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IMPACT OF SUPERSONIC AIRCRAFT ON UPPER LAYERS OF (ATMOSPHERE) STRATOSPHERE

ABSTRACT

Recent scientific research have continued to assume that aircraft may contribute to the adverse chemical changes in the global atmosphere, especially regarding ozone (O_3) depletion as well as in possible changes in climate.

However, there is substantial uncertainty regarding the real global impact of aircraft emissions, and governments and other organisations worldwide grant funds for such research.

The paper deals with the emission of subsonic and supersonic aircraft, with special reference to the impact of SST aircraft on the upper layers of atmosphere that may be harmed by aircraft operation.

KEY WORDS

supersonic aircraft, stratosphere, ozone,

1. INTRODUCTION

At the end of the century it may be concluded that one of its characteristics has certainly been the aviation whose development dominated compared to other modes of transport both regarding volume and intensity. The main ecological criteria related to international commercial aviation are aircraft-generated noise, emission of harmful aircraft engine components, waste material handling and soil and underground water pollution at airports.

Harmful impact of anthropogenic polluters, including aircraft, is not manifested only regionally but it influences to a great extent the global ecological balance in three main indications:

- change of balance regarding Earth radiation due to anthropogenic greenhouse effect, related to the change of global climate i.e. global warming of the lower layers of troposphere,
- change of ozone content in the atmosphere which influences on the one hand the radiation intensity onto the Earth surface and filtering of the harmful UV radiation, while on the other hand ozone represents an important greenhouse gas,
- change of oxidation capacity of atmosphere due to the increased troposphere ozone concentrations and the influence on the bio-, geo-, chemical circulation of other, ecologically important oligo-substances.

Although the share of air traffic in total emissions of CO_2, NO_x, CH_4, and CO is quantitatively of a small volume, the pollution is maximal at cruising flight altitudes, i.e. in the region of tropopause, where aircraft are the only anthropogenic polluters [1].

These are the altitudes (8-12 km) characterised by the following:

- naturally determined concentrations of these gases are very small,
- duration of their resistance is several times greater than in the lower layers of troposphere,
- measured values of atmospheric temperature are the lowest, thus resulting in greater impact of pollution than in analogous concentrations on the Earth surface.

While cruising, aircraft pollute the air in the upper layers of troposphere, at the level of tropopause and in the lower layers of stratosphere.

Like in piston internal combustion engines, in jet engines also the main harmful components of exhaust gases under control include: carbon (II) oxide (CO), nitrogen oxides (NO_x) unburned hydrocarbons (HC), coke particles, i.e. smoke properties of exhaust gases. Standards specify restrictions of the three listed harmful exhaust gases for new aircraft engines in LTO – cycle[1]. Already in 1981 ICAO has standardised the control of harmful emissions, i.e. aircraft engine certification conditions, in the second part of Annex 16.

However, the ecological compatibility has to be insured before any new generation aircraft starts its commercial flights.

Recent scientific research have continued to assume that aircraft may contribute to the adverse chemical changes in global atmosphere, especially in ozone (O_3) depletion, as well as in possible changes in climate. Reacting to this, ICAO Committee for Environmental Protection (CAEP) continues to give greatest priority to the standards and other measures for exhaust control at altitudes higher than those referred to by the existing regulations at airport community. Aviation is also taken into consideration when developing comprehensive international agreements on environmental protection, especially the Montreal protocol on substances that are harmful to the ozone layer and UN framework congress on the changes in climate.

However, there is great uncertainty regarding actual global influence of aircraft emissions, and governments and other organisations worldwide grant funds for such research. Except for computer simulation of the atmosphere, efforts are invested in direct measurements and laboratory study of characteristics of relevant atmospheric processes and chemical composition of emissions, study of wake, and development of the existing and planned emission regulations. [4]

Ecological care regarding big supersonic aircraft fleet (SST), refers primarily to flights of such aircraft that take place in the stratosphere where engine exhaust gases can change the chemical balance and cause substantial destruction of the ozone layer. Therefore, various hypotheses that predicted the fatal impact of nitrogen oxide ($NO_X + NO_2$) from supersonic transport aircraft (SST) on stratospheric ozone have been taken very seriously and have caused reduced interest for the commercial supersonic technology over many years. Since more was found out about the atmospheric chemical composition, it was accepted that NO_X would probably destroy the ozone as predicted, but also that these very exhaust air-borne elements that fly at subsonic speeds would generate ozone.

Having this in mind, NASA and its research team are investing great efforts in developing the possible influence of the future supersonic aircraft fleet and in technical solutions that would insure ecological compatibility with the project.

2. ATMOSPHERE RESEARCH

What enables people to influence the immense space of atmosphere is that ozone and other important chemicals exist in nature only in trails. For example, ozone appears in amounts of one to 10 parts per million per volume (ppmv) in stratosphere. How little of it there is in atmosphere can be shown by column abundance. If all the ozone could be gathered on the Earth's surface at the sea-level pressure, it would be only three millimetres thick. [7]

Figure 1 shows a typical distribution of ozone in atmosphere and the impact of aircraft. [5]

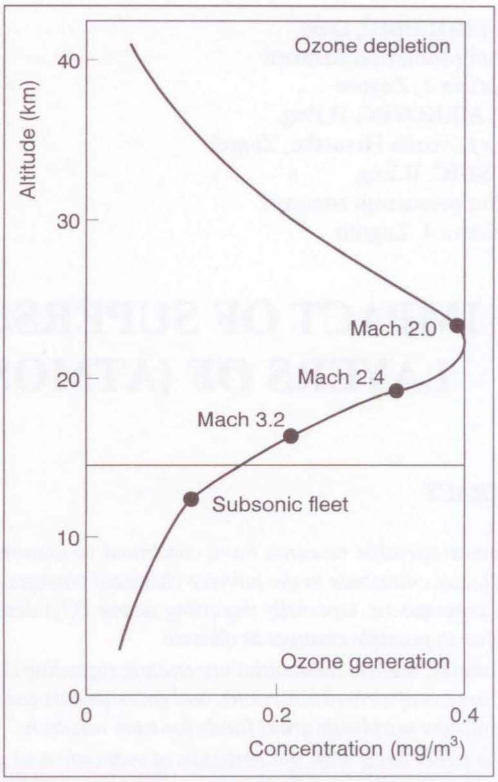

Figure 1 – Typical distribution of ozone in atmosphere and aircraft influence. Ozone concentration for mean latitudes is presented [5]

The aim of studying atmospheric processes that are influenced by aircraft can be summarised to these scientific issues:

- What are the aircraft emissions now and in the future?
- What chemical and physical processes in atmosphere can be disturbed by air-borne emissions?
- Is the study of atmosphere in accordance with the existing understanding of chemistry and physics related to aircraft emissions?
- What planned changes in ozone and influence on climate are related to aviation?
- What uncertainties are present in these predictions?

Very extensive research is being carried out in Europe and USA for a comprehensive scientific evaluation, and in spite of being organised and performed somewhat differently, they include the following topics and activities:

Emission characterisation

Characterisation of the current and subsequent elements from the engine exhaust under all flying conditions.

Interaction with the environment

Studying fluid dynamics and/or chemical processes in aircraft wake that can have influence on the change of engine exhaust properties or on the level of accumulation in any way that might significantly influence their final effect on the atmosphere.

Operative activities

Development and maintenance of a three-dimensional (3D) database with all aircraft emissions with real flying routes for the current and future operations.

Studying of atmosphere

Measuring of chemical and physical characteristics of atmosphere that refer to the possible impacts on ozone and climate.

Laboratory testing

Simulation on Earth and measuring of chemical and physical processes that are relevant for aviation.

Global modelling

Computer models of atmosphere in order to estimate physical influences as well.

3. SUBSONIC AIRCRAFT

Typical research results which refer to the current fleet consisting primarily of subsonic aircraft are those from Aeronox project, which had the special objective of determining the aircraft No_x emissions influence on the atmosphere at altitudes from 8 to 15 km. In order to determine the characteristics of emissions, these have been measured by means of the altitude test chamber under cruising conditions for modern aircraft engines, Rolls-Royce RB 211 and Pratt & Whitney Canada PW 305. From these and other available data, prediction equations for No_x emissions in cruising conditions have been developed.

In total, one fifth of aircraft caused pollutants are emitted in the lower stratosphere layers, and the other four fifths within the troposphere, as represented in Figure 2, showing the ozone destruction due to air traffic. [3]

For the global list of aircraft emissions, developed jointly by the European Civil Aviation Conference (ECAC) and the European Commission, 3-D atmospheric models were used, with various global simulations in order to study the changes in concentration of NO_x and photochemistry. Although aviation contributes only slightly in the amount to the global NO_x from all sources, the calculated surplus to the NO_x concentration in the upper troposphere proved to be substantial, especially above 30 degrees latitude. During winter months aircraft are assumed to be the greatest NO_x source in the upper troposphere of the mean latitude of the upper hemisphere. [1]

Aviation generates today about three percent of CO_2 generated by fossil fuel combustion, an amount

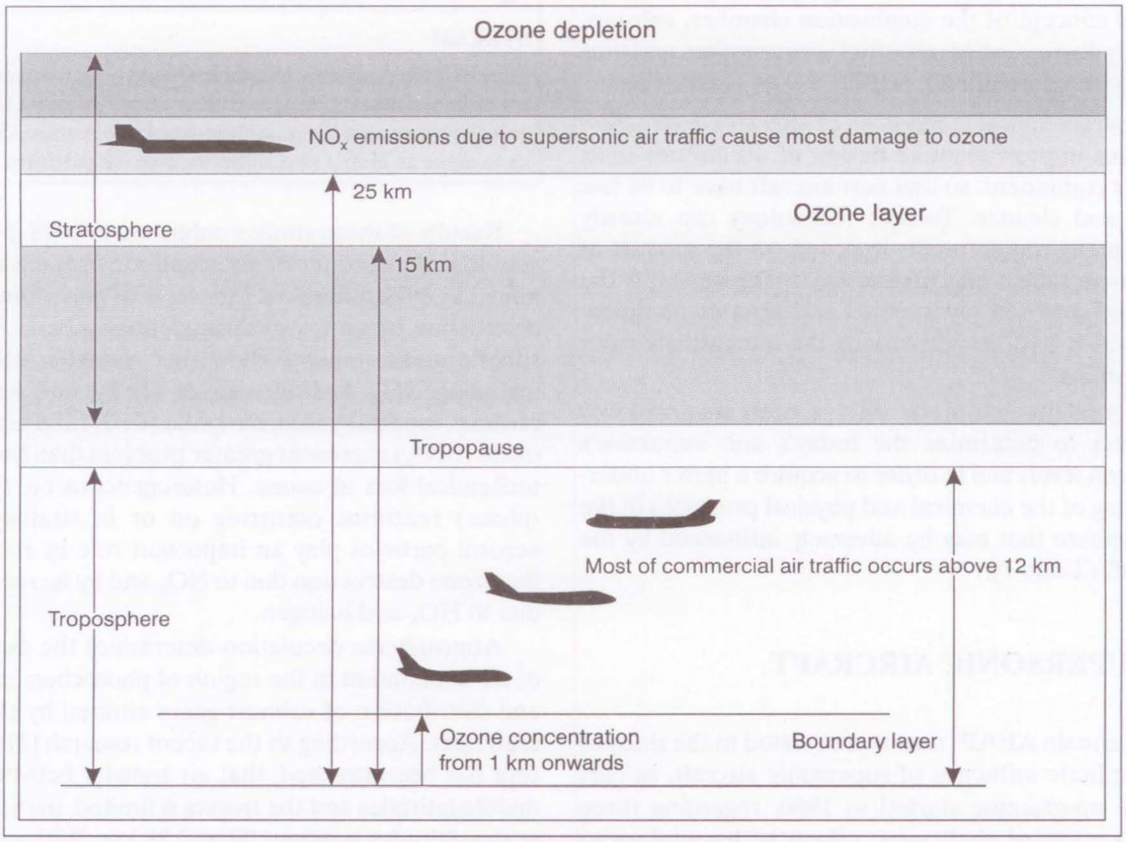

Figure 2 – Ozone depletion due to air traffic [3]

that is likely to continue to grow. Besides, water vapour is an important greenhouse–gas, since its influence at the tropopause boundary is ten times greater than in the lower layers, so that it is assigned an additional climatic action due to the formation of the so-called con-trails which help generate big, icy cirrus-clouds.

New estimates of air traffic share in the ozone generation range from 7 to 12%, and assuming its further growth with the annual rate of 5%, the air-traffic caused ozone concentration increase at cruising altitudes will amount to 20-30%.

Aircraft SO_2 emissions also have special influence on the climate, because they help ozone depletion through sulphate-aerosols, and an annual increase of 5% of its stratospheric concentration has been noted over the recent 20 years. [1]

Research (DASA, MTV)[2] with the aim of preventing harmful exhaust emissions caused by conventionally propelled aircraft include two aspects of reduction measures:

- improvement of the total aircraft aerodynamics, primarily by the so-called variable wing curvature, which due to decreased aerodynamic drag results in a substantial reduction of fuel consumption, and thus in reduction of absolute value of pollution as well,
- design of new generation of propfan engines with a new concept of the combustion chamber, substantially decreasing specific fuel consumption, and thus also the share of NO_x [1],

New ecological technology of aircraft construction includes improvement of design of all aircraft units and its equipment, so that new aircraft have to be less noisy and cleaner. Today's technology can already meet many requirements imposed on the aircraft of tomorrow, since air carriers are trying to avoid the need of constant investments and aircraft modification which have to accompany the increasingly strict regulations.

A great number of scientific projects are under way in order to determine the today's and tomorrow's emission levels and in order to acquire a better understanding of the chemical and physical processes in the atmosphere that may be adversely influenced by the aircraft (Table 1).

Table 1 – various European projects [2]

AEROCHEM
Assessment of 3-D chemical impact of past, current and future subsonic and supersonic aircraft on the atmosphere using global chemical transport models.
AEROCONTRAIL
Formation, growth and evaporation of condensation trails; micro-physics, interaction with aerosols and cirrus clouds, impacts on radiation stocks and climate.
AEROJET
In-flight measurements of aircraft engine exhaust. Measurements of exhaust gases of jet regime Airbus A340 using FTIR-Mirror, FIR-Heterodyne, IR radiometer for recording.
AEROTRACE
Measurements of types of trails in aircraft engine exhaust. Provide quantitative data on exhaust of types of trails from aircraft engines during the whole flying cycle using available and existing on-line and off-line analytical techniques in combination with gas sampling; particle measurement, types of nitrogen, special hydrocarbons; assess the quality of fuel.
MOZAIC
Measurements of ozone and water vapour in aircraft Airbus in service. Assessment of aircraft impact on the atmosphere by expanding the basic scientific experience using measurements in situ on five A340 aircraft.
STREAM
Experiments performed in stratosphere – troposphere using onboard measurements. Future activities will take into consideration also the modification of one Airbus A340 so as to serve as global atmospheric research platform.

4. SUPERSONIC AIRCRAFT

The main AEAP[3] results are related to the study of atmospheric influence of supersonic aircraft, as part of the programme started in 1990, regarding three main ecological challenges: effects of harmful emissions in stratosphere, noise and sound effects.

Results of these studies published in 1995 [5] indicate that the amount of stratospheric ozone is determined by photochemical processes of generation and destruction by air travel through atmosphere. Atmospheric measurements show that catalytic reactions including NO_x, hydrogen oxide (HO_x) and halogen radicals, especially chlorine oxide (ClO_x) and bromine oxide (BrO_x) represent greater problem than the photochemical loss of ozone. Heterogeneous i.e. (multi--phase) reactions occurring on or in stratospheric aerosol particles play an important role by reducing the ozone destruction due to NO_x and by increasing it due to HO_x and halogen.

Atmospheric circulation determines the duration of air detainment in the region of photochemical loss and distribution of exhaust gases emitted by the aircraft fleet. According to the recent research [2] a concept has been reached, that air transfer between the middle latitudes and the tropics is limited, particularly at the altitudes between 20 and 28 km. Without such limitations, the air transfer from primary flying corridors at middle latitudes into the tropics can cause faster spreading of exhaust gases from the lower into the higher atmosphere, where the NO_x caused catalytic destruction of ozone is greater.

Five two-dimensional (2-D) photochemical models have been used in order to calculate the influence of supersonic fleet for a number of cases, including sensitivity test for emission index (EI) NO_x – expressed as gram equivalent nitrogen dioxide (NO_2) per kilogram of burned fuel. Other factors included in the calculation were the cruising altitude, volume of background atmospheric chlorine and the fleet size. Individual models were used in order to test sensitivity to various factors not included in these basic planned calculations. The conditions include the basic fleet of 500 aircraft which can operate at Mach 2.4 and consume 8.2 x 1010 kg fuel annually in the atmosphere with the volume of background stratospheric aerosol that corresponds to the relatively clear period between main volcanic eruptions. The calculated changes in the ozone are the result of the reduction in the middle and upper stratosphere and increase in the lower stratosphere and troposphere.

The scope of results is presented in Table 2 [4]

Table 2 – Calculated stable change of total ozone column [4]

Prediction			2-D model results	
Mach No.	EI_{NOx} Cl_y (pplov)	EI_{NOx} (g NO_2/kg goriva)	Fleet size	Ozone change (%)[a]
2.4	3	0	500	-0.3 to -0.1
2.4	3	5	500	-0.3 to +0.1
2.4	3	5	1000	-0.7 to +0.03
2.4	3	10	500	-0.5 to 0.0
2.4	3	15	500	-1.0 to -0.02
2.4	3	15	1000	-2.7 to -0.6
2.4[c]	3	5	500	-0.5 to +0.02
2.4[d]	3	5	500	-0.06 to +0.1
2.4	2[b]	5	500	-0.4 to +0.02

Northern hemisphere, average values of one year for several predictions of supersonic fleet (a) scope of average values obtained from five 2-D samples used in this research, (b) expectations in 2050 atmosphere (c) cruising + 1 km (d) cruising – 2 km

Substantial time necessary for photochemistry and transfer in order to cause changes in the ozone, include great changes in the ozone near the given flight corridors. Values of the NO_x emission index (EI_{Nox}) in Table 2 provide those expected for the future internal combustion engines (5 grams NO_2 per kg of fuel) and those nearer to the existing engines (15g/kg).

For better simulation of aircraft in computer models, field experiments are used for sampling aircraft exhaust and modelling of the engine process, including dispersion of exhaust gases in atmosphere, in order to define the important chemical and dynamic characteristics of exhaust plumes. In 1995 measurements were carried out of reactive nitrogen (NO_y), condensation nuclei (CN) and CO_2 in the exhaust of aircraft Concorde SST and one NASA ER-2 subsonic aircraft during the flight. The emission indexes were calculated independently of plume dynamics since measurements of CO_2 provide fuel consumption rate.

The measured NOx approached very close to the results obtained earlier from the altitude chamber measurements of Concorde Olympus engine exhaust. These results indicate that the methodology developed in order to calculate the NO_x emission index in cruising, using altitude chamber data, will be suitable for assessment of new aircraft engines.

Sulphur emitted by the supersonic aircraft fleet could substantially increase the area of aerosol covered in the lower stratosphere. Although it is predicted that the increase of area is reduced by NOx emission (i.e. through catalytic conversion into HNO_3), it could increase the ozone loss due to the existing chlorine and hydrogen radicals in stratosphere. If the emitted sulphur immediately formed small, long-lasting particles in the plume, global increase of sulphate area would be maximal. The model that includes the aerosol processes has been used for the calculation of ozone changes when all the sulphur is emitted as small particles into the volcanically undisturbed stratosphere. The change in the total ozone column due to the injection of small particles depends in a complex way on the NO_x emission index and the amount of background chlorine. For EI_{NOx} which equals five grams per kilogram of fuel, the calculated ozone depletion increased when small particles formed, and the total misbalance has become as great or greater than the case where EI_{NOx} was 15 grams per kg of fuel, not taking sulphur into consideration. Therefore, further research is planned regarding sulphur in fuel [2].

Predictions of possible impact of future supersonic transport are related to several classes of uncertainty developed with 2-D models, as presented in Table 2. Uncertainties from the possibilities of failed-to-occur processes or greater errors in our experiences cannot be quantified, but rather discussed within the total assessment reliability. However, the probability that significant processes are predicted, is reduced as disturbances in models continue to be studied and if they continue to be provoked in atmospheric measurements. The primary methodology for improving the prediction capabilities will continue to include studying of the models of atmosphere by comparison with research data.

Substantial improvement will be achieved in that direction soon by systemic comparisons with recently obtained data from measurements performed on the satellite, as well as in the field and remote measurements with ER-2 aircraft and platform measurements.

5. CONCLUSION

Since its foundation in 1990, the Research program on high speeds has been gathering data on the possible impact of the future supersonic aircraft fleet. This program has studied technical solutions regarding three main ecological challenges: effects of harmful emissions, noise and sound effects.

Economic studies show that the increase of intercontinental flights will create also a potential market for supersonic aircraft. The technology holds the key to successful presentation of profitable aircraft since the new generation of supersonic traffic has to face a certain number of ecological requirements.

One of the ecological requirements that received special attention is the impact of supersonic aircraft on the atmosphere (chemical and climate impacts) that will be the basis for further approaches to this problem.

Atmosphere assessment can be supplemented by "in situ" measurements on atmosphere and ozone pollution using special aircraft stationed at great altitudes, with remote control vehicles and development of super precise atmospheric simulation models designed for such measurements.

Operative plans regarding design size of aircraft fleet have been developed and in combination with advanced atmospheric models have been used for prognostics regarding the fleet and its impact on the atmosphere.

Key role in estimating the depletion of the ozone layer due to supersonic aircraft has NO_X emission index which is expressed as gram NO_X per kg of consumed fuel. Scientists believe that current NO_X emissions marked by index (40 – 60) for subsonic commercial aircraft might be reduced to factor 10 or 8 with improved aircraft technology [3]. NASA and its Research team are therefore developing such a technology of combustion whose aim is to reduce engine exhaust gases up to 5 grams of NO_X per one kilogram of consumed fuel, whereas NO_X emission index for supersonic aircraft is yet to be published.

Encouraging is the information given by scientists that the destruction of ozone layer should not be too serious, if supersonic aircraft cruised at lower altitudes, if there were fewer of them and if the energy consumption was more efficient. [3]

The obtained data studied by NASA will enable making correct decisions by the industry regarding manufacture of high-speed aircraft that are economically sustainable and ecologically compatible.

SAŽETAK

UTJECAJ SUPERSONIČNIH ZRAKOPLOVA NA GORNJE SLOJEVE (ATMOSFERE) STRATOSFERE

Znanstvena istraživanja proteklih godina nastavljaju s pretpostavkama da bi zrakoplovi mogli doprinjeti štetnim kemijskim promjenama u globalnoj atmosferi, naročito u debljini ozona (O_3) kao i mogućim klimatskim promjenama.

Međutim, postoji znatna nesigurnost u svezi sa stvarnim globalnim utjecajem emisija zrakoplova, a vlade i druge organizacije širom svijeta sponzoriraju takva istraživanja.

U radu se obrađuju emisije subsoničnih i supersoničnih zrakoplova, s posebnim osvrtom na utjecaj SST zrakoplova na gornje slojeve atmosfere, kako bi se bolje razumjelo kemijske i fizikalne procese u atmosferi na koje zrakoplovi mogu nepovoljno utjecati.

NOTES

1. Landing and Takeoff cycle
2. DASA – formerly Deutsche Aerospace AG, since 1996 Daimler-Benz Aerospace, MTV-Motoren und Turbinen-Union Gmbh
3. AEAP- Project of atmospheric influence of aircraft funded by the US National Aeronautics and NASA and the US Federal Aviation Association (FAA)

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