PM emissions measurements and size distribution in a Turbojet engine test facility

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As the aviation sector continues to grow into the future, there is concern about atmospheric and Local Air Quality (LAQ) particle emissions and their impact on the environment and on human health (Waitz, 2004).

Within this study, a series of particulate emissions experiments were carried out on different turbofan engines at INTA Turbojet Test Centre. A custom-designed single probe was installed in the stack of the testbed located 40 meters downstream of the exhaust nozzle exit plane. Volatile and non-volatile particles were sampled using this probe. The plume sample consists of emissions from the engine combustion exhaust, diluted by the bypass fan air flow and entrained air around the engine. The sample can be considered characteristic of short time-scale plume transformation processes of engine emissions in the environment.

The extractive emissions sampling system and the instrumentation used in the laboratory, located outside of the stack, included an ELPI+ (Dekati), a CPC (TSI 3775) and an SMPS (TSI 3934). Total PM emissions data was acquired across different engine power conditions during endurance testing. The methodology was utilised whilst running multiple engines at reproducible power conditions in cycle tests. Multiple engine tests have shown a same PM response pattern.

Figure 1 shows real-time particle size distribution information and total particle number concentration of the engine plume exhaust over the particle size spectrum from 6 to 1000 nm. Data was acquired at two stable engine power conditions (low and high) and also covered transient conditions (acceleration, deceleration) using the ELPI+ fast response instrument (1Hz).

In Figure 2, it can be observed that the smallest (6 to 16nm) size fraction is the main contributor to the total number concentration, with an increase observed at the higher engine power level (1,3x10^5 particles/cc to 2,4x10^5 particles/cc). This size fraction can be mainly attributed to volatile particles which have formed during the cooling and dilution of the engine exhaust plume through the testbed detuner.

The particle size distribution shape changes as a function of engine power conditions. The geometric mean diameter was found to increase with the increasing engine power, as reported in other studies (Crayford 2012, Lobo, 2015).

At low engine power, the non-volatile (soot) PM size mode is small enough to be merged with the volatile PM size mode. However, at high engine power, the particle size distribution appears bi-modal with the non-volatile PM mode at an increased size. Large particles (>200nm) are observed for a short time during transient engine manoeuvres. These particles are likely 'shedding' of deposited particles from a surface (either from engine or from detuner) due to sudden flow/pressure changes.

These results provide insight into real-world aircraft emissions at airports. The data can be used to help understand aircraft engine steady state and transient emissions, which could impact emissions estimation at airports and related environmental impacts.

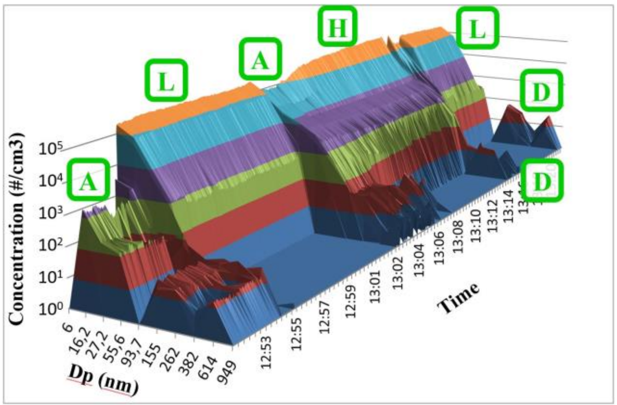

Figure 1. Evolution of particle size distribution at different engine operation phases (A: Acceleration, D: Deceleration, H: High Power, L: Low Power).

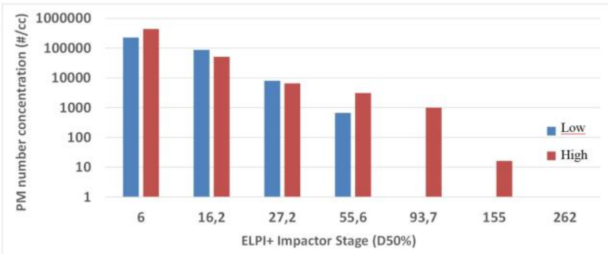

Figure 2. PM Concentration per Impactor Stage at Low and High power conditions.

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