Measurement of Non-Volatile Particulate Matter Mass Emission Indices of Aircraft Gas Turbine Sources

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Particulate matter (PM) emissions from aircraft gas turbines are a concern for human health, environmental pollution and climate change. Expected future regulations on emissions require a reliable determination and understanding of particulate matter emission factors under variable thrust and environmental conditions.

This work presents the measurements and preliminary results of non-volatile PM mass emission indices (mass PM/ mass fuel) for aircraft gas turbine sources. Such measurements are challenging due to the high temperature (up to 750ºC) and pressure conditions in the turbine exhaust. A state-of-the-art sampling system shown in Figure 1 was installed at the engine test cell at SR Technics, Zurich Kloten.

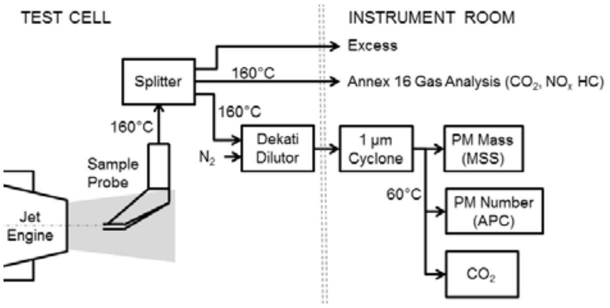

Figure 1. Simplified schematic of the aircraft gas turbine PM mass sampling system installed at SR Technics

PM laden exhaust was continuously sampled by an Inconel sampling probe at the engine exit plane. The aerosol sampled was then diluted with dry nitrogen by a factor of eight to ten and transported via temperature controlled lines to minimize condensation, particle agglomeration, and gas-to-particle conversion. Non-volatile PM mass was determined with a micro soot sensor (MSS, Model 483, AVL Inc.) based on the photo acoustic detection principle. In parallel to the MSS, an AVL particle counter (APC) and a CO_2 analyzer (Model 410i, Thermo Inc.) provided PM number and CO_2 concentrations emitted. The emitted CO_2 concentration was used in the PM mass emission index calculation according to Lobo *et al.* (2007).

The aircraft gas turbines tested to date include a CFM International 56-5B4/2P engine for the dedicated tests and a CFM International 56-7B24/3 and a Pratt and Whitney 4168A engine for piggy-back tests. Dedicated tests consisted of a series of engine thrust conditions defined by the turbine inlet temperature and rotational speed.

Preliminary results of the sampled PM mass concentration and engine thrust of a dedicated CFM 56-5B4/2P engine test are provided in Figure 2.

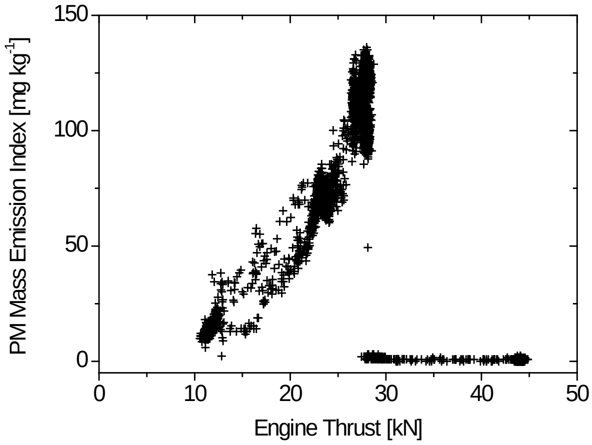

Figure 2. Measured PM mass emission index vs. engine thrust of a CFM 56-5B4/2P engine

Figure 2 indicates that the PM mass emission index increases for thrust levels up to 28 kN. Above 28 kN thrust, a sudden drop in emissions to an index near the detection limit of the instrumentation (< 5 mg kg^{-1}) is observable. This phenomenon is explained by the staged double annular combustor of the CFM 56-5B4/2P. This type of combustor is unique with respect to PM emissions: at low powers, only a pilot combustor zone is fuelled with a rich fuel mix to ensure combustion stability, resulting in high PM emissions; at high powers both the pilot and main combustor zones are fuelled with a lean combustor mix which results in low PM emissions.

Besides the determination of emission indices for various models of engines, current work investigates the effects of variable environmental conditions such as humidity and temperature, so a robust dataset can be provided to policy makers and climate modelling communities.

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Lobo, P.; Hagen, D. E.; Whitefield, P. D.; Alofs, D. J. (2007), Physical characterization of aerosol emissions from a commercial gas turbine engine, *J. Propul. Power*, **23**, 919– 929