Mobile test rig for field measurement of small jet engine particle emissions

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The Czech Republic has a long tradition in the production of small sports airplanes and gliders and holds a global lead in the number of aircrafts produced per capita. Jet engines, with high thrust to weight ratio and high energy density of liquid fuels, are popular prime movers not only for large, but increasingly also for smaller airplanes. They are also a significant contributor to both health and climate relevant air pollution. To decrease emissions of carbonaceous particles, probably the component most hazardous to human health, with black carbon having also substantial positive radiation forcing effect, the International Civil Aviation Organization (ICAO) standards call for measurement of total mass and number of non-volatile particles on engines with thrust over 22.7 kN, while older filter based smoke number is still used for smaller engines. Unlike with ground vehicle piston engines, the concentrations of pollutants of a jet engine vary across the cross-section of the plume, requiring the coverage of multiple sampling points. **This work describes an innovative mobile test rig for measurement of exhaust emissions from small jet engines in the field, with the test being performed on a stationary aircraft.**

The airplane is secured against a movement in a suitable outdoor location. A sample nozzle (here a 8 mm stainless steel tube) is placed facing into the main jet outlet at a distance of less than its radius, and secured to a stand allowing for probe positioning along vertical and horizontal axes. At a suitable distance from the jet exit plane, the probe transitions to a heated (165°C) sampling line leading to the test rig placed in a tent or in a nearby building. The exhaust sample is split between FTIR analyzer (5 m optical path length, 0.5 cm^{-1} spectral resolution, 5 Hz sampling rate, all gaseous compounds incl. CO_2, CO, formaldehyde, NO, NO_2, NH_3, N_2O, CH_4), a non-volatile particle counting system (NanoMet3, Testo), and a heated ejector diluter (8:1 dil. ratio), feeding, in parallel, into 47 mm quartz filters for thermogravimetric (EC-OC) analysis, glass fiber filters for gravimetry and smoke number, photoacoustic soot analyzer (Microsoot sensor, AVL) for non-volatile particle mass, and fast electric mobility particle sizer (Engine Exhaust Particle Sizer, TSI). At each engine trust level, the exhaust is sampled for approx. 260 s, traversing 21 sample points covering the exit plume, starting and ending at the center point, at 10 s per point plus 2 s transition. This allows for discrete online measurement at multiple sampling points as well as providing a representative sample for smoke number measurement. The result of the EC-OC analysis can later be used to calibrate the photoacoustic black soot measurement. At five minutes per thrust setting, four thrust levels, and three repetitions of the sequence, a total of one hour of tests, less than 2 engine hours are required, and the entire test can be performed in one day.

This approach is demonstrated on a type approval grade test (per European Union Aviation Safety Agency) of an auxiliary TJ42 jet engine with < 10 cm nozzle diameter and hundreds of N rated thrust installed in a G 304JS sailplane (https://hph.cz/products/hph-304s-shark/) with a wingspan of 18 m with an aspect ratio of 27. This measurement has posed an additional challenge: The lubrication of the engine with oil mixed with the fuel has resulted in most of the particulate matter measured being uncombusted lubricating oil, while the emissions of non-volatile particles, both by number and mass, were very low.