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Aircraft Gas Turbine Particle Emissions in Cruise

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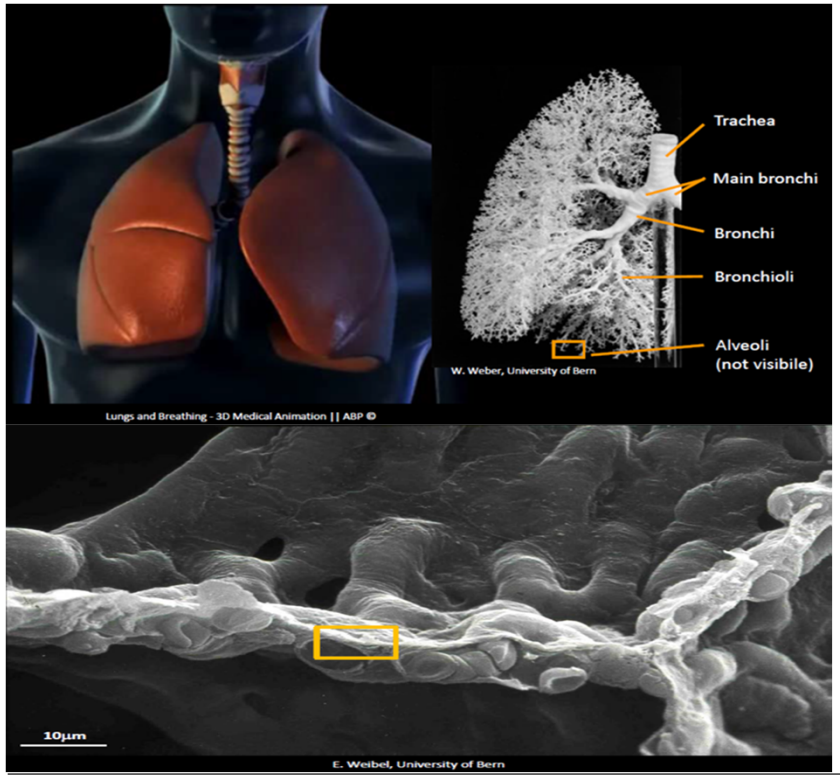
Overview

- Recap: Ultrafine particle regulation in aviation
- Nanoparticle emissions in «cruise»
- Control of nanoparticle emissions in «cruise»
- Conclusions for future work

nvPM ICAO standards prove successful

nvPM = non-volatile particle matter, «**ultrafine soot**»

Precaution for Health impact



Precaution for Climate impact

Around 10 years ago, anticipation that particle number emissions could play a role in contrail cirrus and aviation induced cloudiness

Recap: Ultrafine particle regulation in aviation

- All relevant in-production turbofan engines are characterised by nvPM emission factors at 7, 30, 85 and 100% static thrust.
- Weighted sum of nvPM mass and nvPM number of the four thrust points is regulated.
- The metric is related to local air quality:
- 7% thrust → airport taxi operations
- 100% thrust → max. take-off condition
- 85% thrust → climb out condition
- 30% thrust → approach condition
- Aviation = The only sector with **global** standards for nvPM **number** to control ultrafine particles

Recap: Ultrafine particle regulation in aviation

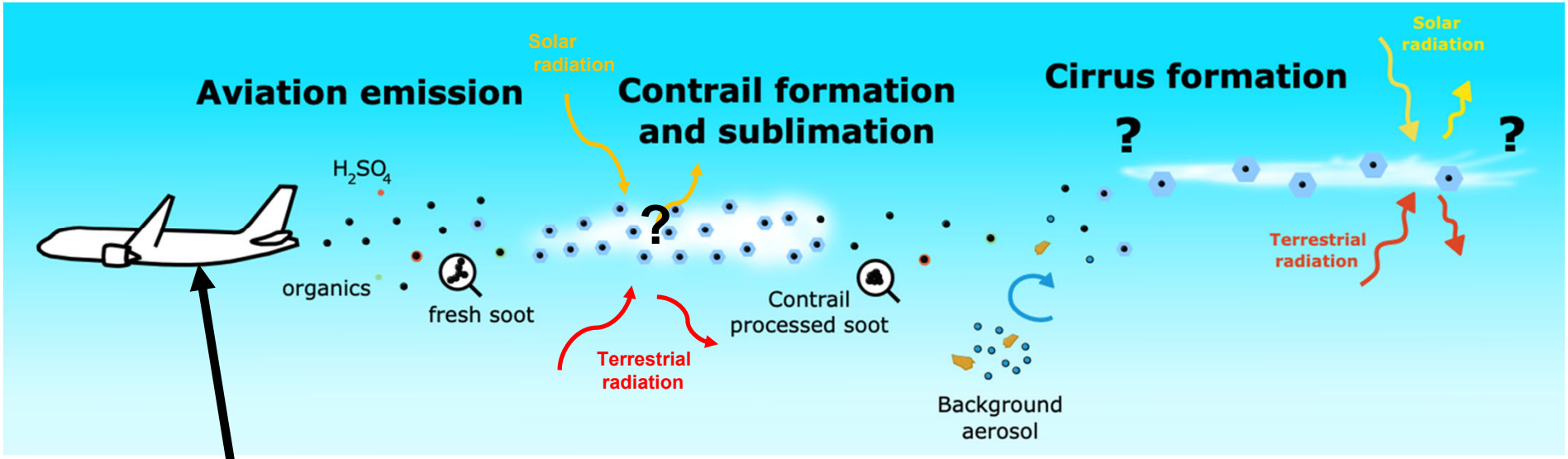
- Dealing with particle losses in measurement systems: Standardisation of systems to generate certification values plus estimated loss correction for environmental impact assessments.
- Certification values publicly available:
- ICAO Aircraft Engine Emissions Databank | EASA (europa.eu)
- Current engines have **not** been deliberately designed for low nvPM number emissions

→ huge differences «by chance»

→ **engine manufacturers learn now how to control nvPM**

- **Substantial reduction of nvPM also by sustainable aviation fuel (higher hydrogen content)**

Nanoparticle Emissions in Cruise



First of all get the **emissions** right and control them!

Warming **and** cooling **impacts**
In **combination** with ambient air conditions

Global estimations with **high uncertainty** on warming **and** cooling
Single flight estimation not currently possible

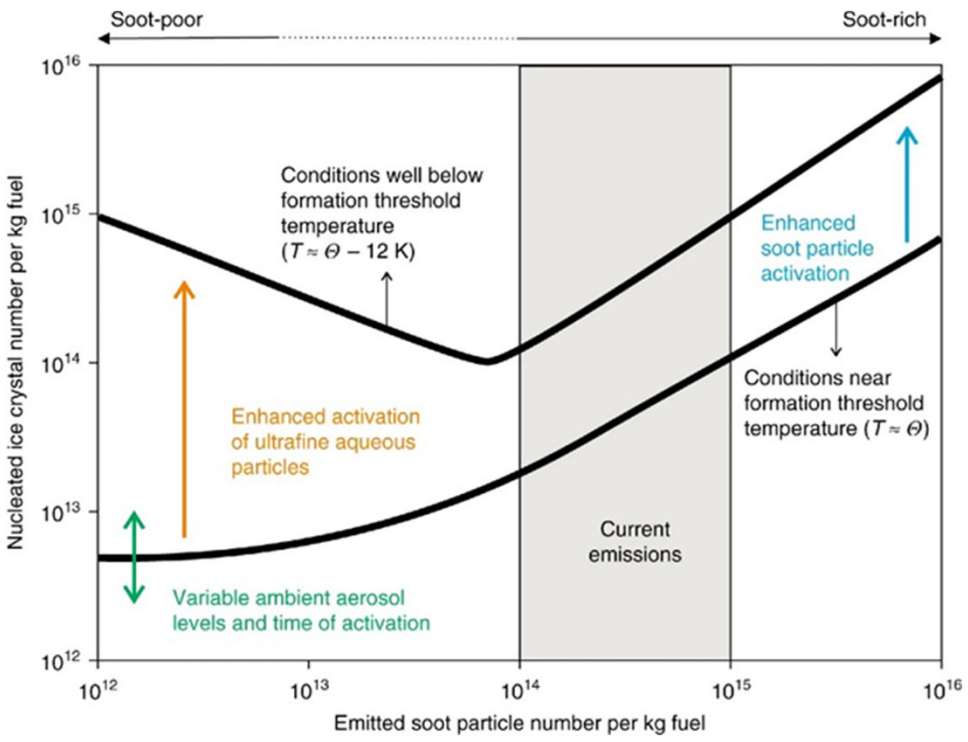
Left out, even lower confidence

Adapted from Source: Testa et al. (2024) *EGUSphere*

Nanoparticle Emissions in Cruise

Source: VOLCAN = Compatibilité et Vol Carburants Alternatifs Nouveaux

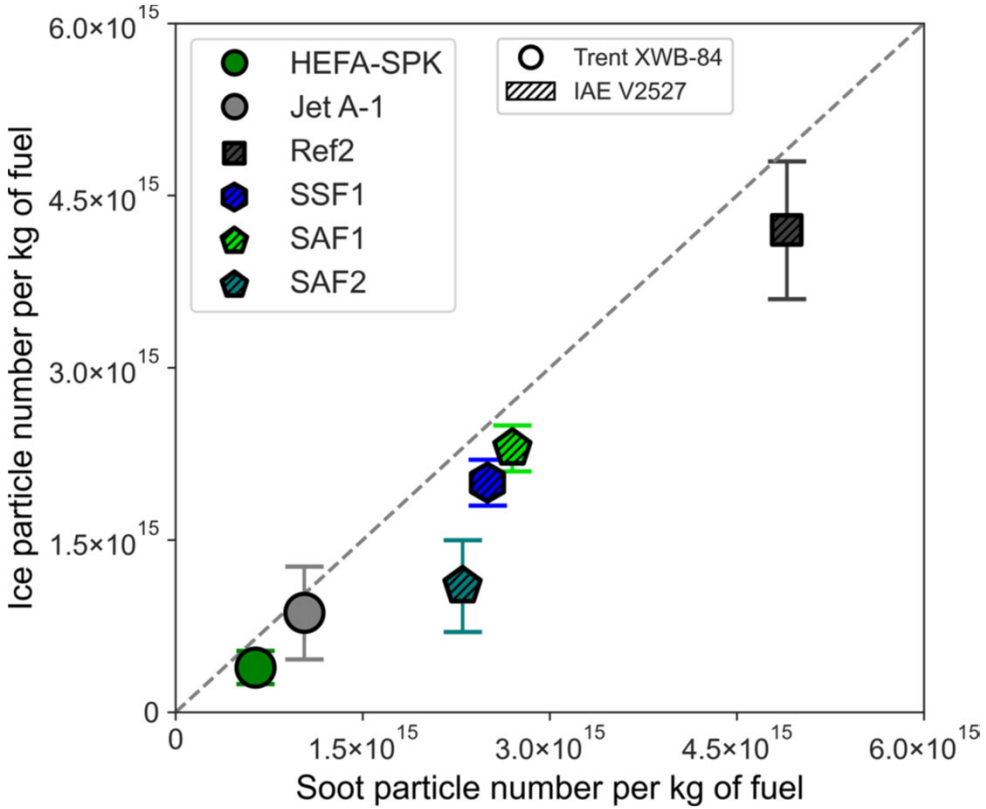
Nanoparticle Emissions in Cruise



- Measurement observations
- The formation of contrail cirrus is currently driven by soot emissions and ice supersaturated regions - the radiation effect varies strongly by location, altitude and time.
- Reduction of nvPM number from 10^{15} to 10^{14} / kg fuel reduces the number of ice crystals, reduces the life-time of contrails and makes them more transparent for heat radiation → desired effect
- For very low soot emissions, current results on one particular engine show that ice crystals can still be formed in similar numbers. **Hypotheses**: Role of Sulfur in the fuel plus the tested engine emits volatile particles through design of the **oil** vent from lubrication system.

Source: Burkhardt et al. (2018) *npj Climate and Atmospheric Science*
Source: Kärcher (2018) *Nature Communications*

Nanoparticle Emissions in Cruise

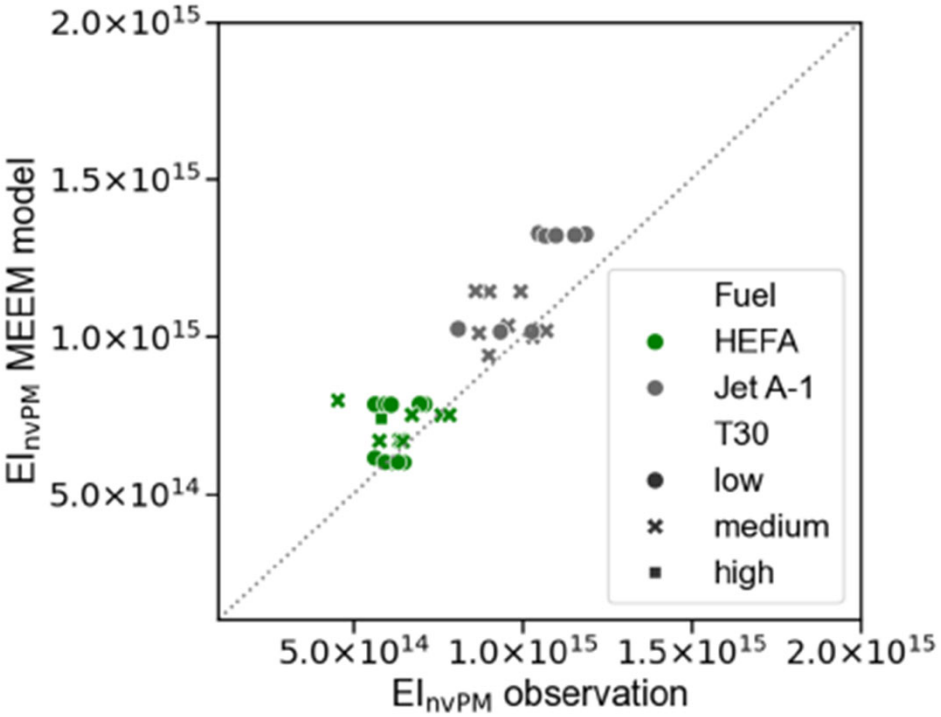


Apparent ice emission indices versus nvPM emission indices for Jet A-1 and HEFA-SPK fuel from the ECLIF3 campaign using a Rolls-Royce Trent XWB-84 engine (circles) compared to fuels investigated during ECLIF1 and ECLIF2/NDMAX (Ref2, SSF1, SAF1,SAF2) using an IAE V2527 engine (hatched symbols) (Voigt et al., 2021).

The symbols represent means of the respective quantities in order to facilitate comparability between ECLIF1, ECLIF2/NDMAX, and ECLIF3 data. The dashed line shows the ideal 1 to 1 relationship between the AEI and nvPM EI.

R. S. Märkl et al.: Powering aircraft with 100% SAF reduces ice crystals in contrails, https://doi.org/10.5194/acp-24-3813-2024

Nanoparticle Emissions in Cruise



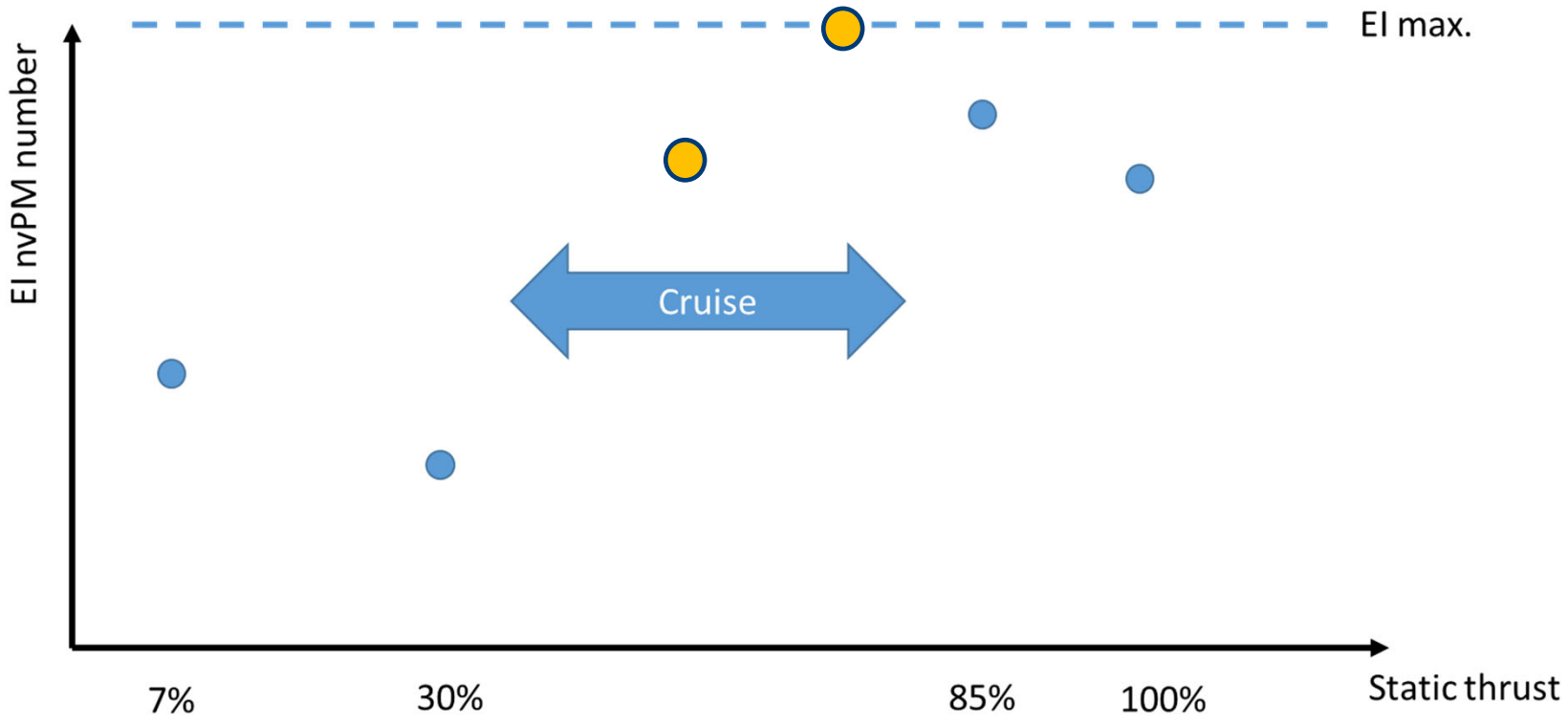
- Prediction of nvPM number from ground measurement compared to in-flight measurement, using MEEM
- MEEM = nvPM Mission Emissions Estimation Methodology
- ASME publication:
- D. Ahrens et al. 2023, https://doi.org/10.1115/1.4055477
- Simplified version based on fuel flow method underway

R. Dischl et al.: Measurements of particle emissions of an A350-941 burning 100% sustainable aviation fuels in cruise, https://doi.org/10.5194/egusphere-2024-1224

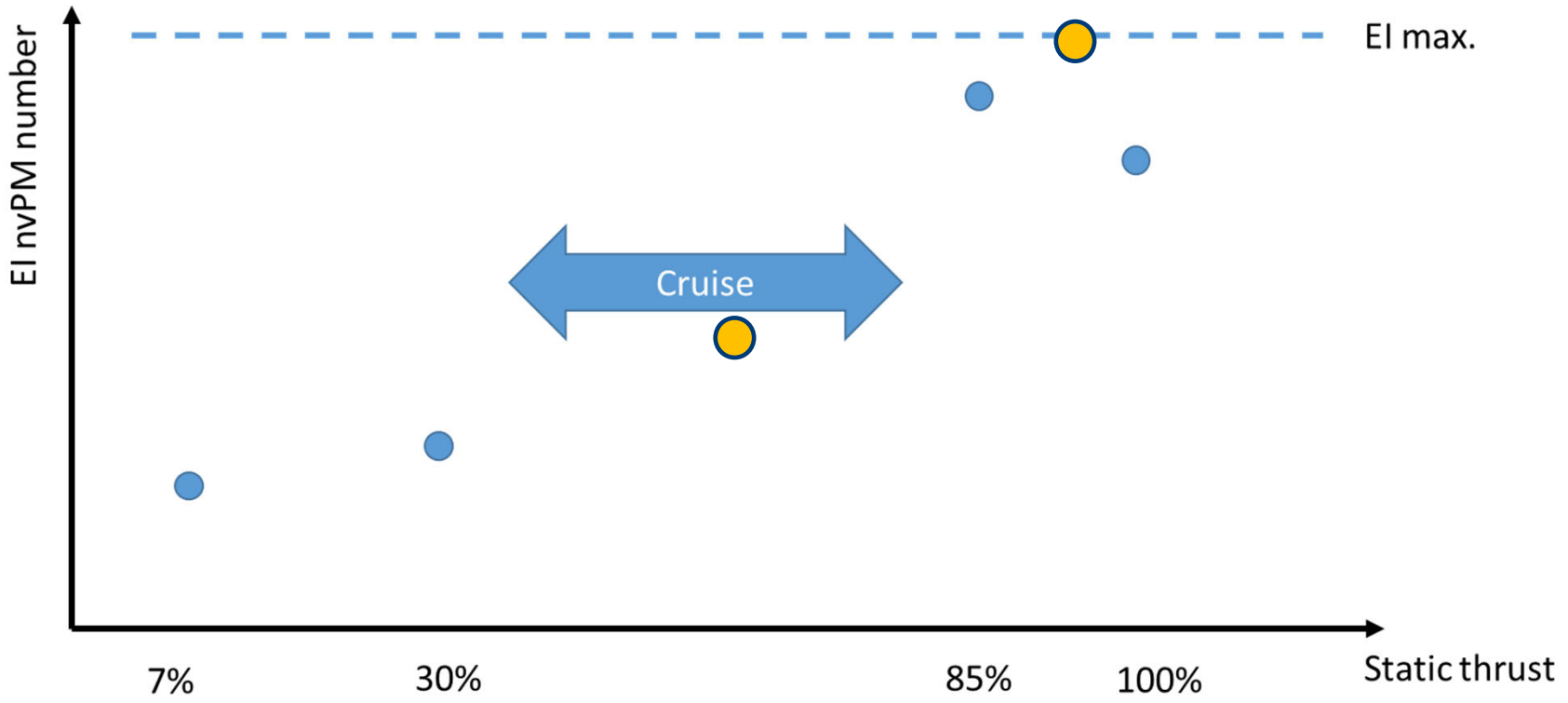
Control of Nanoparticle Emissions in Cruise

- Whereas for NOx, emission factors are generally increasing from idle to take-off and the highest EI NOx is always at take-off, this is not the case for nvPM in current engines. nvPM varies widely depending on engine design.
- For nvPM mass, the maximum emission factor can occur anywhere between around 30% and 100% thrust.
- For nvPM number, the maximum emission factor can occur anywhere between idle and 100% thrust.
- The emission characteristic (emission factor curve) between 30 and 85% LTO thrust points can vary in a wide range – not controlled by the LTO points. As this is relevant for cruise operation, there is a gap in the data.
- **ICAO Emissions technical group found a solution:**
- **Include an nvPM mass and number reporting point for 57.5% thrust**
- **Include % thrust, at which the maximum nvPM mass and number occur**

How the additional nvPM reporting works



How the additional nvPM reporting works



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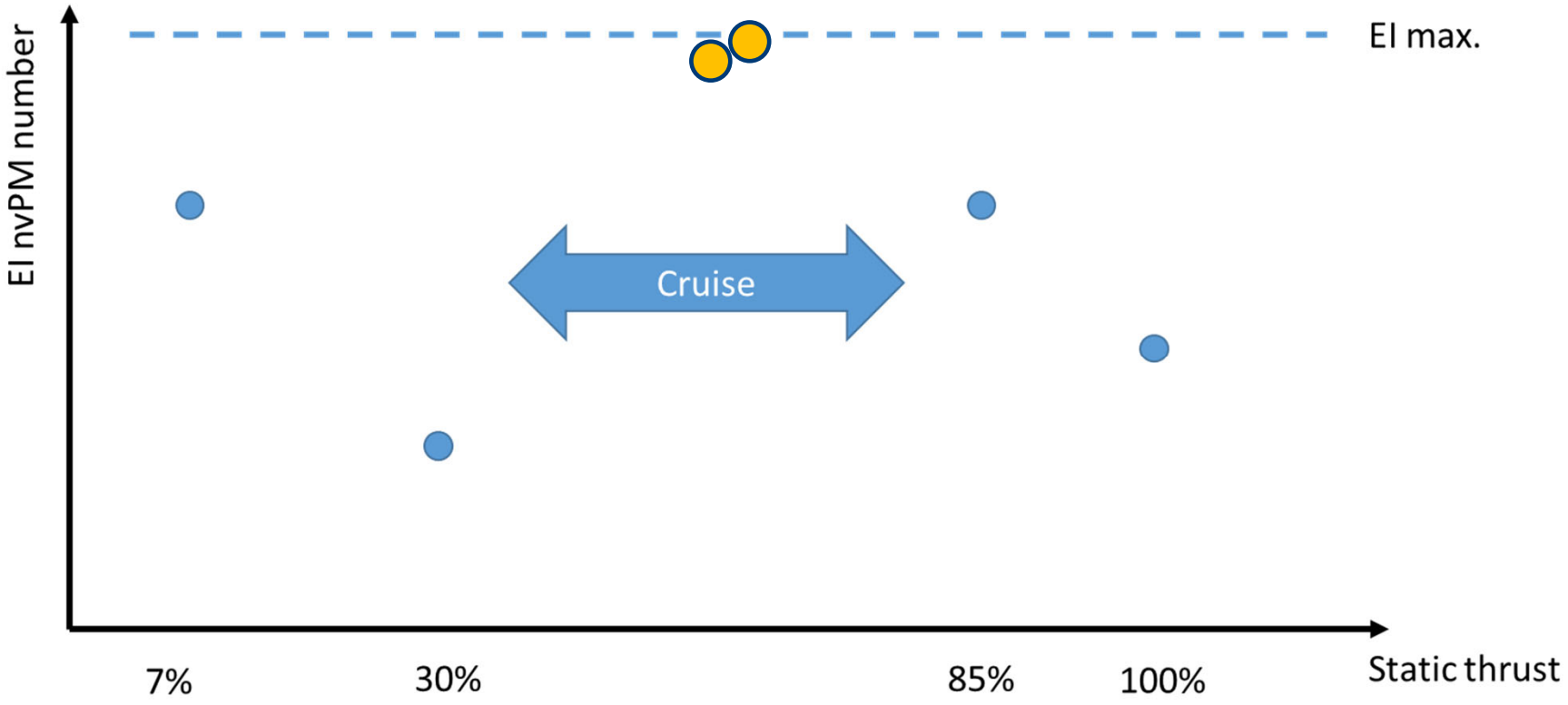

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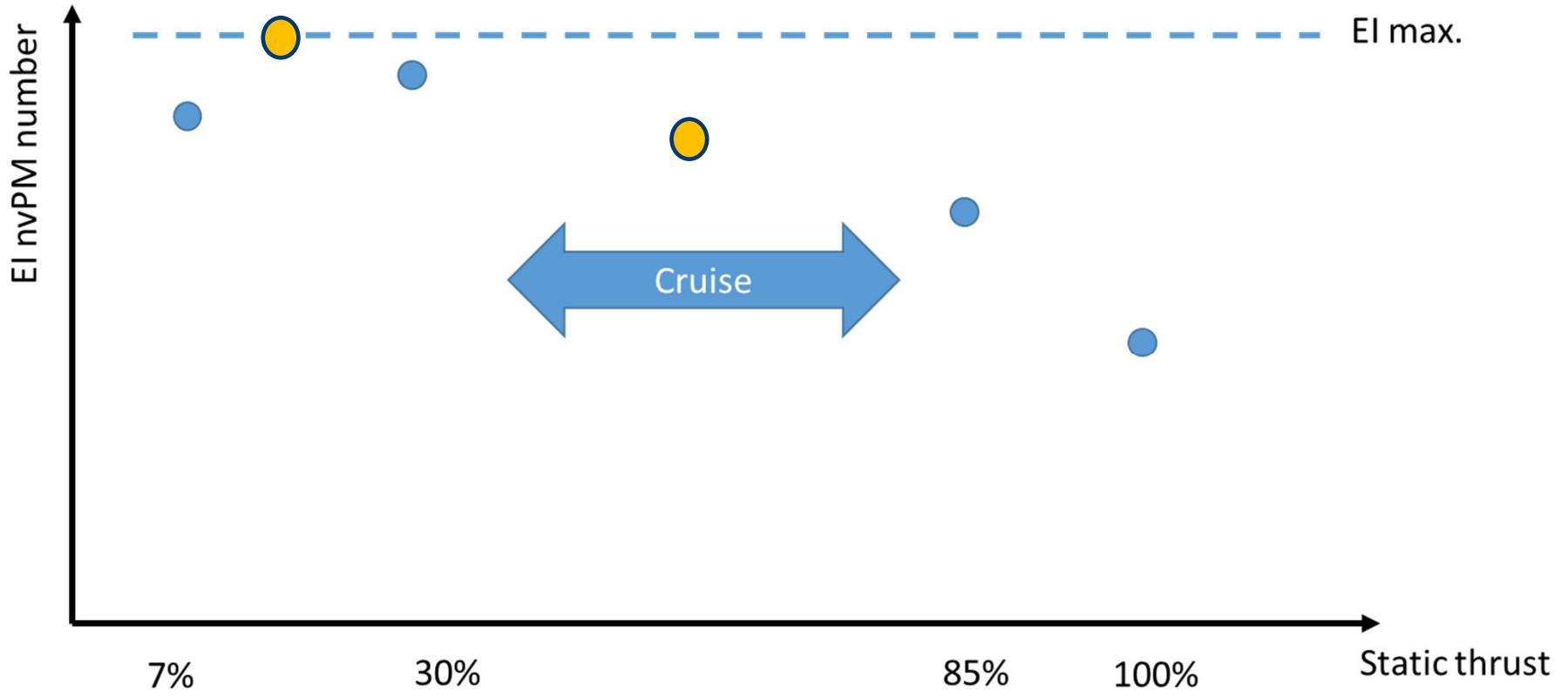

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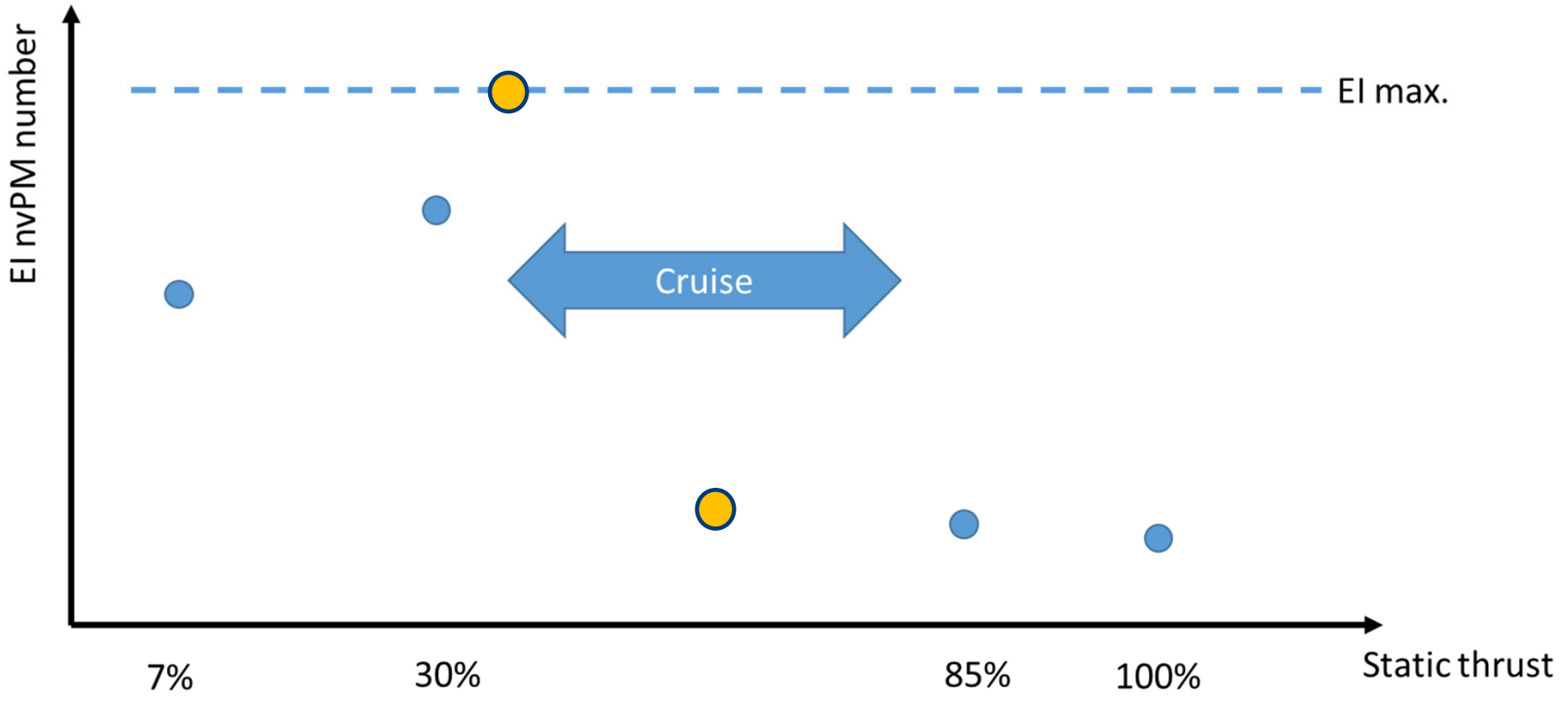

Conclusions for future work

- Include additional nvPM reporting requirements (57.5% reporting point and % thrust for max. nvPM emission factors) into the ICAO Engine emission standards for publication in the next amendment
- Continue work on improvement of nvPM measurement system for certification
- Reduce nvPM measurement uncertainties
- Investigate introduction of particle size measurement, which would be necessary for more robust particle loss correction
- Investigate introduction of particle loss correction for certification

Questions / Comments?