

Aviation and Air Pollution

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1. INTRODUCTION

This 5th US-Dutch international symposium deals with the priority issues and policy trends regarding air pollution in the 21st century. This paper will go into the issue of aviation and air pollution and is based on the Government Policy of The Netherlands on Air Pollution and Aviation [VROM, 1995].

The paper consists of the following parts:

- the current environmental impact of aircraft emissions;
- future emission trends;
- possible ways to reduce aircraft emission trends, and finally;
- a policy to reduce aircraft emission trends.

2. GENERAL

Modern aviation fuels are obtained from the refining of crude oil, and consist mainly of hydrocarbons. When the combustion of the fuel is complete, the combustion of aviation fuels gives rise to emissions of carbon dioxide (CO₂), water (vapor) (H₂O) and sulphur

dioxide (SO₂). Although the combustion efficiency of jet engines is generally very high, combustion is not complete, and a number of other combustion products are also generated, particularly carbon monoxide (CO), volatile organic compounds (VOC) and 'particulates' (this term refers collectively to solid and liquid substances of diverse composition). In addition to incomplete combustion products, the high temperatures in the combustion chamber lead to the formation of oxides of nitrogen (NO_x). Aircraft engines also emit nitrous oxide (N₂O) and methane (CH₄). The emissions of these two substances are extremely small, and they are therefore not considered further.

Aircraft emissions contribute to climate change (depletion of the ozone layer and the greenhouse effect), acidification and disturbance (local air pollution and odors). The main contribution to air pollution is made by civil aviation, but military aviation also plays a role. Light aviation has an impact mainly at the local level.

The scientific understanding of the impact of aircraft emissions on the environment is still rather inadequate. Further research will be required in the coming years to remedy these deficiencies, such as the scientific research program that we currently undertake: the AIRFORCE project. The gaps in our understanding relate particularly to climate change, and the possible role played by NO_x emissions from aircraft in the upper atmosphere and chemical processes resulting in contrail formation and their effects on cloud properties and radiative forcing. The NO_x-issue has received a great deal of attention from the international scientific community in recent years. The contrail-issue has only recently become an area of interest for scientists. In the Special Report of the IPCC on Aviation and the Climate, that is scheduled for release in the end of 1998, further consideration will be given to these questions.

One reason behind the focus on the effects of NO_x emissions on the atmosphere is what is called the 'fuel-NO_x trade-off'. Historically, the fuel efficiency of jet engines has risen steadily. A higher efficiency will as a rule reduce the unit emissions of CO₂, H₂O, CO, VOC and SO₂. In increasing efficiency, however, temperature and pressure in the combustion chamber rise, whereby NO_x emissions will as a rule increase. This effect can be compensated through improvements in the combustion process in the combustion chamber. Examples are lean-burn and staged combustion techniques or revolutionary new combustion chamber concepts. If NO_x emissions would not be of environmental

concern, aircraft and engine manufacturers would not be needing to invest in low NO_x engines.

3. THE CURRENT ENVIRONMENTAL IMPACT OF AIRCRAFT EMISSIONS

3.1. Composition of the atmosphere

The atmosphere, the ring of gases which girds our planet, can be divided into a number of layers, characterized by their temperature profile. The lowest layer of the atmosphere is the troposphere. In the troposphere, the temperature falls with increasing altitude. The troposphere is turbulent and the substances present in it undergo vertical mixing within a week or so. Above the troposphere is to be found the stratosphere. In this layer, temperature first remains constant and then rises with increasing altitude. This makes the stratosphere much more stable than the troposphere, and little vertical transport occurs. The boundary between the stratosphere and the troposphere is called the tropopause. The exact position of the tropopause depends on latitude and season, and is also influenced by weather systems; it fluctuates on a day-to-day basis. Near the poles the tropopause occurs at an average altitude of about 7 km and near the equator at an average altitude of about 18 km. It is exactly in this very complex region of the atmosphere where aircraft fly: both in the troposphere and in the stratosphere. The different characteristics of these two layers mean that the substances emitted by aircraft have different effects in them. Therefore, it is no simple matter to answer the question 'what are the atmospheric effects of aviation?'.

3.2. Depletion of the ozone layer

The aircraft pollutant which plays the most important role in depleting the ozone layer is NO_x. Model calculations indicate that this contribution is expected to be small in quantitative terms. Scientific understanding of the indirect effects of a number of aircraft pollutants is still incomplete, and the possibility that these effects may prove important cannot be excluded. On the basis of present knowledge the international scientific

community estimates that the contribution of aircraft emissions to ozone depletion in the lower stratosphere is at present less than 1%. However, a new generation of supersonic airliners may have a major impact on ozone depletion.

3.3. Enhanced greenhouse effect

Aircraft emissions contribute to the greenhouse effect. The climate effects of aircraft CO₂ emissions are no different from those of other CO₂ emissions, and are relatively clear. The role of aircraft emissions of NO_x has become better understood in recent years. Changes in ozone concentrations due to aircraft NO_x emissions disturb the earth's thermal balance. Quantitatively speaking the effects depend on location and season, and are therefore difficult to compare with the global effects of persistent greenhouse gases such as CO₂. Nevertheless, it is required to gain a better understanding of the relative importance of the NO_x and CO₂ emissions from aircraft in the enhanced greenhouse effect. The international scientific community gathered together in the International Panel on Climate Change (IPCC) at present estimates that the indirect effect on the enhanced greenhouse effect of aircraft NO_x emissions, as a result of ozone formation, is of the same or a smaller order of magnitude as the direct effect of aircraft CO₂ emissions.

There is still a great deal of uncertainty about the effects of water vapor, SO₂ and soot particles. These pollutants emitted by aircraft could play an important part, because of their influence on the formation of clouds and aerosols, in contributing to the greenhouse effect. The radiative effect of aerosols and their ability to modify cloud properties are strongly influenced by the concentrations of the aerosol in the atmosphere, which exhibit very major local variations in magnitude and composition. Overall, changes in cloud cover and optical properties probably result in a net warming effect and the radiative effect in a net cooling. At present our knowledge does not allow us to quantify these climatic effects properly. It is assumed however that the indirect effects of H₂O, SO₂ and particulate emissions from aircraft are not greater in quantitative terms than the effects of aircraft emissions of CO₂ and NO_x.

3.4. Acidification

The contribution of aircraft emissions to acidification is in principle properly to quantify.

Of most importance are the NO_x emissions. SO_2 emissions are less important in this regard. On a global level, the aviation sector contributes about 0.7% to acidifying emissions of NO_x and SO_2 , expressed in terms of acid equivalents.

3.5. Local air pollution in the vicinity of airports

The fourth environmental problem related to aviation emissions is the contribution to local air pollution in the residential areas around airports. In 1993 a study was carried out in The Netherlands for the purposes of the Project Schiphol Mainport and the Environment and the related integrated environmental impact assessment (IEIA). This study examined the nature and extent of air pollution and odor nuisance within a radius of 10 km from Amsterdam Airport Schiphol (AAS) in the period up to 2015.

The study used a dispersion model to calculate the concentrations of certain pollutants in 15 residential areas in the vicinity of Amsterdam Airport Schiphol. It concluded that the relative contribution of the 'Schiphol' emissions to these concentrations will not exceed several percent. It was also clearly demonstrated that in no case are any of the legal standards for NO_2 , CO, SO_2 , black smoke, benzene and benzo(a)pyrene exceeded. The concentrations of these substances in the various locations will decrease if, as assumed in the IEIA, the rise in emissions by air traffic can be offset by a fall in emissions by road traffic.

It is important to note that these results might not be applicable to other airports. For some airports the contribution of aviation to local air pollution is low, for other airports this is high and may cause severe problems. In addition, I must state that further research into this area is ongoing. In general, VOC, CO, SO_2 , NO_x , particulates and odors are the emission products that are of importance with respect to local air pollution.

4. EMISSION TRENDS

4.1. Global

At present, CO_2 and NO_x can be regarded as being the most important aircraft pollutants. In both cases, aircraft emissions accounted for between 2 and 3% of total world

emissions from the combustion of fossil fuels in 1990, as is shown in table 1.

Table 1

Aircraft emissions and their share of the total emissions due to the combustion of fossil fuels (coal, petroleum and gas) in 1990 [RIVM, 1995]

| | CO ₂ (Mton) | NO _x (kton) | VOC (kton) | CO (kton) | SO ₂ (kton) |
|-------------------------------------|---------------------------|---------------------------|---------------|--------------|---------------------------|
| Aircraft | 498 | 1,786 | 406 | 679 | 156 |
| All sources (world total) | 22,000 | 82,000 | 27,000 | 303,000 | 130,000 |
| Percentage attributable to aircraft | 2.3 | 2.2 | 1.5 | 0.2 | 0.1 |

There has been a continuous improvement in the efficiency of jet engines over the years. The specific fuel consumption, i.e. the amount of fuel required to generate one kiloNewton of thrust, has therefore fallen steadily. The emissions of CO and VOC per unit of fuel have generally fallen in line with the improvements in specific fuel consumption and with emission standards set by the International Civil Aviation Organization (ICAO). On the other hand the emissions of NO_x per kg. of fuel have increased. This is a result of the steadily rising temperatures in the engine combustion chamber which accompany the increasing fuel efficiency.

The efficiency trend was not enough, however, to offset the growth in emissions as a result of increased traffic volumes. Over the last two decades, air travel was the fastest growing mode of transport, and this trend is expected to continue.

Civil aviation is a growth market. It is expected to grow faster in future than the economy as a whole. This means that in the years to come the economic importance of air traffic will increase relative to other sectors. There will be a corresponding rise in the pollution caused by this sector, both in absolute and relative terms. That much is clear from calculations carried out for a white paper of the government of The Netherlands on Air Pollution and Aviation. These model calculations indicate that with current emission

trends (including current international regulatory action) and without further policy measures, global aviation emissions in 2015 will be approximately three times those in 1990. Table 2 provides detailed information. Other forecast support these growth figures. According to a forecast by Environmental Defense Fund, the worldwide CO₂ figure for aviation could grow as large as 10 percent by 2050, depending on many factors associated with economic growth.

Table 2

Developments in world aviation emissions of CO₂ and NO_x for the period 1990 - 2015 for three economic scenarios [RIVM, 1995]

| | CO ₂ | | NO _x | |
|---------------------------|-----------------|---------------------|-----------------|---------------------|
| | Mton | Index (1990 = 1) | Mton | Index (1990 = 1) |
| Emissions 1990 | 498 | 1.0 | 1,786 | 1.0 |
| Global Shift 2015 | 1,760 | 3.5 | 5,204 | 2.9 |
| European Renaissance 2015 | 1,409 | 2.8 | 4,166 | 2.3 |
| Balanced Growth 2015 | 1,678 | 3.4 | 4,964 | 2.8 |

4.2. European and national

In the near future similar high growth figures are expected in Europe. In the European Union the CO₂ growth figures associated with aviation will create an unbalance situation, since, under the influence of policy measures driven by the Framework Convention on Climate Change (FCCC), CO₂ emissions in other sectors will stabilize and/or decrease. I assume that a similar situation will arise in the US, depending on the goals, policies and measures that can be agreed in the light of a protocol under the FCCC for the greenhouse gas emissions after 2000.

At the national level, emissions attributable to flights related to The Netherlands will increase by a factor of two, as is shown in table 4. In 1995, the CO₂ emission of national

and international civil aviation in The Netherlands was bigger than the CO₂ emission by heavy duty trucks.

Allowing for the effect that environmental policy will have on national emission sources, aircraft emissions under unchanged policy will become more significant. In 2010, it is estimated that emissions from flights related to The Netherlands will then account for 6% of national CO₂ emissions and 16% of national NO_x emissions. For other European countries and for the European Union as a whole, similar situations apply. It is clear that these numbers can not be neglected.

Table 3

Emissions of flights related to The Netherlands in 1990 and 2010 [VROM, 1995].

| | 1990 | 2010 ¹ | %-increase |
|------------------------|------|-------------------|------------|
| CO ₂ (Mton) | 6,7 | 13,4 | +100 |
| NO _x (kton) | 21,8 | 37,3 | +71 |

4.3. Summary

In summary, aircraft emissions contribute to climate change (depletion of the ozone layer and the greenhouse effect), acidification and disturbance (local air pollution and odors). Although the aviation industry currently can not be regarded as a "climate ciller", its contribution is serious enough to develop a policy that is aimed at reducing the emission trends. The aviation industry is a growth market. It is expected to grow faster in future than the economy as a whole. There will be a corresponding rise in the pollution caused by this sector, both in absolute and relative terms. This should be of great concern.

Table 4 presents a systematic overview of the abovementioned findings.

Table 4

The importance of controlling emissions of the various aircraft pollutants for each of the relevant environmental problems [VROM, 1995]

| Environmental problems | Control important | Control unimportant | Importance uncertain |
|--------------------------------|------------------------------------------------------------------|------------------------------------------------------------------------------------------|--------------------------------------------------|
| Ozone depletion | NO _x | CO ₂ , VOC, CO | SO ₂ , H ₂ O, particulates |
| Greenhouse effect | CO ₂ , NO _x | VOC, CO | SO ₂ , H ₂ O, particulates |
| Acidification | NO _x | CO ₂ , SO ₂ ¹ , H ₂ O, VOC, CO, particulates | - |
| Local air quality ² | VOC, CO, SO ₂ , NO _x , particulates, odors | CO ₂ , H ₂ O | - |

¹ SO₂ is an important acidifying agent. The contribution made by aircraft is small compared with that from other sources, however.

² The impact of the various pollutants depends on local circumstances

5. POSSIBLE AVENUES TO REDUCE AIRCRAFT EMISSION TRENDS

Based on the results of various studies, a number of avenues can be pursued by policy-makers to mitigate the aircraft emission trends. Three categories of measures can be considered: technical measures, operational measures and mobility measures. Technical measures relate to the design of the aircraft engine, to the aircraft itself or to the aviation fuels used. Operational measures refer to measures taken while aircraft are cruising, or during the LTO cycle in and near the airport. Mobility measures can apply to substitution of traffic for shorter journey distances from air travel to more

environmentally-friendly alternatives, such as the high-speed train or the intercity train.

The technical avenue is aimed at development and introduction of new technology in the international civil aviation market. This new technology relates to changes in the overall design of aircraft engines, improvement of the combustion process of the combustion chamber, design of revolutionary new combustion chamber concepts, changes in existing aircraft design and, finally, designing new aircraft types that are optimized for lower cruising speeds that will emit less per passenger-kilometer for equal journey distances.

Operational measures can be changes in cruising altitudes, reducing cruising speeds, changing flight routes, improvement of air traffic control systems, modifying the distribution of airspace between civil and military aviation and, finally, measures related to the landing and take-off cycle at and around airports.

Mobility is a characteristic feature of our society. Civil aviation is one component of the transport network which meets our demand for mobility. The satisfaction of this demand is increasingly coming into conflict with environmental objectives, however. Where this transport network provides opportunities to substitute more environmentally-friendly alternatives there is an environmental gain to be had. Table 5 compares the emissions per passenger-kilometer for a journey of 500 km point-to-point for various transport modes. From an emissions point-of-view the high-speed train and the intercity train are, according to this table, the best alternatives.

Table 5

Emissions per passenger-kilometer for a journey of 500 km for various transport modes [VROM, 1995].

| Mode | Occupancy rate | CO ₂ (g/pkm) | CO (mg/pkm) | NO _x (mg/pkm) | VOC (mg/pkm) | SO ₂ (mg/pkm) |
|-------------------------------|----------------|-------------------------|------------------------|--------------------------|---------------------|--------------------------|
| Bus ¹ | 70% | 22 | 75 | 479 | 56 | 23 |
| High-speed train ¹ | 65% | 48 | 2 | 87 | 12 | 60 |
| Intercity ¹ | 44% | 51 | 2 | 94 | 13 | 64 |
| Private car (gasoline) | 2 people | 86 ¹ | 250-1.600 ² | 270-145 ² | 45-220 ² | 7 ¹ |
| Boeing 737-300 ³ | 71% | 146 | 240 | 440 | 10 | 10 |

¹ Mean for period 1988-1990

² Data for 1990 car with three-way catalytic convertor; first value represents emissions under motorway driving conditions; second value represents emissions in city driving conditions [CBS]

³ Modelcalculation

6. A POLICY TO REDUCE AIRCRAFT EMISSION TRENDS

Let me now present to you an overview of our policy to reduce aircraft emission trends. This policy, which is described in the white paper 'Government Policy of The Netherlands on Air Pollution and Aviation', is predicated on an international approach and consists *inter alia* of the following elements:

- voluntary agreements with the Dutch aviation sector regarding the way that it can contribute to realizing the emissions policy;
- an international agreement between the partners to the Climate Treaty and the Chicago Convention that should provide as a minimum for a reduction in the growth of aircraft emissions on the basis of concrete international objectives for

air traffic and a methodology for calculating and apportioning international aircraft emissions;

- efforts within the International Civil Aviation Organization (ICAO) in order to achieve a substantial tightening of the existing NO_x standards for aero-engines, and the development of CO₂ standards for aircraft or the development of another system which will serve to reduce the growth in aircraft CO₂ emissions;
- introduction of a worldwide levy on kerosine;
- the discontinuance of exemptions on value-added tax for international flights;
- international Research & Development programs for clean and fuel-efficient aircraft and aero-engines;
- improvement of air traffic control systems.

From this policy package, I would like to emphasize two important elements. The first is *emissions regulation* that should preferably be a responsibility of ICAO's Committee on Aviation and Environmental Protection (CAEP). However, recent developments suggest that there consist different opinions between the United States and the European Union with respect to the need to tighten NO_x emissions regulatory rules for new aircraft engines. Although European members of the CAEP recommended the ICAO Council to increase the stringency of the current international NO_x requirement with 16 percent, the US opposed to this recommendation, arguing that there is no clear demonstrated environmental need and that the costs associated with the increased stringency are high. As a consequence, the ICAO Council decided not to increase the stringency and to refer this issue back to CAEP. This might drive Europe into a regional approach, thereby weakening the position of ICAO.

The second point I want to address are price measures, especially a *levy on aviation fuel*. Most countries follow the recommendation by the Council of the ICAO, that fuel used for international aviation should be tax-exempt. Aviation fuel taxation is precluded in most countries by provisions in the bilateral Air Transport Agreements which are the main legal framework for the operation of international civil aviation. High fuel prices drove airlines to achieve high energy intensity reductions during the seventies and the eighties through technical and operational changes. The primary aim of a levy on

aviation fuel would be to reduce the consumption of aviation fuel, and hence reduce the CO₂ emission trend by aircraft. It is our strong belief that this policy measure must become an important element of an international approach towards a more sustainable civil aviation industry. The Netherlands therefore underlines the chairpersons' conclusion of the Informal Meeting of Environment Ministers in Dresden from 21 to 23 march 1997, proposing in paragraph 21 "that the Special Session of the General Assembly of the United Nations in june 1997 considers an initiative to introduce air fuel taxation at the international level".

REFERENCES

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