2026 with a price increase of new aircraft of 2% for each 1% of additional fuel improvement and the aircraft choice mechanism eliminated.
- FTI-1% 07-26 AP2%: as the above option but with default aircraft choice mechanism activated.

12.7.3 The effects of the first three of these policies across the different scenario years are shown in Table 12.5. The comparison of effects for all four above policies for the scenarios M 2026 and M 2026 OTI are shown in Table 12.6.

12.7.4 For the policies FT50 and CScrap25, in table 12.5 we observe a gradual decrease in the demand effect over time (effect 8). This is due to the relative reduction of the cost effects of the measures, as total absolute operating cost levels increase in time. For the measure FTI-1% 07-26 AP2% NoAC we see a totally different pattern. In this case, the cost and demand effects of the measure are directly related to the extent of introduction of the technology measure, progressing in time. In scenario year 2016 the introduction of improved technology, entering the fleet from 2007 onwards, only shows a very limited effect, which can also be verified from the effects on total operating costs and demand (effects 13 and 8). These effects strongly increase in time as a larger part of the fleet is replaced by the more expensive aircraft with improved fuel technology.

12.7.5 Considering the technology effects (fuel/RTK) of the various policies (effect 19), for the measure FT50 we observe a slight reduction in time as the technology differences between the old and current parts of the fleet become smaller, approaching an equilibrium. The technology effect of the measure CScrap25 (removing the older part of the fleet) is almost stable. The effect of the fuel efficiency improvement measure very strongly increases in time with the introduction of more and further improved aircraft in the fleet.

12.7.6 Consequently, the overall effects on fuel use (effect 19) of the measure FT50 decrease in time, both from a reduction in the demand and the technology effect; the fuel effect of the measure CScrap25 decreases in time mainly because of a reduction in the demand effect following from the reduction in the relative cost increase associated with the measure; and the effects of the fuel efficiency improvement measure FTI-1% 07-26 AP2% NoAC very strongly increase in time because of an increase in both the demand and technology effects, along with the introduction of new aircraft in the fleet.

12.7.7 Differences between scenarios M 2026 and M 2026 OTI (optimistic technology improvement) include an additional baseline fuel efficiency improvement (from 0.96% to 1.5%); a reduction of the absolute detour percentage (roughly varying between 7% and 9.5%) with 3.6%; and an additional increase in fuel price with 12.5% (see also Chapter 11). Effects of the above policies are compared for these scenarios in Table 12.6. We see that the demand effects of the measures FT50 and CScrap25 are slightly less (effect 8) for the OTI scenario. This is due to the increase in fuel price and the resulting additional savings in fuel cost, as can be verified from the cost effects (effects 12 and 13). The demand effect for the fuel improvement measure goes up. This is caused by the increase in the baseline new aircraft price (where it is assumed that each 1% of fuel improvement will raise new aircraft price with 1%). Given the optimistic fuel improvement of 1.5% per year, baseline aircraft prices are further increased, which also increases the cost of the measure.

12.7.8 Considering the technology effect (effect 19), for the measures FT50 and CScrap25 we see an increase in the OTI scenario. This is mainly due to the additional fuel improvement, enlarging the difference in fuel use between the old and current parts of the fleet. For FT50 there is also an effect of the fuel price increase which contributes to reinforcing the technology shift. The technology effect of the measure FTI-1% 07-26 AP2% NoAC is slightly reduced, but almost stable.

12.7.9 Given the relatively small and counteracting effects on demand and technology, the overall conclusion is that the relevant effects of these measures, in particular on total fuel reduction, are quite robust against the changes considered in the optimistic technology scenario. It is noted however that for the technology improvement measure this conclusion is only true under the 'no aircraft choice' assumption. With the aircraft choice mechanism in place (see measure FTI-1% 07-26 AP2%), the assumptions under the optimistic technology scenario would significantly further reduce the technology effect on fuel use (effect 19), which also leads to a substantial effect on total fuel reduction. This follows from the fact that the cost differences between old and current aircraft become larger under the optimistic scenario, causing a greater shift from the use of current to older aircraft and a subsequent reduction of fuel improvement if the aircraft choice mechanism is in place.

Table 12.5 Comparison of policy effects for scenarios CAEP8-M 2016, M 2026 and M 2036

Effect	Unit	CAEP8 M 2016	FT50	CScrap25	FTI-1% 07-26 AP2% NoAC	CAEP8 M 2026	FT50	CScrap25	FTI-1% 07-26 AP2% NoAC	CAEP8 M 2036	FT50	CScrap25	FTI-1% 07-26 AP2% NoAC
Air transport demand													
Pax sched. Network Carriers													
1 First/business	billion pax-km	603	-2.4%	-0.2%	-0.1%	976	-2.1%	-0.2%	-0.4%	1550	-1.9%	-0.1%	-1.2%
2 Economy (+ discount)	billion pax-km	5822	-8.0%	-1.0%	-0.3%	9419	-7.0%	-0.7%	-1.5%	15053	-6.3%	-0.6%	-4.2%
3 Discount	billion pax-km												
4 Total pax sched. NC	billion pax-km	6425	-7.5%	-0.9%	-0.3%	10395	-6.6%	-0.7%	-1.4%	16603	-5.9%	-0.6%	-3.9%
5 Pax non-sched. (and LCC)	billion pax-km	1170	-23.8%	-4.3%	-0.6%	1676	-21.7%	-3.2%	-3.1%	2449	-19.9%	-2.8%	-9.7%
6 Total pax demand	billion pax-km	7595	-10.0%	-1.5%	-0.3%	12072	-8.7%	-1.0%	-1.6%	19053	-7.7%	-0.9%	-4.7%
7 Cargo demand	billion tonne-km	281	-11.0%	-2.5%	-0.8%	509	-9.3%	-1.7%	-2.9%	903	-8.2%	-1.1%	-6.0%
8 Revenu Tonne-Km (RTK)	billion RTK	964	-10.3%	-1.8%	-0.5%	1595	-8.9%	-1.3%	-2.1%	2618	-7.9%	-0.9%	-5.1%
Aircraft km													
9 Techn.age > 12 (16) years	billion ac-km	30.0	-15.1%	-20.7%	-0.5%	44.5	-18.1%	-17.3%	-2.2%	65.1	-17.8%	-14.8%	-5.6%
10 Techn.age <= 12 (16) years	billion ac-km	32.6	-8.7%	14.3%	-0.7%	48.1	-3.1%	12.3%	-2.5%	77.6	-2.2%	9.7%	-6.3%
11 Total aircraft km	billion ac-km	62.6	-11.8%	-2.5%	-0.6%	92.6	-10.3%	-1.9%	-2.4%	142.7	-9.3%	-1.5%	-6.0%
Effects on airlines													
12 Direct operating costs	billion US$	425.1	17.2%	1.4%	-1.3%	697.3	16.0%	0.8%	-5.8%	1090.2	15.8%	0.7%	-13.1%
13 Total operating costs	billion US$	839.8	4.7%	1.2%	0.0%	1403.3	4.6%	0.9%	0.7%	2338.0	4.2%	0.8%	2.4%
14 Total operating revenues	billion US$	863.9	4.7%	0.5%	0.1%	1452.8	4.1%	0.4%	0.8%	2419.9	3.7%	0.3%	2.5%
15 Total operating result	% of revenues	2.8%	2.8%	2.1%	2.9%	3.4%	2.9%	2.9%	3.5%	3.4%	2.9%	2.9%	3.5%
Impacts on other actors													
16 Change in consumer surplus	billion US$		-119.9	-20.1	-4.4		-175.7	-24.2	-37.8		-262.2	-31.9	-176.6
17 Revenue from taxation/charges	billion US$		120.1	0.0	0.0		177.8	0.0	0.0		265.8	0.0	0.0
Fuel impacts													
18 Total fuel use	billion kg	274.1	**-12.4%**	**-3.4%**	**-2.2%**	397.4	**-10.5%**	**-2.7%**	**-9.3%**	583.7	**-9.4%**	**-2.4%**	**-20.5%**
19 Fuel / RTK	kg/tonne-km	0.28	-2.3%	-1.6%	-1.7%	0.25	-1.8%	-1.5%	-7.4%	0.22	-1.6%	-1.5%	-16.2%
20 Contr. of demand reduction	%		82%	52%	21%		83%	46%	22%		83%	39%	24%
21 Contr.of techn&eff improvement	%		18%	48%	79%		17%	54%	78%		17%	61%	76%

Table 12.6 Comparison of policy effects for scenarios CAEP8-M 2026 and M 2026 OTI (Optimistic Technology Improvement)

Effect	Unit	CAEP8 M 2026	FT50	CScrap25	FTI-1% 07-26 AP2% NoAC	FTI-1% 07-26 AP2%	CAEP8 M 2026 OTI	FT50	CScrap25	FTI-1% 07-26 AP2% NoAC	FTI-1% 07-26 AP2%
Air transport demand											
Pax sched. Network Carriers											
1 First/business	billion pax-km	976	-2.1%	-0.2%	-0.4%	-0.3%	976	-2.0%	-0.2%	-0.6%	-0.4%
2 Economy (+ discount)	billion pax-km	9419	-7.0%	-0.7%	-1.5%	-1.1%	9419	-6.5%	-0.7%	-2.1%	-1.5%
3 Discount	billion pax-km										
4 Total pax sched. NC	billion pax-km	10395	-6.6%	-0.7%	-1.4%	-1.1%	10395	-6.1%	-0.7%	-2.0%	-1.4%
5 Pax non-sched. (and LCC)	billion pax-km	1676	-21.7%	-3.2%	-3.1%	-2.4%	1676	-20.5%	-3.2%	-4.7%	-3.5%
6 Total pax demand	billion pax-km	12072	-8.7%	-1.0%	-1.6%	-1.2%	12072	-8.1%	-1.0%	-2.4%	-1.7%
7 Cargo demand	billion tonne-km	509	-9.3%	-1.7%	-2.9%	-2.1%	509	-8.7%	-1.7%	-3.9%	-2.7%
8 Revenu Tonne-Km (RTK)	billion RTK	1595	-8.9%	-1.3%	-2.1%	-1.5%	1595	-8.3%	-1.2%	-2.9%	-2.0%
Aircraft km											
9 Techn.age > 12 (16) years	billion ac-km	44.5	-18.1%	-17.3%	-2.2%	26.0%	42.9	-21.1%	-17.0%	-3.0%	34.0%
10 Techn.age <= 12 (16) years	billion ac-km	48.1	-3.1%	12.3%	-2.5%	-28.0%	46.3	0.7%	12.1%	-3.4%	-36.4%
11 Total aircraft km	billion ac-km	92.6	-10.3%	-1.9%	-2.4%	-2.1%	89.2	-9.8%	-1.9%	-3.2%	-2.6%
Effects on airlines											
12 Direct operating costs	billion US$	697.3	16.0%	0.8%	-5.8%	-2.2%	705.3	14.2%	0.5%	-6.5%	-0.9%
13 Total operating costs	billion US$	1403.3	4.6%	0.9%	0.7%	-0.6%	1413.5	4.2%	0.8%	1.1%	-0.5%
14 Total operating revenues	billion US$	1452.8	4.1%	0.4%	0.8%	0.6%	1452.8	3.8%	0.4%	1.2%	0.8%
15 Total operating result	% of revenues	3.4%	2.9%	2.9%	3.5%	4.6%	2.7%	2.4%	2.3%	2.8%	4.0%
Impacts on other actors											
16 Change in consumer surplus	billion US$		-175.7	-24.2	-37.8	-28.5		-163.6	-23.9	-53.4	-38.3
17 Revenue from taxation/charges	billion US$		177.8	0.0	0.0	0.0		165.5	0.0	0.0	0.0
Fuel impacts											
18 Total fuel use	billion kg	397.4	**-10.5%**	**-2.7%**	**-9.3%**	**-5.5%**	368.1	**-10.5%**	**-3.2%**	**-9.6%**	**-3.6%**
19 Fuel / RTK	kg/tonne-km	0.25	-1.8%	-1.5%	-7.4%	-4.1%	0.23	-2.4%	-2.0%	-7.0%	-1.6%
20 Contr. of demand reduction	%		83%	46%	22%	27%		78%	39%	29%	56%
21 Contr.of techn&eff improvement	%		17%	54%	78%	73%		22%	61%	71%	44%

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12.8 Regional effects of data update

12.8.1 Following from the data update, air transport quantities, geographical distributions and schematizations have changed significantly. The following provides an insight into some of the main data changes resulting from the update. These include:

- The regional distribution of air transport quantities in the old and new AERO-MS.
- The country ranking based on RTK in the old and new AERO-MS.
- Change in proportions of non-scheduled /LCC passengers of global RTK, revenues and costs.

12.8.2 In this section we investigate the effect that these changes have on the results of a number of policy measures. As a preliminary, however, we present the changes in distributions of activity that has resulted from the revised regional definitions.

12.8.3 Table 12.7 provides an overview of the regional distribution of air transport quantities (in terms of RTK) in the old and new AERO-MS for a number of major region clusters. Given the changes in the definition of geographical regions considered, a direct comparison is only possible at the level of aggregate region clusters for which the definitions have not changed. The region clusters considered are:

- North America
- Europe + Russia[40]
- Asia
- Rest of the world

12.8.4 Table 12.7 distinguishes between two types of regional definitions, i.e. the carrier region and the geographical region. The first definition pertains to the transport activities of all carriers based in the region. The second is involved with the transport activities associated with the geographical region from the point of view of origin or destination (i.e. all transport activities either from or to a certain region).

[40] With further distinction into EU and other whereby for the Old AERO-MS the EU relates to EU15 and for the New AERO-MS to EU27.

Table 12.7 Regional distribution of air transport quantities in old and new AERO-MS

Region clusters	Old AERO-MS Base 1992				New AERO Base 2006			
	Carrier region		Geographical region		Carrier region		Geographical region	
	RTK	%	RTK	%	RTK	%	RTK	%
North America	1.13E+11	40%	1.11E+11	40%	1.86E+11	32%	1.87E+11	32%
Europe + Russia	7.64E+10	27%	6.99E+10	25%	1.70E+11	29%	1.58E+11	27%
- of which EU	*6.22E+10*	22%	*5.88E+10*	21%	*1.49E+11*	26%	*1.39E+11*	24%
- remaining part	*1.43E+10*	5%	*1.11E+10*	4%	*2.12E+10*	4%	*1.99E+10*	3%
Asia	5.24E+10	19%	5.52E+10	20%	1.38E+11	24%	1.37E+11	24%
Rest of the world	3.68E+10	13%	4.21E+10	15%	8.43E+10	15%	9.60E+10	17%
Total	**2.78E+11**	**100%**	**2.78E+11**	**100%**	**5.78E+11**	**100%**	**5.78E+11**	**100%**
	Old AERO-MS Scenario M 2020				**New AERO Scenario M 2026**			
	Carrier region		**Geographical region**		**Carrier region**		**Geographical region**	
	RTK	**%**	**RTK**	**%**	**RTK**	**%**	**RTK**	**%**
North America	4.69E+11	33%	4.48E+11	32%	4.21E+11	26%	4.17E+11	26%
Europe + Russia	3.91E+11	28%	3.58E+11	25%	4.38E+11	27%	4.03E+11	25%
- of which EU	*3.28E+11*	23%	*3.10E+11*	22%	*3.86E+11*	24%	*3.55E+11*	22%
- remaining part	*6.30E+10*	4%	*4.77E+10*	3%	*5.19E+10*	3%	*4.81E+10*	3%
Asia	4.01E+11	28%	4.40E+11	31%	4.69E+11	29%	4.72E+11	30%
Rest of the world	1.55E+11	11%	1.69E+11	12%	2.67E+11	17%	3.03E+11	19%
Total	**1.42E+12**	**100%**	**1.42E+12**	**100%**	**1.60E+12**	**100%**	**1.60E+12**	**100%**

12.8.5 Comparing the distribution of RTK in the Base situation (1992 for AERO-MS old and 2006 for AERO-MS new), for the new AERO-MS we observe a significant reduction in the relative share of North America (from 40% to 32%). The share of Europe + Russia slightly increases. Within Europe + Russia we see a moderate shift towards the share of the EU, resulting from the EU expansion in the last decade. It is noted that the countries that have joined the EU have added only a little to the EU transport volume, relative to the global total. Both the relative shares of Asia and the rest of the world have somewhat increased. The latter is caused by the relatively strong growth of some of the new economies such as China in Asia and some economies in South America and the Middle East. These observations hold for both the carrier region and the geographical region.

12.8.6 Considering the scenario situation (M 2020 for AERO-MS old and M 2026 for AERO-MS new) we observe almost the same trends when comparing the new with the old AERO-MS. The relative share of North America further goes down; Europe and Russia are almost stable; the share of Asia further goes up to almost the same level in both the new and the old AERO-MS; the share of the rest of the world keeps on going up in the new AERO-MS, while in the old AERO-MS it tends to go slightly down.

12.8.7 Table 12.8 and Table 12.9 show the top 20 country ranking based on the volumes of RTK transported to, from and within the country. The ranking and relative shares (to the global total) are shown for the new AERO-MS for both the Base (2006) and Scenario (M 2026) situation and compared with the ranking and relative shares in the old AERO-MS for the Base (1992) and Scenario (M 2020) situation, respectively.

12.8.8 A first observation is that the list of countries making up the top 20 is quite stable. Both in the comparisons for the Base and Scenario situation, only a few countries in the top 20 lists are different. Also in all cases, the total share of the top 20 countries is of the order of 80% of the total global transport volume.

12.8.9 In all cases the United States by far have the largest share, although in the new AERO-MS this is somewhat less pronounced than in the old AERO-MS. Considering other specific countries there are a number of clear differences. Comparing the new to the old AERO-MS for the Base situation (Table 12.8), we see the relative share of Japan go down substantially and the share of China coming up even more. Significant differences are also observed in the share and position of a number of other countries such as the United Arab Emirates and India. Comparing the new to the old AERO-MS for the Scenario situation (Table 12.9), the above trends are further reinforced.

Table 12.8 Country ranking based on RTK in old/new AERO-MS (Base situation)

New AERO-MS 2006				Old AERO-MS 1992	
Ranking	**Country**	**RTK**	**%**	**Ranking**	**%**
1	United States	1.74E+11	30.0%	1	35.3%
2	United Kingdom	3.53E+10	6.1%	3	5.1%
3	Japan	2.71E+10	4.7%	2	6.6%
4	China	2.64E+10	4.6%	21	1.0%
5	Germany	2.47E+10	4.3%	4	4.1%
6	France	1.79E+10	3.1%	5	2.9%
7	Spain	1.44E+10	2.5%	7	2.3%
8	Australia	1.38E+10	2.4%	8	2.3%
9	Canada	1.29E+10	2.2%	6	2.7%
10	United Arab Emirates	1.28E+10	2.2%	18	1.4%
11	Hong Kong	1.24E+10	2.1%	11	1.9%
12	Singapore	1.16E+10	2.0%	10	1.9%
13	Netherlands	1.13E+10	2.0%	14	1.6%
14	Thailand	1.03E+10	1.8%	12	1.8%
15	India	1.03E+10	1.8%	19	1.1%
16	Italy	1.01E+10	1.7%	15	1.5%
17	Korea	9.19E+09	1.6%	17	1.4%
18	Brazil	9.06E+09	1.6%	16	1.5%
19	Russian Federation	7.36E+09	1.3%	13	1.6%
20	Taiwan	6.82E+09	1.2%	20	1.1%
Subtotal			**79.2%**		**79.1%**

Table 12.9 Country ranking based on RTK in old/new AERO-MS (Scenario situation)

New AERO-MS M-2026				Old AERO-MS M-2020	
Ranking	Country	RTK	%	Ranking	%
1	United States	3.88E+11	24.3%	1	27.6%
2	Japan	9.25E+10	5.8%	2	9.7%
3	China	9.20E+10	5.8%	18	1.4%
4	United Kingdom	9.13E+10	5.7%	3	5.4%
5	Germany	6.42E+10	4.0%	4	4.3%
6	Australia	4.94E+10	3.1%	11	2.2%
7	France	4.88E+10	3.1%	8	3.0%
8	Hong Kong	4.20E+10	2.6%	7	3.1%
9	United Arab Emirates	4.16E+10	2.6%	21	1.1%
10	Singapore	4.06E+10	2.5%	5	3.2%
11	Thailand	3.57E+10	2.2%	6	3.1%
12	India	3.45E+10	2.2%	15	1.8%
13	Spain	3.43E+10	2.2%	9	2.2%
14	Korea	3.14E+10	2.0%	10	2.2%
15	Netherlands	3.10E+10	1.9%	14	1.9%
16	Canada	2.91E+10	1.8%	12	2.1%
17	Brazil	2.73E+10	1.7%	22	1.0%
18	Italy	2.51E+10	1.6%	17	1.5%
19	Taiwan	2.42E+10	1.5%	16	1.8%
20	Malaysia	2.21E+10	1.4%	23	0.9%
Subtotal			**78.0%**		**79.6%**

12.8.10 As part of the data update, the definition and data of the category non-scheduled passengers were adjusted to reflect the characteristics of the low cost carriers (LCC). Table 12.10 provides an overview of the proportions of global RTK, total operating revenues and costs of the flight type category non-scheduled /LCC passengers for both the old and new AERO-MS.

Table 12.10 Proportions non-scheduled /LCC pax of global RTK, revenues and costs

AERO-MS version	Non-scheduled / low cost carriers (LCC)		
	RTK (%)	Operating revenues (%)	Operating costs (%)
AERO-MS old Base year 1992	8.7%	10.8%	10.7%
AERO-MS new Base year 2006	12.9%	9.0%	9.2%

12.8.11 From Table 12.10 it is evident that in the Base Year of the old AERO-MS, the relative share of non-scheduled pax/LCC in terms of RTK is smaller than in the Base Year of the updated model. In the old AERO-MS, the non-scheduled pax represent a disproportional somewhat higher part of operating revenues and costs, whereby it is noted that this is generally true for the RTK associated with passengers as opposed to the RTK associated with freight (representing a lower share of revenues and costs). In the new AERO-MS, the share of revenues and costs represented by the non-scheduled/LCC pax RTK is now substantially lower, indicating that the cost and revenue structure of this part of the flight activity has indeed changed significantly.

12.8.12 Turning now to consider a number of regional policies, we investigate further the possible effects of the various changes in the quantities and (regional) distributions of transportation activities. These regional policies are based on the global fuel taxation measure FT50. They include:

- FT50Dom: a taxation of US$ 0.50/kg applied to domestic flights only.
- FT50Int: a taxation of US$ 0.50/kg applied to international flights only.
- FT50NA: a taxation of US$ 0.50/kg applied to all flights from and within North America only.
- FT50EU: a taxation of US$ 0.50/kg applied to all flights from and within the EU only.
- FT50EUCar: a taxation of US$ 0.50/kg applied to all flight activities of carriers based in the EU only.

12.8.13 Table 12.11 provides an overview of the effects of the above regional policies on global air transport demand (RTK) and fuel use compared to the global FT50 policy. The relative global effects are shown for each of the policies, for both the old and new AERO-MS, for scenarios M 2020 and M 2026, respectively. In addition, the global effects of the regional policies have been expressed as a percentage of the effect of the global policy FT50.

12.8.14 From Table 12.11 it can be observed that, considering the effects of the new versus the old AERO-MS:

- The share of domestic traffic to the global effects increases both in terms of the demand and fuel effects, but more for fuel.
- The share of the region North America to the global effects decreases both in terms of the demand and fuel effects, but more for demand.
- The share of the EU to the global effects slightly increases both in terms of demand and fuel effects, but more for fuel.
- The share of the EU carriers to the global effects slightly increases in terms of demand, but more significantly in terms of fuel. This is caused by the fact that in the old AERO-MS M-2020 scenario the average fuel use (in fuel/RTK) of the EU carriers is more favourable than the global average. In the new AERO-MS M-2026 scenario this is much less the case.

12.8.15 These observations are in line with the general trends in the data changes as shown in Tables 12.7 and 12.8. All in all, the observed changes in the global effects of regional policies are still quite modest on this rather high aggregation level. Larger differences are to be expected when considering more specific regions, routes or countries.

Table 12.11 Global effects of regional policies on air transport demand and fuel use

Regional policies	(Effects on) air transport demand			(Effects on) fuel use		
	billion RTK	% change	% effect FT50	billion kg	% change	% effect FT50
Old AERO-MS (M2020)	1,415			368.0		
FT50		-12.5%			-14.8%	
FT50Dom		-3.1%	**25%**		-4.1%	**27%**
FT50Int		-9.5%	**75%**		-10.8%	**73%**
FT50NA		-4.3%	**35%**		-5.1%	**34%**
FT50EU		-3.0%	**24%**		-3.5%	**24%**
FT50EUCar		-3.4%	**27%**		-3.1%	**21%**
New AERO-MS (M2026)	1,595			397.4		
FT50		-8.9%			-10.5%	
FT50Dom		-2.4%	**27%**		-3.3%	**32%**
FT50Int		-6.5%	**73%**		-7.2%	**68%**
FT50NA		-2.7%	**30%**		-3.3%	**32%**
FT50EU		-2.2%	**25%**		-2.7%	**26%**
FT50EUCar		-2.6%	**29%**		-2.8%	**27%**

12.8.16 Finally, in Table 12.12 the regional effects (in terms of changes in fuel use) are shown of the global policy FT50. The effects are shown for the same region clusters as considered in Table 12.7 in terms of the contribution of each region to the global fuel reduction following from the measure FT50. Moreover, the contributions to the fuel effect by region are expressed as a relative share of the total global fuel reduction. Regions are again distinguished by carrier region and geographical region. When comparing the new to the old AERO-MS, we see the share of the effect on Asia being a bit less, while the share of the effects on the rest of the world is somewhat bigger. Also the share of the fuel effects on Europe and Russia are slightly bigger in the new AERO-MS. In terms of fuel use reduction, the share of North America is only slightly less in the new AERO-MS.

Table 12.12 Regional effects of global taxation policy on fuel use

Region clusters	Old AERO-MS FT50							
	Carrier region				Geographical region			
	Fuel use (kg)		% global change	% of total change	Fuel use (kg)		% global change	% of total change
	M 2020	FT50			M 2020	FT50		
North America	1.17E+11	9.95E+10	-5.0%	**33%**	1.12E+11	9.51E+10	-4.9%	**32%**
Europe + Russia	9.90E+10	8.35E+10	-4.5%	**30%**	8.96E+10	7.60E+10	-3.9%	**26%**
- of which EU	*8.00E+10*	*6.73E+10*	-3.7%	**24%**	*7.48E+10*	*6.31E+10*	-3.3%	**22%**
- remaining part	*1.91E+10*	*1.62E+10*	-0.8%	**6%**	*1.49E+10*	*1.29E+10*	-0.6%	**4%**
Asia	8.96E+10	7.69E+10	-3.7%	**24%**	9.91E+10	8.48E+10	-4.1%	**27%**
Rest of the world	4.21E+10	3.54E+10	-1.9%	**13%**	4.68E+10	3.94E+10	-2.1%	**14%**
Total	**3.48E+11**	**2.95E+11**	**-15.0%**	**100%**	**3.48E+11**	**2.95E+11**	**-15.0%**	**100%**
	New AERO-MS FT50							
	Carrier region				**Geographical region**			
	Fuel use (kg)		**% global change**	**% of total change**	**Fuel use (kg)**		**% global change**	**% of total change**
	M 2020	**FT50**			**M 2020**	**FT50**		
North America	1.10E+11	9.66E+10	-3.3%	**32%**	1.08E+11	9.55E+10	-3.2%	**31%**
Europe + Russia	1.10E+11	9.75E+10	-3.2%	**32%**	1.02E+11	9.04E+10	-2.8%	**28%**
- of which EU	*9.61E+10*	*8.47E+10*	-2.9%	**28%**	*8.83E+10*	*7.84E+10*	-2.5%	**25%**
- remaining part	*1.41E+10*	*1.28E+10*	-0.3%	**3%**	*1.33E+10*	*1.20E+10*	-0.3%	**3%**
Asia	1.10E+11	1.02E+11	-2.2%	**22%**	1.11E+11	1.027E+10	-2.3%	**22%**
Rest of the world	6.58E+10	6.00E+10	-1.5%	**15%**	7.58E+10	6.82E+10	-1.9%	**19%**
Total	**3.96E+11**	**3.56E+11**	**-10.2%**	**100%**	**3.96E+11**	**3.56E+11**	**-10.2%**	**100%**

12.9 Testing of sample cases

12.9.1 The testing of sample cases considers the following examples:

- Possibilities for achieving a fuel efficiency improvement target.
- Effects of specific technology developments (open rotor).
- Variations on the EU emission trading system (EU-ETS).

Possibilities for achieving a fuel efficiency improvement target

12.9.2 The present illustration aims to explore the possibilities to achieve a fuel efficiency improvement target in terms of fuel per RTK, considering the following potential measures:

- Scrapping of old aircraft.
- Additional fuel technology improvement.
- Reduction of detour through ATM improvements.

12.9.3 As a first step, for each of the above measures, estimates are provided for the potential fuel efficiency improvements and measure costs. Since both potential improvements and measure costs are highly uncertain, the illustration considers a number of potential improvements and a range of assumptions on measure costs. In order to facilitate the computation of actual measure costs, and to isolate the net effects on fuel efficiency improvement, the model runs have been carried out without the demand response (that is, with the profit adjustment factor set to 0). Moreover, the measures on fuel technology improvement are carried out without the aircraft choice mechanism in place in order to identify the most optimistic fuel efficiency improvement obtainable. Following from these considerations, two sets of policy measures have been defined.

Policy Measure Set 1

- CScrap25 NoDR[41]: all aircraft with certification year older than 25 years to be scrapped.
- FTI-1% 07-26 AP1% NoAC[42] NoDR: additional fuel technology improvement of 1% per year during a 20-year period (2007-2026). Price increase of new aircraft: 1% for each 1% additional fuel improvement.
- FTI-1% 07-26 AP2% NoAC NoDR: as above with 2% price increase of new aircraft.
- FTI-1% 07-26 AP3% NoAC NoDR: as above with 3% price increase of new aircraft.
- RDF50% RC+100% NoDR: 50% reduction of part of detour factor in excess of 1 and 100% increase in route charges.
- RDF50% RC+200% NoDR: as above with 200% increase in route charges.
- RDF50% RC+300% NoDR: as above with 300% increase in route charges.

Policy Measure Set 2

- CScrap20 NoDR: all aircraft with certification year older than 20 years to be scrapped.
- FTI-1.5% 07-26 AP1% NoAC NoDR.
- FTI-1.5% 07-26 AP2% NoAC NoDR.
- FTI-1.5% 07-26 AP3% NoAC NoDR.
  - As policy measure set 1 with 1.5% fuel technology improvement per year.
- RDF75% RC+150% NoDR.
- RDF75% RC+300% NoDR.
- RDF75% RC+450% NoDR.
  - As policy measure set 1 with 75% reduction of part of detour factor in excess of 1 and increases in route charges of 150%, 300% and 450% respectively.

12.9.4 The two measure sets aim to reflect two different situations regarding possible improvements to be achieved that could be considered as 'moderately' to 'very' optimistic. The different assumptions regarding measure costs are believed to reflect a rather wide uncertainty band. All computations for the above measures have been carried out for the

[41] No demand response

[42] No aircraft choice mechanism

year 2026, based on the scenario CAEP8-M 2026. The results of the computations for the two measures sets are presented in Table 12.13 and 12.14.

Table 12.13 Results of fuel efficiency improvement measure set 1

Effect	Unit	CAEP8-M 2026	CScrap25 NoDR	FTI-1% 07-26 AP1% NoAC NoDR	FTI-1% 07-26 AP2% NoAC NoDR	FTI-1% 07-26 AP3% NoAC NoDR	RD50% RC+100% NoDR	RD50% RC+200% NoDR	RD50% RC+300% NoDR
Air transport demand									
Pax sched. Network Carriers									
1 First/business	billion pax-km	976	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2 Economy (+ discount)	billion pax-km	9419	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3 Discount	billion pax-km								
4 Total pax sched. NC	billion pax-km	10395	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5 Pax non-sched. (and LCC)	billion pax-km	1676	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6 Total pax demand	billion pax-km	12072	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7 Cargo demand	billion tonne-km	509	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8 Revenu Tonne-Km (RTK)	billion RTK	1595	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aircraft km									
9 Techn.age > 12 (16) years	billion ac-km	44.5	-16.0%	0.0%	0.0%	0.0%	-3.9%	-3.9%	-3.8%
10 Techn.age <= 12 (16) years	billion ac-km	48.1	14.4%	0.0%	0.0%	0.0%	-3.0%	-3.1%	-3.2%
11 Total aircraft km	billion ac-km	92.6	-0.2%	0.0%	0.0%	0.0%	-3.4%	-3.5%	-3.5%
Effects on airlines									
12 Direct operating costs	billion US$	697.3	2.5%	-3.7%	-3.6%	-3.5%	1.0%	5.3%	9.7%
13 Total operating costs	billion US$	1403.3	2.4%	-0.6%	2.9%	7.8%	0.1%	2.3%	4.4%
14 Total operating revenues	billion US$	1452.8	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15 Total operating result	% of revenues	3.4%	1.1%	4.0%	0.6%	-4.1%	3.3%	1.2%	-0.9%
Impacts on other actors									
16 Change in consumer surplus	billion US$		0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 Revenue from taxation/charges	billion US$		0.0	0.0	0.0	0.0	30.3	60.6	90.8
Fuel impacts									
18 Total fuel use	billion kg	397.4	**-1.3%**	**-7.2%**	**-7.2%**	**-7.2%**	**-4.1%**	**-4.1%**	**-4.2%**
19 Fuel / RTK	kg/tonne-km	0.25	-1.3%	-7.2%	-7.2%	-7.2%	-4.1%	-4.1%	-4.2%
20 Contr. of demand reduction	%		0%	0%	0%	0%	0%	0%	0%
21 Contr.of techn&eff improvement	%		100%	100%	100%	100%	100%	100%	100%
	Measure cost (billion US$)		34.1	-8.0	41.0	109.2	2.0	32.2	62.4
	Fuel reduction (% per billion US$)		0.04%	NA	0.17%	0.07%	2.07%	0.13%	0.07%

12.9.5 As can be verified from effects 1-8 in Table 12.13, all demand responses are zero. The scrapping measure leads to a shift in aircraft km from old to current. The detour reduction measures more or less equally reduces aircraft km for old and current due to the reduction of flight distances. The fuel technology improvement measure has no effect on old and current aircraft km (no aircraft choice).

12.9.6 The scrapping measure increases both direct and total operating costs. Fuel technology improvement reduces direct operating costs (fuel) and - in principle - increases total operating costs. The reduction in direct operating costs is basically the same for the three measure variations (same technology improvement). The effect on total operating costs varies with measure cost. If the new aircraft price increase is 1%, there is a slight reduction in total operating costs (savings in fuel costs outweighing increases in capital costs and finance charges). For the new aircraft price increases of 2% and 3% we see a rapid increase in total operating costs. For the detour reduction measure we see a small net increase in direct and total operating cost if additional route costs are 100%. For additional route costs of 200% and 300% we see a rapid increase in operating costs.

12.9.7 Impacts on other actors only occur for the detour measure, where the additional route costs are registered as a route charges to be incurred by the government. From these results it can be verified that the total route costs in the scenario year are of the order of 30 billion US$. Overall reductions in fuel use for the scrapping, fuel technology improvement and detour measures are -1.3%, -7.2% and -4.2% respectively. As the demand response is eliminated, these effects are totally due to the improvement in fuel efficiency (fuel/RTK).

12.9.8 The total actual costs of the measure can be directly inferred from the percentage change in total operating costs (effect 13). The measure costs follow from the direct application of this percentage to the total operating costs in the scenario year (1403 billion US$). These costs are shown for each measure in the first of the two lines shown directly under the main Table 12.13. Dividing the fuel reduction achieved by each measure by its total cost yields a 'measure' of effectiveness in terms of the percentage of global fuel reduction per billion US$.

12.9.9 The effectiveness is shown for each measure in the second line below Table 12.13. It can be verified that the scrapping measure is by far the least effective of the measure range considered. For the fuel technology improvement measure, the effectiveness is not applicable in case of a 1% increase in new aircraft price (leading to a net cost reduction). If the costs increase, the effectiveness strongly decreases, but would still be significantly better than the scrapping measure, even if new aircraft price would increase with 3% for each additional 1% of fuel use improvement. A very similar pattern occurs for the detour measure. The measure would be extremely favourable if the cost could be limited to 100% of the route costs. With further cost increases by a factor of 2 and 3, the effectiveness would be of the same order as for the fuel technology improvement measure.

12.9.10 As can be verified from Table 12.14, very similar types of results are found for the second set of measures. The conclusions on the effectiveness of the measures are largely the same. Obviously, under this set of assumptions, the overall effects on fuel efficiency improvement would be substantially larger. From these results it follows that scrapping seems less favourable (limited potential and high cost) where fuel technology and ATM improvement seem about equally promising.

12.9.11 Table 12.15 shows what would be the maximum fuel efficiency improvement that could be achieved if the fuel technology and ATM improvement measures were combined. This table considers two combinations based on the medium cost estimates for each measure set. Both combinations are shown for a situation with and without demand response.

Table 12.14 Results of fuel efficiency improvement measure set 2

Effect	Unit	CAEP8-M 2026	CScrap20 NoDR	FTI-1.5% 07-26 AP1% NoAC NoDR	FTI-1.5% 07-26 AP2% NoAC NoDR	FTI-1.5% 07-26 AP3% NoAC NoDR	RD75% RC+150% NoDR	RD75% RC+300% NoDR'	RD75% RC+450% NoDR
Air transport demand									
Pax sched. Network Carriers									
1 First/business	billion pax-km	976	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2 Economy (+ discount)	billion pax-km	9419	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3 Discount	billion pax-km								
4 Total pax sched. NC	billion pax-km	10395	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
5 Pax non-sched. (and LCC)	billion pax-km	1676	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
6 Total pax demand	billion pax-km	12072	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
7 Cargo demand	billion tonne-km	509	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8 Revenu Tonne-Km (RTK)	billion RTK	1595	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Aircraft km									
9 Techn.age > 12 (16) years	billion ac-km	44.5	-44.5%	0.0%	0.1%	0.0%	-5.8%	-5.7%	-5.6%
10 Techn.age <= 12 (16) years	billion ac-km	48.1	40.5%	0.0%	0.0%	0.0%	-4.5%	-4.6%	-4.8%
11 Total aircraft km	billion ac-km	92.6	-0.4%	0.0%	0.0%	0.0%	-5.1%	-5.1%	-5.2%
Effects on airlines									
12 Direct operating costs	billion US$	697.3	7.3%	-5.5%	-5.4%	-5.3%	1.4%	7.8%	14.1%
13 Total operating costs	billion US$	1403.3	6.2%	-0.7%	4.3%	11.6%	0.2%	3.3%	6.5%
14 Total operating revenues	billion US$	1452.8	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
15 Total operating result	% of revenues	3.4%	-2.6%	4.0%	-0.7%	-7.8%	3.3%	0.2%	-2.8%
Impacts on other actors									
16 Change in consumer surplus	billion US$		0.0	0.0	0.0	0.0	0.0	0.0	0.0
17 Revenue from taxation/charges	billion US$		0.0	0.0	0.0	0.0	44.5	88.9	133.3
Fuel impacts									
18 Total fuel use	billion kg	397.4	**-2.9%**	**-10.6%**	**-10.6%**	**-10.6%**	**-6.1%**	**-6.2%**	**-6.3%**
19 Fuel / RTK	kg/tonne-km	0.25	-2.9%	-10.6%	-10.6%	-10.6%	-6.1%	-6.2%	-6.3%
20 Contr. of demand reduction	%		0%	0%	0%	0%	0%	0%	0%
21 Contr.of techn&eff improvement	%		100%	100%	100%	100%	100%	100%	100%

Measure cost (billion US$)	87.3	-9.3	60.0	162.6	2.2	46.5	90.9
Fuel reduction (% per billion US$)	0.03%	NA	0.18%	0.07%	2.80%	0.13%	0.07%

Table 12.15 Results of combined fuel efficiency improvement measures

Effect	Unit	CAEP8-M 2026	Combination 1 FTI-1% 07-26 AP2% RD50% RC+200% NoAC	Combination 1 FTI-1% 07-26 AP2% RD50% RC+200% NoAC NoDR	Combination 2 FTI-1.5% 07-26 AP2% RD75% RC+300% NoAC	Combination 2 FTI-1.5% 07-26 AP2% RD75% RC+300% NoAC NoDR	FT20	FT30
Air transport demand								
Pax sched. Network Carriers								
1 First/business	billion pax-km	976	-0.9%	0.0%	-1.2%	0.0%	-0.9%	-1.3%
2 Economy (+ discount)	billion pax-km	9419	-2.8%	0.0%	-3.9%	0.0%	-3.0%	-4.4%
3 Discount	billion pax-km							
4 Total pax sched. NC	billion pax-km	10395	-2.6%	0.0%	-3.6%	0.0%	-2.8%	-4.1%
5 Pax non-sched. (and LCC)	billion pax-km	1676	-6.7%	0.0%	-9.1%	0.0%	-10.0%	-14.3%
6 Total pax demand	billion pax-km	12072	-3.2%	0.0%	-4.4%	0.0%	-3.8%	-5.5%
7 Cargo demand	billion tonne-km	509	-4.6%	0.0%	-6.3%	0.0%	-4.1%	-5.9%
8 Revenu Tonne-Km (RTK)	billion RTK	1595	-3.6%	0.0%	-5.0%	0.0%	-3.9%	-5.7%
Aircraft km								
9 Techn.age > 12 (16) years	billion ac-km	44.5	-6.9%	-4.0%	-9.8%	-5.9%	-8.1%	-11.7%
10 Techn.age <= 12 (16) years	billion ac-km	48.1	-7.3%	-4.0%	-10.3%	-6.0%	-1.7%	-2.3%
11 Total aircraft km	billion ac-km	92.6	-7.1%	-4.0%	-10.1%	-6.0%	-4.8%	-6.8%
Effects on airlines								
12 Direct operating costs	billion US$	697.3	-1.8%	1.8%	-2.5%	2.6%	6.6%	9.8%
13 Total operating costs	billion US$	1403.3	1.4%	5.0%	2.1%	7.2%	1.8%	2.8%
14 Total operating revenues	billion US$	1452.8	1.5%	0.0%	2.1%	0.0%	1.7%	2.5%
15 Total operating result	% of revenues	3.4%	3.4%	-1.4%	3.4%	-3.6%	3.3%	3.2%
Impacts on other actors								
16 Change in consumer surplus	billion US$		-64.1	0.0	-91.3	0.0	-72.5	-107.6
17 Revenue from taxation/charges	billion US$		57.8	60.6	83.4	89.1	75.6	111.0
Fuel impacts								
18 Total fuel use	billion kg	397.4	**-14.1%**	**-10.9%**	**-20.1%**	**-15.9%**	**-4.7%**	**-6.8%**
19 Fuel / RTK	kg/tonne-km	0.25	-10.9%	-10.9%	-15.9%	-15.9%	-0.8%	-1.2%
20 Contr. of demand reduction	%		25%	0%	24%	0%	83%	83%
21 Contr.of techn&eff improvement	%		75%	100%	76%	100%	17%	17%

Measure cost (billion US$)		70.2		101.2
Fuel reduction (% per billion US$)		0.15%		0.16%

12.9.12 The total effect of fuel efficiency improvement on fuel reduction of the first combination is around 11% (combination 1 with NoDR). For the second combination this would be around 16% (combination 2 with NoDR). For both combinations the ratio of global fuel reduction to measure cost would be of the order of 0.15% per billion US$. With demand effects taken into account, the total fuel use reductions could be of the order of 14% and 20%.

12.9.13 In practice, the measure combinations could be funded by implementing a fuel equivalent taxation that would generate the amounts needed to pay for their costs. From the cost estimates and fuel reductions in Table 12.15 it follows that a fuel taxation of 0.20 US$/kg and 0.30 US$/kg would be needed to 'pay' for the combinations 1 and 2, respectively. The results of the fuel taxation runs FT20 and FT30 in Table 12.15 show that the revenues generated from these measures (effect 17) would indeed be sufficient to pay for the net costs of the measure combinations (70 and 101 billion US$, respectively). Note that revenues shown are, and should be, a bit higher because the measure combinations will further reduce fuel use and thereby the revenues of the fuel taxation if all measures were indeed combined.

12.9.14 A fuel equivalent taxation as the 'funding mechanism' would potentially further increase fuel efficiency (by roughly 1%) as can be verified from effect 19 in Table 12.15. All in all, the above results suggest that a fuel efficiency improvement target of between 10% to 15% in the next 20 years could be feasible.

Effects of specific technology developments (open rotor)

12.9.15 Specific ongoing and future innovative engine and airframe developments could potentially lead to a more or less 'sudden' improvement in fuel efficiency, once such a development had been generally adopted and applied by major engine and aircraft manufacturers. One such development could be the introduction of the 'open rotor' technology. Without going into any technical details about this concept, the following provides an illustration of how the AERO-MS would be able to support the analysis of the potential consequences.

12.9.16 Supposedly, the open rotor technology would be capable of providing a saving in fuel use that could be of the order of 15%. This technology is still in development and the actual introduction is probably not to be expected before the year 2025 (or 2020 at the earliest). Moreover the expectations are that, if it became available, this technology might only be supplied to a selective subset of common aircraft types. Hence the potential benefits of this technology are uncertain at the moment.

12.9.17 To allow for a practical illustration, computations with the AERO-MS were made under the following assumptions:

- A maximum fuel technology improvement of 15% that might be available for selective aircraft types from 2020 onwards at the earliest.
- Baseline assumption for cost of technology improvement: 2% increase in aircraft new price for each 1% of fuel improvement (leading to a 30% increase in new aircraft price if an improvement of 15% is achieved).
- Variations of 1% and 3% increase in aircraft new price to reflect a reasonable range of uncertainty in the cost of this improvement.

- Introduction of open rotor technology to specific aircraft types only.
- Consideration of two scenario years: 2026 and 2036.

12.9.18 To provide an overview of the possible consequences, model runs were made whereby the introduction of the open rotor technology was applied to each individual aircraft type separately, with the exception of aircraft type 9 (the New Large Aircraft type). This allows for the possibility to show the potential contribution to global fuel reduction of each individual aircraft type. Moreover, a reference run was made assuming the introduction of the open rotor for all aircraft types together (except type 9). The runs were made for both the CAEP8-M 2026 and M 2036 scenarios. For each run it was assumed that an additional fuel technology improvement of 15% would apply to all new aircraft with certification year 2020 or later for the specific aircraft type considered (on top of the baseline development), whereby the additional improvement would be kept constant in time from 2020 onwards. The improved technology (by aircraft type) would then gradually enter into the fleet in the years after 2020, given the assumption that newly purchased aircraft would have a technology age that is from 1 to 8 years older than the purchase year. All model runs were made without the aircraft choice mechanism in place as this would counteract the introduction of the new technology. This provides an optimistic view of future market penetration of the open rotor aircraft and potential emissions reduction. The runs were also made without the demand response, thus allowing for the computation of the cost of introducing the new technology.

12.9.19 An overview of the main results is presented in Table 12.16. For each of the individual aircraft types 0 through 8 (as defined in the table) the effects are shown in terms of the reduction in global fuel use (%) and the change in total operating costs (billion US $) if the open rotor technology were introduced for that specific aircraft type **only**. The cost estimates by aircraft type are based on the assumption that aircraft new price would be increased with 30% (2% per 1% of fuel improvement). In the last three rows of Table 12.16, fuel improvement and cost results are shown if the open rotor technology would be introduced for all aircraft types (except type 9 - the New Large Aircraft). For this total computation, in addition to the cost assumption of 30%, cost estimates are also provided for a cost increase of 15% and 45% (1% and 3% increase in new aircraft price per 1% of fuel improvement, respectively).

Table 12.16 Potential impacts of introduction of 'open rotor' from 2020 onwards

Aircraft type		Scenario CAEP8 M 2026		Scenario CAEP8 M 2036	
Code	Description	Change in global fuel use (%)	Change in total operating cost (billion US$)	Change in global fuel use (%)	Change in total operating cost (billion US$)
0	Short haul < 20 seats	-0.03%	0.77	-0.09%	3.44
1	Short haul 20-100 seats	-0.06%	1.24	-0.22%	6.93
2	Short haul 101-150 seats	-0.13%	4.55	-0.48%	21.16
3	Short haul 151-210 seats	-0.22%	1.14	-0.78%	3.82
4	Medium haul 101-150 seats	-0.18%	0.96	-0.60%	2.97
5	Medium haul 151-210 seats	-0.19%	-0.20	-0.67%	-1.80
6	Medium haul 211-300 seats	-0.31%	7.70	-0.87%	40.01
7	Long haul 211-300 seats	-0.77%	7.12	-1.87%	29.88
8	Long haul 301-500 seats	-0.39%	6.14	-1.65%	30.17
Total (aircraft price increase 2%) (30%)		**-2.27%**	**29.4**	**-7.23%**	**136.6**
Total (aircraft price increase 1%) (15%)		**-2.27%**	**-0.9**	**-7.23%**	**-7.3**
Total (aircraft price increase 3%) (45%)		**-2.27%**	**73.3**	**-7.23%**	**380.1**

12.9.20 The reductions in global fuel use brought about by the introduction of the open rotor for each of the individual aircraft type separately vary by aircraft type and - as expected - are rather modest for the smaller aircraft types. For the scenario year 2026, if the open rotor were to be applied to all aircraft types together, the overall reduction in global fuel use would be about 2.3%. For the scenario year 2036 this would be increased to 7.2%, as the number of aircraft with the new technology substantially increases with time.

12.9.21 As observed in earlier examples, the basic cost assumption of a 2% increase in new aircraft price for each 1% of fuel improvement leads to a total cost effect that at least for certain aircraft types is close to the breakeven point. Given the specific cost performance and cost characteristics by aircraft type, we see quite some variation in the net effects on total operating costs, with the larger aircraft types showing the largest net changes in costs. For one aircraft type (5) the net cost effect is about on the breakeven point, as can be inferred from the slightly negative values.

12.9.22 Going from scenario year 2026 to 2036 the total cost effect strongly increases along with the number of new technology aircraft being introduced in the fleet. If the new aircraft price increase was only 15%, the overall net cost is about at the breakeven point, meaning that the net cost increase would be clearly negative for certain aircraft types and positive for others. If the new aircraft price increase was 45%, the overall net cost sharply rises and all aircraft types would have a significant increase in net operating cost. Note that the improvement in fuel efficiency is independent of the cost assumptions. Differences in costs would only lead to differences in demand effects. Since the model runs were made without the demand response, these are not shown in Table 12.16.

12.9.23 At this time, the open rotor technology is likely to be introduced on the next generation single aisle aircraft within the 101-210 seat classes (e.g. A320, B737). Further applications are not yet clear. Therefore, the present results only provide some indications and do not yet allow for a realistic estimate of the effects. However, the results in Table 12.10 do provide certain insights in the potential effects by aircraft type. If more specific details about the technology improvement, the time path of introduction, and possible applications across aircraft types would become available, further analyses could quite easily be accommodated with the new version of AERO-MS.

Variations on the EU emission trading system (EU-ETS)

Definition of EU ETS variants

12.9.24 The present EC proposal with respect to including aviation in the EU ETS is based on the following principles:

- All flights departing from and arriving in an EU country (including flights within and between EU countries) will fall under the EU ETS.
- The yearly cap for aviation emissions will be 95% of the average amount of CO_2 emissions on the flights under emission trading in the years 2004-2006 (i.e. average across these years).
- 15% of the CO_2 emissions under the cap will be auctioned. Another 3% will be reserved for new entrants (whereby it is assumed these will also be auctioned). The remaining 82% of CO_2 emissions under the cap will be benchmarked.

12.9.25 Presently an alternative option is being debated whereby there will be a so-called "de minimis" provision for smaller air transport countries. This would imply that flights to, from and within the EU operated by carriers from these smaller countries would be excluded from the EU ETS. Also operations of EU carriers between the EU and these smaller countries will be excluded from the EU ETS.

12.9.26 The first obvious question is which countries outside the EU are to be defined as smaller air transport countries, and hence which countries are defined as larger air transport countries. The definition of these two groups of countries is still under discussion. One of the options is that larger air transport countries are defined as countries of which the carriers registered in these countries have a share of more than 0.5% of global RTKs on international flights. According to this definition, the following non-EU countries would be larger air transport countries:

1. Australia
2. Brazil
3. Canada
4. China
5. Hong Kong
6. India
7. Japan
8. Korea, Republic of
9. Malaysia
10. Mexico
11. New Zealand
12. Qatar
13. Russian Federation
14. Saudi Arabia

15. Singapore
16. South Africa
17. Switzerland
18. Taiwan, Province of China
19. Thailand
20. Turkey
21. United Arab Emirates
22. United States

12.9.27 All other non-EU countries are defined as smaller air transport countries. In the AERO-MS country dimension these would represent 194 countries.

12.9.28 In the AERO-MS we have modelled the de minimis variant by assuming that all flights between the EU countries and the smaller air transport countries are excluded from the EU ETS. So the EU ETS would only cover the Intra EU flights and the flights between the EU and the larger air transport countries. Note that the strict definition of the variant seems to be that all operations of carriers registered in smaller air transport countries will be excluded from the EU ETS. However, in the way we have modelled this de-minimis policy variant within AERO-MS, the operations from carriers of smaller countries between EU countries and between the EU and larger countries are still under the EU ETS. At this point in time, AERO-MS only contains information on the region of registration of air carriers (but not of the country of registration), and hence we had to make this simplification. It is assumed that the proportion of flights between EU and larger countries, operated by carriers from smaller countries, is limited. This was subsequently confirmed during the analysis of results (see para. 3.9.41).

12.9.29 Finally, for the modelling of EU ETS in the AERO-MS we had to make assumptions with respect to:

- the carbon price;
- whether the market price of benchmarked allowances is passed on to fares, even if the allowances are obtained free of charge (the market price in this case being referred to as the opportunity cost of the allowances). An allowance is the right to emit one tonne of CO_2.

12.9.30 With respect to the carbon price we have taken on board the ETS carbon prices from the "PRIMES 2009 Reference Scenario”. For the years 2025 and 2030 prices around €18 per ton of CO_2 are assumed (in € 2008). Based on this, for our analysis of effects in the year 2026, we have assumed a price of €17.06 (i.e. inputs in AERO-MS are in € 2006).

12.9.31 Part of the allowances have to be bought by airlines. The benchmarked allowances will be made available to airlines free of charge. The use of allowances implies opportunity costs, whether the allowances have been bought or obtained free of charge. In the first case, the opportunity costs are reflected in actual expenditures on allowances either from the purchase of allowances at an auction or at the EU ETS market. Not passing on the real expenditures to airline clients will negatively affect the operating margins. In the case of freely obtained allowances, the opportunity costs are not reflected in actual expenditures. Instead of using allowances to cover for one’s emissions, the allowances could have been sold against the market price. If the opportunity costs are passed on to airline clients, this may lead to windfall profits for airlines.

12.9.32 We have tested the effects of the EU ETS under two alternative assumptions:

- All of the opportunity costs for the use of benchmarked allowances are passed on to airline clients. In this case the cost increases passed on to the consumer relate to all costs associated with the ETS.
- None of the opportunity costs for the use of benchmarked allowances are passed on to airline clients. In this case the cost increases passed on to the consumer only relate to the purchase of allowances at an auction, or at the EU ETS market, above the benchmarked allowances.

12.9.33 In all runs it is assumed that the costs for real expenditures in obtaining allowances (auctioning and EU ETS market) are fully passed on to consumers.

Effects of EU ETS variants

12.9.34 The effects of both the EU ETS as proposed by the EC and the de minimis variant (i.e. variant 2) have been computed with and without the opportunity costs for the use of benchmarked allowances being passed on to airline clients. This has thus resulted in 4 model runs with the AERO-MS.

12.9.35 Table 12.17 includes a number of effects for two route groups:

- Intra EU routes. This route group includes both national routes (within EU States) and international routes between EU States.
- EU to non-EU and non-EU to EU. This route group includes all routes between EU States and non-EU States.

Table 12.17. Effects of EU ETS on EU related routes relative to CAEP8-M 2026 scenario.

Route group / effect	Unit	CAEP8M 2026	EU ETS EC proposal	EU ETS de minimis	EU ETS EC proposal	EU ETS de minimis
			100% costs benchmarked allowances passed on		0% costs benchmarked allowances passed on	
Intra EU routes						
RTK	billion RTK	98.9	-1.9%	-1.9%	-1.2%	-1.2%
Aircraft km	billion ac km	10.8	-2.3%	-2.3%	-1.5%	-1.5%
Airline revenues	billion US$	131.6	0.3%	0.3%	0.2%	0.2%
Airline costs	billion US$	127.7	0.2%	0.2%	0.1%	0.1%
Fuel use	megaton	32.3	-2.1%	-2.1%	-1.4%	-1.4%
EU to non EU and non-EU to EU routes						
RTK	billion RTK	512.6	-1.4%	-1.0%	-0.9%	-0.6%
Aircraft km	billion ac km	19.2	-1.8%	-1.1%	-1.2%	-0.7%
Airline revenues	billion US$	427.4	0.5%	0.4%	0.3%	0.3%
Airline costs	billion US$	413.5	0.6%[1]	0.5%[1]	0.4%	0.3%
Fuel use	megaton	111.7	-1.8%	-1.3%	-1.2%	-0.8%

[1] This cost increase also include the opportunity costs for benchmarked allowances which are assumed to be passed on the airline consumers.

12.9.36 Table 12.18 relates to the effects for EU carriers, which are all carriers that are registered in one of the 27 EU countries. Both for Tables 12.17 and 12.18 the effects of EU ETS are presented relative to the CAEP-M 2026 scenario.

Table 12.18. Effects of EU ETS for EU carriers relative to CAEP8-2026 scenario.

Effect	Unit	CAEP8M 2026	EU ETS EC proposal	EU ETS de-minimus	EU ETS EC proposal	EU ETS de-minimus
			100% costs benchmarked allowances passed on		0% costs benchmarked allowances passed on	
EU carriers						
RTK	billion RTK	385.8	-1.7%	-1.3%	-1.1%	-0.8%
Aircraft km	billion ac km	21.9	-2.2%	-1.7%	-1.4%	-1.1%
Airline revenues	billion US$	364.5	0.5%	0.4%	0.3%	0.2%
Airline costs	billion US$	355.3	0.5%	0.4%	0.3%	0.2%
Airline op. result1	% of rev.	2.5%	2.5%	2.5%	2.5%	2.5%
Fuel use	megaton	96.1	-2.0%	-1.5%	-1.3%	-1.0%

[1] Excluding windfall profits

12.9.37 Table 12.19 presents the sources of allowances to cover the projected CO_2 emissions in 2026 following from the CAEP-M scenario. The covering of projected CO_2 emissions over the period 2012 (introduction of emissions trading for aviation) to 2026 is also illustrated Figure 12.1. In both Table 12.19 and Figure 12.1, a distinction is made between:

1. Emissions covered by benchmarked allowances.
2. Emissions covered by auctioned allowances.
3. Reduction of CO_2 within the aviation sector. Compared to the situation without emission trading, the aviation sector will emit less CO_2 because of supply side measures leading to improved fuel efficiency and because of a demand reduction. The latter follows from the assumption that costs for allowances are assumed to be (fully or partly) passed on by airlines to their clients.
4. Allowances bought from other sectors. These allowances cover the emissions above the level of the CO_2 emission cap.

Table 12.19. Covering of projected CO_2 emissions in 2026 and financial impacts.

Effect	Unit	EU ETS EC proposal	EU ETS de minimis	EU ETS EC proposal	EU ETS de minimis
		100% pass on benchmarked allowances		0% pass on benchmarked allowances	
Aviation CO_2 emissions on routes under EU ETS					
CO2 emissions under the Cap (95% of average annual 2004-2006 emissions)	megaton	203.8	166.3	203.8	166.3
CO2 emissions 2026 (CAEP-M)	megaton	454.6	363.3	454.6	363.3
Covering of projected CO_2 emissions in 2026 (CAEP-M)					
Allowances benchmarked (82% of Cap)	10^6 allow.	167.1	136.4	167.1	136.4
Allowances auctioned (18% of Cap)	10^6 allow.	36.7	29.9	36.7	29.9
Reduction CO2 by aviation sector	megaton	8.5	6.6	5.5	4.3
Allow. bought from other sectors	10^6 allow.	242.3	190.4	245.2	192.7
Total	megaton	454.6	363.3	454.6	363.3
Financial impacts					
Costs to buy allow. from other sect. (allowances bought * 17.06€)	million €	4,133	3,248	4,183	3,287
Auction revenues (allowances auctioned * 17.06€)	million €	626	511	626	511
Windfall profits for airlines (allowances benchmarked * 17.06€)	million €	2,851	2,327	0	0

12.9.38 Table 12.19 also includes a number of specific financial impacts of emission trading.

12.9.39 In all cases it is assumed that the cost increases for airlines introduced by the EU ETS are passed on to the airline clients by increasing the fares on the routes which are subject to emission trading. These cost increases relate to the costs of acquiring auctioned allowances and for buying allowances from other sectors. For the first 2 runs presented in the tables it is assumed that also the opportunity costs for benchmarked allowances are passed on to the airline clients.

12.9.40 If the opportunity costs for the benchmarked allowances are not passed on, the size of the cost increase passed on is less. Hence, assuming the same allowance price, the effect on demand is less. As can be observed from Table 12.17 this is true for both the EU ETS as proposed by the EC and the de-minimis variant.

12.9.41 The effects on Intra EU routes of both variants (EC proposal and de-minimis) are the same. This follows from the assumption that the proportion of Intra EU flights operated by carriers from smaller air transport countries is negligible. Hence, in both variants all Intra EU flights are assumed to be under emission trading. For the routes between EU and non-EU countries, the picture is different. Because the EC proposal covers all flights in this route group and in the de-minimis EU ETS variant only part of these routes are under emission trading, the effect on the EU to non-EU route group as a whole differs.

12.9.42 Logically, the effects in percentage terms for EU carriers are in between the effects on Intra EU routes and EU – non-EU routes.

12.9.43 In order to be able to cover the projected growth of CO_2 emissions over the period 2005-2026, the airline industry has to either acquire additional allowances from other economic sectors or introduce emission reduction measures within the aviation industry. The passing on of costs for acquiring the additional allowances generates a demand effect, resulting in a reduction of the number of flights and emissions. The projected growth of CO_2 emissions over the period 2005- 2026 will partly be covered by a reduction within the aviation sector and partly by buying allowances from other economic sectors.

12.9.44 Table 12.17 shows that for the two variants (in case of 100% passing on of opportunity costs of benchmarked allowances) the estimated reduction in fuel use (and hence CO_2 emission) within the aviation industry in 2026 is 2.1% on Intra EU routes (for both variants) and 1.8% and 1.3% (for the respective variants) on the EU to non-EU routes. In absolute terms this equals a reduction in CO_2 emissions in 2026 within the aviation industry by 8.5 and 6.6 megaton for the two variants (see Table 12.19). The number of allowances to be bought from other economic sectors, in order to cover emissions above the emission cap, is estimated to be 242.3 and 190.4 million for the two variants in the year 2026. For both variants the vast majority of emissions above the cap will thus be covered by buying allowances on the open market (this is also illustrated by Figure 12.1). If it is assumed that the opportunity costs of benchmarked allowances are not passed on, the demand effect is less and the reduction of CO_2 emissions by the aviation sector is also less. Consequently the number of allowances to be bought on the open market is larger.

12.9.45 Finally Table 12.19 illustrates that in case of the EU ETS de minimis variant the amount of CO_2 emission under the cap will be less (166.3 megaton) compared with that for the present EU ETS proposal (203.8 megaton).

12.9.46 The costs to buy allowances from other sectors can be simply computed by multiplying the number of allowances to be bought with the assumed carbon price (17.06€ per tonne CO_2). As shown in Table 12.19, in the case of EU ETS according to the EC proposal these costs will be over €4 billion in 2026 (in € 2006). For the de-minimis variant these costs are about 80% of this. The costs to buy allowances from other sectors will increase over time, following from the continued growth in aviation demand and resulting growth in aviation emissions.

12.9.47 Auction revenues are computed by multiplying the number of allowances which are auctioned with the assumed carbon price. Windfall profits follow from the opportunity costs of the benchmarked allowances in case these costs are passed on to airline clients. Windfall profits for the airline industry are computed to be €2.85 billion and €2.33 billion in 2026 for respectively the EU ETS as proposed by the EC and the de-minimis variant.

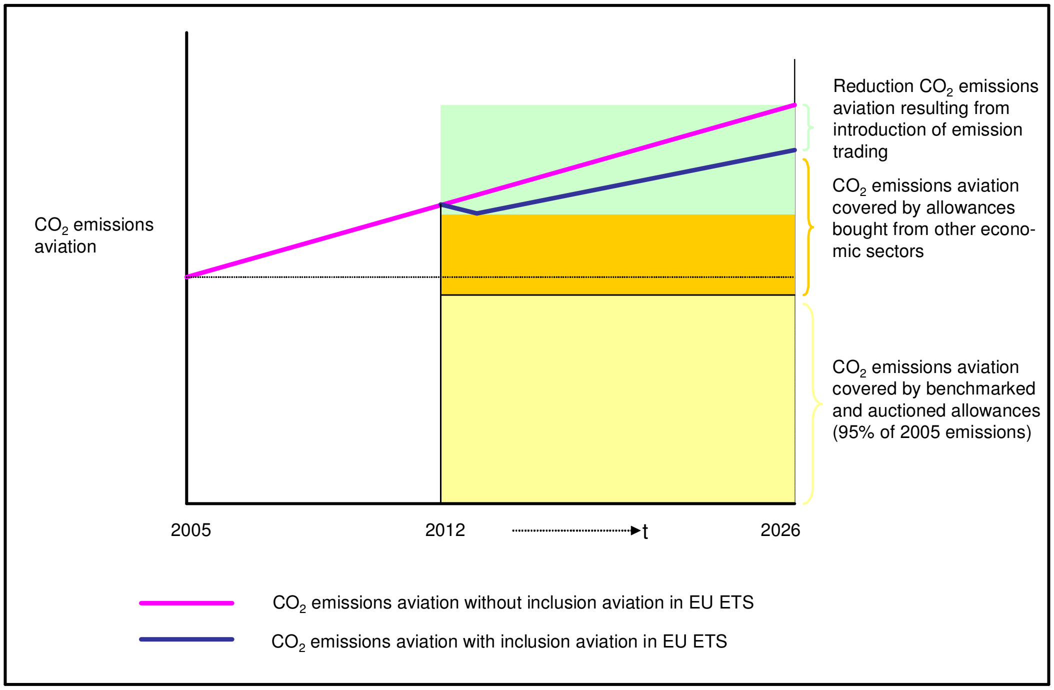

Figure 12.1. Illustration of effect on aviation CO_2 emission resulting from the EU ETS

13 Proposals for further improvements to the AERO-MS

13.1 Introduction

13.1.1 This chapter sets out the Consortium's findings in carrying out Work Package 9 (WP9): "Improved fleet and flight forecasting for environmental assessment". The purpose of WP9 was to contribute to EASA's objective of having an improved forecasting module to develop future fleets and operations with sufficient granularity for environmental assessments. Actual implementation of the proposed enhancements, however, would be beyond the scope of the current project.

13.1.2 The desirability of enhancements to the AERO-MS, or of developing a successor model, has become increasingly apparent. Since the AERO-MS was first used in 1997, there have been major changes to both the aviation sector and background policy considerations. Cases in point are the emergence of different business models among carriers, heightened interest in aviation's noise and air-quality impacts as well as greenhouse-gas emissions, and the need for forecasts at the local as well as strategic level. To continue to provide robust policy-testing forecasts into the future the model needs to be correspondingly updated and, so far as practicable, future-proofed.

13.1.3 With this in mind, the Ministry of Transport, Public Works and Water Management of the Netherlands had previously appointed members of the SAVE Consortium to design a potential successor model to the AERO-MS. Known as "**AERO*plus***", it would introduce enhancements in the following areas:

- ***Broadening policy application to address noise and air quality issues*** as well as greenhouse-gas emissions;
- ***Greater differentiation of aircraft technology***, to improve modelling of compliance with stringencies and of trade-offs between policy goals;
- ***Forecasting horizons to estimate transition effects*** as well as end-states of measures;
- ***Differentiating carrier business models*** and ***allowing for carrier competition***;
- ***Modelling impacts at a more localised level***.

13.1.4 These matters have been re-considered in WP9, though not in the context of a successor model to the AERO-MS so much as what of these might be achievable within the existing basic structure of the AERO-MS.

13.1.5 The following additional topics were identified at the time of the Interim Report:

- ***Consideration of LCCs,*** since it proved not to be possible to include LCCs as a separate movement type within the AERO-MS update;
- ***Intermediate stops to reduce exposure to Emissions Trading Scheme***;
- ***Effect on growth of airport capacity constraints;***
- ***Levying taxes at individual airports***, rather than region-wide;

- ***Take-up of Alternative Fuels***, and its impact on fuel prices and capital costs.
- ***Operational measures to reduce cirrus cloud formation,*** and their commercial consequences;
- ***Links to local models***; these are more fully discussed in Chapter 14.

13.1.6 Subsequently, further issues emerged for consideration in WP9:

- ***Incorporating noise characteristics*** of generic aircraft types;
- ***Detour factors***: the extent to which flights deviate from direct routings;
- ***Aircraft retirement functions***, which are highly influential in the pace of technology penetration into the aircraft fleet;
- ***Suggested improvements to the WISDOM database***, following from its extensive use in updating the Unified Database;
- ***Forecasting fuel price impacts in the Datum case***, instead of this being defined by the model-user;
- ***Additional mappings and interface issues***, to assist the model-user;
- ***Resolving how BADA might support FLEM or use of AEM***.

13.1.7 In conjunction with EASA, all the issues identified for consideration in WP9 were prioritised. The highest priority was accorded to the last topic: resolving the issues in using BADA to support FLEM. This is extremely important for assuring long term applicability and value for the AERO-MS.

13.1.8 The table below summarises the Consortium's perceptions of benefits, costs and priorities of the WP9 issues. Following the table, the topics are discussed in priority order.

13.1.9 Cost levels are defined as follows:

- Low cost = 1 - 3 person-months
- Medium cost = 3 - 6 person-months
- High cost = 6+ person-months.

Table 13.1 Priorities for WP9

Topic Area	Benefits	Issues	Cost	Priorities
Resolving how BADA might support FLEM or use of AEM	Vital to long term future of AERO-MS	Make best use of new BADA	High	**Top**
Enhancing aircraft retirement functions	Represent fleet development more plausibly	Freighter impacts are better represented	Low	**High**
Suggested improvements to WISDOM	Client requirement. Improved data input to reduce pre-processing requirements	Need to coordinate with EUROCONTROL and Volpe on potential future work items.	Low	**High**
Incorporating noise characteristics	Noise impacts important to client. Enables assessment of noise trade-offs from emissions MBMs.	Links to other topics	Medium	**High**
Refining aircraft technology characteristics within existing model structure	Allow the impacts of emission-reduction policies to be forecast at a greater degree of granularity.	Links to other topics	High	**High**
Effect on growth of airport capacity constraints	Provide forecasts of ATMs within airport capacity, for input to local (e.g. noise) models	Links to other topics	Med-High	**High**
Forecasting fuel price impacts in the Datum case	Important for client	Feedback fuel-price policy outputs as a new Datum	Medium	**High**
Differentiating carrier business models and allowing for carrier competition	Improved characterisation and validation of current and future LCC sector and representation of carrier competition	Existing model already has good features	Medium	**Medium**
Forecasting horizons for transition effects	Forecasts for different years, especially in shorter term	Examine features of existing partially implemented sub-model	Medium	**Medium**
Detour factors	SESAR, GHG more accurately estimated	Scope within existing model to represent Datum scenarios, but Policy effects more complex	Medium	**Medium**
Additional mappings and interface issues	Ease of model use	Expect data-handling improvements as need arises	Low	**Medium**
Levying taxes/charges at individual airports	Relevant to existing policies which have been implemented at Member State level		Low-Med	**Low**
Intermediate stops to reduce exposure to Emissions Trading Scheme	Impacts of ETS on carriers' hubbing strategy and competition	Lack of certainty in how the network would evolve	Med-High	**Low**
Refine aircraft technology characteristics	Improved granularity in fleet representation through time	Requires model re-structure	Very High	**Very low**
Take-up of alternative fuels	Not priority for client		n/a	**Very low**
Operational measures to reduce cirrus cloud formation	Not priority for client		n/a	**Very low**

TOP PRIORITY

13.2 Resolving How BADA Might Support FLEM or use of AEM

13.2.1 As described in Chapter 8, major effort was put into a feasibility study to investigate the use of EUROCONTROL's BADA3.7 for supporting FLEM. While much of the data required by FLEM could be sourced from BADA3.7 (supplemented by other sources), it was found that critical FLEM variables could not be populated from BADA3.7. In consequence it has not been possible to update all the characteristics of the "reference" aircraft that FLEM uses to represent the AERO-MS generic aircraft-types in computing their flight trajectories in three-dimensional space. It has been possible to update only – though importantly – the fuel consumption and emission factors of the reference aircraft.

13.2.2 The difficulties encountered in using BADA in FLEM need to be resolved. This is top priority to sustain the general functioning and long term future of the AERO-MS as a trade-off tool of environmental and economic impacts. In discussion between the Consortium, EUROCONTROL and EASA, it was recognised that BADA3.7 could not deliver the amount of detail that FLEM requires. Two courses of action were advanced to resolve the issues:

- Resolution of issues in using BADA within existing FLEM module;
- Incorporation of FLEM capabilities within next-generation version of EUROCONTROL's Advanced Emissions Model (AEM).

13.2.3 With regard to resolving the difficulties of using BADA data, EUROCONTROL is currently working on BADA4.0 which would deliver a greater level of detail than BADA3.7. EUROCONTROL expects that BADA4.0 could deliver most of the data required by FLEM but not all. For FLEM critical variables such as lift and drag, it is expected that BADA4.0 could not directly deliver the required information because the aircraft performance model design philosophy is different in BADA and FLEM. Two options to overcome this were identified:

- Adjust (simplify) the FLEM model to allow calculations based on kinetics and hence the BADA4.0 (like) input data. Depending on the exact contents of BADA4.0, this requires a redesign of FLEM.
- Use BADA4.0 data to derive the necessary inputs on the (kinematic) data for FLEM. Based on the BADA4.0 generated flight profiles the thrust, drag lift and fuel flow need to be extracted using additional sources.

13.2.4 An important consideration is that BADA4.0 contains commercially sensitive information, and is being developed in close cooperation with manufacturers. It is likely, therefore, that access to BADA4.0 would be restricted.

13.2.5 The two options mentioned here are not further developed within the SAVE project. However, it is advised to further investigate the options in detail in order to identify the most favourable option. For the investigation, access to the exact contents of BADA4.0 is required.

13.2.6 The second possible solution is to incorporate FLEM capabilities within the next generation of the AEM which is planned to be developed within the SESAR work programme. FLEM capabilities that are currently not built into AEM include generation of flight profiles and ability to assess operational policy options.

13.2.7 To progress the possible inclusion of FLEM capabilities in the AEM, the Consortium would assist EUROCONTROL to identify more clearly the gaps between FLEM and AEM such that it could be used within AERO. This will enable EUROCONTROL to decide whether to include additional FLEM capabilities in the next generation of AEM.

13.2.8 The capabilities of FLEM that are currently not currently integrated into AEM are related to generating flight profiles, incorporating future aircraft and dealing with operational policy options. Those three functions are now discussed here individually.

Generating flight profiles

13.2.9 FLEM: A flight profile describes the distance and altitude that an aircraft flies along during a flight. The flight profile model is composed of several flight phases (see figure 13.1). The flight phases taxi-out, takeoff, climb out, final approach, landing and taxi-in are in accordance with the standard ICAO LTO cycle. In other flight phases the flight profiles in terms of altitude, speed, thrust and fuel flow as a function of actual flight distance, are calculated by FLEM (Ref. 1, see paragraph 13.2.14 for references). Step climbs in cruise flight is also a feasibility within FLEM. Flight profiles are generated for each reference aircraft and airport/city pair using great circle distance (with a detour factor) and detailed aircraft characteristics.

13.2.10 AEM: The design philosophy of AEM is that the flight trajectory is defined outside of the tool. This provides flexibility in the way the tool can be used. For example for studies where it is important to take into account where the aircraft flies – one can use WISDOM. For simpler studies – one can simply define a very basic trajectory with a few flight segments. It allows data to be presented to it from many sources (e.g. radar, flight planning), and with different levels of complexity. Other EUROCONTROL tools exist which can develop accurate flight profiles as input into AEM. All phases of flight can be addressed by AEM. (See Para. 13.2.14 Ref. 2, 3 and 4)

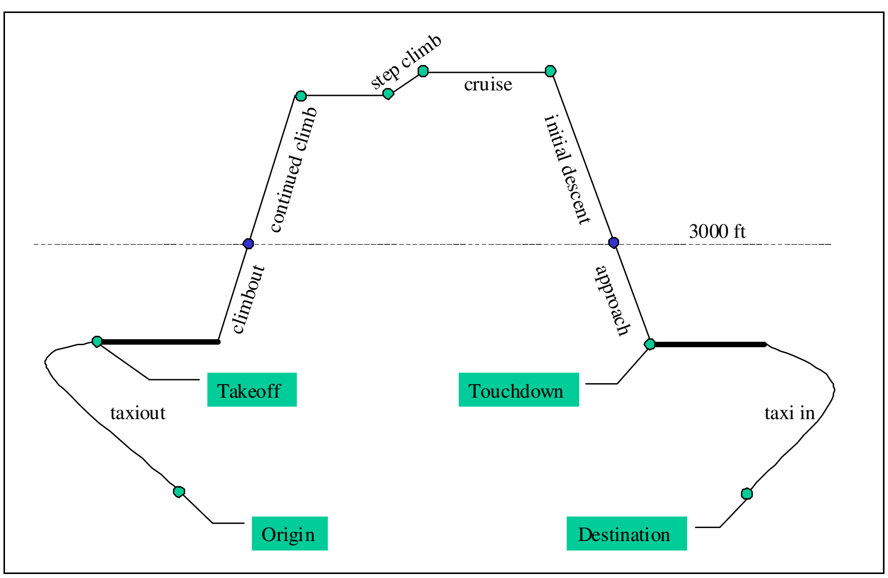

Figure 13.1 Flight Profiles

Incorporating future aircraft

13.2.11 FLEM: The capability of incorporating characteristics of future aircraft in AERO is essential for the execution of policy analysis studies. Data on these future aircraft types which are not yet on the market are generally not available. Characteristics of future fleet are determined by the Aircraft Technology (ATEC) model. FLEM uses technology factors on fuel flow and emissions determined by ATEC to be able to incorporate future aircraft within the calculation of fuel flow and emissions. Future aircraft might also have a larger range than the reference aircraft used in FLEM. Consequently, FLEM needs to process flights that cannot be operated with aircraft having averaged characteristics, but are in fact operated with better than reference aircraft characteristics. A special procedure allows scaling (re-sizing) of the generic aircraft for the given mission while at the same time preserving the primary average technology characteristics such as weight to thrust ratio, fuel use per unit thrust, lift to drag ratios and wing loading (Ref. 1).

13.2.12 AEM: As an input, AEM uses aircraft and engines currently modelled in BADA and ICAO emission databank (Ref. 3). Future aircraft and engines type, with modified emissions characteristics, could be created from the static data sources which AEM uses.

Dealing with operational policy options

13.2.13 FLEM: In order to investigate the possibilities of lowering the environmental impact and the costs accompanied, operational policy options can be studied using AERO. These operational policy options are for instance flying higher, lower, faster or slower. All these options have an impact on the flight profile of an aircraft. FLEM is able to deal with those operational policy options that have an impact on flight profile. The effect on fuel burn and emissions (and therefore economics) and/or the distribution of emissions in the three dimensional atmosphere of a certain operational policy option can consequently be calculated using FLEM. The available operational policies in FLEM which affect the flight profiling are (Ref. 1):

- Flight level limits to simulate flight level restrictions to the flight profile (affecting the flight level at cruise altitude), implying that aircraft may not be able to fly at the optimal altitude for minimum fuel use and/or emissions. The 'flight level limit' can be used to simulate flight restrictions on the altitude profile (per region pair). This limit will have an impact on the fuel use and emissions. This limit, if in effect, prevents aircraft to fly (near-) optimal altitudes.
- The 'cruise Mach number factor' is a multiplier on the maximum cruise Mach number (set per aircraft type and technology level). This factor can be used to simulate flight speed restrictions in terms of Mach number during cruise flight phase. This factor allows studying the emissions and fuel use effects for variations in the aircraft cruise speeds.
- The airspeed might be restricted in terms of maximum Mach number by the maximum true air speed. The effect of such a speed limit is similar to a 'cruise Mach number factor' that reduces airspeed.
- The angle of climb and/or descent may be increased or decreased by a factor to reflect e.g. noise abatement procedures. This policy can be used to simulate the effects of a different flight path angle during the descent or climb flight phases.

- Detouring might be increased or decreased by a factor, reflecting air traffic congestion and efficiency improvements in the ATC system.
- Tankering: an (airline) policy to exploit regional fuel price differences, hence minimise fuel costs, by taking extra (low priced) fuel onboard for the subsequent flight.
- Aircraft aerodynamics changes, to reflect the impact of technological advances or constraints. This measure is similar to a fuel improvement measure. The 'zero-lift drag factor' is a multiplier on the drag coefficient at zero-lift (per aircraft type and technology level). This factor can be used to simulate a future change or improvement in drag.
- The climb speed factor can be used to simulate the effects of a different speed during the climb-out flight phase, e.g. to simulate flight restrictions on the speed during the climb-out flight phase or to reduce the time spent in climb but at a higher thrust setting.

13.2.14 AEM: As per the generation of flight profiles, operational changes are modelled by EUROCONTROL in either real time or fast time simulators. The outputs are then provided as input to AEM in order to calculate fuel burn and consequent emissions. The simulators have a good aircraft performance model within them so that detailed trajectories are produced as output. Many assessments of environmental benefits from operational changes have been conducted within EUROCONTROL using this approach.

13.2.15 The following sources were consulted for identifying the capabilities of FLEM that are currently not covered by AEM:

- 1. J. Middel, T.D. de Witte, Aviation Emissions and Evaluation of Reduction Options (AERO)- FLights and EMissions model (FLEM), General report and technical documentation, NLR-CR-2001-100, march 2001
- 2. Frank Jelinek, Sandrine Carlier, James Smith, Advanced Emission Model (AEM3) v1.5, Validation Report, EEC Report EEC/SEE/2004/004
- 3. EUROCONTROL, AEM III Release 2.0 User Guide Version 1.2, EUROCONTROL Experimental Centre, April 2009
- 4. EUROCONTROL e-mail correspondence, October 2010

HIGH PRIORITY

13.3 Enhancing Aircraft Retirement Functions

13.3.1 There are five different FESG retirement curves, four for passenger aircraft and one for freighter aircraft. The four passenger aircraft retirement curves are specified for MD11's, B727 and B720, all first generation aircraft and all other passenger aircraft operation.

13.3.2 Currently, the AERO-MS makes use of FESG retirement curves, but these appear to severely constrain the ability of the model to represent the base-year fleet accurately and hence plausible fleet development scenarios. It is a high priority to improve this position to maintain the value of the model.

13.3.3 The FESG retirement curve describes the percentage of (passenger) aircraft that is being retired as a function of years in service. This curve is currently implemented in the AERO-MS and acts on both the passenger and the freighter aircraft fleets. This is due to the fact that the current Aircraft Technology model is capable to hold one single retirement curve. Therefore distinction in terms of retirement curves between different aircraft types and/or aircraft purpose is not possible.

13.3.4 It is known that this implemented curve (for passenger aircraft) is significantly different from that of the freighter aircraft. Many of the freighter aircraft are converted from passenger aircraft that have been taken out of service. This implies that the fleet build-up in terms of technology, costs, lifespan is vastly different from the passenger fleet. The lack of a separate curve for freighters in the AERO-MS makes it very hard to find reasonable estimates for the freighter fleet properties, i.e. build-up, capital and operating costs, the operations and emissions.

13.3.5 Introduction of a special freighter dedicated retirement curve (parallel to the passenger fleet retirement curve) would give much better estimates of all freighter fleet properties. This would also allow to better judge the impacts of policy making on freighter operations and the dedicated cargo business separately.

13.3.6 This update fits within the existing model structure. The dimension aircraft purpose needs to be added to a number of ATEC variables related to the retirement functions. Furthermore, software changes to ATEC are required.

13.4 Suggestions for Improvements to WISDOM

13.4.1 The existing Unified Database (base year 1992) was populated using a selection of data sources, but for the update of the Database to a 2006 base year, carried out as part of the SAVE project, it was decided that the Consortium should utilise data contained in the WISDOM Operations Database, a resource developed collaboratively with input from both European and US agencies (EUROCONTROL and Volpe).

13.4.2 WISDOM is regarded as the definitive source of global aviation activity, and as such would be used as the sole source of movement data for the update of the Unified Database. However, in processing the WISDOM data, it was recognised that there were a number of key areas where improvements would facilitate improved accuracy and ease of development for future updates to the Unified Database. This task is assigned high priority under the Work Package 9 banner.

13.4.3 Two main issues became evident in the processing of WISDOM data in order to create the updated Unified Database. Firstly, there were areas where minor coding inconsistencies were identified in the data. These inconsistencies are likely the result of the fact that WISDOM is compiled from a number of different sources, each using slightly different notation for certain departure and arrival airport codes, aircraft types and carrier codes. As a result of this, it was necessary to perform a large number of manual checks and updates to the data, the need for which could be eliminated at source, given common coding conventions.

13.4.4 Secondly, there were also instances where the variables contained in the version of WISDOM that was supplied to the Consortium could not completely fulfil the data requirements of the Unified Database. The following paragraphs present a list of the information **not** contained in the current version of WISDOM, but which if available in future would greatly improve the representation of aviation activity for the purposes of economic modelling such as the AERO-MS performs.

Movement Type Information

13.4.5 Because of the differing responses of different traffic segments to policy measures, as well as their different rates of development through time, the AERO-MS requires the segmentation of global aviation movements by scheduled and charter, and by passenger and cargo movements. However, the sample of WISDOM data supplied to MVA contained no information on movement type.

13.4.6 For this update of the Unified Database, movement type information was inferred by defining a primary "nature" (scheduled/charter) and "function" (passenger/cargo) to each carrier. However, this method does not account for airlines which operate both passenger-only and cargo-only services, or offer a combination of scheduled and charter services, only allowing them to be classified to a single grouping.

13.4.7 If a future version of the WISDOM included data on the movement type, separating passenger and cargo services, identifying movements by low cost carriers, and differentiating those movements which are scheduled from those which are charter, it would facilitate more accurate forecasting of the development of the aviation sector and the impact of policy measures on it.

Geographic Context

13.4.8 In addition to the departure and arrival codes provided in the WISDOM dataset, the Unified Database required detailed geographic information, which was provided to MVA by EUROCONTROL as an external correspondence source. It would be beneficial for future updates to the Unified Database if WISDOM were able to contain information which could act as a cross-check.

13.4.9 For example, any information which could be made available on actual distances flown by movement would act as a check for the distances calculated using latitudes and longitudes of departure and arrival airports, and information on the city or country of departure and arrival (in addition to the departure and arrival airport code) would allow similar checks on the distribution of flight stages to AERO-MS regions and route groups.

Aircraft Type Information

13.4.10 WISDOM does contain information on aircraft type which was used to allocate movements to the generic aircraft classes contained within the AERO-MS, but does not specifically denote passenger and freighter variants of the same airframe. If this information were included, it could be used in conjunction with the movement type information discussed above to improve segmentation of movement data, and therefore the responsiveness of the AERO-MS.

13.4.11 Similarly, the current version of WISDOM contains no information on payload, aircraft capacity information or take-off weight, which if included could be utilised in conjunction with the demand data requirements outlined below to determine load factors within the AERO-MS.

Demand Data

13.4.12 The Unified Database provides information not only on aircraft movements, but also on the number of passengers and the volume of freight transported. However, the WISDOM sample contained only movement information, with no associated demand data which could be used to populate the Unified Database.

13.4.13 For this update to the Unified Database, demand data was identified in other data sources (ICAO Traffic by Flight Stage [TFS] data and US Department of Transport T-100), and combined with WISDOM movement data to complete the Unified Database.

13.4.14 If a future version of WISDOM included data on the number of passengers and volumes of cargo carried on each movement, this would improve the validity of the Unified Database as it would not require demand data to be estimated using external data sources.

Conclusion

13.4.15 The provision of movement type information, additional geographic context and aircraft type information, as well as the possibility of passenger/freight demand and capacity information would greatly improve the functionality of WISDOM with respect to future updates of the Unified Database. It would reduce the amount of time spent ensuring harmonisation between WISDOM and supplementary datasets, and could lead to improved classification and categorisation of aviation movements.

13.4.16 However, it is recognised by the Consortium that the original data sources (air navigation service providers) may have no interest or capability to provide "better" data which is more suited to the requirements of the AERO-MS.

13.5 Incorporating Noise Characteristics

13.5.1 Enabling the AERO-MS to address noise implications of GHG policies and – if practical – the market implications of noise policies themselves is important to EASA. Incorporating noise characteristics is thus a high-priority topic.

13.5.2 Two complementary approaches are proposed. One would pass forecasts of aircraft movements by generic type, with their noise levels estimated in the AERO-MS, to STAPES to permit calculation of future noise contours for the 27 major European airports currently included in STAPES. That approach is presented in more detail in Section 14.5.

13.5.3 In this section it is proposed that the same noise level estimates for generic aircraft types as passed to STAPES would also be used to compute a noise burden measure that could be aggregated across airports for the purpose of judging more generally whether emission reduction policies have an adverse noise impact. This would offer an important additional dimension in the evaluation of emission reduction measures.

13.5.4 The main requirement would be for noise metrics for each generic aircraft type, allowing also for the distinction between "old" and "current" technology. The noise metrics should be standard, recognised formulations, such that there could be valid accumulation of noise over the forecast number of movements by different generic types. The accumulation might be output at different levels of aggregation, though for airports in particular.

13.5.5 Noise characteristics by generic aircraft type and technology level according to the present AERO-MS concept could be specified in terms of the Effective Perceived Noise level expressed in decibel (EPNdB), as considered in the certification requirements of large subsonic aircraft types. Given the computation of an annual number of movements by aircraft type and technology level, this would allow for the computation of a simplified 'noise burden indicator'. This indicator could for example be based on the calculation of the Total Volume of Noise (TVN) according to the following standard procedure:

$$TVN = 10 * \log (\Sigma_{at,tl} (N(at,tl) * 10^{(Lavg(at,tl)/10)}))$$

where:

N(at,tl): Number of LTO-cycles per aircraft type (at) and technology level (tl)

Lavg(at,tl): Average (certificated) noise level (in EPNdB) per aircraft type (at) and technology level (tl)

13.5.6 Such noise impacts could be computed at the airport level. More aggregate applications beyond the airport level could be based on a weighted aggregation across the relevant airports in the areas considered.

13.5.7 Average certificated noise levels by generic aircraft type and technology level as considered in the AERO-MS would be needed. For the fuel use and emission characteristics, such computations presently take place in the model ATEC. These computations are based on a specification of fuel and emission characteristics by generic aircraft type and technology age (certification year) of the aircraft, driven by a user defined scenario specification. Given the projected fleet development and the related patterns of aircraft purchases and retirements in time, ATEC then computes the average technical characteristics by aircraft type and technology level associated with the technical development defined by a given scenario specification and target year. In computing these technology development patterns and resulting technical characteristics, ATEC can take into account the effects of certain policies, such as accelerated scrapping of older aircraft and the application of stricter certification standards (stringencies).

13.5.8 In principle it would be possible to include a specification of noise characteristics within the present ATEC application, e.g. in the form of a certificated noise level (EPNdB). This would allow for the computation of an average certified noise level by generic aircraft type and technology level in essentially the same way as is presently done for the fuel use and emission characteristics. As with the latter, developments in noise characteristics should be projected into the future as part of the scenario specification.

13.5.9 The noise characteristics to be associated with each generic aircraft type and technology age would have to be inferred from additional pre-processing of the PRISME fleet data, taking into account the ICAO noise certification standards that would apply to the (named) aircraft in the database. The computation of the TVN as described earlier would be based on a single certificated noise level averaged across the certificated noise levels (take-off, sideline, approach), or using the departure noise levels (the first two) and arrival metric separately.

13.5.10 While these improvements would not be trivial to implement, they would not involve any significant changes to the dimension structure of the present AERO-MS. Moreover, estimating noise levels for generic aircraft types, and projecting these into the future, would be essential in enabling STAPES to make use of the AERO-MS movements forecasts in calculating noise contours at individual airports.

13.6 Refining Aircraft Technology Characteristics Within Existing Model Structure

13.6.1 This section relates to improving the discrimination of the representation of aircraft technology characteristics within the existing structure of the AERO-MS. This would potentially allow the impacts of emission-reduction policies to be forecast at a greater degree of granularity than hitherto, and a high priority is attached to advancing this enhancement of the AERO-MS.

13.6.2 In principle, this enhancement would lead to the consideration of additional technology categories within generic aircraft types. However, the number of technology categories directly affects the dimension structures of all models and the fundamentals of the aircraft choice modelling, and the potential modifications required to the AERO-MS in consequence are expected to be substantial.

13.6.3 In the AERO-MS as updated in this project, generic aircraft-types (defined by capacity and range bands) are divided into "old" and "current" technology. This classification is achieved by allocating aircraft in the PRISME database to "old" and "current" technology according to whether their engines were certificated before or from 1991. The "old" and "current" fleets thereby identified are aggregated to the generic types so that the average characteristics relevant to fuel consumption (and CO_2 emissions) of the technology classes within each generic type can be calculated.

13.6.4 Improved granularity could be represented in the AERO-MS by sub-dividing the existing technology categories ("old" and "current") for each generic aircraft type. Further investigation will be required to determine whether an adequate number of actual aircraft types falls into each of the more refined categories to allow reasonable "average" values to be calculated. More importantly, while this modification would remain within the basic AERO-MS structure, there could be major ramifications for parameterising and calibrating some of the sub-models, such as fleet build-up in ATEC and the aircraft choice component in ADEM and ACOS. Like all models, they are heavily reliant on there being identifiable systematic relationships embedded within the "noise" of empirical data, but the greater the refinement of classification the more dominant the noise can become, especially as the samples of actual aircraft types within categories are simultaneously being reduced.

13.6.5 This risk was recognised in the specification prepared for the previously-mentioned **AERO*plus*** model, and the idea of "floating attributes" was conceived to address it. These would avoid the further disaggregation of technology levels by instead indicating the proportions of aircraft ***within*** a technology level that possessed some particular characteristic. In the **AERO*plus*** model specification, these characteristics were expected to relate primarily to noise or emission bands, with a view to identifying what proportions of generic aircraft types would meet the stringencies being tested by the model-user. These were described as "floating" attributes because the breakdown within the "fixed" technology levels would be variable between model runs, according to the measures being tested.

13.6.6 "Floating attributes" were expected to be used in connection with measures such as stringencies that define a clear boundary between compliance and non-compliance. While the distinction would not apply in the Datum (without measures) forecast, in the Policy case non-compliance would give rise to penalties, such as higher charges and operating bans, which would be reflected (for example) as an increase in the average operating cost of "old" aircraft (relative to the Datum case). Obviously, the more severe the measure, the larger the proportion of non-compliance, the greater the impact on average costs, and the stronger the incentive to shift away from "old" aircraft.

13.6.7 The essence of the "floating attributes" concept could be transferred to the AERO-MS. Some model development would be needed, but obviating the further explicit breakdown of the fleet build-up in ATEC and the aircraft choice component in ADEM and ACOS would be a compensating saving. The main difficulty, however, would be that measures associated with fuel-burn and CO_2 emissions are less frequently expressed in terms of compliance and non-compliance. It needs first to be considered, therefore, the extent to which measures to be tested through the AERO-MS could be expressed in these terms.

13.6.8 Supposing that to have been resolved, the first step would be to define compliance/ non-compliance boundaries of potential policy interest. The PRISME database would next be analysed to estimate the ***proportions*** of each generic type and technology class that fell into each of the resulting bands. These preparatory steps would allow the disaggregation of movements in the Unified Database by generic type and technology class to be further broken down by the relevant bands, as needed for the model-user's tests. Two modes of operation might be envisaged.

13.6.9 First, the model-user could set a stringency at one of the boundaries between the bands, implying that proportions of movements in each generic type and technology class would not be compliant with the stringency. To maximise consistency with the existing structure of the AERO-MS, it would be necessary to map this non-compliance with a stringency into already-available functionality in the model: in particular, the treatment of operating bans and scrapping. If it were presumed that the stringency would impact only on "old" technology aircraft (i.e. all "current" technology aircraft would be compliant), this mapping would ensure that the aircraft choice model responded appropriately to the stringency. If this presumption could not be made, further investigation would be required to determine how feasible the approach would be under the current model structure.

13.6.10 The second mode of modelling compliance/ non-compliance measures could be to allow the model-user to specify different environmental charges for different bands. Such measures might be applied through variable landing fees or route charges, subject to the spatial options that the model-user might have to test these measures.

13.6.11 Supposing that aircraft in certain bands were penalised with higher charges, the effect to be modelled would be a shift of movements from non-compliant aircraft to compliant aircraft. This could be achieved through a subsidiary aircraft-choice model. Essentially, this would estimate the appropriately revised "average" landing or route charge for each generic type and technology class in the main aircraft-choice model. It would correspondingly modify the proportions in each band, from which the revised "average" of the attribute in question for each generic type and technology class could be calculated.

13.7 Effect on Growth of Airport Capacity Constraints

13.7.1 Now that the AERO-MS represents movements by airport-pair rather than city-pair it has become more desirable to take the capacities of individual airports into account in some way.[43] This is particularly the case in the context of exporting AERO-MS forecasts of movements to "local" models for processing noise (and air quality) impacts. It would potentially negate the value of the previous sections if forecasts of movements in excess of airport capacity were being exported: hence the priority level given to this topic is high.

13.7.2 A relatively simple development might be a reporting mechanism as to when the model was forecasting movements in excess of capacity at individual airports. This would require potentially capacity-constrained airports to have their capacities in future years specified. The model would aggregate its movement forecasts at the level of individual airports, and compare these with the capacities. Any excess of (unconstrained) movements over capacity would then be reported.

13.7.3 A very promising option to deal with airport capacity constraints for the linkage between the AERO-MS and local airport models, is to make use of a toolset which is under development by DLR, and due for completion in the early part of 2011, with subsequent presentation to CAEP meetings. This will include validation, which is already in hand. Subject to appropriate interfacing, output from the AERO-MS at the airport level could be passed to this toolset for the identification of capacity constraints and the dispersal or suppression of "excess" traffic.

13.7.4 This DLR toolset contains airport capacity and re-routing modules. The first module outputs the existing capacity of airports and their feasible capacity in a future year, taking into account infrastructure, curfews, and political, noise and local emissions restrictions. The re-routing module re-distributes demand and traffic of airports where the projected number of movements exceed the (future) feasible capacity for airports. It takes into account, if available, the unconstrained capacity of neighbouring airports. A distinction is made between various market segments of demand, the main distinction being between the re-routing of originating passenger demand and transfer passenger demand.

13.7.5 The DLR tool set has been designed as a standalone development which basically allows to feed in unconstrained movements on an airport-pair basis and delivers as output the constrained movements in the form of an updated airport-pair table. To establish the linkage between the AERO-MS and the DLR tool set, an interface would be required to export the movements from the AERO-MS into a format which can be imported by the DLR tool set.

[43] This has become more significant in the UK, at least, in recent weeks, following the announcement of the present government that all runway proposals for the main London airports have been cancelled.

13.7.6 Since the DLR model covers the 500 largest airports in the world, and 80% of the AERO-MS Unified Database's 33 million flights for 2006 are to or from the 500 largest airports, airport capacity constraints in relation to about 80% of global air traffic would be covered. It can be reasonably assumed, moreover, that most of the other airports do not have capacity constraints, so their omission from this treatment will not compromise the overall findings or results for individual constrained airports.

13.7.7 The output of the DLR tool set (in terms of the number of movements per airport) can be used by the airport tools (STAPES, ALAQS) to assess local impacts. It is expected that the DLR tool set will only significantly change the outputs (and thereby the impacts) at an airport level. Generally it is not expected that the economic and environmental impacts at a global and regional level, as computed by the AERO-MS, will significantly change when the capacity constraint consequences assessed by the DLR tool set are taken into account. For the environmental impacts this expectation can be easily tested by feeding the updated airport-pair table into FLEM instead of the original airport-pair table computed by the AERO-MS.

13.8 Forecasting Fuel Price Impacts in the Datum Case

13.8.1 EASA regards the introduction of this capability with high priority.

13.8.2 The effects of changes in fuel costs due to (for example) fuel taxation can already be investigated in Policy forecasts. It is important for consistency that the identical effects would be forecast if a given fuel-cost change occurred in the Datum case, due to a fuel-price change.

13.8.3 This consistency would be assured if the outcome of a Policy forecast inclusive of fuel-cost changes could be fed back into the model to adjust the Datum value of relevant variables to represent the effects of the fuel-cost changes in the Datum case. Facilitating this is a matter of "case management". Each model run is defined as a "case", inclusive of its required inputs and its outputs; what is required here is a mechanism that allows the relevant output of the selected Forecast run to become part of the input of the Datum run of interest. Further investigation would be needed, however, to establish how to exactly implement it.

13.8.4 An alternative way forward could be that in the ADEM model an additional scenario variable is defined. This scenario variable could be a 'flag' which can be set by the user with two distinct meanings:

13.8.5 Fuel price costs increases within Datum case (and other unit cost increases) are not passed on into passenger fares and freight rates. It is left up to the AERO-MS user to define fare changes as part of a scenario; this setting thus reflects the current principle adopted in an AERO-MS Datum run.

13.8.6 Fuel price cost increases within Datum case (and other unit cost increases) are incorporated in passenger fares and freight rates, whereby the AERO-MS assesses the extent by which fares have to go up to fully include the unit cost increases. A similar principle is adopted as in a Forecast run where the default assumption is that increases in unit costs are passed on to consumers.

13.8.7 However, it is not clear at this stage how easy it would be to implement the new variable.

13.8.8 Thus two approaches appear to be possible though both need to be further explored in order to be able to decide which is the most appropriate to implement.

MEDIUM PRIORITY

13.9 Differentiating Carrier Business Models and Allowing for Carrier Competition

13.9.1 Since the formulation of the original AERO-MS, there have been major developments in the business models applied among airlines, most notably the rapid growth of low-cost carriers and – not unrelated – the decline of the inclusive-tour or charter market. It is clearly important that these developments are recognised in a fully up-to-date AERO-MS. While one of the motivations of the proposed new model structure, **AERO*plus***, was to allow more comprehensively for these developments, several essential elements are already available in the existing AERO-MS model, as described below, and it may therefore not need to be as high a priority to advance these further as was previously thought.. For these reasons, this topic is given a medium priority.

13.9.2 In accordance with the historical position, the AERO-MS has always included two distinct business models, in effect: scheduled and non-scheduled (or charter). The AERO-MS differentiates these in terms of cost structures, fare levels, and demand response (elasticity) to fare changes. During the current SAVE project it was hoped to be able to create a third category of business model (carrier-type) in the AERO-MS, specifically to accommodate LCCs (see the Interim Report, Memo 6), but this turned out to be more complex than the current project could support. However, reflecting that LCCs have much in common with charter operators (for example, cost levels, fares, load factors, demand elasticities and aircraft utilisation), it was agreed with EASA that a reasonable means of recognising the distinction between LCCs and full-service carriers (FSCs) was to reserve the "scheduled" category in the AERO-MS for FSCs and put LCCs in the (hitherto) "charter" category.

13.9.3 This bundling of actual charter and low-cost operations is perhaps more than a modelling convenience in that LCC demand does appear to have grown at the expense of charter activity (For example, from the UK to the rest of the EU over the period 1996-2005, charter traffic levels were static at 25 mppa, while LCC traffic rose from 3 to 51 mppa (CAA CAP770, Figure 2.4). It may therefore be reasonable to link the two types of operation for the purpose of projecting their combined growth. This will net out the apparent substitution of low-cost for charter demand, as well as allowing for absolute growth in LCC operations.

13.9.4 Formally, the AERO-MS cannot model competition between business models: essentially, between LCCs and FSCs, and major changes would be needed to the model structure to introduce this feature explicitly. However, the extent of competition in reality between LCCs and FSCs is far from clear. Where low-cost operations figure prominently, the evidence appears to be that most of their demand is generated; had low-cost flights not been available, a large proportion of low-cost passengers would not have flown. (Albeit that demand growth for FSCs has slackened as LCC demand has grown, data show a positive correlation between air traffic growth from the UK to individual countries and the share that LCCs carry of that traffic, and between 2000 and 2005 LCC services added more than 200 UK-EU airport-pairs to the 140 or so operated by network-carriers, without materially reducing the latter number (MVA commentary on data presented in CAA CAP770).)

13.9.5 Thus a reasonably realistic representation of the future balance between LCC and FSC traffic might still be achieved in the AERO-MS by assuming different growth rates of demand for the carrier-types. At present this facility is not available in the model, but a proxy might be achieved through the separate growth rates for business and leisure passengers that are allowed for, with FSCs being presumed to carry both passenger segments and charter/LCCs only leisure passengers.

13.9.6 In terms of responsiveness to measures – especially those affecting costs and/or fares – there is no facility in the AERO-MS for down- or up-trading, either between classes within scheduled, or between scheduled and charter (and therefore also not between FSCs and LCCs). Each class simply has a different demand elasticity. However, these elasticities have an empirical basis in which the observed data will have implicitly contained the net effects of shifts between classes (as well as between making and not making journeys).

13.9.7 The differential responsiveness of demand not only depends upon elasticities but also on the proportional size of fare changes. In turn, these will often be related to proportional changes in costs. For example, the lower the cost base of a carrier, the greater the ***proportional*** impact of a given increase in fuel prices. It will therefore be helpful to check that the cost differentials between LCCs and FSCs are fully represented in the AERO-MS.

13.9.8 The upshot is that there appears to be merit in continuing to combine LCC and charter operations for the purpose of modelling in the AERO-MS, bearing in mind that the tendency has been for LCC activity to substitute rather than complement charter operations. Preceding paragraphs indicate, however, that there are some changes that might usefully be made to represent LCC activity more specifically where it has come to dominate the combination of LCC and charter operations.

13.9.9 As a separate point, the AERO-MS has the capability of discriminating the impact of EU (only) measures on EU and non-EU carriers. The theoretical basis of this capability is the "Cournot equilibrium" of duopolistic competition. While this basis remains appropriate, details of its implementation may merit re-appraisal.

13.10 Forecasting Horizons for Transition Effects

13.10.1 The AERO-MS is a "snapshot" tool. It forecasts for a user-selected future year as the difference between policies and measures being in place in that year and a Datum case in which the policies or measures have not been introduced.

13.10.2 The model-user can investigate the profile through time of this difference, simply by running the model for each of a series of future years. Subject to the considerations below, there may be a case for facilitating this, by (for example) accumulating results from successive runs in a comparable manner.

13.10.3 The current presumption is that, for every modelled year, the with-measures situation is in equilibrium in the sense that response to the measures is complete and no longer working its way through (e.g.) aircraft fleet acquisition. It would be desirable also to be able to model shorter-term transitional effects of measures.

13.10.4 The model in fact already includes an earlier attempt at implementing such a capability. It recognises that, to achieve the full adjustment to policy measures which the standard operation of the AERO-MS represents, a sales growth curve for adding new aircraft to the fleet (and a corresponding rate of retirement of older aircraft) is implied. In essence, the mechanism considers what proportion of this sales growth would in practice be achievable in the period between the year in which policy measures are "announced" and the model-user's selected forecast year. While the mechanism was never fully tested and is not currently operational, it could be investigated to establish whether it could form a viable basis for shorter-term forecasting.

13.10.5 Two specific issues arise in shorter-term forecasting:

- Not only would response to measures be in transition but also reaction to Datum characteristics, notably economic cycles and fuel-price changes;
- If measures are tending to restrain demand growth and hence fleet growth, what should the balance be between reducing the rate of new aircraft purchase and increasing the rate of aircraft disposal?

13.10.6 Fully to accommodate a shorter-term forecasting capability would require a different model structure in which fleet evolution (aircraft acquisitions and retirements) is forecast year-on-year, as proposed for the **AERO*plus*** model. On the assumption that that this scale of model development cannot currently be considered, forecasting for different time horizons will rely on deploying "smartly" the existing processes of the AERO-MS. Any refinement of these (within the existing structure) would therefore be a medium priority.

13.11 Detour Factors

13.11.1 At present in the AERO-MS, detour factors vary between region pairs based on information from IEOGG (see section 8.4). Distance is not in fact increased, since the three-dimensional flight profiles generated by FLEM do not vary in response to the detour factor. Rather, the time spent is increased, this giving rise to the increased fuel consumption that is the primary intention of the detour factors in their present role.

13.11.2 Given a firmer basis for the extent of "average" detouring by region-pair and aircraft-type, the detour factors in the AERO-MS could be differentiated more finely between region-pairs and aircraft-types.

13.11.3 A more application-oriented approach would be to have Datum values reflect changes in ATM performance between the base and forecast years. With ATM development, lower factors might be appropriate. This could relate especially to SESAR, given the client's European perspective and also EUROCONTROL's central interest in the SAVE project.

13.11.4 A new variable – to be used multiplicatively with the existing variable – might allow specifically for ATM performance changes. This variable could allow for more localised spatial application.

13.11.5 It should be noted that the foregoing would be suitable as a ***Datum*** representation of ATM performance changes, but would need substantial further development if ATM improvements were to be assessed as a ***Policy***. This is because implementation and operating costs of the improvement would need to be included as part of the policy package, against which the benefits (in reduced fuel-burn, lower emissions, improved aircraft utilisation, passenger time-savings,…) could be measured. It is not immediately clear what costs there would be, or how they would be paid for, though possibilities are route charges or landing fees to cover ANSP implementation and operating costs and aircraft purchase costs to cover new navigational equipment.

13.11.6 Given the foregoing considerations, a medium priority level is appropriate.

13.12 Additional Mappings and Interface Issues

13.12.1 Additional mappings and improving the interface would assist the AERO-MS user. The following are suggested.

13.12.2 Mapping from flight stages to the 23 route-groups used by CAEP for the presentation of outputs: given EASA's objective of addressing the issues raised by CAEP and the straightforward nature of this task, there is little question that it should be implemented, and therefore this has already been done.

13.12.3 Mapping directly from airports to countries, and from flight-stages to country-pairs: this also appears to be straightforward. Including this dimension would allow for the specification of a policy measure (for which the related AERO-MS variable is dimensioned by flight stage) for any subset of country pairs. Moreover, outputs by flight stage could be aggregated to the level of country pair. A possible caveat is that, if national boundaries were to change, and cities thereby changed countries, there would be the additional task of also changing the countries of airports, which under the existing mapping is implicit through the association of airports with cities.

13.12.4 A mapping option to simultaneously consider two mapping dimensions in splitting flight stage outputs, one mapping dimension always pertaining to the split in international versus domestic traffic: this would allow results by a matrix of (for example) region-pair and international/domestic traffic to be reported. Intra-regional results (e.g. Intra EU) would also be split into domestic and international. (In a past project where the AERO-MS was used, something along these lines was implemented tentatively. This could be revitalised in the updated AERO-MS in a more structured way.)

13.12.5 Labelling flight stages at the user-interface rather than just numbering them: this also looks to be relatively simple to implement, though the form of "labelling" would need to be determined. It is also worth considering whether being able to identify individual flight stages more easily risks the implication that it is reasonable to interrogate the AERO-MS's forecasts for flight stages individually, rather than treat them as building blocks for reliable forecasts at a more aggregate level.

13.12.6 Many variables have to be populated in the AERO-MS, categorised as "input", "assumption", "scenario" or "policy" variables. This categorisation can affect the flexibility with which the variables can be specified or employed by the model-user. In the light of much experience of applying the AERO-MS, it is appropriate to consider whether any variables should be re-categorised.

13.12.7 While none of the improvements in this section is vital, they represent an ongoing strand of desirable data-handling developments, for which some provision should be made. The topic has therefore been accorded medium priority.

LOW PRIORITY

13.13 Levying Taxes/Charges at Individual Airports

13.13.1 There are two issues for this possible development:

- Dimension the airport-charge policy variable by airport rather than region;
- Take account of traffic being diverted to competing airports from airports where charges are imposed.

13.13.2 Implementing the first of these without the second would give a distorted picture of the effects of charges at individual airports. Either the impact on the individual airports would be understated (and the revenue benefits of the charge thereby overstated), or the effects on traffic restraint as a whole (across all airports) would be too severe.

13.13.3 It may be possible to make use of the principles of the model's existing "Amsterdam-only" capability, which includes diversion of traffic between airports. However, there would be additional complexity not only in expanding the arrangement to cover other individual airports (which for each one requires interaction with a set of competitor airports), but also in allowing for "cross-competition" between airports that are affected by the same measure.

13.13.4 In the light of this complexity, and since providing for taxes or charges at individual airports is not at present a topic of major interest to EASA, it is accorded only a low priority.

13.13.5 That said, there is greater interest in the possibility of applying taxes or charges at the level of EU Member States, or across the EU as a whole. The AERO-MS already provides for passenger taxation (applied directly to fares) and "landing charges" (which enter aircraft operating costs) at the world region level. These would cover EU-wide taxes and charges as they stand, and the spatial dimension could be expanded to country to allow for state-specific measures.

13.14 Intermediate Stops to Reduce Exposure to Emissions Trading Scheme

13.14.1 The specific issue here is that, when the European ETS is extended to aviation, there might be advantage to carriers in having en-route stops in their long-haul operations to/from Europe, if thereby they could significantly reduce the length of haul to which the ETS was applicable. It would not apply to flight stages with both ends outside Europe. This would appear in the first instance to benefit carriers who operate via hubs that are intermediate to longer-haul travel. Examples are Middle Eastern airlines and US carriers with eastern-seaboard hubs.

13.14.2 Potentially, such carriers would be able to gain market share from other carriers that currently provide non-stop services for that travel segment. The trade-off for travellers would be between an additional stop, with possibly a transfer, and fares that were less affected by the pass-through of ETS costs (which would apply only to the journey stage commencing or terminating in Europe).

13.14.3 There is a route-choice mechanism in the existing AERO-MS. This might be employed or modified to emulate the above trade-off and the resulting shift of traffic from non-stop to indirect routings Since the AERO-MS forecasts at the level of flight-stage, this would involve identifying the pairs of flight-stages (via specific hubs) that could substitute for non-stop flight stages.

13.14.4 If this proved to be practical, the outcome typically would be that the balance of traffic between carriers domiciled in different regions would change. The model would tend to show that the balance would shift in favour of non-European carriers.

13.14.5 However, a second effect could be that the non-stop carriers might be incentivised to introduce (non-European) stops in their very long-haul operations. While this effect would not be immediate, it could take place within the timeframe between the base and forecast years of the model. Thus it might be important to model both this and the previous response together, to avoid creating an incomplete or distorted picture of the future.

13.14.6 On the grounds that this topic would involve highly speculative assumptions regarding network development (in reality) and route choice (in the model), it justifies only a low priority in terms of model development. Given a specific ETS scenario, however, the model might be applied through suitable adjustment to input data and interpretation of outputs.

VERY LOW PRIORITY

13.15 Refine Aircraft Technology Characteristics

13.15.1 This heading relates specifically to a new model structure being required, as distinct from what might be done within the existing structure, as described in Sections 13.5 and 13.6 above. Those sections show that it seems to be possible to include in the existing structure several developments that were proposed for the **AERO*plus*** model. However, the following topics would require a new model structure:

- Explicit treatment of aircraft disposal and acquisition;
- Allowing ownership costs to be affected by fleet purchase discounts and commonality savings;
- Selecting aircraft types on individual routes by reference to payload-range envelopes.

13.15.2 The priority level for these is therefore very low.

13.16 Take-up of Alternative Fuels

13.16.1 EASA has explicitly declared that this is a very low priority at present as alternative fuels which may be available in the short/medium term will be "drop-in" fuels with similar fuel specifications to that of kerosene. Environmental benefits will come from the production rather than the combustion phase.

13.17 Operational Measures to Reduce Cirrus Cloud Formation

13.17.1 EASA has explicitly declared that this is a very low priority topic at the moment.

14 Interface of the AERO-MS with other modes

14.1 Introduction

14.1.1 EASA has requested the SAVE consortium to investigate the necessary structure and data protocols to be able to interface with EUROCONTROL environmental models and relevant elements of their Data Warehouse. The investigation will take into account past work performed within the EEMA study. The EUROCONTROL models involved are for example AEM, STAPES, and ALAQS.

14.1.2 The Advanced Emission Model (AEM) is an aircraft stand-alone system used to estimate aviation emissions and fuel burn. The System for Airport Noise Exposure Studies (STAPES) is a new aircraft noise model capable of performing multi-airport noise studies. Airport Local Air Quality Studies tool (ALAQS) contains a GIS graphical user interface for developing emission inventories and a flexible interface to different dispersion models. This provides classical LAQ analysis features enhanced to allow comparison of different inventory and dispersion methods.

14.1.3 By establishing interfaces between AERO-MS and other models, the capabilities for performing (local) environmental and economic assessments in a standardized way are further increased.

14.1.4 The interfaces are not limited to the mentioned EUROCONTROL environmental models. Interfaces with other models such as GHG climate models CTMK and Sausen, would be facilitated as well.

14.1.5 In Work Package 10 the interface facilitating export of AERO-MS data has been considered. This encompasses traffic and aircraft properties relevant to post processing (local air quality, noise, capacity, etc.). The interface with the Unified Database to accommodate traffic from the EEMA Data Warehouse has also been examined. At the same time, the compatibility and interfacing issues of AERO-MS with the prototype EEMA/EUROCONTROL input data structure and with the EUROCONTROL environmental toolset has been investigated. These matters will feed into implementation of an interface between AERO-MS and EUROCONTROL models and other models, though is not within the scope of the SAVE project.

14.1.6 The investigation has taken into account past work performed within a previous EASA project called EEMA (Environmental Modelling System for Aviation). A practical and relevant approach to bringing together Europe's aviation environmental modelling capability was developed in the EEMA project in the form of a Data Warehouse concept. This has demonstrated the feasibility and value of collecting and controlling the model input data [EEMA, 2007]. It is expected that the development of the Data Warehouse concept will progress under SESAR WP16, to support current and future aviation and environmental assessment modelling. The SESAR WP16 Data Warehouse is likely to contain both static and dynamic data and most probably will be a distributed system (geographically) bringing together different data sources in a coherent way through a single portal. It is foreseen that one major component of this Data Warehouse will be a global air traffic movement database such as WISDOM.

14.1.7 Connectivity of environmental models will also be investigated in the TEAM_Play project, focusing mainly on policy modelling issues. In TEAM_Play a Data Warehouse Platform and Harmonised Database structure will be developed to facilitate model interdependency and to provide consistent data for the various modelling components. This will also be based on the EEMA results.

14.1.8 Within TEAM_Play, SESAR WP16.3 initiatives on the data warehouse will be considered. On the other hand, in case the development in the TEAM_Play project advances prior to SESAR, the results will be taken into account in SESAR.

14.2 Background

14.2.1 The aim of the EASA EEMA study was to further develop European economic and environmental modelling capabilities in aviation environmental policy and rule making. As part of the study a prototype basic modelling system was developed, taking into account a selected set of models. The concept of a Data Warehouse was used in this system to link the various models. Using a Data Warehouse approach in this way has the advantage that no direct coupling between models has to be specified, only the interface between a model and the Data Warehouse must be specified. Furthermore, a clear separation was achieved between the data contents used for the interface and the interface protocols used. Given the general nature of the Data Warehouse approach, this approach is also a possibility for the future development of the interface between AERO-MS and the environmental models based on the SAVE results. In order to specify the interface it will then be necessary to specify the contents of the data to be stored in the Data Warehouse, the functionality required for interfacing with the Data Warehouse, and to specify the protocols used for data exchange.

14.2.2 PRISME is the EUROCONTROL Data Warehouse, offering an integrated set of data for ATM purposes. Applications for accessing data form part of the PRISME warehouse.

14.2.3 A quick review of the models under consideration, followed by a general overview of the concepts taken into account in this study are described.

14.3 Models

14.3.1 In WP10 the following systems and models have been considered: AERO-MS, AEM, STAPES, ALAQS.

14.3.2 The AERO Modelling System (AERO-MS) is a policy-testing tool for quantifying the environmental and economic consequences of measures that are anticipated to reduce emissions from aircraft. The basic data on aircraft movements are contained in the AERO-MS "Unified Database". In this project the AERO-MS has been updated, which includes an update of the Unified Database.

14.3.3 AEM (Advanced Emission Model) is an aircraft stand-alone system developed and maintained by the EUROCONTROL Experimental Centre (EEC) in Brétigny, France. The system is used to estimate aviation emissions (CO_2, H_2O, SO_x, NO_x, HC, CO, Benzene, VOC, TOG) and fuel burn. This is done by analyzing flight profile data on a flight-by-flight basis[44]

14.3.4 The STAPES project was initiated by EASA, and jointly funded by the European Commission and EUROCONTROL. The objective was to develop a new aircraft noise model capable of performing multi-airport noise studies that fully complies with the latest guidance provided by ECAC Doc.29. The model will support all types of noise impact assessments in relation to EU or ICAO future policy options, as well as any new operational concept designed under the SESAR programme[45].

14.3.5 ALAQS-AV was developed on behalf of EUROCONTROL. It is a customised Geographical Information System (GIS) application for the capture of airport pollution sources and for the processing of the different types of emission sources into a standard format in preparation for dispersion modelling.

14.3.6 The CTMK model from KNMI is a three-dimensional chemistry transport model to study the impact of aircraft emissions on the atmosphere. It is an off-line model driven by analysed ECMWF (European Centre for Medium-Range Weather Forecasts) wind fields (periodically updated). CTMK includes a chemistry module with day- and night-time chemistry.

14.3.7 Other models, such as the GHG Sausen model, have been considered as well in the current study.

14.4 Approach

14.4.1 By using open standards for the interface between AERO-MS and other models, and decoupling the interfaces as much as possible from the model itself, the maintenance for future developments would be facilitated significantly. Furthermore, by using a general approach where possible, the flexibility to establish links with other models as well would be increased.

14.4.2 The compatibility between the AERO-MS data and the data used by the environmental models, as represented e.g. in the EEMA Data Warehouse, has been investigated. Work performed in WP8, for updating the AERO-MS data access layer, has been taken into account for the interface specification in WP10.

14.4.3 Several options are available for establishing an interface between AERO-MS and the environmental models. The options range from straightforward interfaces between pairs of models to general solutions applicable for a wide range of models. The final choice of the type of interface between AERO-MS and the environmental models is still open.

14.4.4 A straightforward approach is to connect models directly, by specifying converters between pairs of models and using simple data exchange protocols. This could be extended to a more standardized approach, using e.g. an xml-based data exchange protocol.

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[44] AEM III - Advanced Emission Model III, http://www.eurocontrol.int/environment/public/standard_page/AEM.html

[45] ENVISA website, System For Airport Noise Exposure Studies – STAPES, www.env-isa.com, 31/08/2010

14.4.5 A more general approach for establishing interfaces between AERO-MS and the environmental models is the Data Warehouse approach as specified in the context of the EEMA study[46]. In the Data Warehouse approach, a Data Warehouse Layer represents the common data of the models, together with layers interacting with the Data Warehouse layer for storing and retrieving data. In EEMA, the models under consideration include AERO-MS, AEM and ALAQS. STAPES was developed after the EEMA project, however EEMA did investigate a number of additional models. For interfacing AERO-MS with other models, the model output may be stored in the Data Warehouse. In addition, also an interface from the Data Warehouse to the Unified Database is then foreseen, to retrieve traffic from the EEMA Data Warehouse. In that case a survey of both the input and the output of the models under consideration must be carried out, in order to match them to the current EEMA Data Warehouse and the current set of output categories.

14.4.6 EASA has expressed a clear preference for the general approach given in paragraph 14.4.5. For such an approach it will then be necessary to map both the AERO-MS data and the data needed for the EUROCONTROL Environmental models (AEM, STAPES, ALAQS) to the Data Warehouse contents developed under SESAR WP16. Even though the main focus is on these three environmental models, the interfaces with the CTMK and Sausen models is taken into account as well. As the Data Warehouse has not been realised yet, the level at which this is possible depends on the maturity of the SESAR WP16 Data Warehouse concept. Using the Data Warehouse approach there would be no direct coupling between AERO-MS and the models. The interface is then an overview of the data to be transferred/system architecture rather than a direct interface between models.

Data Warehouse Approach

14.4.7 In the Data Warehouse approach a Data Warehouse Layer represents the common data of the models, together with layers interacting with the Data Warehouse layer for storing and retrieving data. Figure 14.1 from the EEMA Final Report, depicts the various layers.

[46] Study on a Basic Economic and Environmental Modelling System for Aviation (EEMA) Final Report.

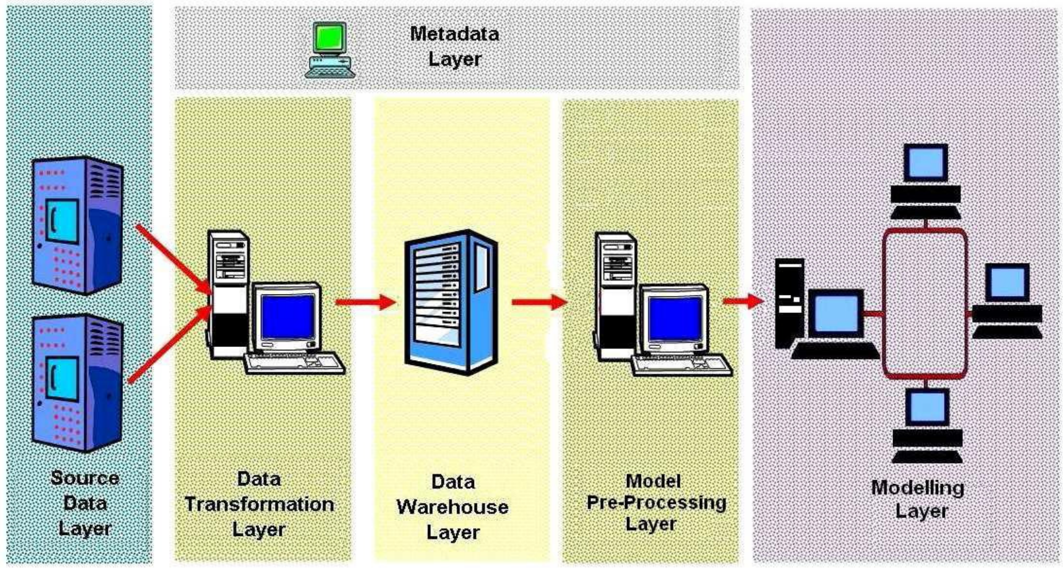

Figure 14.1 Data Warehouse and data exchange protocol[47]

14.4.8 The Source Data Layer contains all input data, with both static data (e.g. airport and aircraft data) and dynamic data (e.g. aircraft movements, meteorology, data used for scenarios and policies). Data may be supplied by experts, obtained from a UI, etc.

14.4.9 In the Data Transformation Layer the data is reformatted and transformed for import to the Data Warehouse Layer. This Data Warehouse Layer provides in one place and in one common format all relevant data.

14.4.10 Even though conceptually the Data Warehouse Layer contains all data in one place, the underlying implementation is not necessarily as one physical database. Large data files may for instance be stored as separate files, and distributed data storage over various locations may be possible.

14.4.11 In the Model Pre-Processing Layer data is transformed to specific input formats required for models. New models can then be plugged in by adding appropriate routines in this layer.

14.4.12 The Modelling Layer contains the actual models under consideration. Even though this is not explicitly represented, the output for the models is also stored in the Data Warehouse Layer, in a Model Post-Processing Layer.

14.4.13 The layers for storing and retrieving data contain functionality for each of the models to be connected with the Data Warehouse. The Metadata Layer is used to store logs, and to provide a data dictionary.

14.4.14 The existing EUROCONTROL Data Warehouse PRISME, further developed under SESAR WP16, is used below for a possible specification for interfacing the various models, including the AERO-MS.

[47] Study on a Basic Economic and Environmental Modelling System for Aviation (EEMA) Final Report.

14.4.15 The core of the Data Warehouse is the Data Warehouse Layer. This layer stores common data used by multiple models. In the EEMA Final Report[48] categories are proposed for the various types of data stored in the Data Warehouse, based on a survey of the input necessary for each model. Table 14.1 summarises these categories.

Table 14.1 Data Warehouse Categories

Category	Table Name	Description
Operations	Flight Operations	Flight Operations for various scenarios
	Flight Trajectories	Flight Trajectories for various scenarios
Aircraft & Engines	Aircraft Equivalent	Aircraft types considered equivalent
	Aircraft List	Aircraft types and data
	Aircraft-Noise Match	Aircraft NPD information
	Aerodynamic Coefficients	Aerodynamic Coefficients
	Standard LTO Profiles	Aircraft Profiles (Landing and Take-Off)
Airport	Airport Coordinates	Airport Information
	Runway Coordinates	Runway Information
Emissions	LTO Emission Rates	Various Emission Data
	LTO Times-in-Mode	Time in Approach, Taxi In/Out, Take-Off, Climb
Noise	Noise-Power-Distance Data	Available Noise-Power Distance Data
	Spectral Classes	Available Noise Spectral Data

14.4.16 These categories capture the input data of the models used. Based on the survey for the input data a Data Warehouse contents description was specified. In EEMA also surveys for the output data were conducted. These surveys were however not (yet) taken into account for the Data Warehouse contents description. Table 14.2 summarizes the survey results in relation to the models relevant for the SAVE project.

[48] Study on a Basic Economic and Environmental Modelling System for Aviation (EEMA) Final Report.

Table 14.2: EEMA Output Categories

	AERO-MS	AEM	STAPES	ALAQS	CTMK	Sausen
Flight trajectory processing	Direct	Direct	Unknown	N/A	N/A	N/A
Pollutants	Direct	Direct	N/A	Direct	N/A	N/A
Noise metrics	N/A	N/A	Direct	N/A	N/A	N/A
Groupings	Direct	Direct	Unknown	Direct	N/A	N/A
Local Air Quality regulatory metrics	N/A	Post-processing	N/A	Post-processing	Unknown	Unknown
Output geographical area	Direct	Direct	Unknown	Direct	Unknown	Unknown
Grids (emissions)	Direct / Post-processing	Direct	N/A	Direct	N/A	N/A
Grids (concentrations)	N/A	N/A	N/A	Direct	Direct	Direct
Contours	Post-processing	Post-processing	Post-processing	Post-processing	Unknown	Unknown
Economics	Direct	N/A	N/A	N/A	N/A	N/A

14.4.17 "Direct" means that the information is part of the model's output, "post-processing" means that the information can be obtained by post-processing the model's output, "unknown" means that the information is not known at the moment, and "N/A" means that the data is not available from the model. A more detailed survey, specifying the data per output field, is available in the EEMA final report[49].

14.5 AERO-MS

14.5.1 For interfacing the AERO-MS with other models, the model output could be stored in the Data Warehouse. In addition, also an interface from the Data Warehouse to the Unified Database is foreseen, to retrieve traffic from the Data Warehouse.

14.5.2 Outputs of the AERO-MS which are potentially relevant for use by other models, and could therefore be stored in the Data Warehouse, relate to the following categories:

- Air transport operations
- Air transport emissions
- Economic effects for airlines
- Other economic effects.

[49] Study on a Basic Economic and Environmental Modelling System for Aviation (EEMA) Final Report.

14.5.3 Table 14.3 provides a detailed overview of the relevant AERO-MS outputs within these various categories. The table includes the AERO-MS dimensions by which the various AERO-MS outputs are computed.

14.5.4 The four categories can be linked to categories as defined in the EEMA study. The category 'air transport operations' is defined as a Data Warehouse Category (see Table 14.1). As indicated in Table 14.2, in the EEMA study air transport emissions are referred to as 'grids (emissions)'. The economic effects for airlines and the other economic effects can be included in the EEMA output category 'economics'.

Table 14.3: Overview of AERO-MS model outputs for Data Warehouse

Output categories / output	Unit	Dimensions
Air transport operations		
Flights	flights/yr	airport pair, aircraft type, technology level, aircraft purpose
Movements	mov./yr	airport, aircraft type, technology level, aircraft purpose, arrival/departure
Air transport emissions		
CO_2 emissions	kg/yr	3-D grid (longitude/latitude cells of 1° by 1°, altitude layers of 500 m)
H_2O emissions	kg/yr	3-D grid (longitude/latitude cells of 1° by 1°, altitude layers of 500 m)
SO_2 emissions	kg/yr	3-D grid (longitude/latitude cells of 1° by 1°, altitude layers of 500 m)
C_xH_y emissions	kg/yr	3-D grid (longitude/latitude cells of 1° by 1°, altitude layers of 500 m)
CO emissions	kg/yr	3-D grid (longitude/latitude cells of 1° by 1°, altitude layers of 500 m)
NO_x emissions	kg/yr	3-D grid (longitude/latitude cells of 1° by 1°, altitude layers of 500 m)
Direct economic effects for airlines		
Passenger-km	pax-km/yr	airport pair, carrier region[50]
Freight-km	tonne-km/yr	airport pair, carrier region
Revenue tonne-km (RTK)	tonne-km/yr	airport pair, carrier region
Available tonne-km (ATK)	tonne-km/yr	region pair, carrier region
Cabin crew costs	2006 US$/yr	region pair, carrier region
Capital costs	2006 US$/yr	region pair, carrier region
Finance costs	2006 US$/yr	region pair, carrier region
Flight crew costs	2006 US$/yr	region pair, carrier region
Fuel costs	2006 US$/yr	region pair, carrier region
Maintenance costs	2006 US$/yr	region pair, carrier region
Landing costs	2006 US$/yr	region pair, carrier region
Route navigation costs	2006 US$/yr	region pair, carrier region
Volume related costs	2006 US$/yr	region pair, carrier region
Total operating costs	2006 US$/yr	region pair, carrier region
Operating revenues	2006 US$/yr	region pair, carrier region
Operating results	2006 US$/yr	region pair, carrier region
Direct employment airlines	2006 US$/yr	carrier region
Contribution of airlines to GVA	2006 US$/yr	carrier region
Other economic effects[51]		
Gov't income from charges	2006 US$/yr	region pair, carrier region
Change in consumer surplus	2006 US$/yr	carrier region

[50] A carrier region relates to all carriers which are registered in one of the 14 AERO-MS Regions.

[51] The other economic effects are only computed in case of an AERO-MS Forecast (policy) run.

14.5.5 Outputs from the AERO-MS can be stored in the Data Warehouse for various scenarios with or without the effect of policies for the reduction of aircraft emissions. The difference in the outputs between runs for the same scenario with and without policy measures (the difference between AERO-MS Forecast and runs) will also be of interest (see also below). As indicated in the EEMA study it is a crucial requirement to also store meta information in the Data Warehouse. For the AERO-MS the meta information should at least relate to:

- A textual description of the scenario and policies underlying the AERO-MS run for which the outputs are stored in the Data Warehouse
- The version of the AERO-MS used for creating the outputs
- The date and time when the AERO-MS outputs were created.

14.5.6 Figure 14.2 provides a schematic overview of how the AERO-MS outputs in the Data Warehouse could potentially be used by other models. With respect to the AERO-MS a distinction is made between the outputs of the economic models in the AERO-MS (ATEC, ADEM, ACOS and DECI) and FLEM.

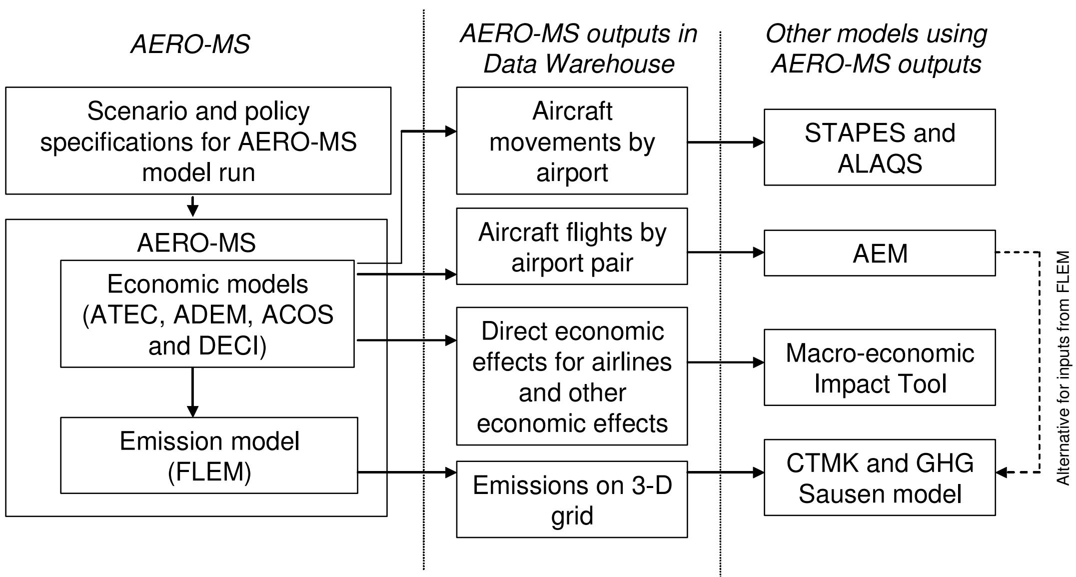

Figure 14.2: AERO-MS outputs in Data Warehouse for use by other models

14.5.7 The number of aircraft flights in the updated AERO-MS is output by airport pair and a number of other dimensions like aircraft type, technology level (old versus current) and aircraft purpose (passenger aircraft versus freighters). The flights can be aggregated to departure and arrival airport.

14.5.8 The number of movements (arrivals and departures) per airport can be an input for models like ALAQS and STAPES which operate on an airport level. It is recognised that the AERO-MS cannot provide all the detailed input required by these airport models, but potentially could on a more generic level (see Section 13.5). These models will need to distribute movements across runways, flight paths and time of day.

14.5.9 However, it has to be recognised that a typical application of the AERO-MS is to forecast for a situation well into the future, for which runway use, the time-of-day profile and the detail of the types of aircraft then operating will themselves need to predicted or described in scenario form. In effect, it can be said that the AERO-MS assesses the main trends in the number of movements given certain global and regional scenario and policy developments. These trends, together with inputs from other sources, could then be used to define a set of inputs for airport models.

14.5.10 Within the AERO-MS the number of flights by airport pair computed by the economic models is used in FLEM to compute aircraft emissions. Alternatively flights by airport pair can (via the Data Warehouse) be fed into the AEM for the computation of the global aircraft emissions.

14.5.11 FLEM computes emissions on a 3-D grid. The size of the horizontal grid in longitude and latitude direction can be set by the user. The minimum value is 1°, and the default value is 5°. The height of altitude layers is also user-defined. The default value is 1000 m, and the minimum value is 500 m. The FLEM aircraft emissions by 3-D grid can be an input for climate models (CTMK and GHG Sausen model). As illustrated in Figure 14.2, alternatively the air transport emission quantities computed by the AEM could be used as an input for the climate models

14.5.12 As part of the TEAM_Play project it is foreseen that a Macro-economic Impact Tool will be developed. This tool will make use of input-output tables on the basis of which the macro-economic effects resulting from changes in the level of air transport activity will be estimated. The direct economic effects for airlines, as computed by the AERO-MS, can be the input for the Macro-economic Impact Tool.

STAPES

14.5.13 Stapes uses the PRISME Data Warehouse as the primary source of information, complemented with airport local data. PRISME data consists of A/C ICAO code, A/C series, A/C engine, certified MTOW, Operations date and time, airport provenance and destination. The ICAO Aircraft Noise and Performance (ANP) database, and airport local information, is then used to model operations and calculate noise contours at the 27 major European airports currently included within STAPES.

14.5.14 For accurate calculation of noise around airports STAPES uses local information from airports (e.g. runway usage and departure/arrival flight profiles). STAPES has no capability to determine future fleet or traffic forecasts, which therefore provide as input into the model.

14.5.15 AERO-MS delivers forecasts of numbers of movements by the future aircraft fleet, as expressed in terms of generic aircraft types. The previous chapter (Section 13.5) suggests how noise metrics might be associated with the generic types, and projected to represent the noise characteristics of aircraft in future years. Thus a potential way forward is for the STAPES baseline traffic to be categorized into FLEM seat/range bands with then, for a future scenario, the number of aircraft operations in the detailed STAPES baseline year being scaled up in line with the AERO-MS forecasts of movements by the corresponding generic aircraft types. The future noise characteristics of these types would also be available, to provide a first order approximation of the impact on noise exposure. Calibration could be performed against the CAEP/8 noise goals results (for a selection of future scenarios). A preliminary calibration of the STAPES 2006 baseline results using PRISME data, with the results which used the CAEP COD in CAEP/8, would be useful to ensure that the STAPES baseline was appropriate.

14.5.16 Moving on from this first order approximation would require information or assumptions regarding the detailed noise characteristics of future aircraft designs. The further ahead the forecasts were being made, the more the aircraft fleet would be increasingly made up of these aircraft, In other words, the longer the forecasting horizon, the greater the role of assumptions in estimating the noise characteristics of the future aircraft fleet. Nonetheless, the AERO-MS forecasts of numbers of movements by generic aircraft types would provide a framework or boundaries for these assumptions.

AEM

14.5.17 AEM III uses several underlying system databases (aircraft, aircraft engines, fuel burn rates and emission indices) provided by external data agencies in order to assure the quality of the information provided. This system information is combined with dynamic input data, represented by the air traffic flight profiles. To perform calculations, the flight profiles are split into two portions, below and above 3,000ft altitude. For the portion of the flight below 3,000ft, the method can use either a full flight profile provided by the user or it can "complete" the profile using its own methods. For the portion of the flight below 3,000ft, the calculation of fuel burn and emissions is based on standard thrust levels and times in mode, using data from the ICAO Engine Emissions Databank. For the portion of the flight above 3,000 altitude, the calculation of fuel burn and emissions uses the BADA method (currently Version 3.7). This contains data for a wide range of aircraft types (a total of 103 for Version 3.7).

14.5.18 The requirements for interfacing AERO-MS with AEM would therefore need to ensure that the relevant operations and profile data were output to the Data Warehouse. The operations data must include, for each flight to be modelled, the aircraft type and the route flown (the departure and arrival airports), together with the flight call sign and the departure time (which may be synthetic). Because AEM includes a wide range of aircraft types (together with a synonym table for mapping a further 191 types to those in the model), the data stored must include the actual aircraft type as well as the generic type used in AERO-MS.

14.5.19 For the Datum and Policy cases, AERO-MS applies the effects of technology improvements to the calculations of fuel burn and emissions. In order to deal with future technology calculated by the AERO-MS in terms of fuel use and emission factors, an approach could be used similar to the approach described for STAPES above.

14.5.20 The associated flight profile data should be stored with the full definition (including the segments below 3,000ft) so that the user of AEM can elect to use the full profile if required. The profile data needs to include the flight call sign (for mapping to the operations data), the flight attitude, ground speed, climb/descent rate and the 4D point coordinate (time, latitude, longitude and altitude). Ideally, the associated flight profile would be stored with the full definition (including the segments below 3,000ft) so that the AEM user could elect to use the AERO-MS profile if required. However, the data storage and transfer requirements would be severe, and the run time of AERO-MS would be extended excessively.

ALAQS

14.5.21 The input of ALAQS contains movement data. The data for one movement consists of movement date and time, on-block/off-block date and time, aircraft registration and type, gate identifier, arrival or departure code, runway identifier, engine name, vertical profile identifier, horizontal track identifier, taxi route instance identifier.

14.5.22 As mentioned in paragraph 14.5.8, the AERO-MS does not provide all input data required for ALAQS. Additional contents in the Data Warehouse should therefore be provided, e.g. by other tools, or based on assumptions supplied by experts.. This includes, e.g., data in the Data Warehouse Airport, Aircraft and Emissions categories.

14.5.23 The output of ALAQS consists of emission results for all sources: Aircraft, Ground Support Equipment, Ground Power Units, Auxiliary Power Units for defined combinations of Aircraft Groups and Gate Types.

14.6 Climate Models

14.6.1 The climate models, CTMK and Sausen, require the calculated emission data to be available in a gridded form. Therefore, to allow these models to interface with the AERO-MS results through the Data Warehouse, there will be a need for AERO-MS to output its data in such a format to the Data Warehouse. The current format of the gridded data output from AERO-MS is a three-dimensional grid with each element being 5° (latitude) by 5° (longitude) with 15 layers vertically. The current standard output from the EUROCONTROL gridding tool is 1°(latitude) by 1°(longitude); the vertical structure is a constant cell height of 500ft. Only non-empty cells (i.e. ones which are crossed by at least one flight) are output. It is proposed that the gridded output from AERO-MS be updated to this standard, though it should be noted that the flight trajectories modelled by AERO-MS are great circle tracks, with detour factors applied to the distance flown, fuel burnt and emissions produced to allow for the deviation from these tracks.

14.6.2 The format of the file for the EUROCONTROL gridded data is shown in Table 14.4 (one record per cell).

Table 14.4:Format of the file for the EUROCONTROL gridded data

Field No.	Field Name	Description
1	ARRAY_X	Cell's longitude index (1 to 360)
2	ARRAY_Y	Cell's latitude index (1 to 180)
3	ARRAY_Z	Cell's altitude index (1 to 141)
4	ARRAY_LAT	Cell's minimum latitude (-90° to +89°)
5	ARRAY_LON	Cell's minimum latitude (-180° to +179°)
6	HEIGHT	Cell's minimum altitude (0ft to 70,000ft)
7	DISTANCE	Total distance flown inside cell (nm)
8	NUM_FLIGHTS	Number of flights inside cell
9	FUELBURN	Total fuel burn inside cell (kg)
10	NOX	Total NOx emitted inside cell
11	CO	Total CO emitted inside cell
12	HC	Total HC emitted inside cell
13	SOX	Total SOx emitted inside cell
14	CO2	Total CO_2 emitted inside cell
15	H2O	Total H_2O emitted inside cell

14.6.3 For the CTMK and Sausen models to perform calculations taking account of the full emissions sources, it will be necessary to include ground emissions from ground sources, such as road traffic, shipping, etc., which are then applied in the layer nearest the surface of the earth in the climate model calculation. Ground emissions are not computed by the updated AERO-MS. However, a former sub-module of the AERO-MS – OATI – performed such calculations. Consideration could be given to re-activating OATI.

14.7 Interface Implementation

14.7.1 The choice for the level of automation of the interface between the models is still open. This involves also the architecture of the solution to interface the models. Further steps also dependent on the solutions developed in SESAR WP16 and TEAM_Play.

14.7.2 The Data Warehouse as described in the EEMA study is a combination of a data broker (or service bus) exchanging data between two applications, and a data store that contains the relevant outputs of many source applications for further use in a different context (e.g., reporting). For WP10, the role as data broker is the most relevant.

14.7.3 There are many off-the-shelf implementations for data brokers, and there are also a lot of best practices available for the design of the various layers.

14.7.4 One of the best practices is that the owner of the Data Warehouse is responsible for the data dictionary (for data brokers also known as the canonical data model). Formally the AERO-MS has to be informed what data (and to what detail) it should publish via the Source Data Layer. For the implementation of the interface of the models a re-evaluation of the data elements specified in the EEMA study, both input and output, may be necessary. Progress in

SESAR WP16 and TEAM_Play, in which the EEMA results are further developed should be taken into account for the interface implementation.

14.7.5 The data dictionary or canonical data model does not only specify what data is available in the Data Warehouse and to what level of detail, but also its semantics (e.g., units). There may be a mismatch in the semantics of data in the Data Warehouse and the data as provided or used by models. It is best practice that the Data Transformation Layer provides tools for common (unit) transformations. The owner/developer of the Data Warehouse is responsible for implementing and configuring the tools, the model owner/developer is responsible for delivering the specifications for the transformations.

14.7.6 The owner/designer of the Data Warehouse dictates both the format in which the data is handed over to the Data Transformation Layer. The model owners/developers are responsible for the conversion of the model-specific database formats to the formats understood by the Data Transformation Layer. The format can be text-based formats like SOAP or XML, binary formats like NetCDF, or a combination of both. It is best practice to choose open, technology-independent formats that are widely supported by many development platforms.

14.7.7 The owner/designer of the Data Warehouse also dictates the transport protocols by which the data is handed over to the Data Transformation Layer, and the way the transport is initiated. E.g., the model can publish the data to a web service via HTTP, or the Data Warehouse can ask the model to return a set of files via FTP.

14.7.8 The same arguments hold for the Model Pre-processing Layer: the owner/developer of the Data Warehouse dictates the format and transport protocol and provides tools for common transformations.

14.7.9 As the owner/designer of the Data Warehouse dictates the connection between models and Data Warehouse, concerns about the integrity of the data (e.g., via checksums), data protection (for sensitive data, e.g., by the use of secure transport, authentication and encryption) have to be addressed by the owner/designer of the Data Warehouse.

14.7.10 Provided the Data Warehouse design follows the best practices, the implementation of the interfaces for AERO-MS is practical. The proprietary AERO databases can be accessed by an API (application programming interface) that is available in Delphi 2010, Visual C++ 2008 and .NET 2.0. It is expected that every common data format and common transfer protocol is either supported by one of these development platforms, out of the box or via a library.

14.7.11 Implementation of the interfaces can commence once the data formats, transfer protocols and the contents of the data dictionary have been agreed.

14.7.12 Provided there is no (or limited) need for transformations in the Data Transformation Layer and Model Pre-processing Layer, and all models can implement the interfaces using the same data format and transfer protocol, the interfaces can be used for a direct transfer of data between the models. This solution bypasses the Data Warehouse Layer, and may be a viable short-term solution to be used while the Data Warehouse is still in development.

14.7.13 If transformations are needed, or if the various models cannot support the same format or transport protocol, there is no value in implementing the interfaces before the Data Transformation Layer and Model Pre-processing Layer become available. A direct transfer of data between the models is still possible as a temporary solution. Such a solution would typically be implemented as cheaply as possible, employing the least complex data format and transfer protocol (e.g., manual transfer of text files) and omitting all but the most essential metadata.

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Abu Dhabi
AS Business Centre, Suite 201, Al Ain Road, Umm al Nar, P.O. Box 129865, Abu Dhabi, UAE
T: +971 2 510 2402 F: +971 2 510 2403

Birmingham
Second Floor, 37a Waterloo Street
Birmingham B2 5TJ United Kingdom
T: +44 (0)121 233 7680 F: +44 (0)121 233 7681

Dublin
First Floor, 12/13 Exchange Place
Custom House Docks, IFSC, Dublin 1, Ireland
T: +353 (0)1 542 6000 F: +353 (0)1 542 6001

Edinburgh
Second Floor, Prospect House, 5 Thistle Street,
Edinburgh EH2 1DF United Kingdom
T: +44 (0)131 220 6966 F: +44 (0)131 220 6087

Glasgow
Seventh Floor, 78 St Vincent Street
Glasgow G2 5UB United Kingdom
T: +44 (0)141 225 4400 F: +44 (0)141 225 4401

London
Second Floor, 17 Hanover Square
London W1S 1HU United Kingdom
T: +44 (0)20 7529 6500 F: +44 (0)20 7529 6556

Lyon
11, rue de la République, 69001 Lyon, France
T: +33 (0)4 72 10 29 29 F: +33 (0)4 72 10 29 28

Manchester
25th Floor, City Tower, Piccadilly Plaza
Manchester M1 4BT United Kingdom
T: +44 (0)161 236 0282 F: +44 (0)161 236 0095

Marseille
76, rue de la République, 13002 Marseille, France
T: +33 (0)4 91 37 35 15 F: +33 (0)4 91 91 90 14

Paris
12-14, rue Jules César, 75012 Paris, France
T: +33 (0)1 53 17 36 00 F: +33 (0)1 53 17 36 01

Woking
Dukes Court, Duke Street, Woking
Surrey GU21 5BH United Kingdom
T: +44 (0)1483 728051 F: +44 (0)1483 755207

Email: info@mvaconsultancy.com

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