EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 11(2) (2018) 164-171
DOI 10.14456/ea.2018.31
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Environmental Effect Studies on Aviation Contrails and Cirrus Clouds

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Receiced: November 29, 2017; Accepted: April 6, 2018

Abstract

Vapor trails or contrails, which are emitted by the exhaust of aircraft engines, act as a radiating force affecting the earth's radiation balance. These contrails in some cases form cirrus coverage, which cannot be differentiated from the natural cirrus clouds, which are atmospheric clouds, distinguished by their thin and wispy strand-like appearance. Contrails contain traces of black carbon soot, sulphates, nitrogen oxides and to a lesser extent of metallic particles. Studies have found that vapor trails or contrails trap the outgoing radiation emitted by the earth's surface and atmosphere at a very high rate and they throw back the incoming solar radiation. The environmental effects and thermodynamic parameters of the aviation contrails on the Earth's atmosphere were studied. The vapor trails or contrails trap the outgoing radiation emitted by the Earth's surface and atmosphere at a very high rate and throw back the incoming solar radiation. The interaction between outgoing and incoming radiation often is referred to greenhouse effect which heats up the atmosphere.

Keywords: Contrail; Exhaust; Engine; Aircraft; Cirrus cloud; Condensation; Global; Atmosphere

1. Introduction

Contrails are defined as the unnatural clouds of condensed water, which are the visible trails of vapor formed by the exhaust of aircraft turbines. It is also known as "condensation trails", the hot gases left behind by the aircraft cool the surrounding air that may cause microscopic water droplets to condense. If the air is cold enough this trail will comprise of tiny crystals that is observable for only a few seconds or may linger for many hours, which can affect the climatic condition (Appleman, 1953). The most important byproducts, which are obtained by the combustion of hydrocarbon fuel, are carbon dioxide and water vapor. At

Figure 1. Contrails formed by air traffic (Appleman, 1996)

high altitudes the resultant water vapor is exposed to extremely low temperatures and the local increase in water vapor can increase the water content of the past air saturation point. This causes the vapor to condense in the form of ice particles or tiny droplets. The vapors require a trigger to encourage deposition or condensation at high altitudes. The consequence of contrails is warming. This consequence varies daily and the overall magnitude of the radiative forcing is not well known. The analysis of the effects of contrails on the atmosphere and the estimation of radiative forcing of climate by various aircrafts and thermodynamic studies are elaborately studied. (Appleman, 1966).

2. Control measurement of Contrails

According to Anderson *et al.* (1998b), the mechanism of contrail formation include Contrails are formed 8 km above sea level. At around -40 °C, vapor sublimates into ice without the need of ice nuclei such as dust particles, forming ice crystals. There was a discussion on the potential climate effects of contrails between the 1960s and the 1980s. The outcome of aviation contrails on the atmosphere and rate of radiative forcing (RF) of climate from the exhaust of diverse aircrafts were discussed in a report by the IPCC. The three basic parameters which control contrail formation are water, ambient temperature and relative humidity. (Anderson *et al.,* 1998a).

At cruise altitudes, the water, which is liberated, is a function of the quantity of fuel, which has undergone combustion reaction. Temperature and relative humidity determine the contrail persistence and formation.

According to Anderson *et al.* (1999), the liquid aerosols consists of traces of sulphuric acid (H_2SO_4), water and other organic condensate species which are a result of homogeneous nu cleation and non-volatile combustion of aerosols comprise of minimal amounts of me-tallic particles and black carbon soot.

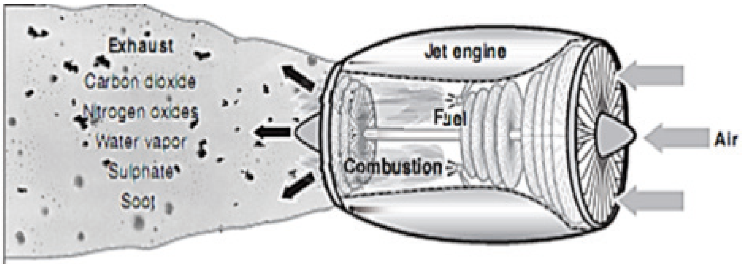

Figure 2. Exhaust fuels (Anderson, 1999)

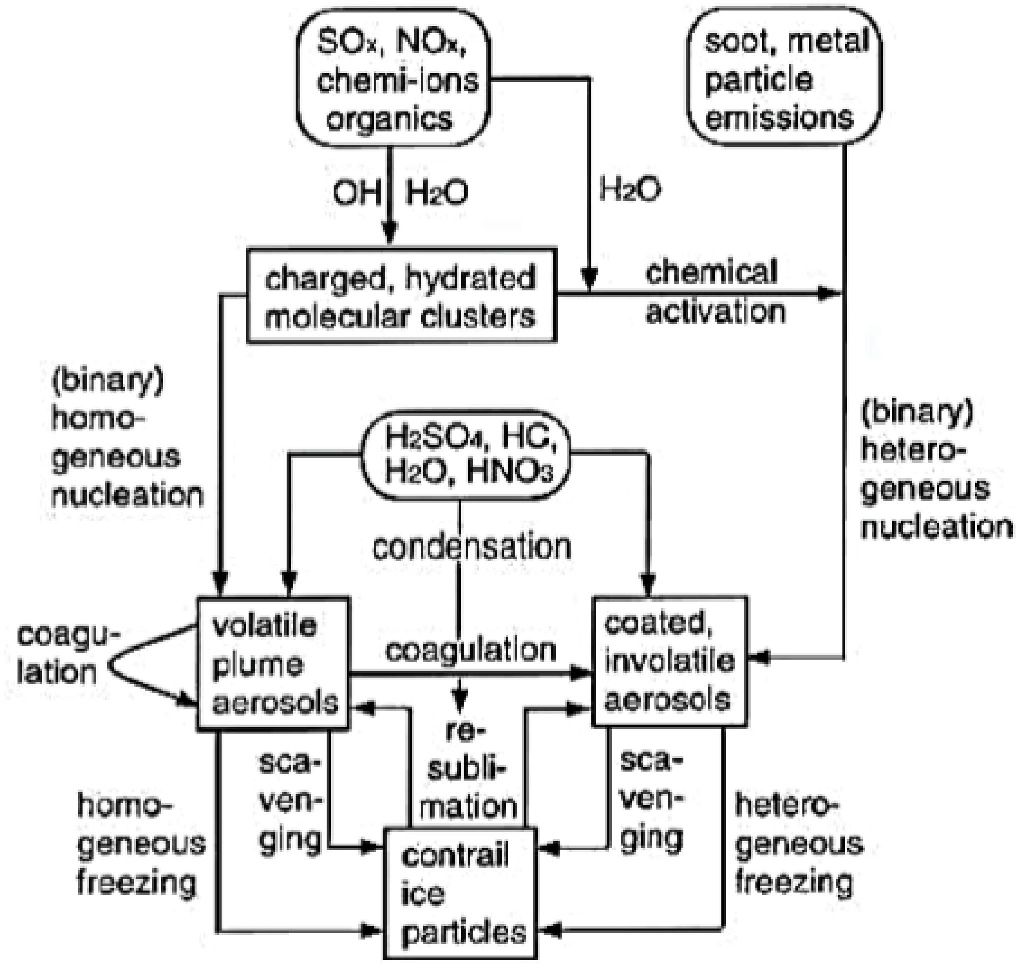

Figure 3. Schematic diagram of related chemistry and aerosol dynamics in aircraft contrails and exhaust plumes (Anderson, 1999)

Ice particles resulting from the freezing nucleation in contrails; swiftly take up the H_2O, which is released to an initial growth stage. In some cases, the cirrus coverage can be formed when many contrails are present. These cannot be distinguished from the natural cirrus.

Aviation Contrails – Potential Chemical Effects

Soot, NO_x and SO_x particles produced by aircrafts at cruising altitude have adverse chemical effects (Schumann, 1997). Primary products resulting from the engine combustion include water and CO_2. Secondary products resulting from the combustion include soot particles, carbon monoxide, partially burnt hydrocarbons, SO_x and NO_x. Incomplete combustion products like soot particles, CO and HC are a consequence of the operation and design of jet engines. NO_x vapor formation is contributed by the higher operating temperatures of jet engine combustor and the SO_x vapor emitted is directly related to the amount of fuel burnt or consumed in the jet engine (Möhler et al., 2005).

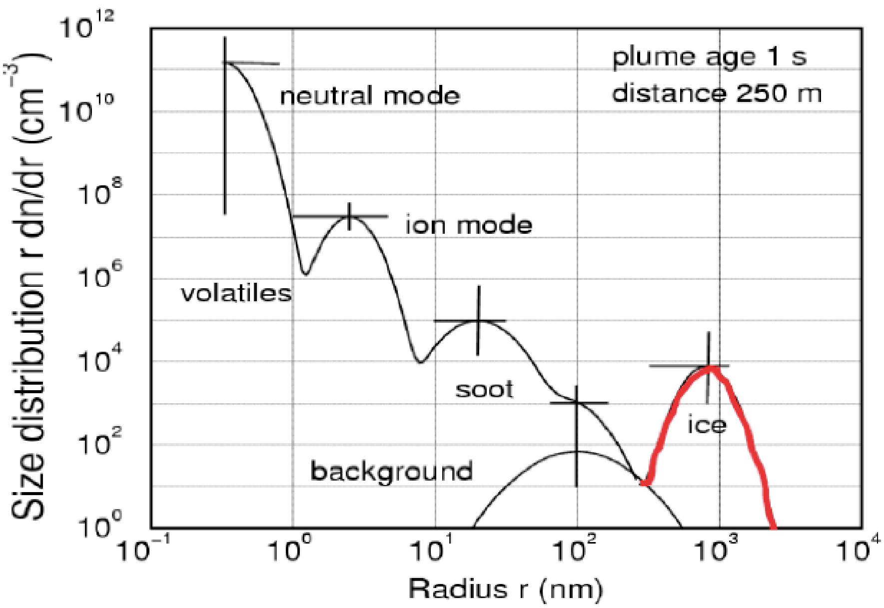

Figure 4. Particle size distribution of different type of particles in aircraft exhaust (Anderson, 1998).

When the water vapor in the lower stratosphere from cruising aircrafts increase, it may cause faster heterogeneous chemical reactions on the aerosol particles that are already present or suspended in the stratosphere, which may be an issue and should be rectified, especially if a fleet of supersonic jets is developed.

The size distribution of the exhaust particulates for plume age of 1s and distance 250m is described in Figure 4. Below the radius range of 10nm, the overall distribution consists of volatiles of sulfuric acid and water. The volatiles consist of two modes of particles with different sizes, namely, neutral and ion mode. Neutral mode particles are smaller in size and are formed by the coagulation of nucleated clusters of sulfuric acid molecules. Ion mode particles are slightly larger in size and are formed by the swift scavenging of a charged collection of chloride molecules. Ice and soot particles have significantly large radius when compared to the volatiles.

Reactions involving activation of chlorine occurs on the aerosol surfaces and cirrus clouds as was stated by the American Chemical Society. Hence, contrails and cirrus clouds that are induced by contrails can alter the Ozone levels in this region.

3. Cirrus clouds

Cirrus clouds are usually defined as atmospheric clouds which are characterized by thin and wispy strands. They cover up to 25% of the Earth, can reflect the sunlight to a large extent, can have a net heating effect, and can absorb the infrared radiation leaving the Earth's atmosphere. As a result of their potential warming effects, cirrus clouds are potentially one of the sources of global warming according to Reed Christena (2006).

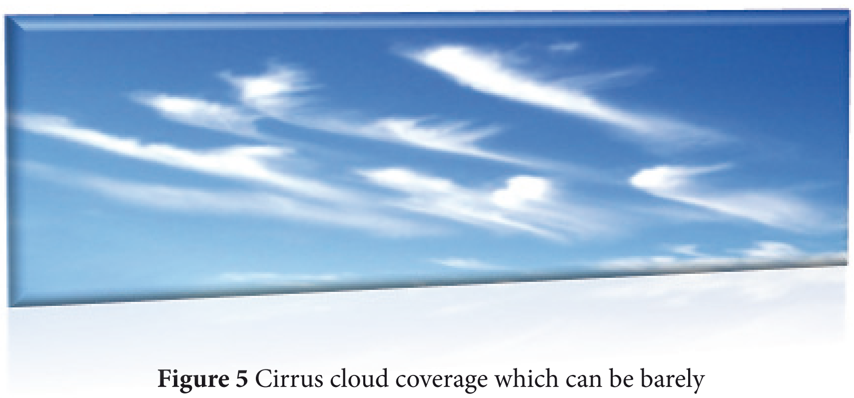

Figure 5 Cirrus cloud coverage which can be barely differentiated from natural clouds (Perkin Sid, 2002).

Scientists have speculated that eventually cirrus cloud cover would increase, thereby increasing temperatures and humidity. Demonstrations from satellite and in situ observations concluded that the linear contrails can get transformed into extended cirrus cloud decks.

The exhaust from aircraft turbines can potentially modify the cirrus cloud evolution. Soot particles, which get emanated from the aircraft turbine, which are ice nuclei, have efficiency higher than the surrounding particles bounded by the same air mass. The particles resulting from the short-lived contrails might be better ice-forming agents than fresh soot.

Modern aircraft engines used in jetliners include high bypass ratio turbofan or a turboprop. Turbofan aircraft engines having high propulsion efficiencies and higher bypass ratios have resulted in lowering the temperatures of the exhaust gases. Schumann (1996) pointed out that the increased bypass ratios lead to lowering the exhaust temperatures to a considerably low value. When temperatures of the exhaust gases are lowered, the threshold temperature for contrail formation is lowered.

Schumann *et al.* (2000) have validated the first principles of thermodynamics involved in contrail formation. In their study, comparison of two jetliners, namely Airbus A340 which is powered by four CFM56-5C2 and Boeing 707 equipped with four engines of PW JT3D-3B, was made. It was concluded that Airbus with relatively recent engine technology formed clear contrails. Hence, as the bypass ratio increases, there is an increase in the propulsion efficiency further leading to the formation of contrails.

The standard fuel which is used to power the jet engines is White Kerosene or the Jet-A fuel. Kerosene constitutes a small percentage of Sulfur, which is limited by International Civil Aviation Organization (ICAO) to 0.3% by mass. In the future, if a considerable size of hydrogen-powered aircraft fleet were to be developed, the increase in contrail coverage would be due to the larger amount of emissions of water vapor. Usage of hydrogen as a fuel would significantly decrease the formation threshold temperatures (Schumann, 1996).

Defense research has been mostly without success at reduction of contrails using technological measures. The most successful strategy being one of 'detection–response–avoidance', which involves the examining of, the aircraft exhaust i.e. plume and wake, CO_2 and NO_x production. Reduced levels of sulphur in fuel might not reduce sufficient amount of particles to make a substantial effect on the contrail formation according to American Chemical Society.

Mannstein *et al.* (1999) have described an algorithm which can be effectively used for detection of linear features in contrails. Aspects of satellite imagery were used by Minnis *et al.* (1998) to demonstrate the similarity between contrails and cirrus clouds. The study described that over a period of time, contrails can merge with naturally occurring cirrus clouds and cannot be distinguished.

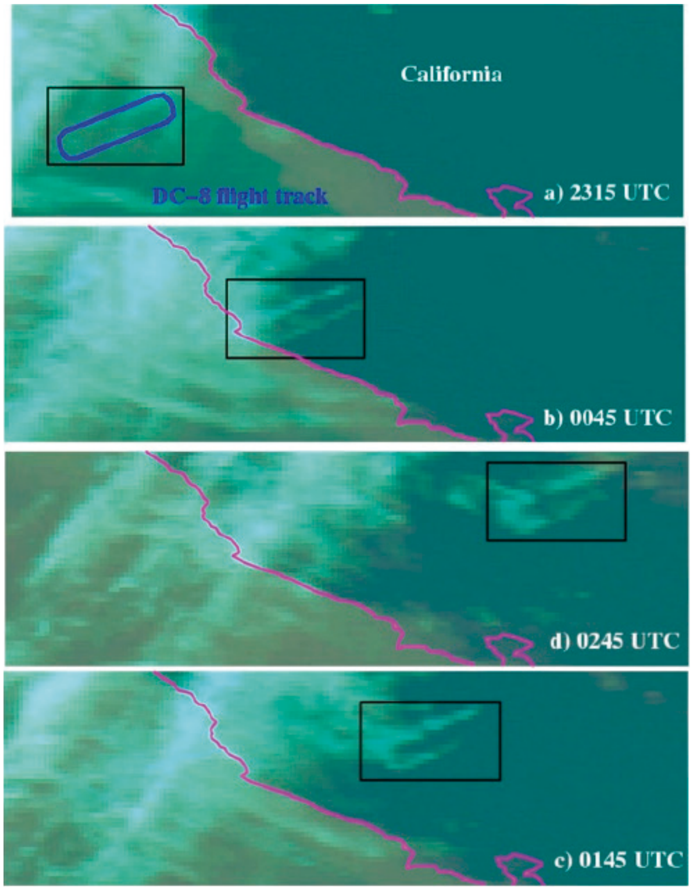

Figure 6. Contrail-Cirrus formation from a NASA McDonnell Douglas DC-9 aircraft over California skies (Minnis et al., 1998)

4. Conclusions and Future Aspects

Changes in engine technology and quantification of Contrail measurements and RF effects have led to the decrease in the radiative forcing caused from the aviation generated cirrus clouds.

The uncertainties in estimation of aviation contrails are dependent on the microphysical and radiative properties.

Bacterial Culture involved in breaking down of ice particles, ice-nucleating bacteria *P. syringae* and use of Chemical Sprays which could melt the ice particles formed and brings them down as rain. Studies on use of *P. syringae* and Chemical Spray (De-icing) in unison can eliminate ice formation.

Altering the flight mechanics such as increasing the engine bypass ratio can make them fuel-efficient and less prone to the contrail formation (Schumann *et al., 2000*).

References

Anderson BE, Cofer WR, Barrick JW, Bagwell DR, Hudgins CH and Nowicki GD, Airborne observations of aircraft aerosol emissions. 1. Total and nonvolatile particle emission indices, Geophysical Research Letters 1998a, 25, 1689–1692.

Anderson BE, Cofer WR, Barrick JW, Bagwell DR, Hudgins CH and Brunke KE, Airborne observations of aircraft aerosol emissions. 2. Factors controlling volatile particle production, Geophysical Research Letters 1998b, 25, 1693–1696.

Anderson BE, Cofer WR., Gregory GL, Vay S, Brunke KE, Kondo Y, Koike M, Chlager H, Baughcum S, and Jensen EJ,An assessment of aircraft as a source of particles to the upper troposphere. Geophysical Research Letters 1999, 26, 3069–3072.

Appleman H, The formation of exhaust condensation trails by jet aircraft, Bulletin of the American Meteorological Society 1953, 34, 14–20.

Appleman H, Effect of supersonic aircraft on cirrus formation and climate, American Meteorological 1966, 369

Christena Reed, Hot Trails, Scientific American news scan 2006, 295 (3), 28

Perkins and Sid, Shutdown of airlines aided contrail studies, Science News 2002, 161(19), 291

Society and American Institute of Aeronautics and Astronautics, Conference on Aerospace Meteorology, March 28–31, 1966, AIAA Paper 66-369.

Travis DJ, A Carleton and RG Lauritsen, Contrails reduce daily temperature range, Nature 418 (6898), 601

Schumann U, Air Traffic and the Environment, Lecture Notes in Engineering 1990, Springer-Verlag, Berlin.

Schumann U, On conditions for contrail formation from aircraft exhausts, Meteorol Zeitschrift 1996, N.F. 5, 4–23.

Schumann U, Influence of propulsion efficiency on contrail formation, Aerospace Science and Technology 2000a, 4, 391–401.

Minnis P, Young D, Garber D, Nguyen L, Smith W, Palikonda R, Transformation of contrails into cirrus during SUCCESS, Geophysical Research Letters 1998, 25, 1157–1160.

Möhler O, et al., Effect of sulfuric acid coating on heterogeneous ice nucleation by soot aerosol particles, Journal of Geophysical Research 2005, Atmospheres 110 D11.