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Non-volatile PM emissions of a business jet aircraft: Ground measurements and cruise estimates

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BAZL

Big countries like big VIP planes…

gas and smoke/PM emission standards

Only visible smoke certification (<26.7 kN thrust)

…the Swiss “Air Force One” is *slightly* smaller

Question: How do nvPM emissions of business jets compare to airliners?

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- Business jets burn only 2% of the world's jet fuel
- However, they may have significantly higher emissions relative to their fuel burn potentially due to technical and economic reasons
- only visible smoke is regulated

Source: youtube.com, Cargospotter

Objectives

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- Determine nvPM emission characteristics of the Dassault Falcon 900EX on the ground using certification-type measurements
- Estimate nvPM emissions at cruising altitude
- Compare results with the previous study for the Boeing 737 airliner

Experimental setup

- Swiss Mobile Aircraft Engine Emissions Measurement System (SMARTEMIS) compliant to emission certification requirements

Emission test in progress (take-off thrust)

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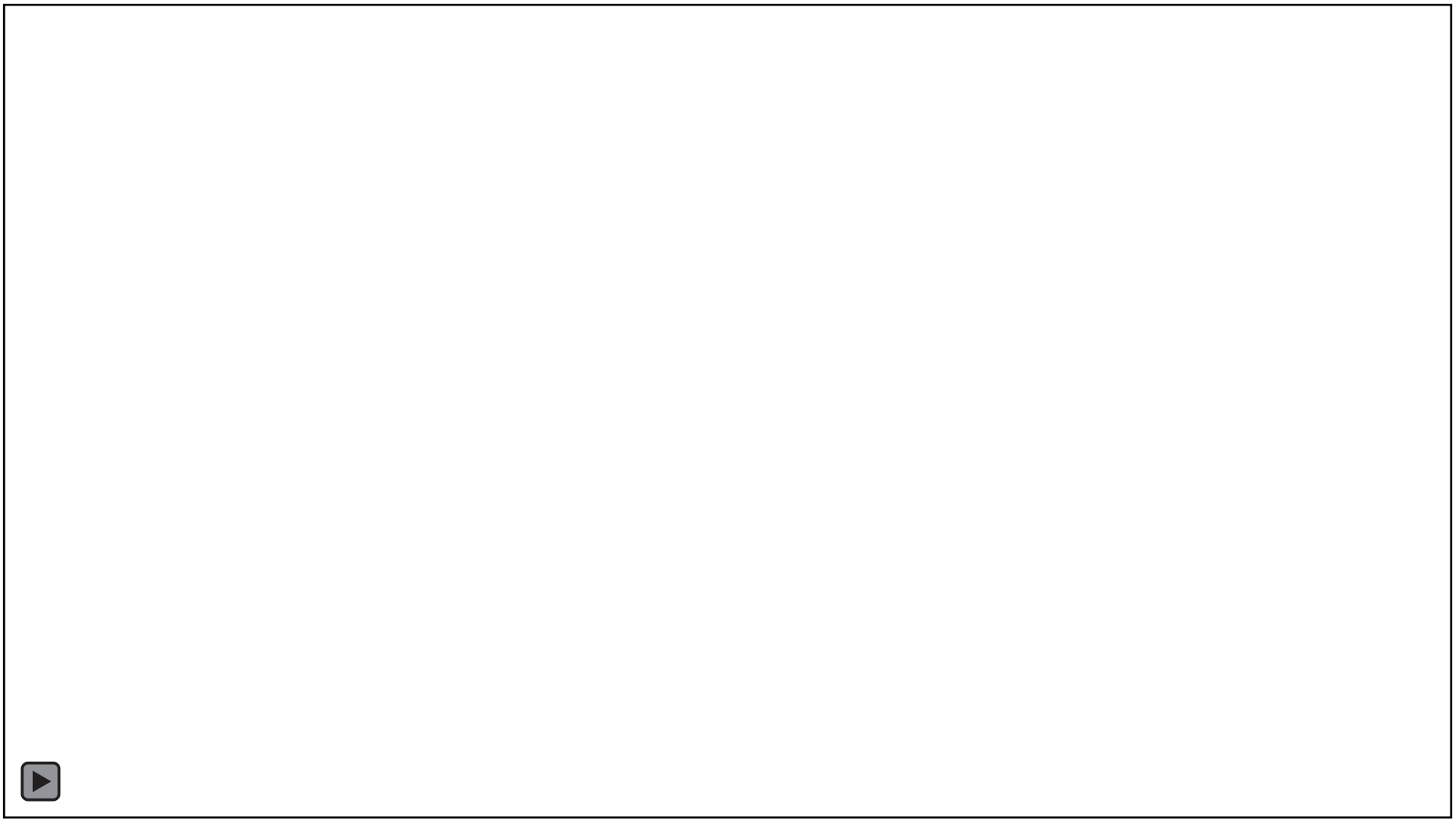

Results

- **Particle size distributions**
- Emission indices
- Landing and take-off cycle emissions
- Cruising altitude emissions

Particle size distributions depended strongly on thrust

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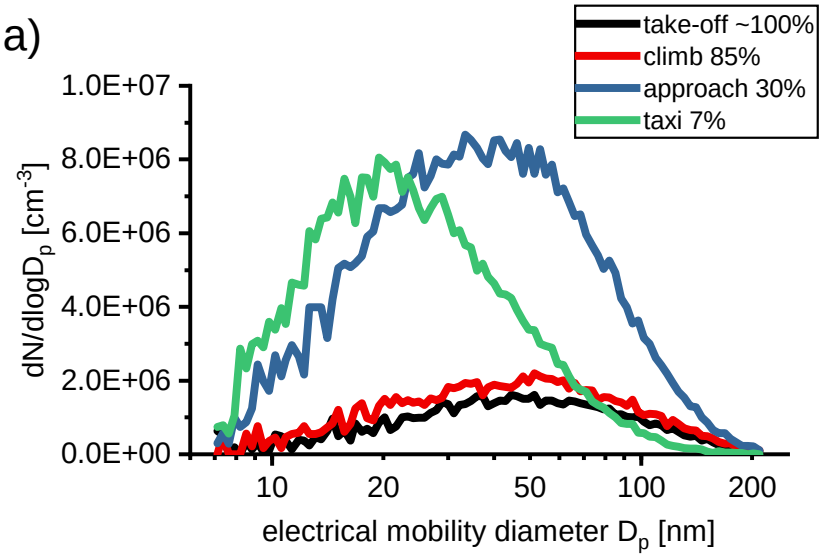
a)



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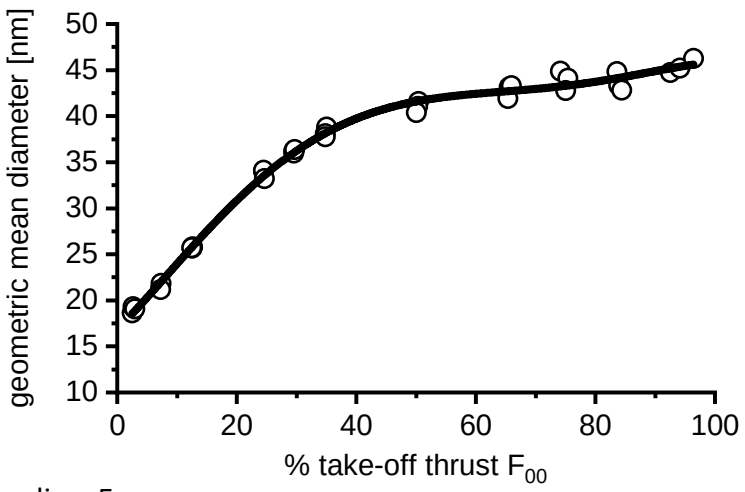

- Particle concentration peaked at ~30% and decreased with further thrust increase – a characteristic we have not seen on larger engines
- Geometric mean diameter (GMD) increased with thrust from 18 nm to 45 nm
- *All data corrected for particle loss in the sampling system*

Results

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- Particle size distributions
- **Emission indices**
- Landing and take-off cycle emissions
- Cruising altitude emissions

Emissions indices were high at low thrust and low at maximum power

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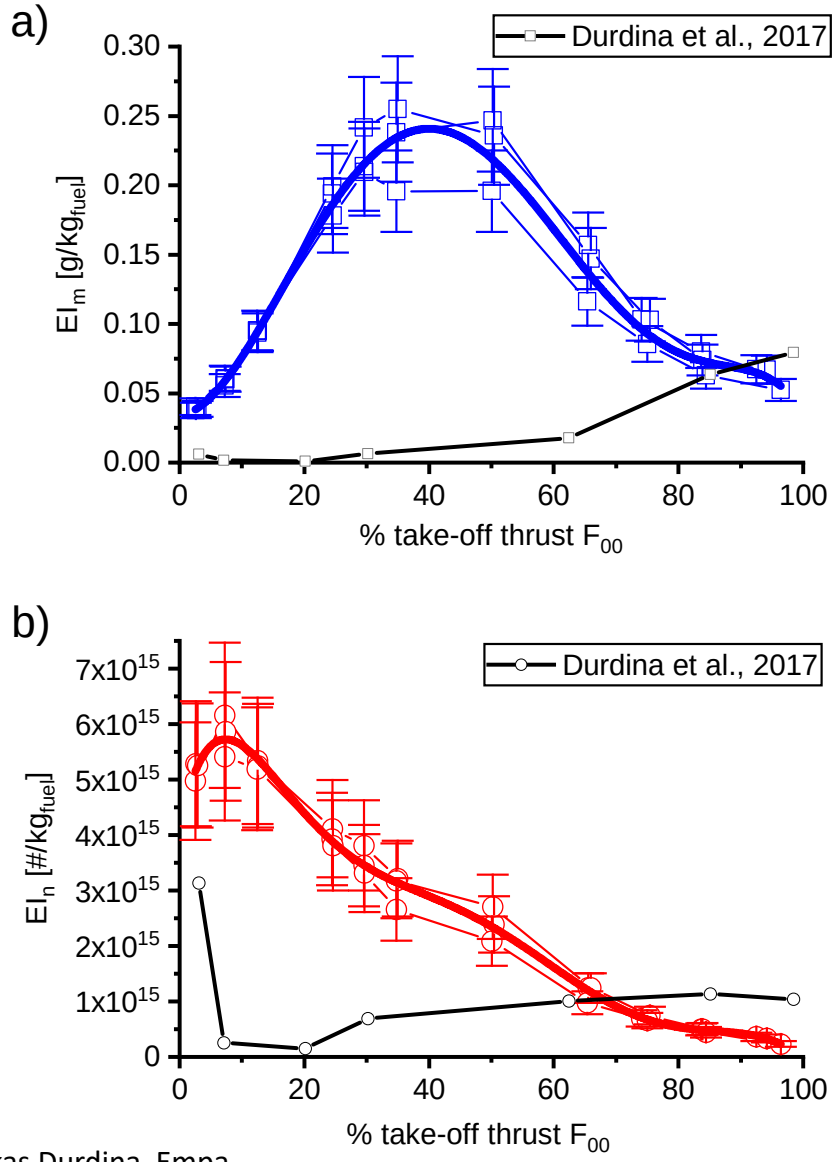

- Mass-based emission index maximum at ~40% thrust
- Number-based emission index maximum at ~10% thrust
- Unusual thrust dependence (maximum nvPM mass emissions typically at take-off for)

Results

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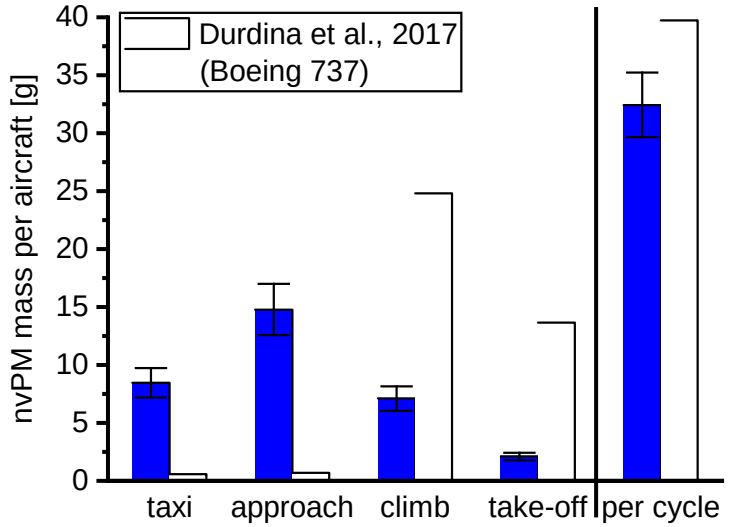
- Particle size distributions
- Emission indices
- **Landing and take-off cycle emissions**
- Cruising altitude emissions

Landing and take-off cycle (LTO) emissions were dominated by taxiing and approach

a)



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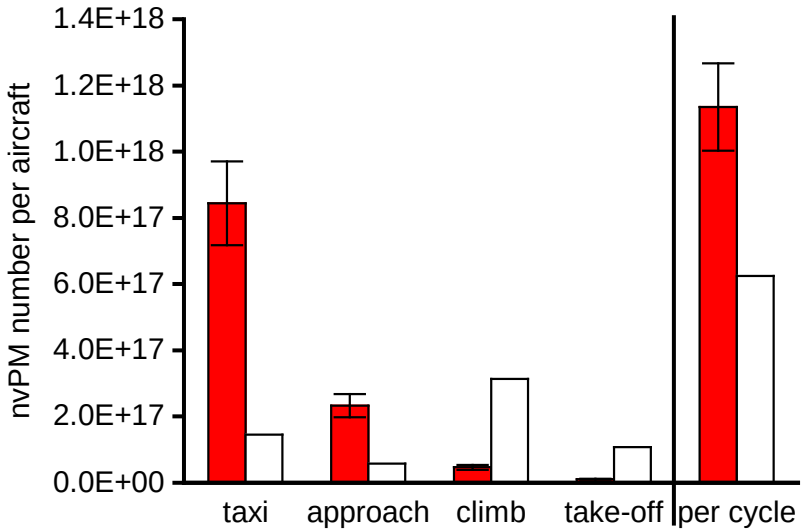

- 50% of nvPM mass emitted during approach
- Up to 75% of nvPM number emitted during taxiing
- Overall LTO emissions higher than the Boeing 737

Results

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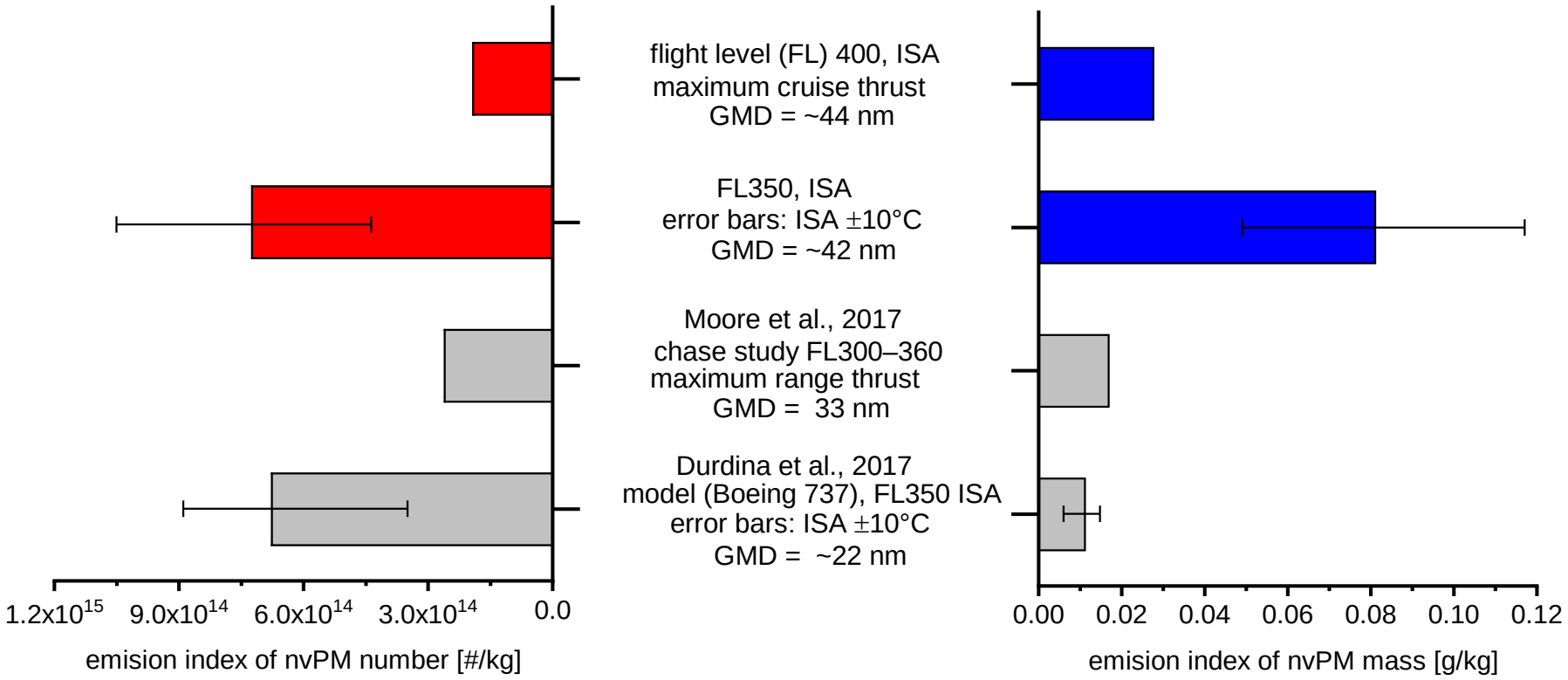
- Particle size distributions
- Emission indices
- Landing and take-off cycle emissions
- **Cruising altitude emissions**

NvPM number at cruise comparable to previous study, nvPM mass up to a factor of 10 higher

- Calculations done using a detailed engine performance model in GasTurb 13 calibrated to engine test data (Durdina et al. ,EST, 2017)



Overall flight emissions of nvPM mass were more than twice as high as those of the airliner

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- Example: LTO cycle + 2h cruise (without climb and descend)

	Falcon 900	B737-800	Delta
nvPM mass	190 g	81 g	**+134%**
nvPM number	2.5×10^{18}	4×10^{18}	**-37.5%**

Conclusions

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- First and successful use of the Swiss mobile aircraft emissions measurement system (SMARTEMIS) on a small jet engine
- The findings indicate that the contribution of business jets to environmental impacts of aviation nvPM emissions may be significant despite their relatively low fuel burn
- Potentially a need to regulate emissions of small engines

A big thanks to the Swiss Air Force for making this work possible

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- *Crew Bern: Ralph Loosli, Thierry Dey, Michael (Mick) Lüthy*
- *Crew Payerne: Thierry Roulin, Canisius Brodard, Bruno Carrard, Pierre Dubi, Christian Guillaume, Christian Bangerter*

- We also thank MeteoSwiss for the meteorological data

Supporting information

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Ambient conditions and fuel properties

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- Ambient temperature 11.3 °C – 20.8 °C
- Ambient RH 40.3% – 70.4%
- Ambient pressure 964.6 hPa – 968.3 hPa

- Fuel aromatics 17.2% (V/V)
- Fuel Naphthalenes 1.41% (V/V)
- Fuel Hydrogen 13.4% (m/m)
- Fuel Sulfur 0.1% (m/m)