Effective Density Characterization of Soot Particles Emitted from Aircraft Gas Turbine Engine Sources

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Aircraft particulate emissions have received much attention in the recent years due to the growing air travel and prepared legislation standard for aircraft PM emissions. The study of morphology of aviation-produced particulate matter (PM) advances our understanding of its behaviour and potential negative effects both on the local and global scale. Particle effective density establishes the relationship between mobility size and aerodynamic size. It is also required for conversion of size distributions to mass distributions.

Recent studies of effective density of aircraft engine soot particles based on the total mass and particle size measurements sacrifice the size dependence of effective density and dynamic shape factor. Also, this method cannot be used at low engine power due to low soot loadings [1]. A useful technique for obtaining size-resolved effective density at each thrust level is the combination of a differential mobility analyzer (DMA) and a centrifugal particle mass analyzer (CPMA, Cambustion Ltd.). Here we present the methodology and initial results obtained with this technique.

The CPMA classifier consists of two concentric rotating cylinders with voltage applied between them. Only particles in a narrow range of mass to charge ratio can penetrate the classifier [2]. Particle mass distribution of singly charged particles can then be easily obtained without charging corrections. For CPMA scan the inlet aerosol should be as monodisperse as possible. Therefore, DMA is used upstream of the CPMA to pre-classify the aerosol. During the scan, CPMA steps the angular velocity of the cylinders and voltage. Uncertainties of the mass and effective density determination are 8% and 12%, respectively [3].

Experiments were performed in an aircraft engine test cell at SR Technics, Zurich airport. Prototype of an aircraft engine emissions measurement system installed in the test cell offers a world-wide unique opportunity to measure aircraft engine emissions. Schematic of the system and experimental setup for particle effective density measurement is seen in Fig. 1.

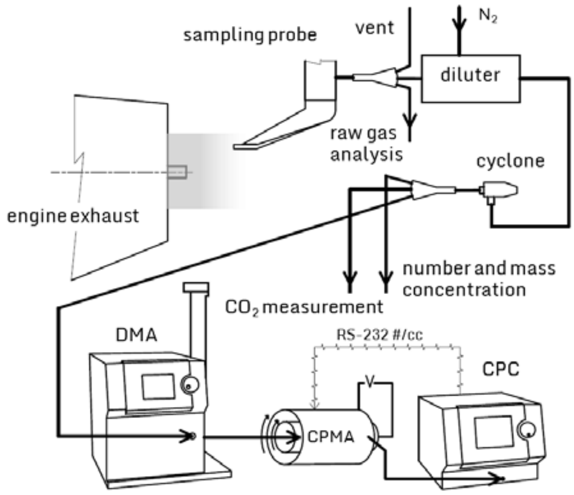

Figure 1. Experimental setup

A CFM56-5B4/2P engine (high by-pass turbofan, 120 kN rated takeoff thrust) was operated on an increasing and decreasing power curve. 4 representative engine power levels from low to high PM concentration were identified during an engine ramp and used for this study [4].

Diluted engine exhaust was sampled at 1.5 l/min. It was drawn through a radioactive charge neutralizer and then classified in a differential mobility analyzer (Model 3080, TSI Inc.) by mobility diameter. The DMA was set on 10 l/min sheath flow. Aerosol then entered the CPMA where the particles were classified by mass. Exiting particles of the CPMA were counted by a condensation particle counter (CPC, Model 3775, TSI Inc.).

Two DMA-CPMA-CPC setups were run in parallel with the aim to obtain particle mass data for more particle sizes during the limited time of one engine test point. The selected particle sizes lied in the range of highest number concentration of the engine PM. Effective density was then calculated as the mode of the particle mass distribution divided by the volume of the mobility-equivalent spherical particle.

Aircraft emissions measurement community assumes particle sphericity and unit density [5]. Particle effective density in this study was observed to decrease with increasing particle size due to the structural nature of fractal agglomerates. Effective density of particles between 20 and 50 nm was found to be in the range of 0.65 - 1.25 g/cm^3. An increase of effective density with engine thrust on the increasing power curve was observed in particular for the 40 and 50 nm particles; however more tests are required to investigate this behavior.

A disadvantage of this setup is the need for longer sampling times at stable engine conditions (approx. 5 minutes per particle size). An experimental setup allowing faster measurement is needed for measurements at short engine test points and is currently under investigation.

During the ongoing aircraft engine emissions measurements we intend to investigate the influence of several factors on the effective density of aircraft engine PM such as engine thrust, engine warm-up effect, ambient conditions and engine to engine variation.

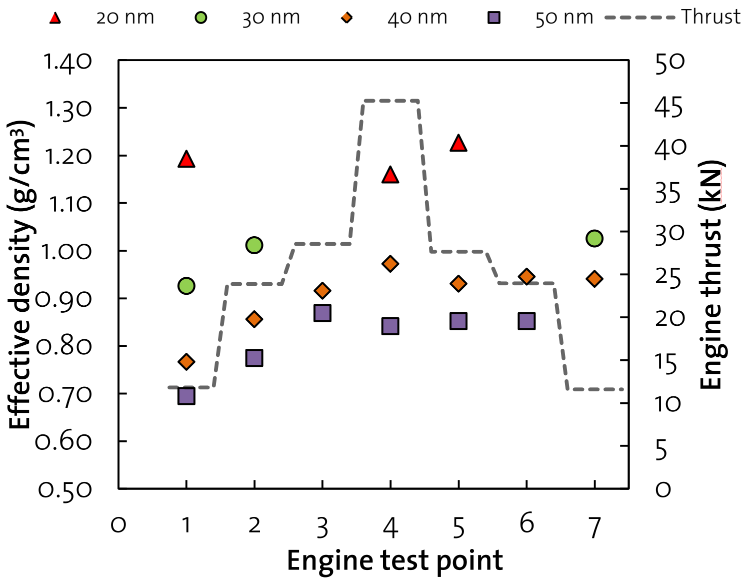

Figure 2. Size-resolved effective density obtained per engine test point. Test point duration was 16 minutes.

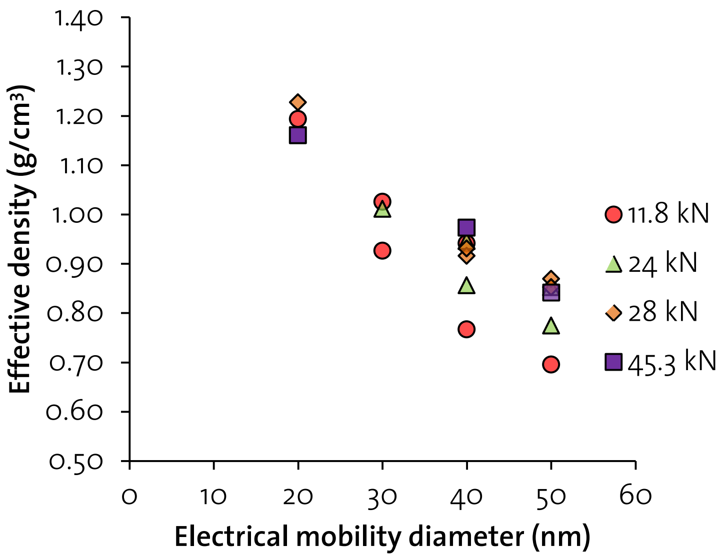

Figure 3. Effective density as a function of particle size and engine thrust.

References

[1] Timko, M.T. et al. (2010) Particulate emissions of gas turbine engine combustion of a Fischer-Tropsch synthetic fuel. *Energy and Fuels,24*(11), 5883-5896.

[2] Olfert, J.S. et al. (2006). The experimental transfer function of the Couette centrifugal particle mass analyzer. Journal of Aerosol Science, 37, 1840 – 1852.

[3] Crayford, A. et al. (2012) SAMPLE III: Contribution to aircraft engine PM certification requirement and standard. Second Specific Contract - Final Report *European Aviation Safety Agency*.

[4] Symonds, J.P.R. et al.(2012). The Centrifugal Particle Mass Analyser as a Fundamental Particle Mass Standard. Cambridge Particle Meeting, Cambridge, UK, May 18, 2012.

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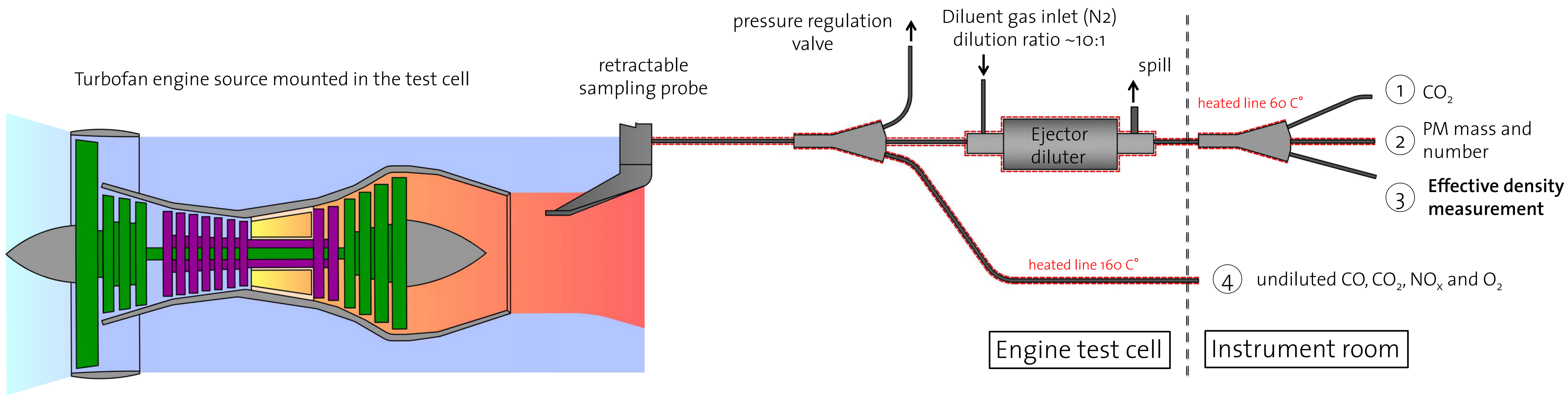
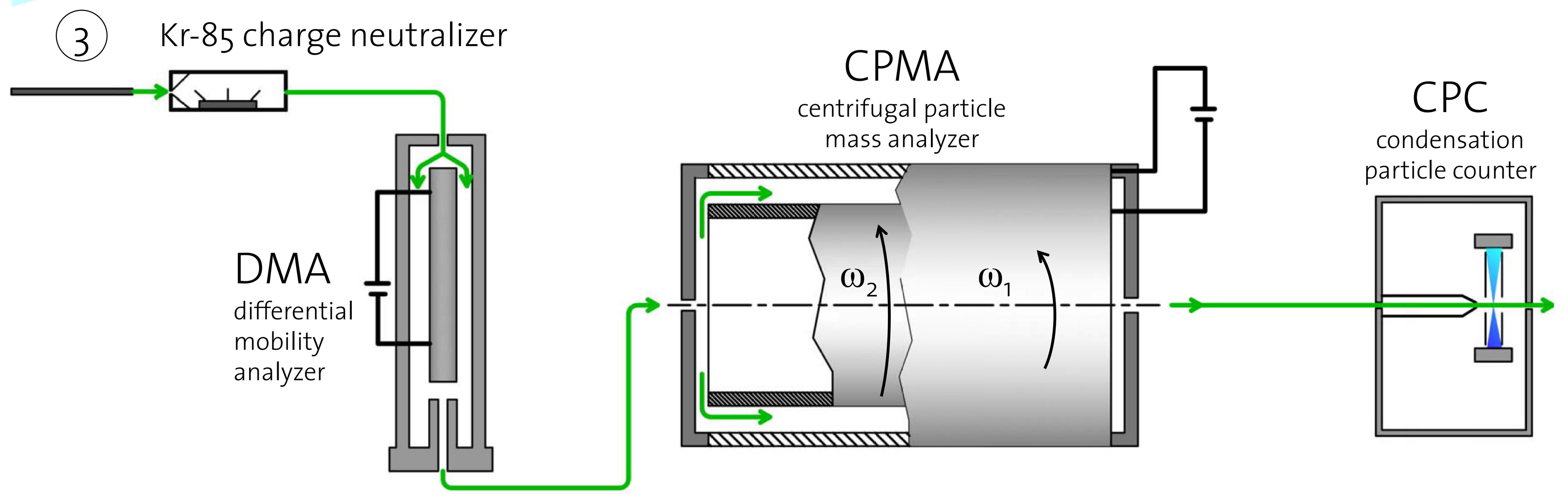
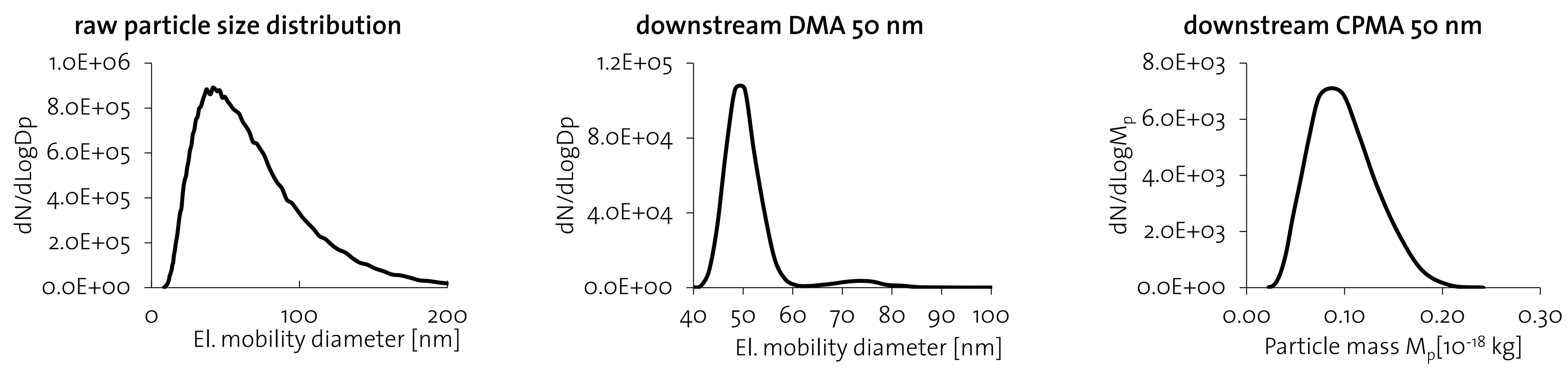
Introduction

Aircraft particulate emissions have received much attention in the recent years due to the growing air travel and prepared legislation standard for aircraft PM emissions. Particle effective density establishes the relationship between mobility size and aerodynamic size. Recent studies of this property based on the total mass and particle size measurements sacrifice the size dependence of effective density and dynamic shape factor. Also, this method cannot be used at low engine power due to low soot loadings [1]. A useful technique for obtaining size-resolved effective density at each thrust level is the combination of a differential mobility analyzer (DMA) and a centrifugal particle mass analyzer (CPMA). Here we present the methodology and initial results obtained with this technique.







Engine Run

- Prototype of an aircraft engine emissions measurement system is installed in the engine test cell at SR Technics, Zurich airport.
- A CFM56-5B4/2P engine (high by-pass turbofan, 120 kN rated takeoff thrust) was operated on an increasing and decreasing power curve.
- 4 representative engine power levels from low to high PM concentration were identified during an engine ramp and used for this study [2].

Experimental Setup

- CPMA classifies particles based on their mass to charge ratio [3].
- During the scan, CPMA steps the angular velocity of the two concentric cylinders and voltage between them.
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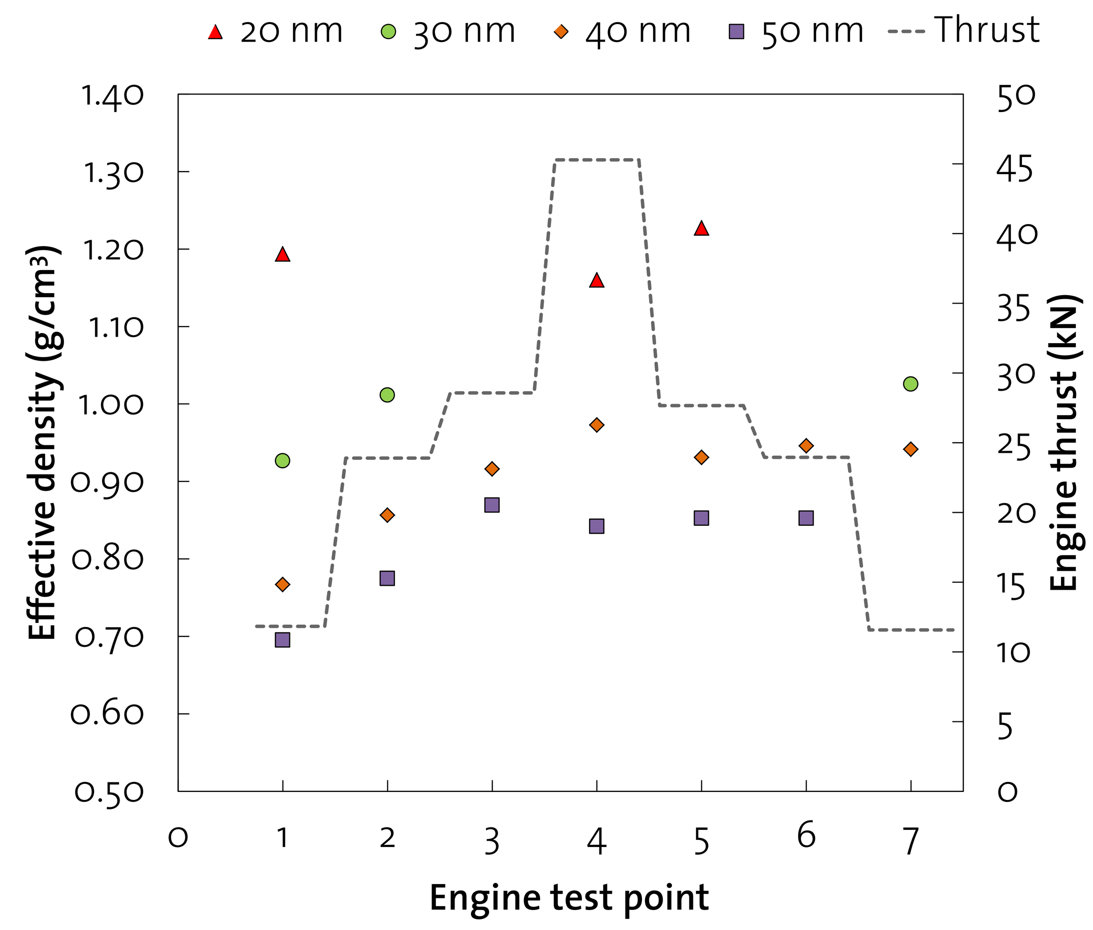

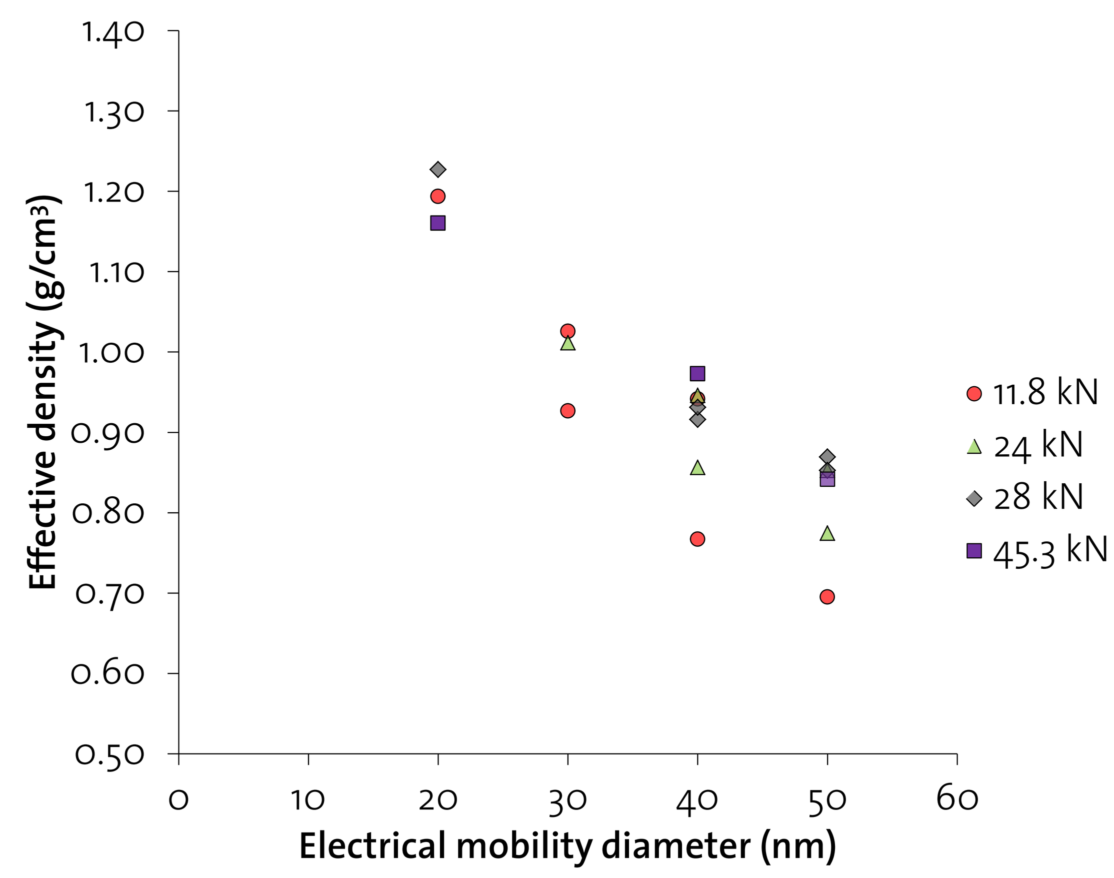

Results

- Particle effective density was observed to decrease with increasing particle size due to the structural nature of fractal agglomerates.
- Effective density of particles between 20 and 50 nm was found to be in the range of 0.65 - 1.25 g/cm³.
- An increase of effective density with engine thrust on the increasing power curve was observed in particular for the 40 and 50 nm particles, however more tests are required to investigate this behavior.

Conclusions and Outlook

- DMA-CPMA-CPC setup was deployed during an aircraft engine emissions measurement campaign.
- This setup allows measuring size-resolved effective density of aircraft engine PM at stable engine conditions.
- Aircraft emissions measurement community assumes particle sphericity and unit density [5]. Effective density in this study for 20 – 50 nm particles was found to be in the range from 0.65 to 1.25 g/cm³, decreasing with particle size.
- A disadvantage of this setup is the need for longer sampling times at stable engine conditions (approx. 5 minutes per particle size). A faster experimental setup is under investigation.
- Ongoing work will investigate the influence of various parameters on the effective density such as engine thrust, engine to engine variation and ambient conditions.

References

[1] Timko, M.T. et al. (2010) Particulate emissions of gas turbine engine combustion of a Fischer-Tropsch synthetic fuel. *Energy and Fuels*,*24*(11), 5883-5896.

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Acknowledgements

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