Comparison of non-CO_2 Turboshaft Engine Emissions using Jet A-1, HEFA- and FT-SPK

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In this presentation, experimental data on the reduction of non-CO_2 emissions is presented, based on the use of neat and blended sustainable (HEFA-SPK) and synthetic (FT-SPK) aviation fuels in comparison to Jet A-1. These findings are derived from measurement campaigns conducted between 2022 and 2024 [1,2] on a turboshaft engine (Allison 250-C20B) used for helicopters.

For all fuels, the emission indices (EIs) for gaseous compounds decreased at higher operating conditions, driven by enhanced combustion chamber efficiency resulting from improved fuel atomization, better fuel-air mixing, and higher temperatures. While the differences in gaseous emissions between HEFA-SPK and Jet A-1 were negligible for all ICAO-regulated pollutants (CO, UHC, NO_x), FT-SPK exhibited distinct behavior. Specifically, the use of FT-SPK led to significant reductions in EI_{CO} (22%) and EI_{UHC} (37%) compared to both Jet A-1 and HEFA-SPK. A similar trend was observed for volatile organic compounds (VOCs) in the C_2-C_9 range.

In addition, non-volatile particulate matter (nvPM) emissions also varied significantly. Using zero-aromatic and higher hydrogen-containing fuels resulted in substantial changes in the number, mass, properties, and formation behavior of soot particles. Number concentrations were reduced by up to 80% with 100% HEFA-SPK compared to Jet A-1. Additionally, due to changes in particle diameter, the particle mass decreased by up to 40%. Sustainable and synthetic fuels shifted the mode of the particle number size distribution (PNSD) by 50% in diameter [2]. For a detailed comparison of soot particles, which were corrected for size-dependent losses, the number $EI_{numEP10}$ and mass $EI_{massEP10}$ concentrations as well as size distributions (SMPS+DMS) were analyzed.

These emissions improvements can be attributed primarily to fuel composition. Unlike Jet A-1, HEFA- and FT-SPK lack aromatics and consist mainly of n- and iso-alkanes. Even minor differences in hydrocarbon class compositions (e.g., between HEFA- and FT-SPK) can significantly influence the formation of non-CO_2 emissions. This research underscores the environmental advantages of SAFs in reducing both gaseous and particulate emissions, offering valuable insights for advancing cleaner aviation technologies.

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Determination of aircraft gas turbine nvPM charge state and its impact on sampling system losses

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Aircraft gas turbine engines produce ions through chemi-ionisation and thermal ionisation leading to charged non-volatile Particulate Matter (nvPM) emissions[1]. In typical combustion systems, nvPM charging results in a bipolar equilibrium charge distribution[2]. However, due to high temperatures and pressures observed in an aircraft engine combustor, aircraft nvPM is predicted to have a non-equilibrium charge distribution[3]. If aircraft nvPM does carry a non-equilibrium charge distribution, this could have several far reaching implications, including; enhancement of contrail formation[4], and unaccounted-for additional particle losses for regulatory measurements.

This study aimed to quantify the charge state of aircraft nvPM for three different engines running on four different commercially used fuels (two JetA-1 and two 50% blended SAF), over a range of engine conditions from idle (low power) to near take-off (high power). For this study, the charge state was quantified for all engines, powers, and fuels by determining the charge fraction and mean charge per particle.

From Figure.1.a, it was observed that as the engine power (exhaust temperature) increased, more of the particles became charged - up to 45% at near take-off power. To add to this, a small fuel dependence was observed where JetA-1 produced more charge nvPM than SAF. From the mean charge per particle plot (Figure.1.b), it was observed that at low engine powers, the charge distribution was slightly biased towards negative polarity, which flipped to positive as the engine power increased. This result confirms the theoretical predictions that aircraft nvPM charge distributions are non-equilibrium, which are particularly evident at high engine powers.

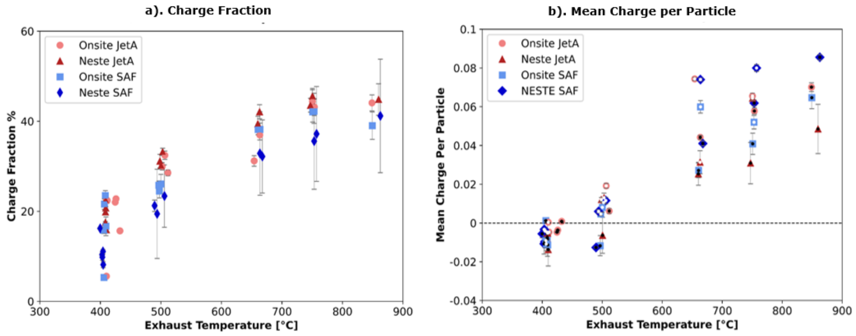

Figure.1: Charge state of aircraft engine nvPM as a function of engine exhaust temperature for four different fuels. a). is the charge fraction and b). is the mean charge per particle.

By using the mean charge per particle measurement, an estimate of additional unquantified particle losses has been developed. Assuming that all particles carry one charge, and correcting for diffusional losses and system dilution from sampling probe to measurement instrumentation, the ion concentrations can be calculated. From this, a prediction of the charged nvPM losses through sampling systems can be predicted. This estimation predicts that there could be an additional unquantified nvPM loss of up to 15% inside sampling systems for high engine powers. Therefore, this study shows that it may be necessary to adopt new charged nvPM correction methodologies in sampling systems to accurately determine the aircraft nvPM emissions.

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