Secondary organic aerosol formation from aircraft turbine engine exhaust

D. Kilic[1], R.-J. Huang[1], B. Brem[2], L. Durdina[2], I. El Haddad[1], F. Klein[1], A. Lavi[3], S. Pieber[1], T. Rindlisbacher[4], Y. Rudich[3], J. Wang[2], J. G. Slowik[1], U. Baltensperger[1], and A. S. H. Prévôt[1]

[1]Laboratory of Atmospheric Chemistry, Paul Scherrer Institute, Villigen PSI, 5400, Switzerland
[2]Laboratory for Advanced Analytical Technologies, Empa, Dübendorf, 8600, Switzerland
[3]Department of Earth and Planetary Sciences, Weizmann Institute of Science, 76100, Rehovot, Israel
[4]Federal Office of Civil Aviation, Bern, 3003, Switzerland
Keywords: Secondary organic aerosol, aircraft exhaust, aromatics, emission factors
Presenting author email: jay.slowik@psi.ch

Aircraft engine emissions include both primary organic aerosol (POA) and organic gases which can react in the atmosphere to produce secondary organic aerosol (SOA). These emissions include compounds known or suspected to cause adverse health effects. While it is thus possible that airports may adversely affect local air quality, such an assessment requires detailed characterization of the primary and secondary emissions. In particular, quantitative investigation of aircraft SOA and its dependence on engine operating conditions has received attention, though prior studies suggest efficient SOA formation (Miracolo et al, 2011). The atmospheric importance of aircraft SOA is thus poorly constrained.

We present measurements of non-methane organic gases (NMOGs), POA, and SOA from 7 aircraft engine models operated under thrust settings representative of idling, taxiing, approach, climb, and take-off. Experiments were conducted at the SR Technics engine test facility at the Zurich International Airport. Particle composition was measured by an Aerodyne high-resolution time-of-flight aerosol mass spectrometer (HR-ToF-AMS), while the NMOGs were characterized by a proton transfer reaction time-of-flight mass spectrometer (PTR-ToF-MS). SOA was produced by oxidation of engine emissions in a potential aerosol mass (PAM) flow tube, which utilizes higher-than-ambient OH concentrations to simulate days of atmospheric aging on the timescales of minutes. In the present experiments, the integrated OH exposures (OH concentration x time) were varied, with the studied range corresponding to approximately 10 to 80 hours of atmospheric aging.

Rapid SOA formation was observed, with significant production even at the lowest studied OH exposures. The rate of SOA production slowed significantly after approximately 20-30 hour-equivalents, enabling estimation of the maximum SOA potential from each engine condition.

The SOA production potential increased with decreasing thrust, ranging from 5 mg / kg fuel at 85-90% thrust up to 100 mg / kg fuel at 2.5-5% thrust. For comparison, Euro 5 light-duty diesel vehicles (LDV) produce approximately 40 mg / kg fuel, while older LDV produce on the order of 150-200 mg / kg fuel (Platt et al, 2014). Aircraft SOA production results in SOA/POA ratios ranging from approximately 2 (85-90% thrust) to 200 (2.5-5% thrust), indicating that total aircraft OA emissions are dominated by SOA.

Oxidation in the PAM decreases NMOG concentrations. By combining the reacted mass of individual NMOGs with their known SOA yields, one can estimate the amount of SOA formed due to the reaction of each NMOG. A sample calculation for an engine at idle is shown in Fig. 1. Here we show the amount of SOA predicted to be formed from the reaction of each individual aromatic species. The figure indicates that >80% of the SOA mass can be explained by aromatic precursors, with approximately 50% explained by benzene derivatives alone. The SOA fraction explained by aromatics decreases to 50% at 85-90% thrust. However, given the greatly increased emissions at idle thrust, it is clear that aromatics play a dominant role in SOA formation from aircraft exhaust.
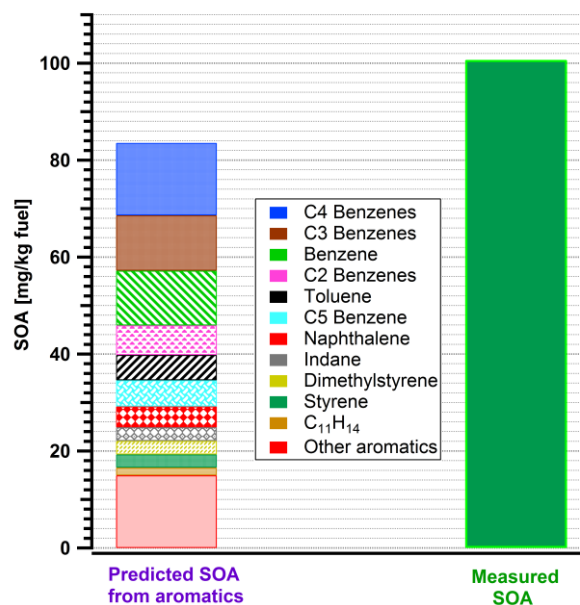

Figure 1. Comparison between the measured SOA and that predicted from the reaction of aromatic precursors, with the engine operated at 3.5-5% thrust.

Miracolo et al. (2010) *Atmos. Chem. Phys.* **11**, 4135-4147.
Platt et al. (2014) *Nature Communications* **5**, 3749.