Correlations of nonvolatile particulate matter mass and number emissions and particle size with smoke number determined for commercial aircraft jet engines

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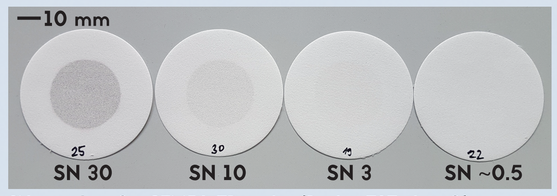
Background

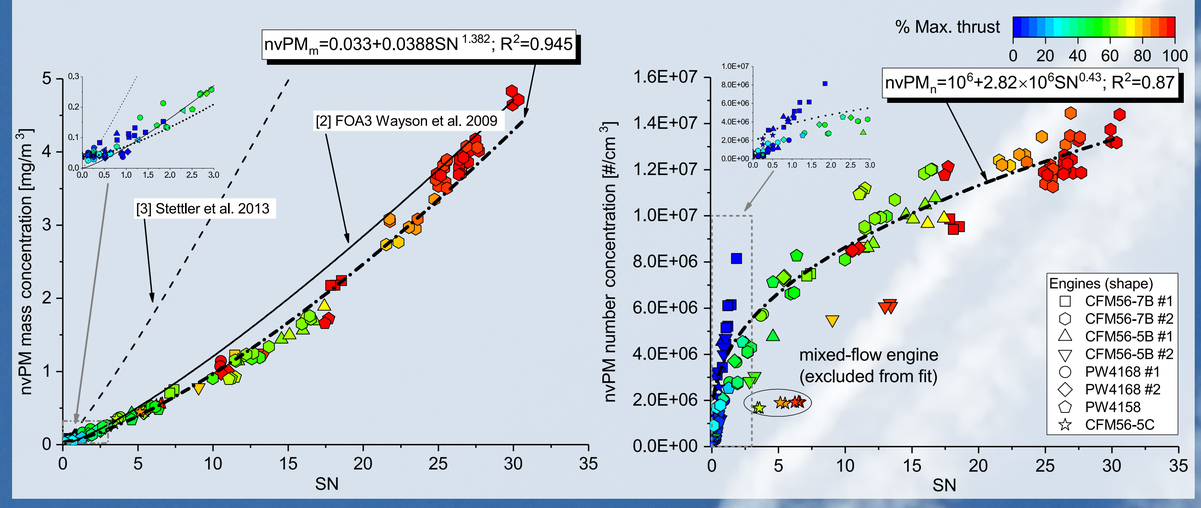
- Non-volatile PM (nvPM) emissions from aircraft engines worsen airport air quality and contribute to climate change
- First aircraft engine nvPM emissions standard will be introduced in 2020 [1]
- The nvPM standard will replace the standard based on exhaust smoke visibility – smoke number (SN; →figure)
- Certification SN data are available for most in-service commercial jet engines
- Various methods approximate nvPM mass emissions from certification SN for the assessment of airport air quality and global emissions [2-4] – the recommended method is the First Order Approximation v3 (FOA3) [2]
- We have developed correlations of nvPM emissions and particle size with SN from standardized emission measurements of five types of widely used commercial aircraft jet engines (→figure)



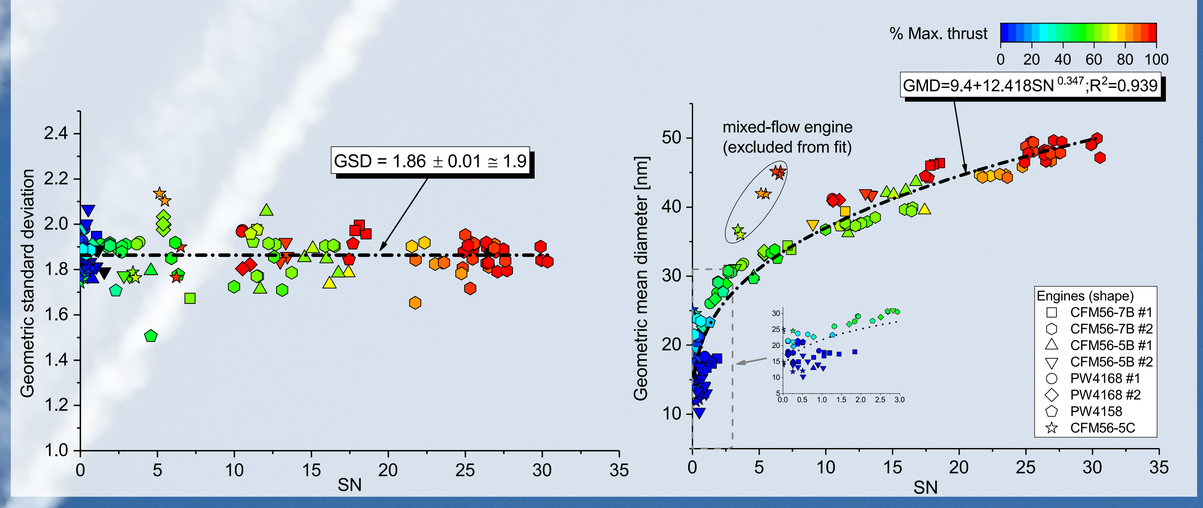
SN samples of a CFM56-7B engine (Boeing 737 aircraft). $SN=100(1-R_s/R_w)$, where R_s and R_w is the stained and clean filter reflectance, respectively.

Overview of the engine types tested in this study and their applications. These engine types together power around 1/2 of the fleet.

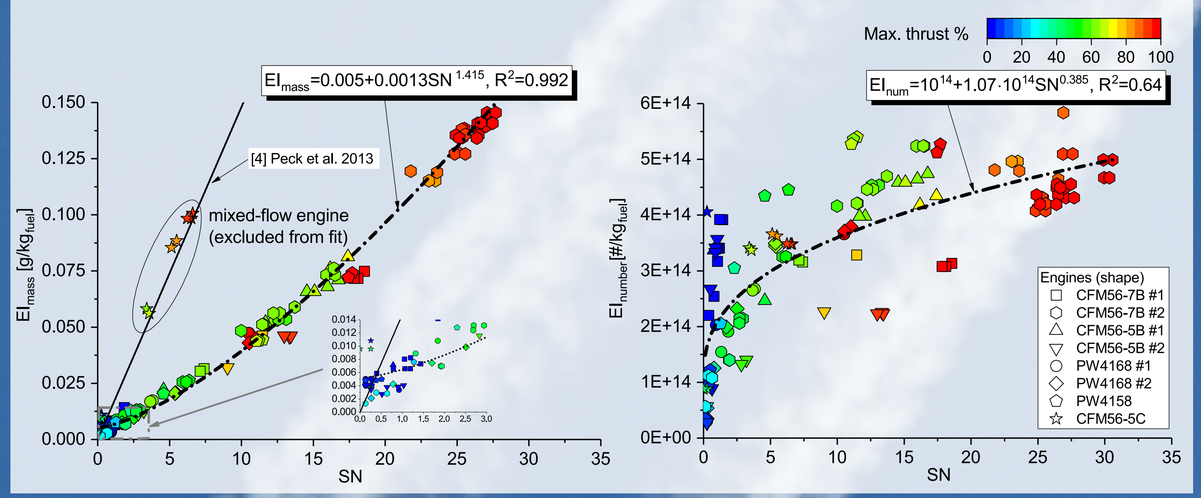
NvPM mass and number concentrations



Particle size distribution parameters



Emission indices (emissions/kg fuel burned)

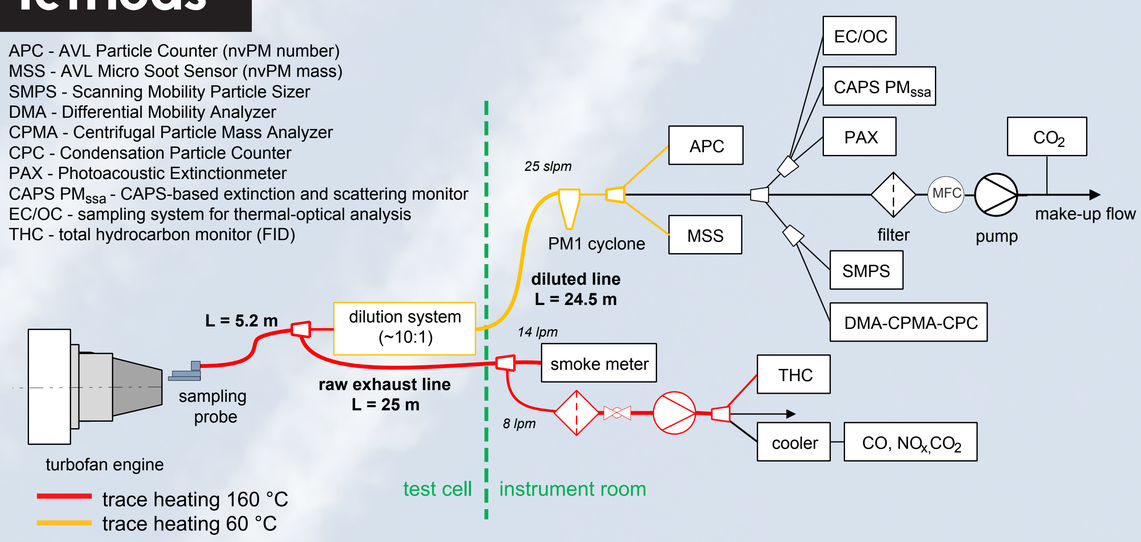


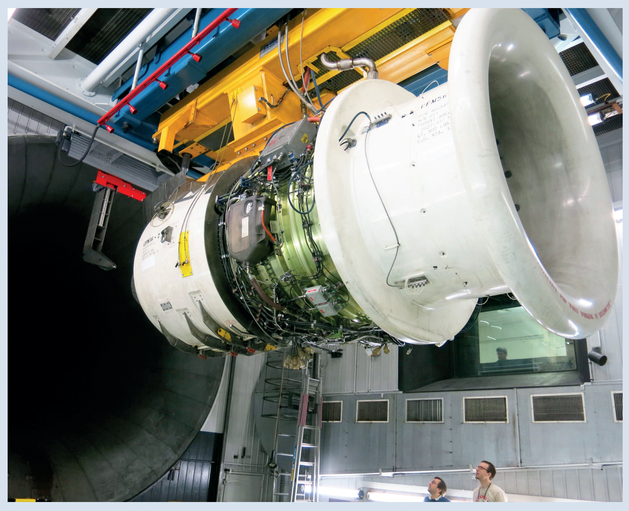
Conclusions

- Overall good correlation of all the parameters investigated with SN; especially mass-based emissions and GMD correlate strongly with SN
- Mixed-flow engines (exhaust dilution with bypass air upstream of the sampling location) are outliers – the dilution ratio is unknown, but can be estimated from engine performance data
- NvPM mass concentrations as a function of SN agree well with the recommended FOA3 [2]
- Up to a factor of ~3 lower nvPM mass concentrations and emission indices as a function of SN than recently proposed updated correlations [3,4]
- To estimate emissions from engines with ultra-low SN, we propose offsets in correlations, which may be significant for number-based emissions: the number concentration at SN ~0 reached well over 10^6 /cm³
- These data will contribute to more accurate assessments of aircraft engine nvPM emissions; further development will include more measurement data and correction for particle loss in the sampling system

Methods

APC - AVL Particle Counter (nvPM number)
MSS - AVL Micro Soot Sensor (nvPM mass)
SMPS - Scanning Mobility Particle Sizer
DMA - Differential Mobility Analyzer
CPMA - Centrifugal Particle Mass Analyzer
CPC - Condensation Particle Counter
PAX - Photoacoustic Extinctionmeter
CAPS PM_{ssa} - CAPS-based extinction and scattering monitor
EC/OC - sampling system for thermal-optical analysis
THC - total hydrocarbon monitor (FID)





Engine in the test cell of SR Technics with the exhaust sampling probe at the engine exhaust exit plane (left)

Raw gas and smoke number measurement equipment

NvPM measurement system and particle classifiers

References

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