Particle Emissions from Aircraft Gas Turbines: A Coarse Size Mode from Low Emission Engines

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This presentation is about coarse particle emissions from a commercial aircraft gas turbine engine. These particles were found in a series of test campaigns focused on understanding and improving methodology for measuring non-volatile particles from these engines. Measuring or even finding coarse particles was unexpected. Before describing these measurements, some background is useful.

Motor vehicle engine exhaust particle size distributions typically show three distinct modes: a nucleation mode between about 3 and 30 nm diameter consisting mainly of semi-volatile material, an accumulation mode between about 30 and 300 nm diameter consisting mainly of carbonaceous aggregates, and a coarse mode consisting of larger mechanically generated particles – from oil atomization and re-entrainment from in-cylinder and exhaust surfaces.

Measurement of particles from commercial aircraft gas turbine engines is much more challenging than from ground-based vehicles with exhaust temperatures as high as 900 C or more and exhaust velocities approaching Mach 1. This necessitates the use of very long sampling lines that complicate particle measurements. These lines tend to adsorb much of the semi-volatile material and suppress the formation of a nucleation mode. The carbonaceous aggregates in the accumulation mode are much smaller than from typical piston engines with geometric mean diameters in the 15 to 50 nm range. Coarse mode particles are also smaller and here we define them as particles larger than 150 nm.

The results reported here were observed during a series of measurement campaigns conducted by the U. S. Environmental Protection Agency in collaboration with the U. S. Air Force's Arnold Engineering Development Complex. The main purpose of these campaigns was to refine methodology for measurement of non-volatile particles from aircraft engines. A General Electric J-85 turbojet running with a range of test conditions and fuels was used as the particle source. Particle size and concentration measurements were made using a range of instruments. The focus of these studies was measurement of accumulation mode soot aggregates. Compared to piston engines there is less opportunity for the exhaust to interact with surfaces and there are no piston rings to atomize oil so coarse particles were not expected to be an issue.

Coarse particle size measurements were made using a range of instruments. Four measurement campaigns were conducted. In the first, a pair of TSI SMPSs operating in the sizing range of 8 to 300 nm were used. In the second, SMPSs in the 6 to 225 nm range were used. In the third, SMPSs were still operated in the 6 to 225 nm range but a TSI EEPS that operated in the 6 to 500 nm range was added. In the fourth and final study, three SMPSs were operated in the 6 to 225 nm range, and a fourth in the 15 to 690 nm range. The TSI EEPS was again used in the 6 to 500 nm range and a Cambustion DMS500 operating in the 5 to 1000 nm range was added.

The significance of the course mode was not noticed until the fourth campaign when volume fractions, (V above 150 nm)/Vtotal, V150/V) of nearly 50% were observed in some tests. After that, all test campaigns were reexamined. In most case, V150/V varied inversely with engine load and total volume (mass) emissions. Biofuels, hydrotreated camelina oil blends with Jet-A generally produced higher V150/V.

Test results will be presented, and possible sources and formation mechanisms will be discussed.