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# Impact of alternative jet fuels on aircraft-induced aerosols

C. Rojo [a], X. Vancassel [a], P. Mirabel [b], J.-L. Ponche [b], F. Garnier [c,*]

[a] Onera – The French Aerospace Lab, F-92322 Châtillon, France
[b] Institut de Chimie pour les Procédés, l'Énergie, l'Environnement et la Santé, UMR 7515, Université de Strasbourg, France
[c] École de Technologie Supérieure (ÉTS), Montréal, QC H3C 1K3, Canada

## HIGHLIGHTS

- Evolution of aerosols in aircraft plumes is simulated for alternative fuels.
- Composition of aerosols vary depending on fuel, which may modify their growth.
- Contrail formation is altered when using alternative fuels due to ice nuclei changes.
- Background particles can play an important role when alternative fuels are used.

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## ABSTRACT

While using alternative aviation fuels represents a promising approach to reduce the industry's impact on climate change and local air quality, the influence of these new fuels on the chemical composition of exhaust plumes, and, in particular, on aviation-produced aerosols must be assessed. This paper studies the influence of using alternative jet fuels on induced particles, including contrails, in a near field of an aircraft.

A computational model with detailed microphysics taking into account the condensation of organic species, homogeneous freezing, and soot activation was used to study the effect of different fuels on the formation and evolution of particulate matter in the exhaust plume of an aircraft flying at cruise conditions.

Three different fuels were considered and compared: conventional kerosene (Jet A-1); a pure alternative fuel (with similar properties as Fischer–Tropsch (FT) or hydro-processed esters and fatty acids (HEFA) fuels); and a blend consisting of a 50/50 mixture of kerosene and the mentioned alternative fuel. Several conclusions can be drawn when using pure alternative and blended fuels instead of standard kerosene. The contribution of soluble organic matter in the composition of mixed aerosols increased on average by 29% with Jet A-1 to 45% with a blended fuel. The reduction in soot particles favors the homogeneous freezing pathway and the ice crystals formed were larger and evidenced lower number densities. The background particles can no longer be neglected, since they can account for more than 50% of the particles after 5 s behind the nozzle exit. All these changes are expected to alter the optical properties of contrails.



## 1. Introduction

Aviation has a direct impact on climate, on atmospheric composition at flight altitudes, and on local air quality in the vicinity of airports, since it releases gases such as carbon dioxide, nitrogen and sulfur oxides, as well as particulate matter (soot).

These emissions are also responsible for new particle formation in the plume, including aerosols and contrails. Of particular interest are the climatic effects of these particles, since aerosols are known to have a potential impact on climate, either by direct or indirect radiative forcing. Through direct radiative forcing, they affect the scattering of solar radiation and the absorption/emission of terrestrial radiation. Through indirect forcing, they interact with clouds, leading to changes in cloud reflectivity and lifetime. Persistent contrails can spread out and become high-altitude cirrus clouds. They cool the climate by reflecting incoming sun radiation back into space, but they also trap infrared radiation emitted by the earth surface, leading to a warming effect. All these climatic effects are strongly correlated to particle properties (number density, size distribution, and composition), which, in turn, depend on the type of fuel burned.

* Corresponding author. Tel.: +1 514 396 8425.
*E-mail address:* Francois.Garnier@etsmtl.ca (F. Garnier).

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Aviation is a fast growing sector of the economy and, as air traffic keeps increasing, these environmental issues become more important. Scientists are working on various options for mitigating aviation's future impact on the atmosphere [1].

A viable choice for reducing this impact may be using alternative fuels. In addition to benefiting the environment, this would also be a step toward achieving energy independence from petrol-based fuels. Indeed, as the price of a barrel of oil rises, other energy sources are explored and favored [2].

Therefore, this research aimed at studying the influence of using alternative jet fuels on induced particles in an aircraft plume with a detailed microphysical model. Three different jet fuels were tested, including regular kerosene (Jet A1), an alternative fuel (with similar properties as Fischer–Tropsch (FT) or hydro-processed esters and fatty acids (HEFA) jet fuel), and a blend consisting of a 50/50 mixture of kerosene and alternative fuel.

## 2. Alternative fuels

Various types of alternative fuels have been tested in commercial aviation. These fuels must meet several criteria that concern diverse areas [3], such infrastructure compatibility, the similarity of the fuel's properties, and the environmental and financial cost of its development. The alternative fuels likely to be used in the near future are the "drop-in" fuels, that is, fuels that can be used with current infrastructure and engines [4], and that can also be blended with standard aviation fuel (Jet A1) without altering the fuel's properties. This type of fuel can be considered as a potential replacement for conventional kerosene. Alternative fuels should have characteristics similar to standard fuels for safety reasons. For instance, their properties have to be constant within the large temperature and pressure variations commonly encountered during flight (from −60 °C at 150 hPa to up to 50 °C at ground levels).

Another major concern, which has to be taken into account when developing an alternative fuel, is efficient land use so as to avoid competition with food production or water resources. Additionally, these new fuels should emit lower life-cycle greenhouse gases to be beneficial for the environment [3]. To this end, several processing pathways are currently being investigated such as fuels with Fischer–Tropsch (FT) synthesis or hydro-processed esters and fatty acids (HEFA, formerly known as HRJ). FT fuels can be produced from various sources such as coal (CtL), gas (GtL), biomass (BtL), and mixed coal and biomass (CBtL). BtL fuels, however, are more beneficial for the environment, since they induce a reduction of carbon-dioxide emissions across their life cycles. HEFA jet fuels can be produced from animal fat or biomass (e.g., waste cooking oil). Since 2011, many airline companies have integrated these new sustainable fuels in their flights after certification. The fuels are generally blends of 20% to up to 50% of FT or HEFA fuels [5]. A recent European directive (2009/2/EC) promotes the use of biofuels in the transportation sector to reach a goal of 10% of alternative fuels used by 2020 [6].

The introduction of new fuels in aviation is likely to modify the chemical composition of turbine-engine exhaust and therefore affect the evolution of aircraft-produced aerosols. In turn, these changes in aerosol composition and surface properties will impact particle growth and contrail formation. Therefore, the influence of these new jet fuels on the entailed emissions in the near field of an aircraft must be assessed.

Comprehensive studies have been conducted on aerosol formation in aircraft plumes for typical kerosene [7–11] but the few studies available for alternative fuels mostly concern emission characterization [12–14]. Typically, synthetic fuels have lower sulfur and aromatic contents than kerosene. For example, Timko et al. [12] showed that the aromatic content of the JP-8 fuel was 19 vol%, whereas the fuel aromatic content of the synthetic fuel (Fischer–Tropsch fuel) was below the method's detection limits. As a consequence, reducing the aromatic content will decrease the production of soot particles. Their diameters vary from 35 nm for Jet A-1 to 25 nm for 100% alternative fuel at cruise conditions, and from 20 to 14 nm at idle [12,15,16]. Based on these data, Fig. 1 summarizes the variation of the soot number densities and sizes associated with the different fuels used in this study. Finally, the fuel sulfur content (FSC) generally ranges from 300 and 800 ppm (with a maximum allowed of 3000 ppm) for standard jet fuel. As alternative fuels are extra low sulfured, the FSC of a blend, depending on the percentage of alternative fuel incorporated, will reduce the formation of ultrafine acidic aerosols. Throughout the rest of this study, the pure alternative fuel referred to is therefore characterized by an extra low sulfur content and a very low aromatic content as are both FT and HEFA fuels, the main alternative fuels tested and certified for aviation [13,16].

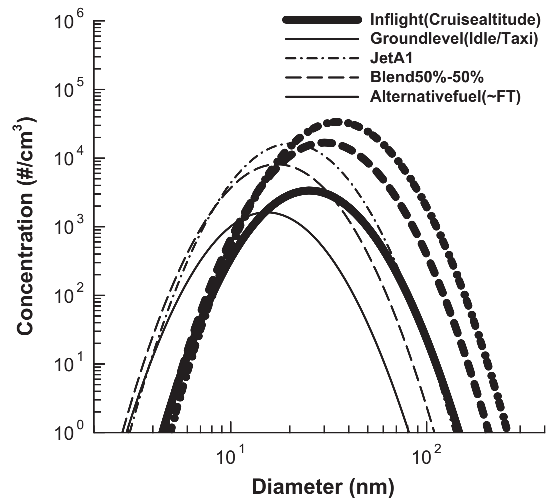


**Fig. 1.** Initial emitted soot number densities and diameters for kerosene, pure alternative fuel, and a 50/50 mixture of kerosene and alternative fuel, from Table 1.

Herein, the influence of using alternative jet fuels on induced particles in an aircraft plume was modeled, using detailed microphysics and simple dilution models. Three different jet fuels were tested: regular kerosene (Jet A1), a pure alternative fuel, and a blend consisting of a 50/50 mixture of kerosene and alternative fuel.

## 3. Aircraft-plume microphysical model

During flight, ambient air is sucked up by the jet engine and at the engine nozzle exit, where the temperature is around 580–600 K. The jet rapidly mixes with ambient air and the plume undergoes very fast cooling and dilution. During the early stage of the cooling, some of the gases released in the engine jet undergo phase transitions leading to aerosol formation. In particular, sulfur contained in the fuel leads to the formation of sulfur oxides in the plume, which are partly converted into sulfuric acid [17], which is known to promote aerosol formation through heteromolecular nucleation with water vapor.

Note that, during the mixing with ambient air, background aerosols are entrained and can provide additional condensation nuclei. They were introduced into the calculation and their relative importance is supposed to increase when burning alternative fuels.

The process of aerosol formation was simulated using a trajectory box model (e.g., [9,18]), characterizing aerosol microphysical properties in a parameterized jet plume, diluted isobarically and