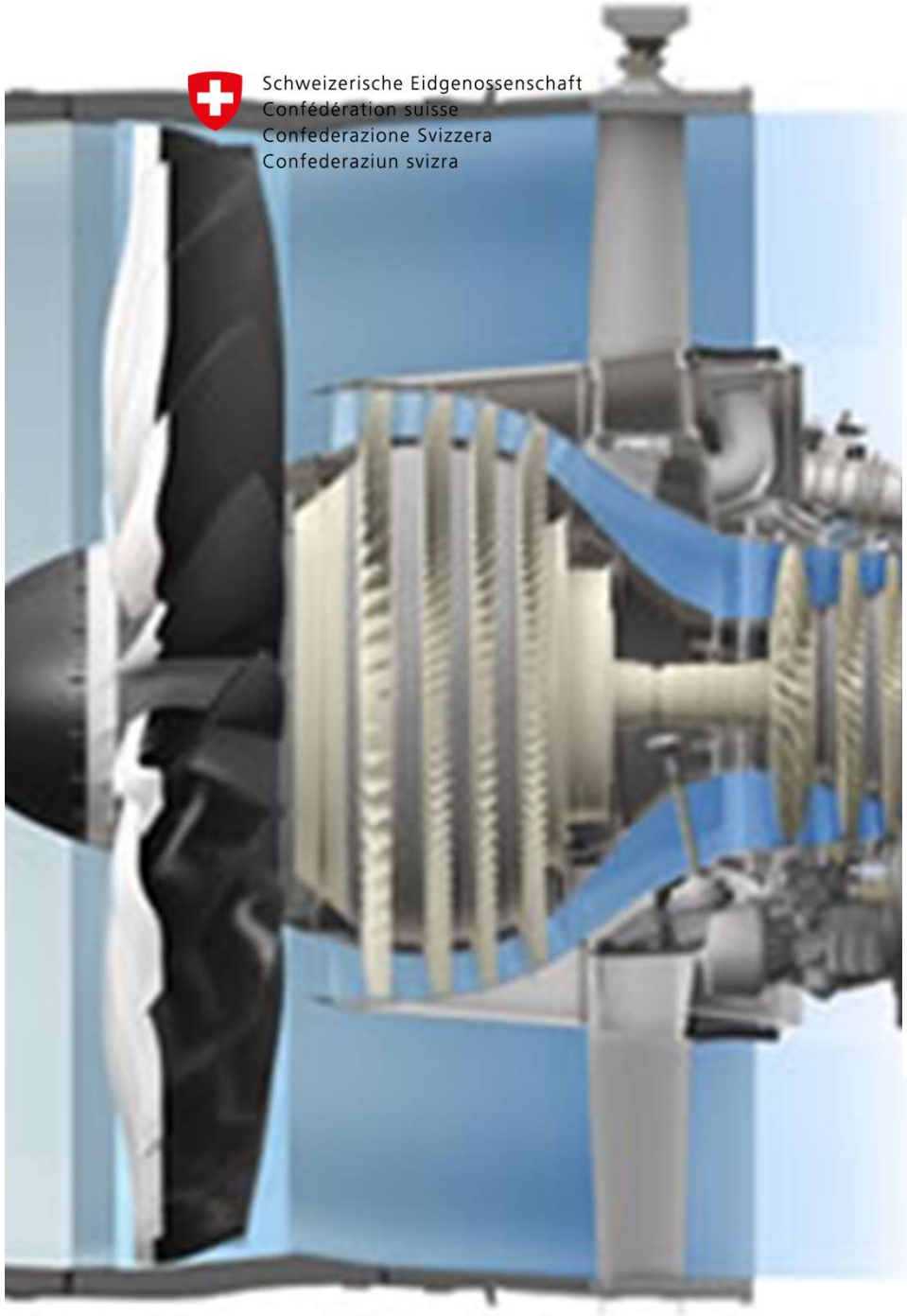

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Federal Office of Civil Aviation FOCA
Aviation Policy and Strategy

The First Global Regulatory Limits for Aircraft Engine Particle Mass and Number Emissions

11th VERT Forum

March 25th 2021, Theo Rindlisbacher

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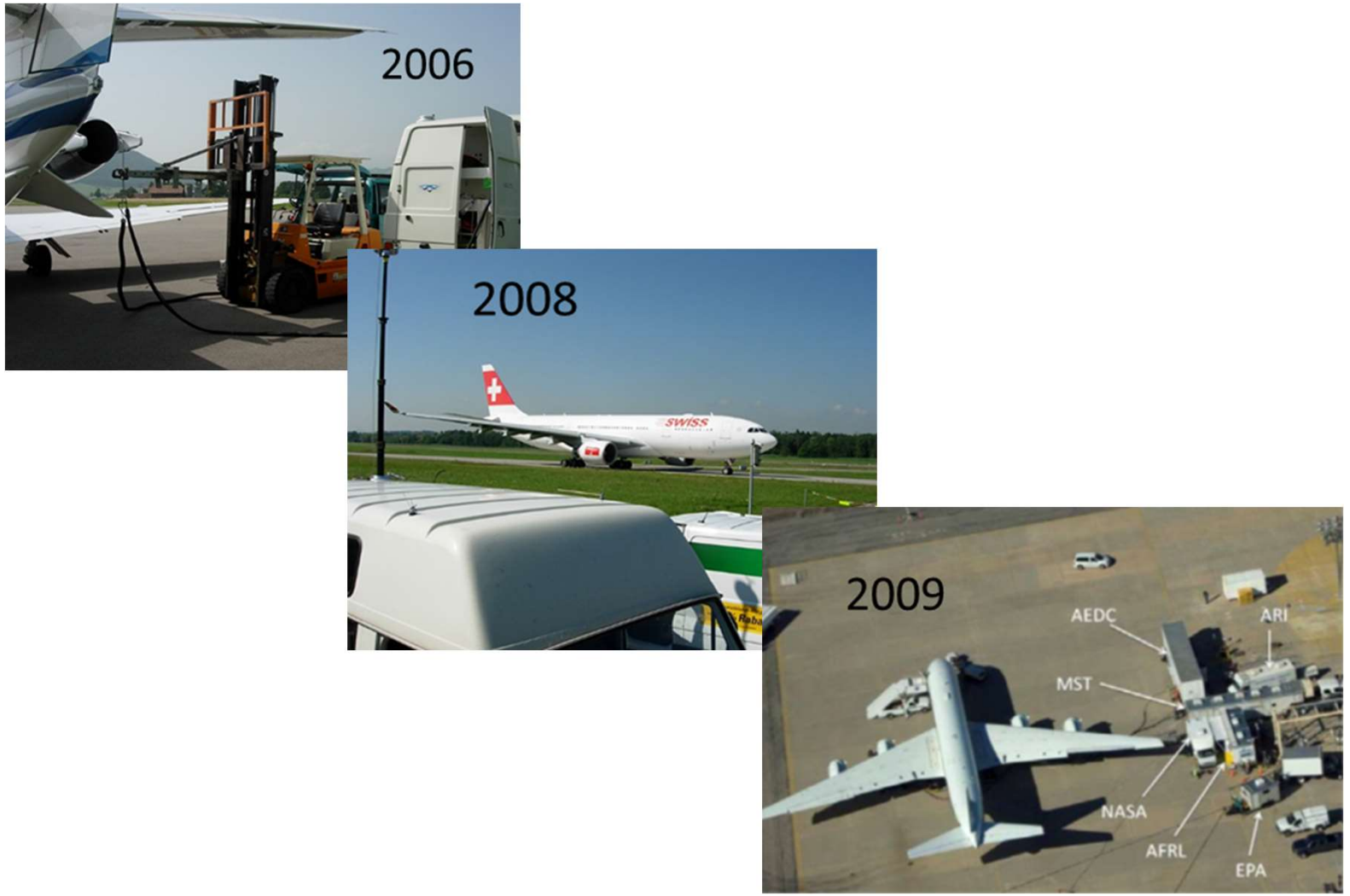
Background



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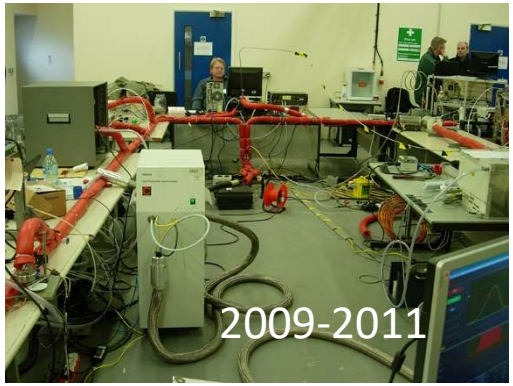
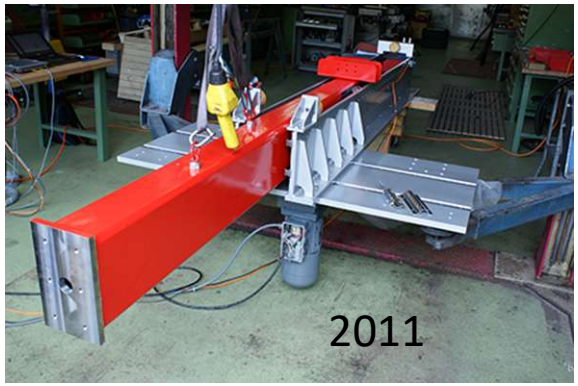
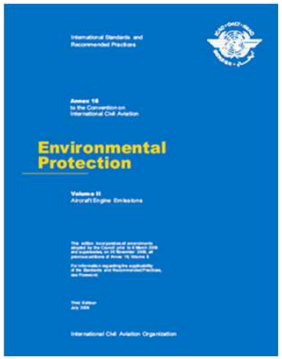




Breakthrough: Use of engine test cell at the maintenance facility of SR Technics, Zurich Airport. FOCA built and installed the system prototype, then Empa and International measurement campagins in CH. ICAO agreement on measurement Protocol in spring 2016 → start of globally standardised UFP measurements

Aviation introduces the first global UFP standards



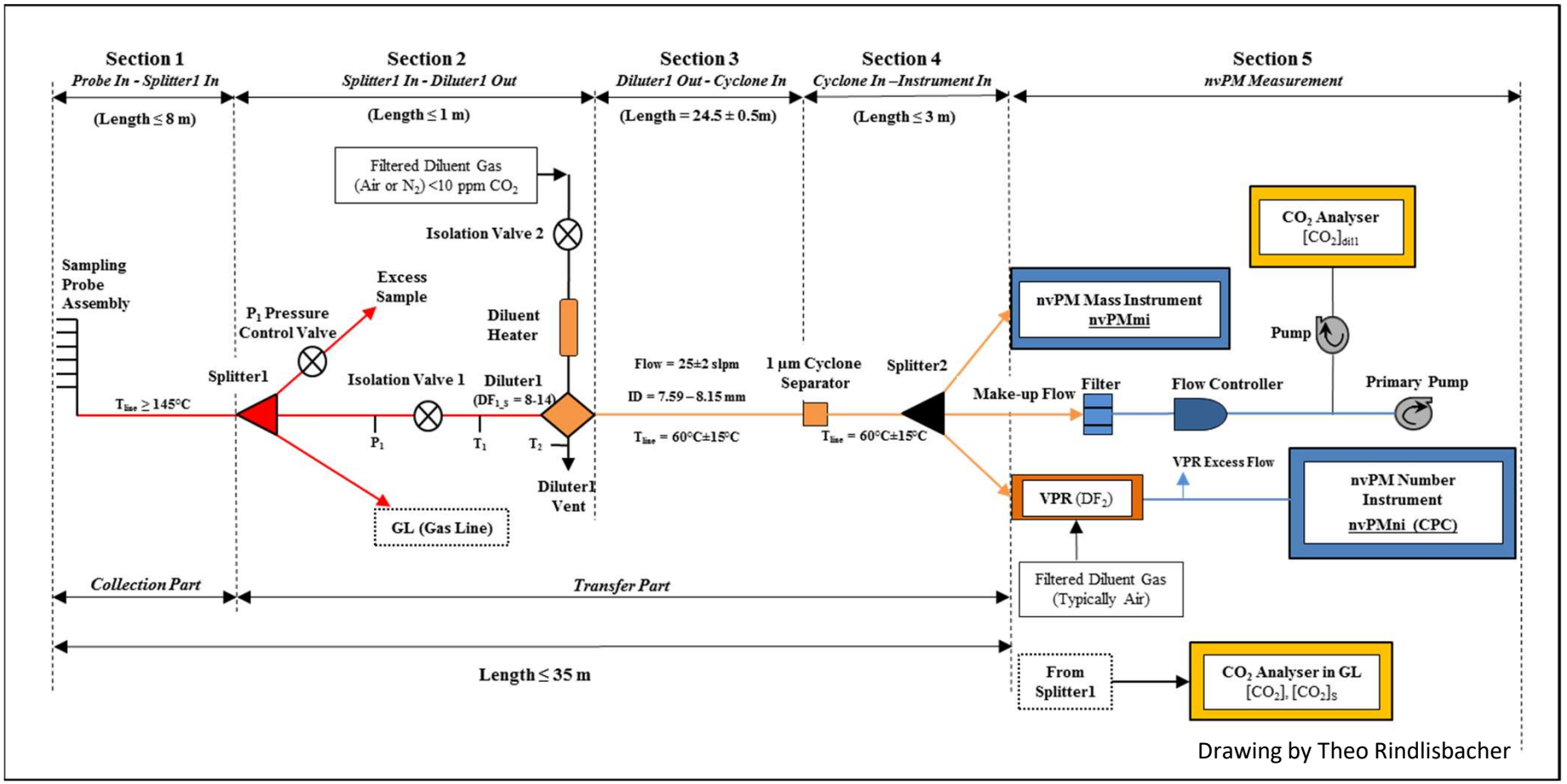
Since 1st January 2020, all in-production (larger than small business jet size) require additonal emission certification according to the new measurement protocol for non-volatile* particle (nvPM) mass and number emissions.

Published in ICAO Annex 16 Volume II, Chapter 4 and Appendices

In 2019, the ICAO Council adopted regulatory limits for nvPM mass and number emissions in the landing and take-off cycle (LTO), both for in-production and new type engines, applicable globally from 1st January 2023.

* particles, which do not volatilize when heated to 350°C, mostly Black Carbon, Soot

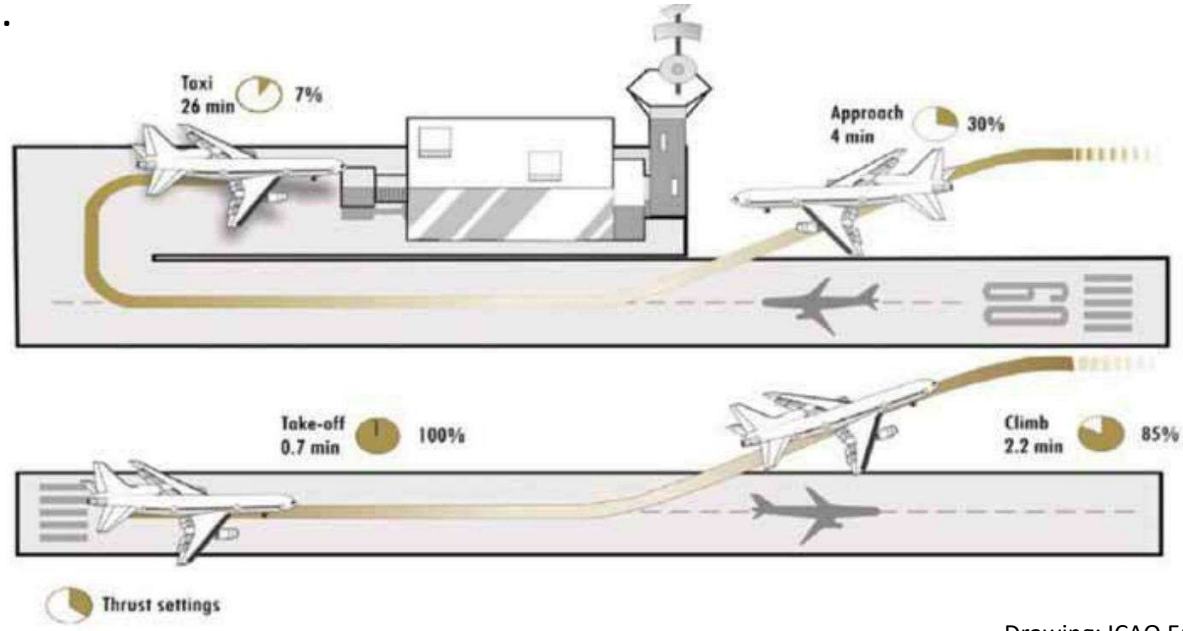
nvPM Measurement System Overview



Drawing by Theo Rindlisbacher

Standard LTO – Cycle is base of Metric

- An engine moves virtually in a standard landing and take-off cycle (LTO cycle).
- The generated emission load (grams of particle emission and number of emitted particles) divided by the maximum rated thrust of the engine must not exceed a regulatory limit value (details on next two slides).



Drawing: ICAO Environmental Report 2013

Figure 1: *Illustration of ICAO Emissions Certification Procedure in the LTO Cycle.*

Elements of the Metric System

- Four engine modes:
  - Take-off (100% thrust) time t_m = 0.7 minutes = 42 s
  - Climb (85% thrust) time t_m = 2.2 minutes = 132 s
  - Approach (30% thrust) time t_m = 4.0 minutes = 240 s
  - Taxi (7% thrust) time t_m = 26 minutes = 1560 s

- For each mode the ISA normalised fuel flow W_f (kg/s) and the emission factor EI (mass of particles / kg fuel) or (number of particles / kg fuel) is reported

- Emission of a mode = W_f * EI * t_m
- LTO-Emissions = Sum of the emissions of the four modes
- The LTO-Emissions of an engine are then normalised by the rated thrust F_{oo} of the engine

Final Metric Values

- Mass

$$\frac{LTO_{nvpm\_mass}}{F_\infty} = \frac{\sum_{LTO} t_m \times W_f \times EI_{nvpm\_mass}}{F_\infty}$$

- Number

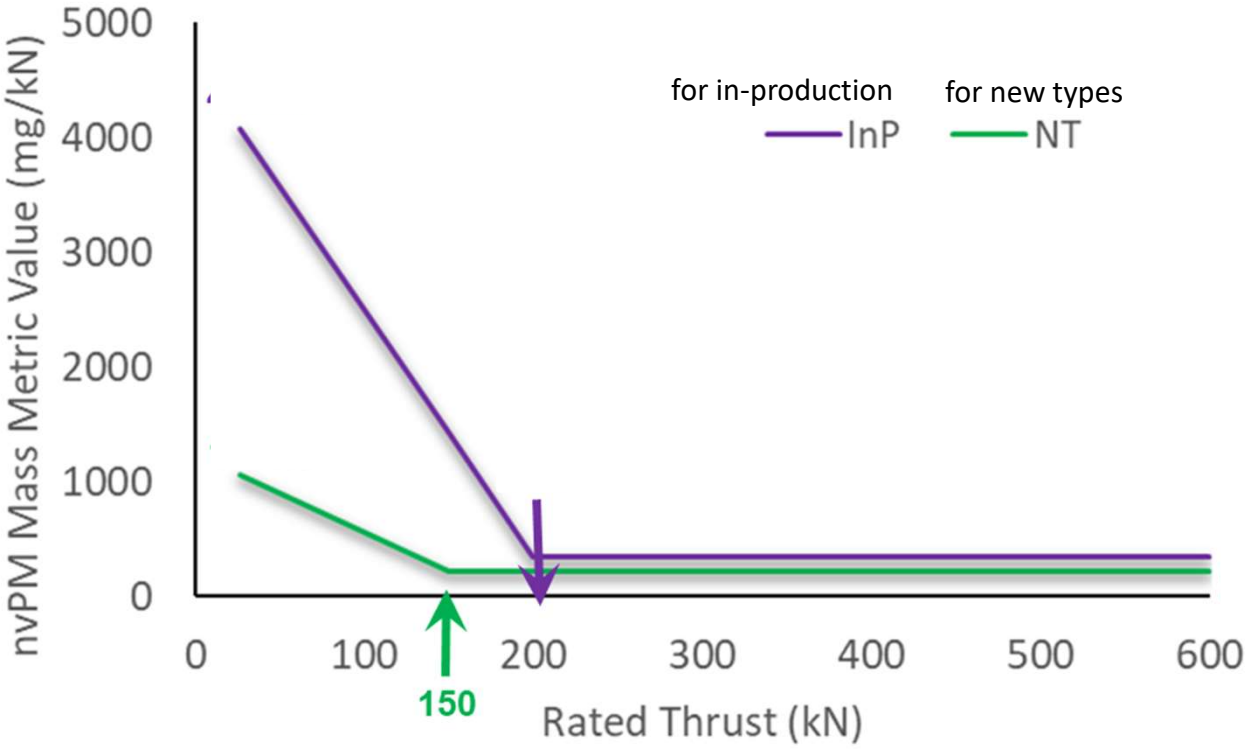
$$\frac{LTO_{nvpm\_num}}{F_\infty} = \frac{\sum_{LTO} t_m \times W_f \times EI_{nvpm\_num}}{F_\infty}$$

- NOTE: Sustainable Aviation Fuels (SAF) are zero aromatics and zero sulfur. They lead to significant (…70%) PM reductions in existing engines. SAF is Win-Win for fossil CO_2-reduction, climate and local air quality impact reduction in existing fleets and future aircraft!
- For certification however, the fuels have to be normalized to an average (fossil) fuel aromatics content in order to compare engines to reg. limits.
- EI's are normalized to 13.8%mass fuel hydrogen content and corrected for thermophoretic loss in the collection section of the sampling system.

Final Metric Values

- The metric values (LTO emissions / rated thrust) are adjusted for the number of engines tested to obtain the characteristic metric value for that engine type. (e.g.) one engine serial number tested with a minimum of three curves → measured metric value is increased by 39%. This increased metric value is the characteristic value.
- **The characteristic metric value is the value used to demonstrate compliance to the standard (one for nvPM mass, one for nvPM number)**

Regulatory Limits from 1st January 2023 (nvPM mass)

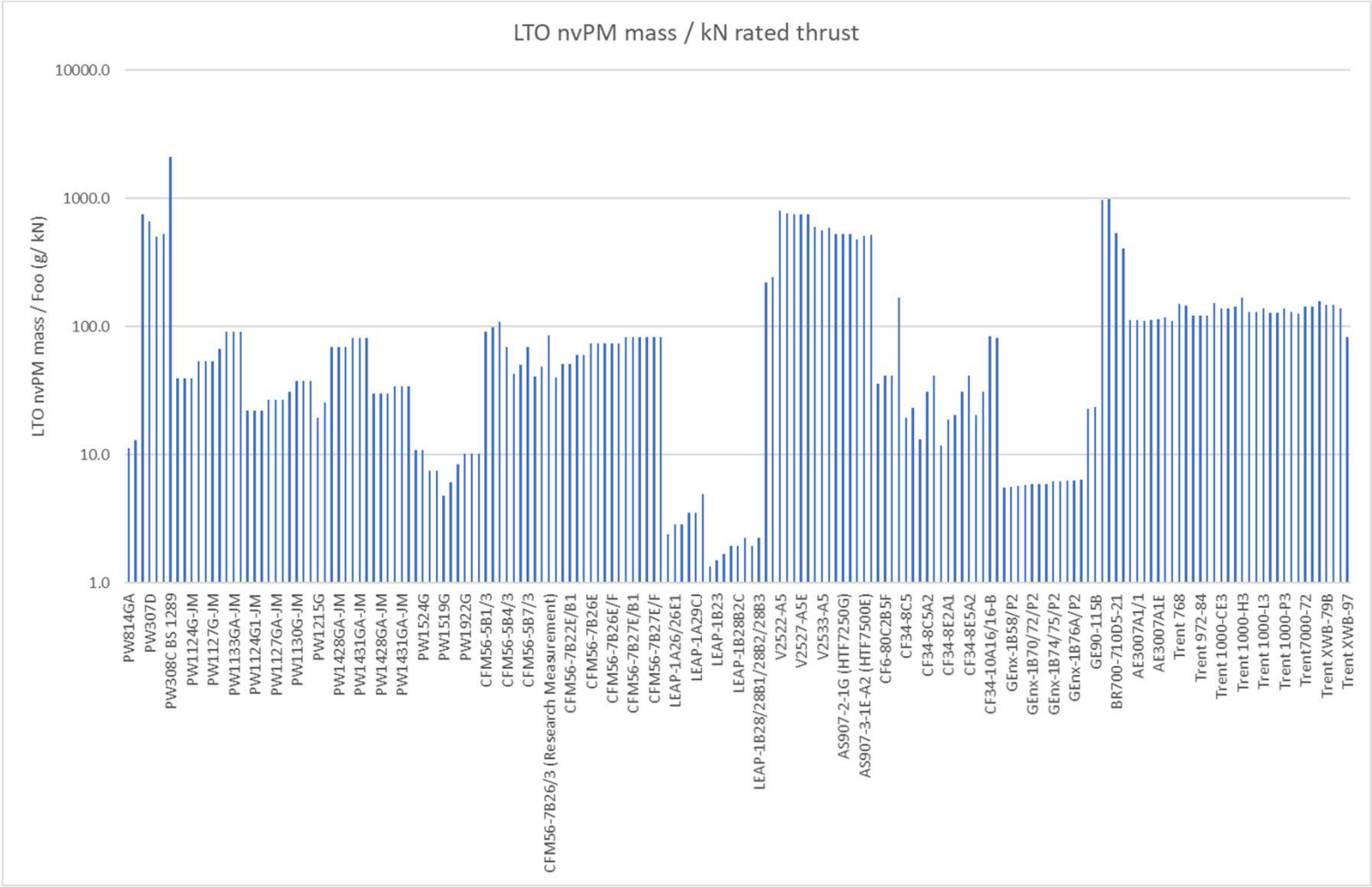


Note: Current in-production engines have not been designed for low nvPM mass emissions.

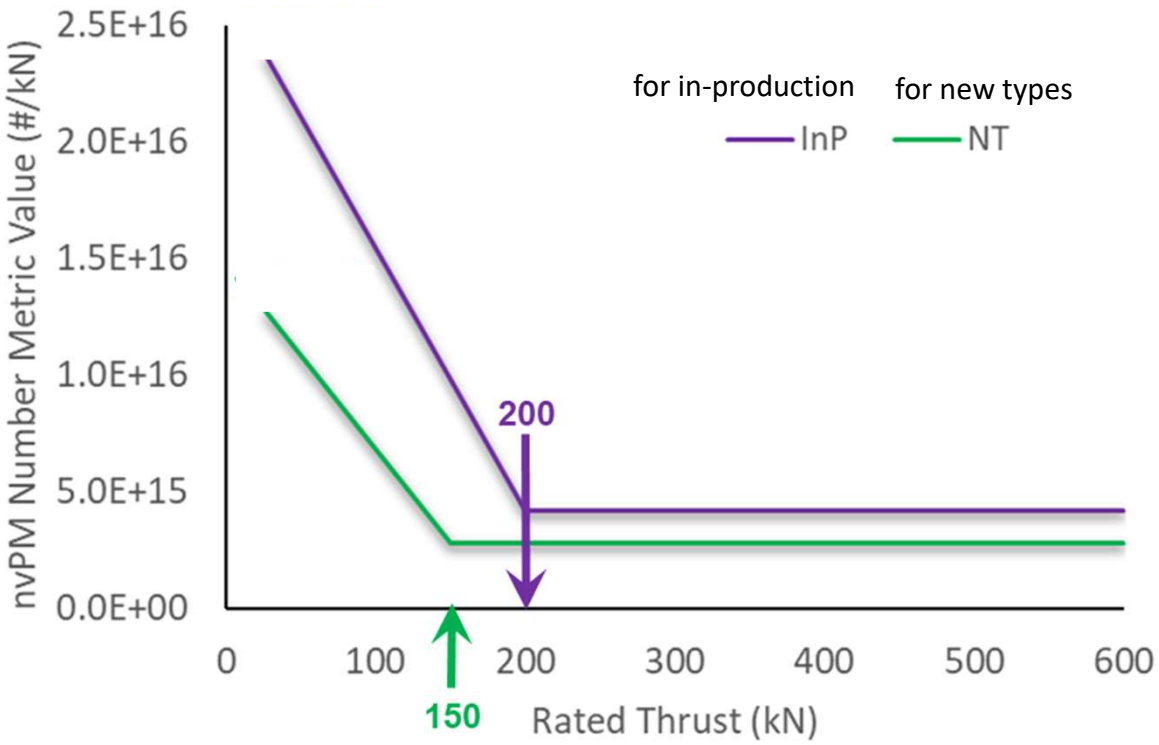
Emissions Certification Data (nvPM mass)

Note: Publicly available: [Environmental Research - Engine Emissions | EASA (europa.eu)]

Log Scale!



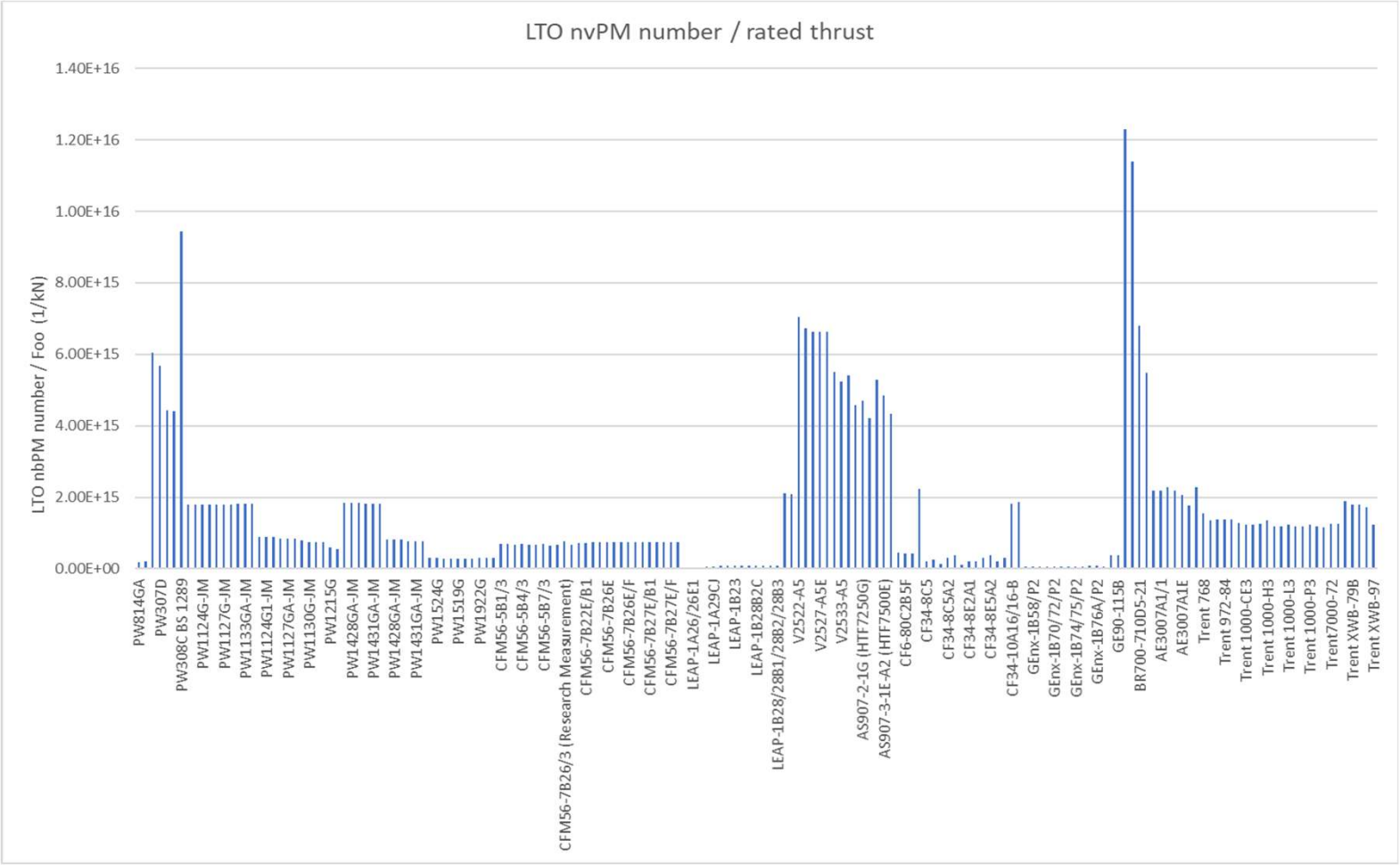
Regulatory Limits from 1st January 2023 (nvPM number)



Note: Current in-production engines have not been designed for low nvPM number emissions.

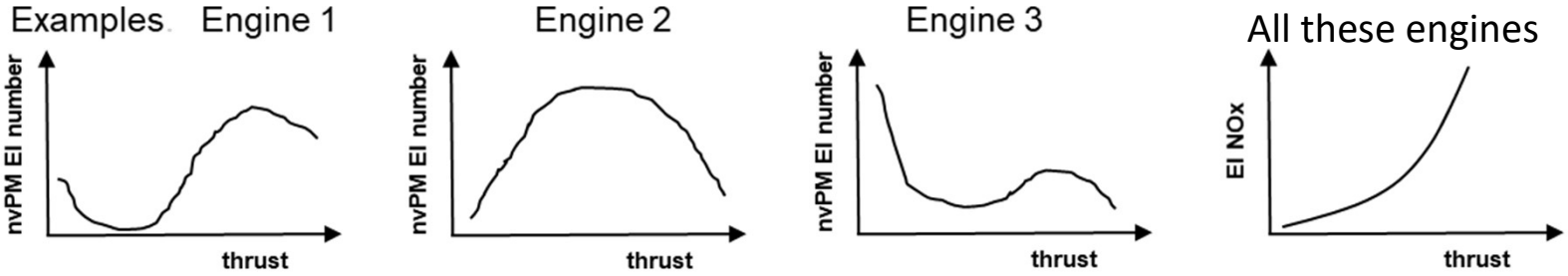
Emissions Certification Data (nvPM number)

Note: Publicly available: [Environmental Research - Engine Emissions | EASA (europa.eu)]



Special Challenges for Combustion Technology

- Especially nvPM number is not well behaved compared to e.g. NOx



- Engine manufacturers are learning to understand this
- Some reduction strategies have trade-offs with other pollutants
- Lean burn combustion technology can address both NOx and nvPM
  (Currently two engine types in daily aircraft operation worldwide)
- Technologies are not scalable to full range of engine sizes

Thank you for your attention – Questions?