Measurements of Ultrafine particles and chemical traces from aviation emissions near the Zürich airport

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Aircraft particle emissions at the engine exit are largely composed of Ultra Fine Particles (UFPs, diameter of <100 nm). Due to their small size, UFPs are transported deeper in the human body, causing adverse health effects [1].

In the framework of the Aviation Plume PROPeRtIes AT point of Exposure (APPROPRIATE) project, a state-of-the-art set of gas- and aerosol-phase instrumentation was deployed 1 km at the east-side of Zürich airport to characterize aircraft UFPs during 1 month in fall 2022. The EESI-ToF mass spectrometer was used to measure their chemical composition at a molecular level, using previously reported oil tracers [2]. Measurements showed that airport activities are the principal contributor to the UFPs measured at the site, thus driving their median diameter (around 17.5 nm) and bringing high number concentrations (> 30000 cm^{-3}). While the literature tends to identify UFPs from aviation by their typical small diameter, we highlighted that their modal diameter can grow up to 40 nm by condensation and/or coagulation processes. Figure 1 shows the total particle number (PN) concentration – mostly made of UFPs - as a function of the EESI-ToF signal intensity for two lube-oil tracers (the tricresyl-Phosphate TCP, and a C_{25} ester). An increase of the PN concentration with the lube-oil signal has been found. This finding highlights that online detection of lube-oil tracers can be used as a predictor for high UFPs concentrations from the airport.

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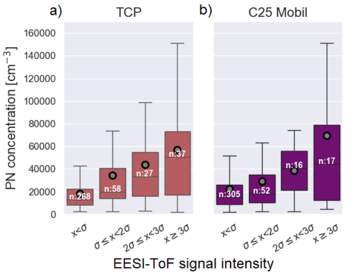

Figure 1. Particle number concentration measured at Kloten as a function of the EESI-ToF signal intensity for a) TCP and b) C_{25} ester, two lube-oil tracers. Signal intensities (x) are grouped by ranges of values related to the standard deviation of the signal during blank measurements σ.

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Gaseous and Non-Volatile Particulate Emissions from a Private Jet Using Fossil Jet A-1 and a 30% HEFA-SPK Blend

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Small turbofan engines (<26.7 kN thrust), widely used in private and business aviation, remain exempt from emissions regulations despite their growing contribution to aviation's environmental impact. This study examines gaseous and non-volatile particulate matter (nvPM) emissions from a popular small turbofan engine using fossil Jet A-1 (two batches) and a 30% Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK) blend. Compared to the fossil fuels, the HEFA-SPK blend contained up to 5% fewer aromatics by volume, about half the naphthalene content, and up to 75% less sulfur. The fuel hydrogen content of the HEFA-SPK blend was ~0.33% higher.

Measurements at ground level, performed with advanced instrumentation and a standardized exhaust sampling and measurement system, revealed significant reductions in nvPM emissions with the sustainable aviation fuel (SAF) blend. The nvPM mass and number emission indices (EIs) were reduced by ~35% and ~20% at idle, respectively. The reductions were less pronounced at higher thrust settings, aligning with known trends for fuel composition effects. SO_2 emissions were proportional to the blend's lower sulfur content, while VOC analysis highlighted reduced emissions of complex unsaturated hydrocarbons due to lower aromatic content. Notably, nvPM number EIs at cruise were estimated to decrease by ~10%, suggesting a corresponding reduction in contrail ice particle concentrations. These findings underscore SAF's potential to mitigate climate and air quality impacts of small turbofan engines while highlighting the need for improved predictive models of fuel composition effects on nvPM emissions.

Effects SAF use & Fuel composition on Volatile and non-Volatile PM aviation emissions

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Recent on-wing measurements of Particulate Matter (PM) emissions have been made using Sustainable Aviation Fuels (SAFs) and low Fuel Sulfur Content (FSC) jet fuels. These tests have achieved minimal to no sulfur contamination of 100% SAF, allowing the importance of FSC at levels below a few ppmm to be examined. The dramatic changes when sulfur emissions are no longer significant demonstrate the potential of 100% neat SAF for improving local air quality near airports. These results also indicate that there may be possible benefits of reducing the formation of condensation trails with very low FSC fuels. In all recent tests of current aircraft engines, the contributions of oil are a major component and cannot be ignored, especially as aircraft engine combustion emissions continue to decrease.

A "2nd" (> 150 nm) Size Mode in Aircraft Gas Turbine Engine Exhaust

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Several years ago, we presented preliminary work on this topic. This report is a describes additional analysis and interpretation of our results. Motor vehicle piston engine exhaust particle size distributions (PSD) typically show three distinct modes: a nucleation mode between about 3 and 30 nm diameter consisting mainly of semi-volatile material, an accumulation or soot mode between about 30 and 300 nm diameter consisting mainly of carbonaceous aggregates, and a coarse mode consisting of larger mechanically generated particles – from oil atomization and re-entrainment from in-cylinder and exhaust surfaces. Measurement of particles from commercial aircraft gas turbine engines is much more challenging than from ground-based vehicles with exhaust temperatures as high as 900 C or more and exhaust velocities approaching Mach 1. This necessitates the use of very long sampling lines that complicate particle measurements. These lines tend to adsorb much of the semi-volatile material and suppress the formation of a nucleation mode. The carbonaceous aggregates in the soot mode are smaller than from typical piston engines with diameters in the 15 to 50 nm range. Compared to piston engines there is less opportunity for the exhaust to interact with surfaces and there are no piston rings to atomize oil so coarse particles were not expected to be an issue. However, under some conditions, especially when soot concentrations were low, we observed a distinct size mode, a "2nd mode", in the coarse mode size range consisting of particles larger than about 150 nm. Also note that no evidence was found for mechanical generation by particle shedding from the sampling system as demonstrated during the daily pre-test zero checks of the system and response to step changes in concentration. The results reported here were observed during a series of measurement campaigns, VARIAnT 1-4, conducted by the U. S. Environmental Protection Agency in collaboration with the U. S. Air Force's Arnold Engineering Development Complex. The main purpose of these campaigns was to refine methodology for measurement of non-volatile particles from aircraft engines. The results presented here are based on the last two campaigns, VARIAnT 3 and 4. A General Electric J-85 turbojet and Libby Welding Model GT-05 and LGT-60 turbine powered start carts running with a range of test conditions and fuels were used as particle sources. Particle size, concentration, and composition measurements were made using a range of instruments. The focus of these studies was measurement of accumulation mode soot aggregates. The coarse mode was unexpected. PSD measurements were made using a range of instruments. In VARIAnT 3, two TSI SMPSs (6 - 225 nm) and a TSI EEPS (6 - 500 nm) were used. In VARIAnT 4, three SMPSs (6 - 225 nm), a low flow SMPS (15 - 690 nm), a TSI EEPS (6 - 500 nm) and a Cambustion DMS500 (5 - 1000 nm) were used. Additional measurements related to the coarse mode were made using an Aerodyne CAPS PMSSA that measures light extinction and scattering in both campaigns. In VARIANT 4, a single particle laser ablation mass spectrometer (miniSPLAT) that measures particle size, morphology, composition and mass was also used. We define the 2nd mode in two ways; Volume above 150 nm (V150) and V 2nd, where V 2nd is determined by fitting the PSD to a bimodal lognormal distribution. V 2nd and V150 are well correlated. With the J-85, V 2nd/Vtotal ratios of nearly 50% were observed in some tests. In most cases, V 2nd/Vtotal ratios varied inversely with engine load and total volume (mass) emissions. Formation of the mode was much more pronounced with the J-85 than with the start carts. The formation of the 2nd mode was also associated with an increase in the single scattering albedo (SSA) measured by the CAPS and appearance of particles with different compositions and morphologies in the miniSPLAT data.