Aircraft condensation trails: facts and figures

- We must distinguish between **contrail formation** and **contrail persistence**.
- Contrail formation is similar to breathing in cold air where the moisture in the warm breathing air condenses while it mixes with sufficiently cold ambient air. For contrails to form it needs **ambient temperatures below about −40°C**, temperatures that are typical for cruise levels. First, tiny water droplets form by condensation. Within tenths of a second they freeze, forming an ice contrail.
- Contrail formation needs particles that serve as **condensation nuclei**. Such particles are present in the exhaust (soot and volatile aerosol) in very large numbers, and also present in the ambient air, in smaller but still large numbers.
- Contrails can form even in dry ambient air, because the necessary **water vapour for condensation is produced by burning the fuel** and contained in the engine exhaust gas. However, contrails will not survive a few minutes if the ambient air is too dry.
- Contrails can **persist only if the ambient air is in a state of ice-supersaturation**, a state where ice crystals grow by consumption of ambient water vapour. About 15% of cruise level flight time is in ice-supersaturated air.
- Most ice contained in a persistent contrail comes from ambient air humidity. **Only persistent contrails contribute to climate effects** (heating by absorbing infrared radiation or cooling by reflecting sunlight). Avoiding ice-supersaturated regions avoids the formation of persistent contrails and is a good mitigation option.
- Persistent contrails have an **average lifetime of 2-3 hours**, but much longer lifetimes (exceeding 17 hrs) have been observed occasionally.
- A single contrail's climate impact depends on its microphysical and optical properties, but dominantly on the ambient situation. This offers a **large potential for mitigation** if flight in regions and times where a large climate effect can be predicted are avoided.
- Lowering of the ice crystal concentration, for instance by use of alternative fuels and/or lean combustion, leads to weaker effects on solar and terrestrial radiation (weaker greenhouse forcing) and it can lead to faster contrail decay.

Demonstration of the influence of exhaust gas temperature on contrail formation. An older B707 without contrail (right, hotter exhaust gas) alongside a modern A340 with contrail (left, cooler exhaust gas); Photo taken from the cockpit of DLR's research aircraft Falcon. (Schumann et al., J. Aircraft (2000)).

Further reading: Gierens, K., 2010: Contrails and contrail cirrus. In: Encyclopedia of Aerospace Engineering, Vol. 6. R. Blockley and W. Shyy (Eds.). John Wiley & Sons Ltd., Chichester, UK, pp. 3683-3694.