Nanoparticle and contrail ice formation in next generation aviation fuels and engines

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Currently, there is an urgent need to understand contrail formation from developmental aviation fuels (sustainable aviation fuels (SAF) and liquid hydrogen (LH2)) and lean burn combustion technologies. The value proposition of next generation aviation fuels is primarily from realizing net reduced or zero levels of CO_2 emission. The value proposition for lean burn combustion technologies includes not only higher engine efficiency, but substantially lower values of soot emission levels. There is confidence that these stated benefits can be realized. However, a substantial risk relates to the climate impact from non-CO_2 emissions – namely, an increase in contrail formation from these could substantially reduce the benefits of CO_2 mitigation. This aspect has been studied by Kärcher and Yu (2009), where they have pointed out that at orders of magnitude less soot conditions, other aerosols can contribute towards contrails, especially volatile nanoparticles formed in the plume. Up until the onset of contrail formation, the concentration and size of the volatile nanoparticles depends on the concentration of H_2SO_4 vapor (and condensable organics) in the plume, and the effects of ionization and mixing process (Yu & Turco, 1997). In a recent publication on the climate impact of aviation emissions (Lee et al., 2023), Lee has pointed out that the areas of low confidence mostly cover novel jet fuels and low soot emitting engines where there is a great need to conduct studies to better understand the formation and potential contribution of volatile nanoparticles to contrail formation.

Here we use use a detailed aerosol and contrail microphysics model (an improved version of the model used in Kärcher and Yu (2009)) to study the formation and controlling parameters of contrails observed during ECLIF (Emission and CLimate Impact of alternative Fuels) campaigns 1-3 (Voigt et al., 2021 and Markl et al., 2023). The model can overall capture the dependence of ice number concentrations on soot emission index, as observed during ECLIF1-3 for aircrafts running on jet-A, jet-A and SAF blended, and 100% SAF. We find that the activation of soot particles during contrail formation is likely determined by the sizes of primary soot particles rather than the effective sizes of aggregates assumed in previous studies of soot activation calculation. The smaller sizes of primary soot particles (compared to the measured aggregates sizes) delay starting time of contrail formation and increase the maximum supersaturation reached in the contrail and thus increase the probability of small volatile nanoparticles to be activated into contrail particles. Conditions favor the formation of volatile nanoparticles and their contributions to contrail ice formation in next generation gas turbine engine fuels and engines will be discussed.

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