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En route to sustainable aviation: from climate science to mitigation policies

Abstract

Nicolas Jeuland, Thomas Viguier

Reducing non-CO_2 effects through aircraft emission reduction: a science of compromise

Non-CO_2 effects are estimated to account for about two thirds of aviation's effective radiative forcing, dominated by contrail cirrus and NO_2. This has led to a widespread assumption: reducing NO_2 and particle emissions, through combustion technology and fuel composition, would directly reduce these effects without penalising CO_2. This presentation examines that assumption from the perspective of engine and aircraft manufacturers.

We first show that emission reduction is constrained by physical trade-offs. NO_2 rises with overall pressure ratio, as reflected in ICAO certification limits. Lean-burn combustion reduces soot by three orders of magnitude but narrows stability margins. Higher propulsive efficiency lowers exhaust temperature and favours contrail formation. Fuel chemistry acts mainly on particles, through aromatic, naphthalene and sulphur content, but its optimisation is bounded by drop-in requirements: safety, fleet-wide compatibility, production capacity and cost.

We then review ten years of in-flight measurement campaigns conducted by Airbus and DLR with industrial (including Safran) and research partners, covering three engine generations from older rich-burn to lean-burn combustors. In the soot-rich regime, contrail ice crystal numbers scale with soot emissions. These tests have demonstrated that below about 10^{14} particles per kg of fuel, this relationship breaks down. Ice formation is then governed by volatile aerosols, whose number depends on fuel sulphur content and possibly on lubrication oil emissions.

These results show that the relative weight of technological levers is still uncertain, while aircraft and engine development cycles commit choices for decades. Further R&T is still needed in several areas:

- characterising detailed fuel chemistry effects;
- quantifying the role of oil and sulphur;
- establishing metrology for volatile particles;
- integrating these mechanisms into contrail and climate models, as a basis for both technology decisions and operational contrail avoidance.