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RELATIONSHIP OF METEOROLOGICAL PROCESSES AND CONTRAILS

Jakub Kraus[1] - Jakub Hrubčo[2] - Marek Štumper[3] - Šárka Hulínská[4] - Iveta Kameníková[5]

Abstract: *Air transportation has a non-negligible effect on the Earth's atmosphere. Contrails are one of the factors causing changes in the atmosphere. Their global influence on the climate is not yet well understood, but there is a presumption that the dominating effect should be the greenhouse or the warming effect. Their formation depends on suitable atmospheric conditions and phenomena that create these conditions. Because their influence on the radiation balance is presumed to be positive, it is important to focus on the reduction of the formation of persistent contrails and to mitigate their effects. Methods and technologies that are needed to accomplish desired objective, however, require an increase in the economic, operational and technological capacities in the air transportation. We described global and operational changes to the operating methods such as shifting of cruise altitudes and spatial and temporal regulation of flights. From the technological viewpoint, we mentioned engine efficiency, alternative fuels and physical changes to airframes and their effect on the contrails formation. In this research, we identified the elements that contribute to the increase of the radiation forcing and the formation of contrails and contrail-cirrus and the relations between them. The conclusion outlines gaps, filling of which would improve the understanding of the formation of contrails.*

Keywords: Contrail, atmosphere, aircraft emissions, albedo, radiative forcing.

1 INTRODUCTION

Air transport has relatively small but considerable effect on the Earth's atmosphere. Today it expands by the 5% p.a. and it is assumed that by the 2050 the air transportation will be the main contributor to the global warming among all of the modes of transport.

Condensation trails are the phenomenon that is connected to air transport from its origin. At the beginning, the contrails were not considered as threat. Research of contrails, their formation, persistence, morphology and transformation into contrail-cirrus started relatively not long ago. The very first researches started along with the beginning of the World War II, when ability to detect aircraft had a crucial impact. After the war, the researches were stopped and they have been "re-opened" in the late 1990's. This time it was because of their environmental impact.

The impact of emissions of civil aviation on the Earth's atmosphere is a subject of discussions for a long time. The observations of dark plumes behind first jets increase an interest of air quality. In the 70's the United States Environmental Protection Agency introduced the legislation against aircraft emissions. This legislation forms the basis of ICAO emission certificates within production of unburned hydrocarbons, nitrogen oxides and carbon monoxide.

In the late 70's the supersonic aircraft Concorde was introduced. It was supposed to fly in stratosphere that raised concerns about changes in the atmosphere and Crutzen [1] described how production of nitrogen oxides could lead to decrease of an ozone in the stratosphere.

At the end of the 20th century, the research has started to focus on subsonic aircrafts and the influence of their emission on the atmosphere. Emissions include carbon dioxide, water vapor, nitrogen oxides, sulfur particles and other gases and solid particles. These emissions generated by subsonic air transportation causes anthropogenic changes of climate by increasing of amount of ozone and cloudiness in the upper troposphere and subsequent increase in greenhouse effect. Several researches paid their attention to this issue (e.g. [2], [3], [4], [5], [6], [7], [8], [9], [13], [14]). Later the main objective had moved to contrails, because contrails can spread and forms the artificial contrail-cirrus.

The aim of this paper is to summarize current research and compare methods of preventing of their formation or mitigation their influence. The next aim is to identify gaps in current research about contrails and especially their formation and that entails an identification of the elements that contribute to the increase of the radiation forcing and the formation of contrails and contrail-cirrus and the relations between them.

2 REDUCTION OF CONTRAILS

There are two main reasons why to reduce contrail formation. The first one is for military purpose and the second one is their impact on the environment. Contrails can be divided in terms of their persistence into:

- Temporary.
- Persistent non-spreading.
- Persistent spreading.

The most significant impact on the environment has persistent spreading contrails. The following chapters discussed this type of contrails.

2.1 Identification of elements

From the existing papers the technological and operating elements was identified, which plays a major role in terms of formation of contrail-cirrus and its influence on radiative forcing. Elements and their relations are given in Figure 1. The structure has four levels: Radiative forcing ← Occurrence of contrails/contrail-cirrus and their radiative forcing properties (green) ← Ambient conditions (blue) ← Technological and operating elements (orange). The solid lines represent strong connection between element, dashed lines weaker connection.

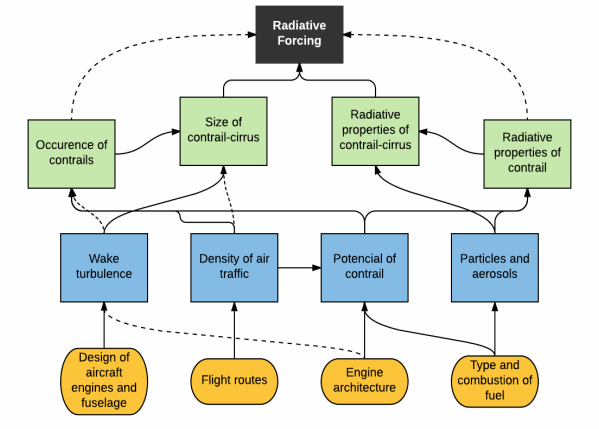

Fig. 1 Structure of elements, which influence contrail formation and subsequent radiative forcing

Radiative Forcing is defined as the difference between amount of energy absorbed by the Earth and the amount of energy radiated by the Earth back to the space. The amount of absorbed energy depends on the intensity of solar radiation. If the amount of absorbed energy is higher than the amount of radiated energy, we can talk about positive radiative forcing and the atmosphere is getting warmer.

Occurrence of contrails indicates the number of persistent contrails, which occur over region at a same time. Density of air traffic and the Potential of contrail have a major influence on the occurrence of contrails. Potential of contrail represents ambient conditions, which are favourable for contrail formation. Occurrence of contrails naturally affects the Size of contrail-cirrus in case that it forms. The most significant element that influences morphology and growth of contrail and subsequent contrail-cirrus is the Wake turbulence. The Radiative properties of contrail-cirrus is a result of Radiative properties of contrail from which it originates. These features depend on the number of solid particles in the ambient air (Particles and aerosols) which act as a condensation nuclei and cause formation of ice crystals.

Technological and operating elements are those through which we can affect formation and appearance of contrails.

Design of aircraft engines and fuselage – all changes and innovations to physical form of engines and fuselage.

Flight routes – temporal or global changes in trajectories *of fly routes.*

Engine architecture – changes in the principle of operation of aircraft's engines.

Type and combustion of fuel – reducing emissions, using of different energy sources

2.2 Adjustment of air traffic

From operational point of view there are three methods how we can attain reduction of contrail formation: time adjustment of air traffic, spatial adjustment of air traffic and shifting of flight levels.

2.2.1 Time adjustment

The idea of the time adjustment of air traffic is that the most flights would avoid certain times of day when the probability of contrail formation is low or when their effect on the radiation forcing is low.

Radiation forcing of cirrus clouds differ between day and night. They reflect a fraction of shortwave solar radiation back to space during the day whereas they retain longwave radiation emitted by the Earth during the night. Because of that, the state of atmospheric conditions when contrails do not form during the day and form during the night can be considered as the most significant in terms of positive radiative forcing. Stuber [10] implies that the night flights have the most significant impact on positive radiative forcing and Stordal et al. [11] report that an increase of density of air traffic during the sunrise and sunset would reduce the effect of radiative forcing from contrails. Although this approach is respectful to the environment the time adjustment of air traffic is very difficult to manage. Nowadays the air traffic take place during the whole day and it would be very difficult or almost impossible to restrict it to only certain day times.

2.2.2 Spatial adjustment

Similar to the time adjustment, the idea of the spatial adjustment of air traffic is that flights should avoid areas with suitable ambient conditions for contrail formation or that flight should take place in areas where contrails form but their radiative forcing potential is low. It means that flight paths should be relocated above the surface with low albedo. This approach is limited by the massive reduction of the number of flight routes and by the capacity of airspace. Moreover, if no low albedo surface is present near airport this approach is unfeasible.

2.2.3 Shifting of cruise altitudes

The main idea of preventing persistent contrail formation is to avoid cruise altitudes in which contrails form with high probability. Theoretically, we can assume that it would be effective to shift cruise altitudes upwards in the mid-latitudes, because the most flights would take place in dry lower stratosphere

while in tropics it would be convenient to shift cruise altitudes downwards where temperature is too high for contrail formation.

In the research [12] the formation of contrails was simulated at global downshift of cruise altitudes by 2 000 ft, 4 000 ft a 6 000 ft and upshift by 2000 ft. In general, it was found that for all three downshift cases the contrail coverage was reduced in tropics. In the mid latitudes, it has to be differentiate between continental flights, which take place in lower cruise altitudes, and intercontinental flights, which take place in higher altitudes. Many intercontinental flights occur in lower stratosphere so shifting cruise altitudes upwards would result in more flights in stratosphere and reduction of contrail formation. On the other hand, downshift of cruise altitudes of intercontinental flights would lead to increase in formation of contrails due to more humid but still cold enough ambient air. Continental flights occur in lower altitudes so each downshift would result in lower probability of contrail formation. It has also been found that changes in contrail coverage by shifting cruise altitudes strongly depends on time of year.

Because of differences in various regions and dependency on time of year it appears that global shift of cruise altitudes would not be useful. Operational adjustment of air traffic to latitude, time of year and short-term changes in ambient air parameters would be a better strategy for avoiding contrail and subsequent contra-cirrus formation.

2.3 Engine efficiency

Today's tendency is increasing the efficiency of aircraft engines. However, it is not that straightforward solution, as it appears to be. In the IPCC Special Report [15] it is reported that, however, increasing of engine efficiency reduce fuel consumption and emitted particles, it increase the potential of contrail formation, because of more water vapour emitted. It means that if the trend continues, there will be fewer emissions like carbon dioxide, nitrogen oxides or various solid particles at the expense of more frequent contrail formation.

2.4 Fuselage

The geometry of an aircraft has an impact on the dynamics of wake turbulence behind the aircraft. According to Lewellen [16], the wake dynamics influence contrails in three ways: they support horizontal and vertical spreading of contrails, in the core of vortices there is a depression and increase in relative humidity and rapid damping of turbulence causes sublimation of some ice crystals due to adiabatic compression. According to first two cases, an emplacement of engines closer to the fuselage would lead to reduction of dispersion of contrails and smaller amount of exhaust fumes would occur in the core of vortex where higher humidity is. On the other hand, an emplacement of engines closer to the tip of the wings can lead to more sublimated ice crystals due to more intensive adiabatic compression.

3 CONCLUSION

Reduction of contrail formation can be realized via four input elements: design of aircraft's engines and fuselage, flight routes, engine architecture and type and combustion of fuel. Today, the best way to achieve relevant results is to reduce contrails by making operational changes of flight routes, especially flight altitudes.

We have outlined few gaps in current researches filling of which would improve the knowledge about formation of contrails and subsequent contrail-cirrus. The application of more accurate particle counter instruments that measure size and number of ice particles in cirrus clouds can lead to better differentiate natural cirrus from contrail-cirrus. Development of a method which can lead to better understanding the formation of ice crystals in their initial phase, e.g. how many crystals survive the wake turbulence, can be useful. The third and the most significant gap is absence of research of jet streams and their impact on growing and possible movement of contrails and contrail/cirrus respectively.

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AUTHORS ADDRESSES

[1] Jakub Kraus

Department of Air Transport, Faculty of Transportation Sciences, Czech Technical University in Prague, Horská 3, 128 03 Prague, Czech Republic

E-mail: kraus@fd.cvut.cz

[2] Jakub Hrubčo

Department of Air Transport, Faculty of Transportation Sciences, Czech Technical University in Prague, Horská 3, 128 03 Prague, Czech Republic

E-mail: hrubcjak@fd.cvut.cz

[3] Marek Štumper

Department of Air Transport, Faculty of Transportation Sciences, Czech Technical University in Prague, Horská 3, 128 03 Prague, Czech Republic

E-mail: stumpmar@fd.cvut.cz

[4] Šárka Hulínská

Department of Air Transport, Faculty of Transportation Sciences, Czech Technical University in Prague, Horská 3, 128 03 Prague, Czech Republic

E-mail: hulinsar@fd.cvut.cz

[5] Iveta Kameníková

Department of Air Transport, Faculty of Transportation Sciences, Czech Technical University in Prague, Horská 3, 128 03 Prague, Czech Republic

E-mail: kamenive@fd.cvut.cz