Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

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A Netherlands policy analysis model on global environmental issues

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Summary

Global aviation emissions are increasing. The Intergovernmental Panel on Climate Change (IPCC) concludes that the current growth rate of about 5% in global aviation cancels out the reductions in specific emissions from the continuing improvements in technology and operational procedures. Although the environmental impacts of aviation emissions are difficult to quantify, it is generally agreed that aviation emissions do harm the environment and should therefore be reduced.

The National Aerospace Laboratory NLR participates in a consortium for the development of a modelling system for the analysis of aviation emissions and the evaluation of reduction options (AERO). AERO analyses have been performed for e.g. the International Civil Aviation Organisation (ICAO) and the European Commission.

This publication gives a broad account of AERO and some illustrations of its application.

Contents

(12 pages in total)

1 Introduction

The principal aviation emissions include
- the two greenhouse gases carbon dioxide (CO_2) and water vapour (H_2O),
- nitrogen oxides (NO_x),
- sulphur oxides (SO_x), and
- soot.

The emissions affect the climate through various mechanisms. CO_2 has a long atmospheric residence time of about 100 years. In this time, the CO_2 becomes well mixed throughout the atmosphere and affects the global climate as a green house gas.
NO_x, SO_x, water vapour and soot, on the other hand, have shorter atmospheric residence times. Near flight routes, these gases and particles continuously alter the concentration of local atmospheric greenhouse gases, including CO_2, ozone (O_3) and methane (CH_4) (Ref. 1), and thus may lead to climate change.
Emission of NO_x at altitudes around the tropopause (Fig. 1) leads to an increase in atmospheric ozone, whereas emission of NO_x at higher altitudes leads to a decrease of atmospheric ozone, thus influencing the amount of ultraviolet radiation at the surface of the Earth.
Furthermore, the emissions of NO_x, SO_x, water vapour and soot trigger the formation of condensation trails (contrails) and may increase cirrus cloudiness - all of which contribute to climate change.

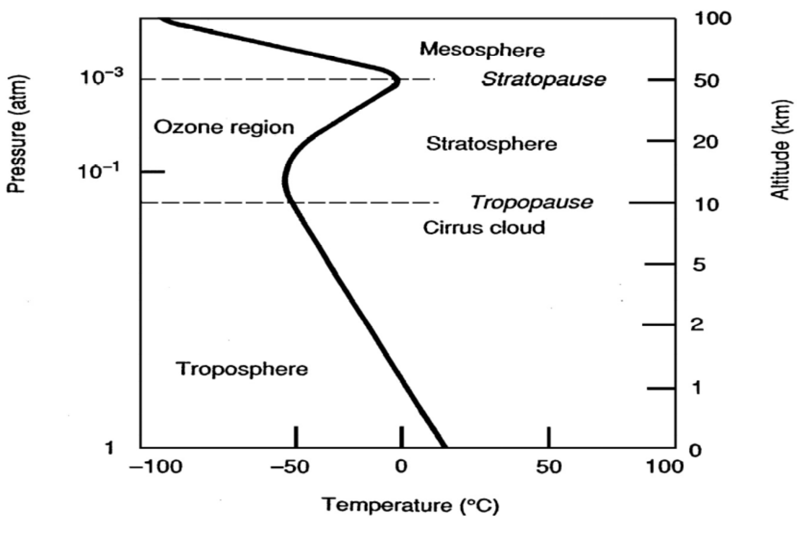

Fig. 1 Schematisation of the Earth's atmosphere. The altitudes of the tropopause and stratopause are defined by a change in the temperature gradient and can vary at different geographic locations.

Many of these environmental effects of aviation emissions are as yet insufficiently quantifiable. Studies are ongoing to determine the environmental effects of aviation emissions. Consensus is, however, that there is an impact of aviation on both climate and local air quality and that this impact is growing due to the substantial growth in aviation itself.

In the following chapters, insight is given into the problems for introducing measures in the aviation sector for the protection of the environment, and the need for a modelling system to evaluate various options. The modelling system AERO is described in chapter 3, with some small examples of application of AERO.

2 Consideration for the environment

In recent years, substantial improvements have been made regarding aircraft emissions per passenger-kilometre. For example, aircraft engines now are less pollutant and more fuel efficient, and reduction of airframe weight has resulted in even better fuel efficiency. The amount of fuel burnt is directly linked to the emission of CO_2, so all this means less CO_2 emission.
Another example is the establishment of international emission regulations for the take-off and landing cycles, by the International Civil Aviation Organisation ICAO. The regulations limit the total amount of emissions around airports of, among others, NO_x and CO.

In spite of the initiatives, the emission reductions achieved per aircraft and per flight are not sufficient to compensate for the increase in emissions as a result of the growth of global aviation. More measures are therefore advisable.
However, the question is which measures are effective enough to justify the extra costs in the aviation and other sectors? Finding answers to this question is of vital importance, but it is not easy.
Firstly, there is the problem of variety in global aviation: a large number of flights over an extremely wide range of distances, involving many different kinds of aircraft, of diverse size and type, and of varying age, equipped with different engines. All these differences influence fuel consumption and emissions.

Secondly, there seem to be many possible emission reduction measures, both of a technical as well as an economic nature, such as influencing the demand for transport. Obviously, the effects of such complex measures are not easy to assess. A highly structured approach is necessary in which the uncertainties in the data, assumptions, scenarios and methods of calculation, can be studied.

Thirdly, aviation has an inherently international character. For example, a unilateral (regional) measure of aviation fuel taxation was shown to have limited result only, and, to negatively affect the competitiveness of various airlines and airports (Ref. 2). This means that measures must be taken at the international level. However, various countries in the world may have different points of view. Some governments may not be convinced that a problem actually exists, whereas others may have widely divergent views regarding the direction in which a solution must be sought. In short, only the measures considered by all parties involved to produce a substantial improvement in the environment at acceptable cost, will be accepted internationally and are a candidate for implementation.

The AERO modelling system (Ref. 3) serves to evaluate options for the reduction of emissions at a global or a regional level. AERO offers the possibility of comparing the costs of reduction options to the environmental results achieved. The reduction options analysed with AERO include operational, technical and economic measures:

- operational measures, e.g. flying at lower altitudes, following other routes, flying according to other procedures of ascending and descending, flying at lower speeds, improvement of air traffic control (shorter routes and reduction of holdings), etc.
- technical measures such as tightening regulations for NO_x emissions or the introduction of CO_2 standards,
- economic measures, e.g. introducing excise duties on kerosene and taxes on tickets at national, regional or global level.

For a short description of the development consortium, the reader is referred to Appendix 1.

3 The AERO modelling system

The AERO modelling system consists of four interacting subsystems (Fig. 2), viz. Technology, Economy, Atmosphere, and Environment. The four subsystems are described in the following sections.

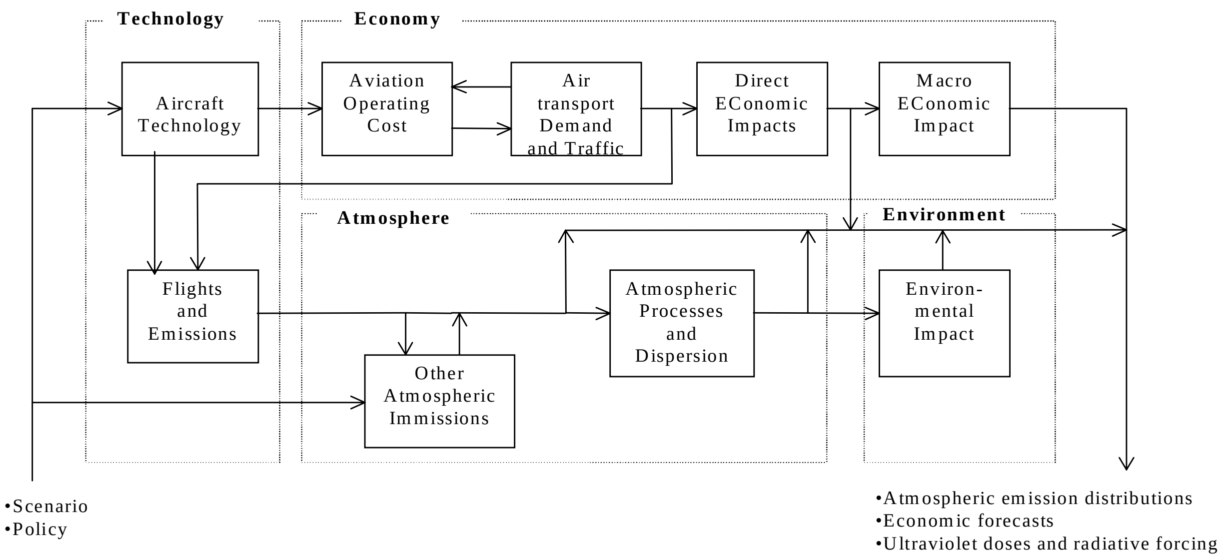

Fig. 2 Data flow within the AERO modelling system

3.1 Technology

The Technology group in the AERO modelling system was developed by the National Aerospace Laboratory NLR.

The *Aircraft Technology* model forecasts the technological development of aircraft, in particular the development in fuel use characteristics and emission indices of the fleet. These are used in the *Operating Cost* model and the *Flights and Emissions* model.
The technical improvements are a combined result of autonomous development (reduced emissions as a result of fuel use reduction) and policy-induced development.

With the *Flights and Emissions* model, the emissions during the flight are calculated. Three dimensional flight profiles of an aircraft flying from point A to point B are used to calculate distribution of emissions in a 3D-grid.
The *Flight and Emission* model uses the aircraft movements from *the Air Transport Demand and Traffic* and aircraft and engine data, partly calculated in *the Aircraft Technology* model and partly supplied by the AERO database.
The results of the *Flight and Emission* model are aircraft emissions that are used by the *Atmospheric Processes and Dispersion* model, actual fuel and oxygen use and flight time specified per grid cell.

3.2 Economy

In the *Aviation Operating Cost* model, the single flight cost as well as the single flight cost increase as a result of applied measures are estimated. The cost of providing a given level of capacity (seats, cargo space) may vary over time, for instance as a result of the imposition of emissions-related policy measures. This effect is included in the model.
Cost estimates are made for each aircraft type on each flight stage, including the costs for flight crew, cabin staff, maintenance, fuel, airport and navigation fees and capital charges.

The purpose of the *Air Transport Demand and Traffic* model is to forecast aircraft movements, based on the cost and airfare information from the *Aviation Operating Cost* model. In the *Air Transport Demand and Traffic* model, the aircraft movements are generated from the aircraft movements in a reference year[1]. and various scenarios of the future and alternative policy measures. These policy measures are intended to influence the volume and spatial distribution of emissions. On overland flight stages of up to 700 km length, competition from surface modes, including high-speed rail, is accounted for.
If costs are increased, for example through a carbon tax, fares may increase. Demand will become lower as will the offered capacity. This mechanism is shown in Figure 3. These complex real-world interactions are modelled in the interaction between the *Air Transport Demand and Traffic* model and the *Aviation Operating Cost* model.

With the *Direct Economic Impacts* model, the direct financial and socio-economic impacts for airlines at a global level, based on their operating costs and aviation demand are calculated. In addition, direct impacts are computed for two other actors: the airlines' clients (the 'consumers' of aviation transport services) and the 'government'. The 'government' is introduced as a third

[1] Global aircraft movements for the base year (1992) are quantified in a database. Air passenger (both scheduled and chartered) and cargo flights have been collected. The data consist of flight routes, actual flight times and the types of aircraft used. Flight stages connecting about 350 major world cities are recorded individually, other flight stages are grouped by world region. For 1992, 24 million civil flights are represented. Military traffic is included through a representation of the ANCAT (Abatement of Nuisances Caused by Air Transport) database

party, which may interact with airlines and consumers by means of taxation and subsidy measures, introducing and affecting flows of money between each of the three parties. An example of this is the introduction of a ticket tax, which will affect the ticket price and consumer demand, which in its turn could trigger the same mechanism as shown in Figure 3.

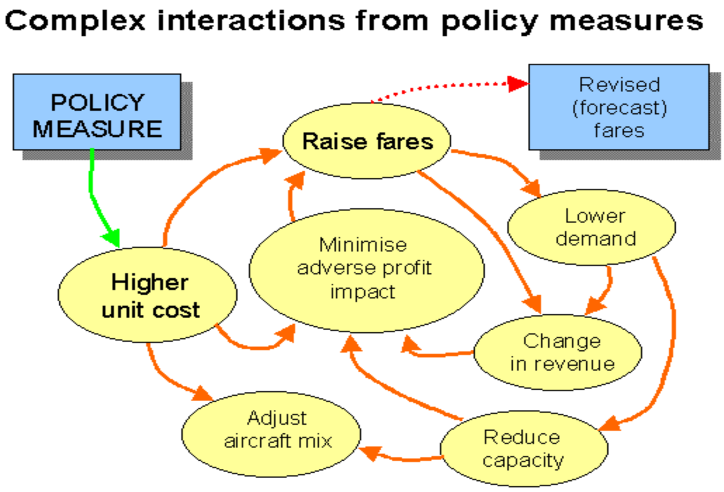

Fig. 3 Example of interactions within Economy subsystem

The socio-economic impacts concerned within the *Macro Economic Impact* model include impacts in the aviation sector, and in other sectors which are directly and indirectly related to aviation activities.
The impacts considered are employment and income, measured in number of employees and million US$ of gross value added (or GDP) respectively.

3.3 Atmosphere

Within the *Other Atmospheric Immissions* model the present and future atmospheric emissions from non-aviation ground sources are surveyed and estimated. The data include a global overview of emissions from anthropogenic and selective natural sources. By definition, these emissions take place in the troposphere, the first layer of the Earth's atmosphere (Figure 1).

With the *Atmospheric Processes and Dispersion* model the concentrations of CO_2, NO_x en O_3 as a result of both the aviation and the non-aviation emissions are calculated. The computations of

CO_2-concentrations are based on simplifying assumptions like complete mixing and linear change in emissions (from ground sources as well as air-traffic) over time.

3.4 Environment

The *Environmental Impact* model calculates the effective ultraviolet doses, based on the previously calculated CO_2 concentrations and ozone distributions. Finally, the importance of a potential climate change mechanism is established.

3.5 Applications of the AERO modelling system

Within the framework of the Focal Point on Charges, a working group of the International Civil Aviation Organization (ICAO), AERO has been applied to study the environmental effects of various charge possibilities (Ref. 4). Figure 4 shows the costs of several levies versus the resulting decrease in fuel use, which is a measure for the reduction in emissions. Conclusions from the study are:

– Increased levies yield larger reductions.
– A ticket tax involves higher costs than a fuel charge to obtain a certain emission reduction level.

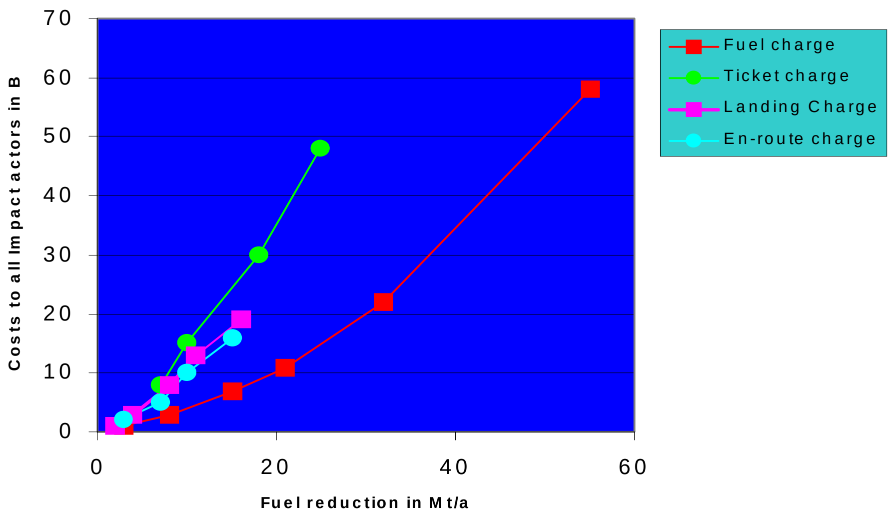

Fig. 4 Levy costs versus fuel use decrease

AERO has also been applied to perform an analysis of the taxation of aircraft fuel, as a study for the European Commission (Ref. 2).

4 Concluding remark

As global aviation is expected to grow in the future, the reduction of aviation emissions is of importance to restrain their environmental impact.
The AERO modelling system offers an opportunity to policy makers and stakeholders to evaluate which reduction options will be most effective at acceptable cost.

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Acknowledgements
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Appendix 1 The AERO development consortium

The Netherlands Department of Civil Aviation (RLD) of the Netherlands Ministry of Transport, Public Works and Water Management took the initiative to develop the AERO modelling system (Aviation Emissions and Evaluation of Reduction Options).
The development of AERO started in 1993. The system was developed in close co-operation between MVA of London, the National Aerospace Laboratory NLR of Amsterdam, Resource Analysis of Delft, the Royal Netherlands Institute of Meteorology (KNMI) of De Bilt and RLD. MVA dealt with the economic and prognosis part of the model. The NLR was responsible for the flight technical aspects and the actual determination of emissions. Resource Analysis was entrusted with the construction of the aggregate models and the computer system (the shell). Finally the KNMI contributed its know-how in the field of atmospheric models and environmental effects.