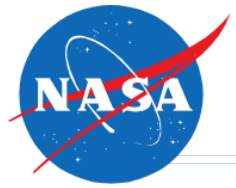




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When do contrails form and persist?

Contrails form when the cooling engine exhaust plume becomes supersaturated with respect to liquid water ($RH_{\text{water}} > 100\%$), which is often referred to as the Schmidt-Appleman Criterion.

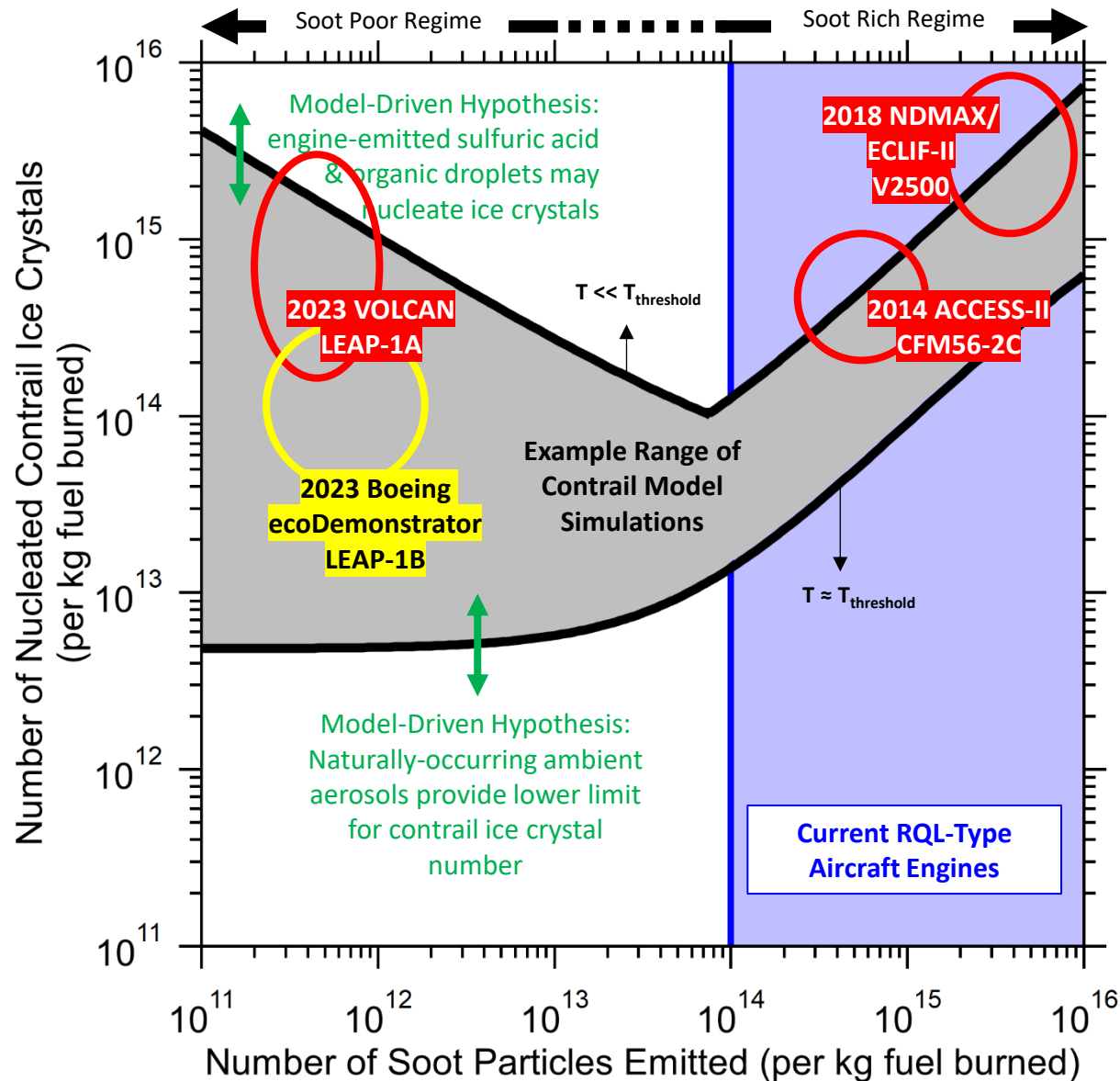
Depends on:

- Atmospheric temperature, pressure, and relative humidity
- Fuel properties (hydrogen content and heat of combustion)
- Engine propulsion efficiency

Contrails persist when the surrounding atmosphere is supersaturated with respect to ice ($RH_{\text{ice}} > 100\%$).

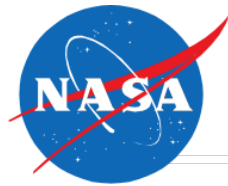
Particle Emissions Impact Initial, Near-Field Contrail Properties

Photo from 2023 NASA Boeing ecoDemonstrator SAF Emissions Flight Test
Credit: NASA / Andy Barry

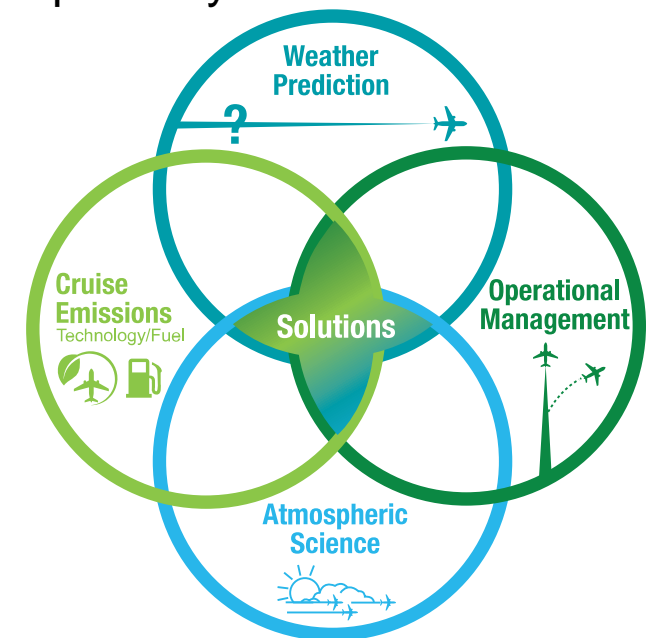


Left figure adapted from Kärcher, *Nature Communications*, 2018. Red circles show the approximate Number EIs observed during the 2014 ACCESS-II, 2018 ND-MAX/ECLIF-II, and 2023 VOLCAN. Yellow circle is 2023 Boeing ecoDemonstrator flight test series. Moore et al., *Nature*, 2017; Voigt et al., *Nature Comms. Earth & Environ.*, 2021.

Where are the gaps?



- **Upper tropospheric water vapor and temperature meteorological fields are uncertain**
 - Satellite infrared sounders launching soon in Europe/Asia, expected in the US GeoXO in the 2030s
 - Development/deployment of water vapor sensors on commercial aircraft alongside existing temperature probes
- **Aircraft engine emissions and contrail ice properties vary across aircraft/engine families and fuels**
 - Limited observational data at cruise conditions to inform technology/fuel pathways
 - Sustainable Aviation Fuels (SAF) in rapid development, but **not all have same soot reduction benefits!**
- **Predictive models struggle** to identify which flights are the most strongly warming
 - Radiative forcing from individual flights/contrails (not global averages)
 - Limited observational data at cruise to improve predictive models
- **Trusted, science-based decision-making architecture for operational contrail management**



Thank You

