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INFLUENCE OF AIRCRAFT ENGINE EXHAUST EMISSIONS AT GLOBAL LEVEL AND PREVENTIVE MEASURES

ABSTRACT

The work considers the differences in the aircraft engine exhaust emissions, as well as the impact of the emissions on the environment depending on several factors. These include the age of the engine, i. e. technical refinement, engine operating regimes at different thrusts during time periods: takeoff, climb, approach, etc. Also, the exhaust emissions do not have the same influence on different atmospheric layers. The pollutants emitted at higher altitudes during cruising have become a greater problem, although the volume of pollutants is smaller, due to the chemical complexity and sensitivity of these layers as compared to the lower layers of atmosphere. One of the reasons why these problems have long remained outside the focus of interest of the environmentalists is that the air transport of goods and people is performed at high altitudes, so that the pollution of atmosphere does not present a direct threat to anyone, since the environment is being polluted at a global level and therefore is more difficult to notice at the local level.

KEY WORDS

ecology, atmosphere pollution, aircraft engines, exhaust emissions, preventive measures

1. INTRODUCTION

Harmful impact caused by the growth of air traffic originates from three types: aircraft noise, exhaust emissions and finally, the problems related to the air traffic management itself.

Regarding worldwide the exhaust emissions generated by air traffic, it accounts for about 3.5 per cent of the global warming caused by people. The main air pollutants related to aircraft engine emissions are considered to be carbon dioxide, nitrogen oxides, water vapour and particles of soot and sulphur. These emissions are expected to grow – in the period from 1992 to 2015, at an annual rate of 3 per cent, since air traffic is growing faster than the technical development which contributes to the improvement of aircraft energy efficiency. In the entire world, 16,000 commercial jet aircraft generate annually more than 600 million tonnes of CO_2, the most significant greenhouse gas /5/.

In order to sustain the growth of aviation, 30 to 50 per cent of the busiest national airports have planned the expansion, and about 60 to 100 biggest airports have planned the construction of new runways, which has its environmental consequences. /6/

The fact that had not been considered until recently, is that the airports and the aircraft are the biggest individual polluters and that they cause enormous growing damage to the environment at the local level around the airports (dangerous exhaust gases and noise) and at the regional and the global level (greenhouse gases, and depletion of the ozone layer).

Polluters which are emitted at the higher altitudes during cruising represent a greater problem, although the quantities of emitted pollutants are smaller since these layers are chemically more complex than the lower levels of atmosphere where the exhaust gases are emitted during the takeoff and landing cycles. The aim is, therefore, to provide an overview of the data on aircraft engine exhaust emissions and their impact at a global level as well as the possibilities of reducing the emissions i. e. carrying out the preventive measures.

2. INFLUENCE OF EXHAUST EMISSIONS AT THE GLOBAL LEVEL

The aircraft harmful emissions could participate in 2050 with 15 per cent in the global warming of the Earth, which can be blamed on the humans. /4/

There are two global environmental problems today that can be considered to have consequences due to the aircraft impact. These include: climatic changes, including changes in the weather models (e. g. for precipitation, temperature, etc.) and regarding supersonic aircraft, depletion of the stratospheric ozone and as consequence the increase in the UV-B radiation on the Earth surface.

Large number of aircraft emissions can influence the climate. Carbon dioxide (CO_2) and water (H_2O) do this directly; other factors (e. g. ozone generation in the troposphere, different methane life-cycle, formation of contrails and the change in the cirrus clouds) act indirectly. Emissions which influence the atmospheric ozone (e. g. nitrogen oxides, particles and water vapour) act indirectly changing the chemical balance in the stratosphere. Besides, civil air traffic is constantly growing. Over the next 10 to 15 years, an increase in air traffic demand by 5 per cent annually is expected (Airbus 1997, Boeing; 1997, Brasseur, 1998) although regional deviations in demand are likely to be present.

The EU Commission claim /5/ that the current fleet of subsonic aircraft consumes about 130 to 160 million tonnes of fuel annually. Although aviation consumes 13 per cent of fossil fuels that are used in traffic, it is the second largest form of transport regarding consumption, following road traffic which consumes 80 per cent of all fuels in transport (IPCC, 1996). Due to the increased growth of aviation there are numerous questions regarding the future influence of aviation emissions on the global environment: if the number of supersonic aircraft (flying mainly in the stratosphere) increased significantly, what special effects would there be? The research studies indicate that the planned fleet of supersonic aircraft would spend 2-3 per cent of the remaining ozone in the stratosphere within 10 years, damaging most the ozone layer at the altitudes of 25 – 28 km above sea level. /1/

Figure 1 shows the ozone depletion due to air traffic, concluding that overall one fifth of aircraft-generated pollutants is emitted in the lower stratospheric layers, whereas the remaining four fifths are within the troposphere /1/.

Some of the processes which refer to aircraft emissions and the areas of emissions are shown in **Figure 2**.

Subsonic aircraft fly in the troposphere and lower stratosphere, whereas supersonic aircraft spend 80 – 85 per cent of their flying time in the stratosphere and cruise at an altitude of several kilometres above subsonic aircraft. The diversities in chemical and physical processes in these two areas have to be taken into consideration.

Table 1 shows the aircraft emissions that are significant from the aspect of atmosphere and gives a summarised description of their individual roles.

These emissions can be divided into two groups, depending on their effect on the climate:

– *direct effect:* such as CO_2 (the emitted element is a substance which can change the climate);

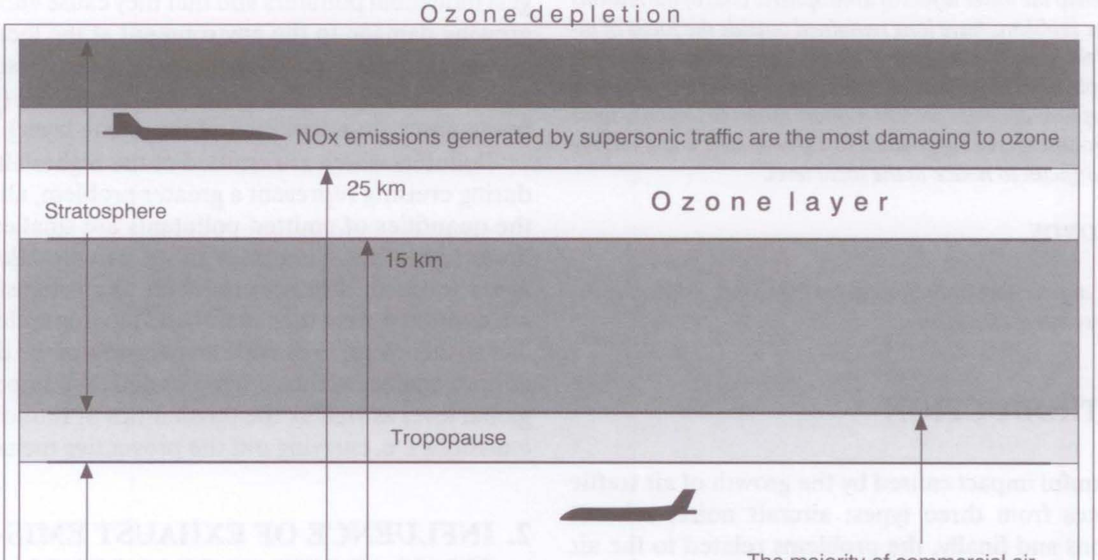

Figure 1 – Ozone depletion due to air traffic /5/

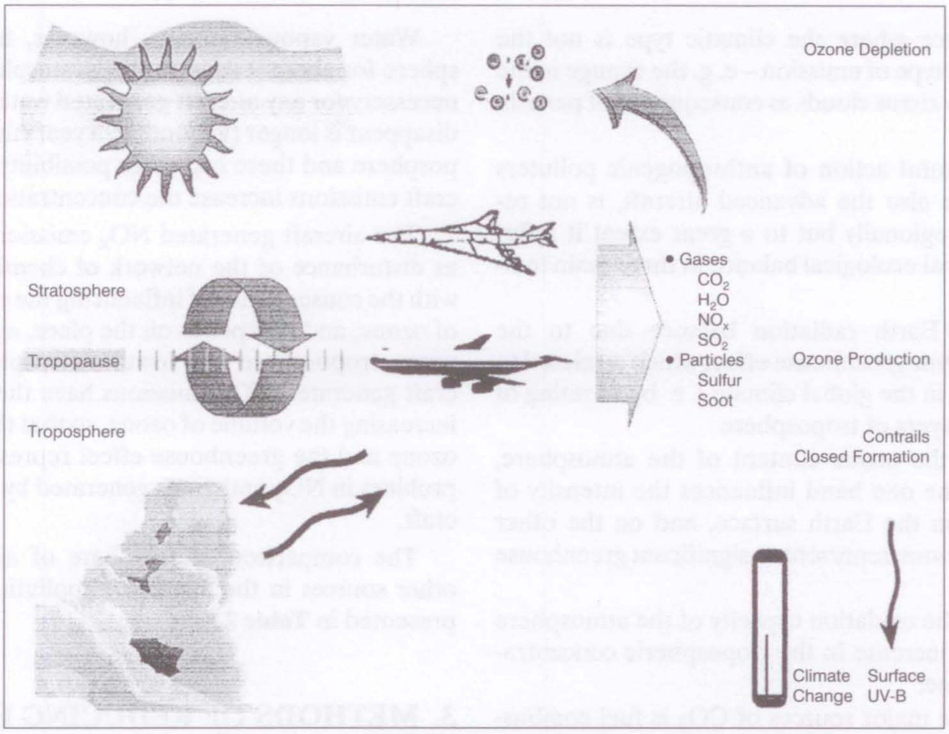

Figure 2 – Emissions by sub- and supersonic aircraft and their influence in atmosphere /IPCC: "Aviation and the global atmosphere – Special Report", 1996, 1997/

Table 1 – Types of components that influence the climate and the ozone change

Emitted type	Role and main effect on Earth surface
CO_2	/Troposphere and Stratosphere/
	by direct radiation stimulates warming
H_2O	/Troposphere/
	by direct radiation stimulates warming
	increased formation of contrails and warming by radiation
	/Stratosphere/
	by direct radiation stimulates warming
	increased formation of PSC (polar stratosphere clouds), depletion of O_3 (ozone), increase of UV-B radiation
	changing the chemistry of O_3, depletion of O_3, increase of UV-B
NOx	/Troposphere/
	formation of O3 in upper troposphere
	stimulates warming by radiation
	decrease of UV-B
	decrease of CH_4, lower radiation, causes cooling
	/Stratosphere/
	generation of O_3 below 18-20 km decreases UV-B
	generation of O_3 above 18-20 km increases UV-B
	increased formation of PSC, depletion of O_3 (ozone), increased UV-B radiation
SOxO and H_2SO_4	/Troposphere/
	Increase in concentration of sulphate aerosol
	causes cooling by direct radiation
	forming of contrails, by radiation causes warming
	greater coverage by cirrus clouds, by radiation causes warming
	changes the chemistry of ozone
	/Stratosphere/
	changes the chemistry of ozone
Soot	/Troposphere/
	by direct radiation causes warming
	forming of contrails, by radiation causes warming
	greater coverage by cirrus clouds, by radiation causes warming
	changes the chemistry of ozone
	/Stratosphere/
	changes the chemistry of ozone

(IPCC: "Aviation and the global atmosphere – Special Report", 1996, 1997)

- *indirect effect:* where the climatic type is not the same as the type of emission – e. g. the change in the coverage by cirrus clouds as consequence of particle influence.

Thus, harmful action of anthropogenic polluters which include also the advanced aircraft, is not reflected only regionally but to a great extent it influences the global ecological balance in three main indications:

- change in Earth radiation balance due to the anthropogenic greenhouse effect which is related to the change in the global climate i. e. by warming of the lower layers of troposphere
- change in the ozone content of the atmosphere, which on the one hand influences the intensity of radiation on the Earth surface, and on the other hand, the ozone represents a significant greenhouse gas;
- change in the oxidation capacity of the atmosphere due to the increase in the tropospheric concentration of ozone;

One of the major sources of CO_2 is fuel combustion. The amount of CO_2 generated by aircraft fuel combustion is determined by the total volume of carbon in the fuel, since CO_2 is an inevitable by-product of the combustion process (just as water). CO_2 emitted from aircraft gets mixed with other CO_2 from fossil fuel origins and becomes a component which equally influences the climate. The growth rate of aircraft generated CO_2 emissions is faster than the global economic growth, so that the contribution of aviation, together with other transport modes, to the emission generated by human activities is showing the tendency of growth in the years to come.

Water vapour remains, however, in the troposphere for about 9 days. In the stratosphere, the time necessary for any aircraft generated water emission to disappear is longer (a month to a year) than in the troposphere and there is greater possibility that the aircraft emissions increase the concentration in space.

The aircraft generated NO_x emission is best seen as disturbance of the network of chemical reactions with the consequence of influencing the concentration of ozone, and it depends on the place, age, etc. In the upper troposphere and lower stratosphere, the aircraft generated NO_x emissions have the tendency of increasing the volume of ozone, so that the increase in ozone and the greenhouse effect represent the main problem in NO_x emissions generated by subsonic aircraft.

The comparison of the share of air traffic and other sources in the amount of pollution have been presented in **Table 2**.

3. METHODS OF REDUCING HARMFUL SUBSTANCES GENERATED BY AIRCRAFT ENGINES

Technological achievements concretely reduce the majority of emissions per passenger km. However, there are possibilities for further improvements. Any technological change can cause change in the balance of the range of impacts on the environment.

The subsonic aircraft manufactured today are about 70 per cent more fuel efficient per passenger km than forty years ago. The majority of improvements in

Table 2 – Comparison of share of air traffic and other sources in the volume of pollution

FUEL CONSUMPTION			
Air traffic (mil. t/year)		Total (mil. t/year)	
176		3140	
EMISSIONS			
Pollutant	Air traffic (mil. t/year)	Other sources (mil. t/year)	Source
CO_2	554	20900	fossil fuel combustion
H_2O	222	45 525000	oxidation of methane in atmosphere evaporation from Earth surface
NO_x	3.2	2.9 ± 1.4 90 ± 35	Stratosphere-troposphere transfer Anthropogenic sources
CO	0.26	600 ± 300 1490	Oxidation of methane Anthropogenic sources
CH	0.1	90	Anthropogenic sources
Soot	0.0025	–	–
SO_2	0.176	0.0625 134	Stratospheric aerosol Fossil fuel combustion

efficiency have been achieved by improving the engine and the rest by improving the aircraft structure design.

The forecast improvement in fuel efficiency or utilisation by the year 2015 is 20 per cent, and by the year 2050 it amounts to 40 to 50 per cent compared to the present aircraft fuel efficiency.

The improvements in engine efficiency have reduced the specific fuel consumption and the majority of various emissions. However, the volume of contrails as well as the emission of nitrogen oxides (NO_x) has increased, and there is unlikely to be any reduction here, unless the combustion technology improves.

The development of engines and aircraft structure in the future encompasses the complex procedure of decision-making and of requirements, uniform taking into consideration various factors, e. g. emission of carbon dioxide (CO_2), emissions of NO_x at the Earth surface, emission of NO_x at higher altitudes, emission of water vapour, generation of contrails or cirrus clouds (jet cirrus).

At the international level, actual research programs for engines are developed with the aim of reducing NO_x emission in LTO cycle by 70 per cent compared to the present regulation standards, as well as in order to improve, i. e. reduce the engine fuel consumption by 8 to 10 per cent compared to the latest engines by the year 2010. Reduction of NO_x emission at cruising altitudes could also be achieved, although maybe not in the same proportion as for the LTO cycle. If it is assumed that these objectives are possible and feasible, the transition of the new technology to a certain and substantial number of more recently manufactured aircraft will take longer – the usual ten-year period. The research programs for supersonic aircraft generated NO_x emissions are also being developed.

Research (DASA, MTV) in the area of preventing harmful exhaust generated by conventionally propelled aircraft (kerosene) is directed exclusively to technical improvement which includes two aspects of measures:

- improvement of the overall aircraft aerodynamics, primarily by applying the so-called variable wing curvature (bearing surfaces), which due to the reduced aerodynamic drag results in substantial reduction of fuel consumption and consequently also in the reduction of absolute value of pollution;
- designing of new generation of propfan engine with the new concept of combustion chamber, where the specific fuel consumption has been substantially reduced as well as the relative share of pollutants, especially nitrogen oxides.

The policy of measures undertaken in order to reduce the emissions includes also much stricter regulations regarding aircraft engine emissions, abolishing extra taxes and incentives that have negative impact on the environment, measures on the market principle such as environmental contributions (fees and taxes), then emission trade, voluntary agreements, research programs and replacement of air carriage by railway or road carriage.

4. CONCLUSION

The problem of aircraft engine exhaust emissions as one of the influencing factors of aviation on the environment appeared in wider and more serious considerations already in the sixties of the 20^{th} century.

Today's scenarios of future development and aircraft engine emission effects take into consideration also the supersonic air traffic which operates mainly in the still little known layers of stratosphere. These scenarios are interpreted as the means of studying different future results, and they are based on the assumptions of the growth of population and economy, of technological changes, availability of energy and fuel and the land usage.

The specific characteristic of emissions in aviation is the distribution in several vertical layers of atmosphere, from the marginal layer at the Earth surface, through troposphere and tropopause to stratosphere. Such distribution is the reason for an even greater caution and control of emissions.

A quotation from the book "Le fin de ciel bleu – les supersoniques" (Eng: The End of the Blue Sky – Supersonic Aircraft) which was written in the seventies of the last century, makes us think about the future development of aviation /2/:

"Speed is not the goal! It is the means and the technological development. Development can be justified only if it brings advantage. If it is nothing else but an automatic mechanism that cannot be stopped, then people need to know how to control it. This is the price of man's freedom. The main problem of our times is not to conquer the nature and its laws but to conquer the technology.

We should learn not to succumb to temptation of useless development, but to use scientific power wisely."

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SAŽETAK

UTJECAJ EMISIJE ISPUŠNIH PLINOVA ZRAKOPLOVNIH MOTORA NA GLOBALNOM PLANU I MJERE PREVENCIJE

U radu su sagledane razlike u emisiji ispušnih plinova zrakoplovnim motora, pa tako i utjecaj emisije na okoliš koji ovisi o nekoliko čimbenika. To su starost motora tj. tehnička dotjeranost, režimi rada motora pri različitim potiscima u vremenskim periodima: polijetanje, penjanje, prilaz i sl. Isto tako emisija ispušnih plinova nema isti utjecaj na različite slojeve atmosfere. Onečišćivači koji se emitiraju u višim slojevima za vrijeme krstarenja postaju veći problem, premda je količina zagađivača manja, zbog kemijske kompleksnosti i osjetljivosti tih slojeva u odnosu na niže slojeve atmosfere. Jedan od razloga što je ova problematika dugo bila izvan interesa ekoloških stručnjaka je ta da se prevoženje robe i putnika zrakoplovom odvija na velikim visinama pa onečišćenje atmosfere nikoga izravno ne ugrožava, jer se okoliš onečišćuje na globalnoj razini i teže se uočava na lokalnoj razini.

KLJUČNE RIJEČI

ekologija, onečišćenje atmosfere, zrakoplovni motori, ispušni plinovi, mjere prevencije

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