Measurements of Aircraft Engine Soot Emissions Using a CAPS PM_{ssa} Monitor During the VARIAnT2 Campaign

Timothy Onasch [1], Kevin Thomson [2], Lindsay Renbaum-Wolff [1], Richard Miake-Lye [1], Greg Smallwood [2] and Andrew Freedman [1]

[1]Aerodyne Research, Inc.,Billerica, MA 01821 USA
[2]Measurement Science and Standards, National Research Council Canada, Ottawa, K1A 0R6, Canada
Keywords: soot, aircraft engine, mass absorption coefficient.
Presenting author email: Kevin.Thomson@nrc-cnrc.gc.ca

We present results of aircraft engine soot emissions measurements during the VARIAnT2 campaign using two different CAPS PM_{ssa} monitors. VARIAnT2, an aircraft engine non-volatile particulate matter (nvPM) emissions field campaign, was focused on understanding the variability in nvPM mass measurements using different measurement techniques and accounting for possible nvPM sampling system losses.

The CAPS PM_{ssa} monitor, shown in Fig.1, measures both the optical extinction and scattering (and thus single scattering albedo and absorption) of an extracted sample using the same sample volume for both measurements with a time resolution of 1 second and sensitivity of better than 1 Mm^{-1}.[1] Briefly, particle optical extinction is measured using the cavity attenuated phase shift technique, which is an analog of the cavity ringdown technique. The square wave modulated output of a 630 or 660 nm LED is directed into a near-confocal optical cavity comprising two high reflectivity (R~0.9999) mirrors and then detected using a vacuum diode. The highly distorted waveform is then characterized as a phase shift from the initial square wave; the difference in the cotangent of the phase shift measured with and without the presence of particles in the optical cavity is directly proportional (within a known constant) to the total optical extinction.

The CAPS PM_{ssa} monitor also incorporates an integrating sphere within the measurement cell, thus providing a simultaneous measurement of scattered light on the same sample volume using integrating nephelometry. The scattering channel is calibrated versus the extinction channel allowing the SSA to be measured with ±0.01. Absorption is obtained by subtracting the scattering signal from the total extinction. Given that the single scattering albedo (SSA) of the particulates emitted from the aircraft engine measured at both 630 and 660 nm was on the order of 0.1, any inaccuracy in the scattering measurement has little impact on the accuracy of the determined absorption coefficient. The absorption is converted into nvPM mass using a documented mass absorption coefficient (MAC) of 6.5 m^2 g^{-1} at 630 nm and 6.2 m^2 g^{-1} at 660 nm determined using a 1/λ extrapolation. [2]

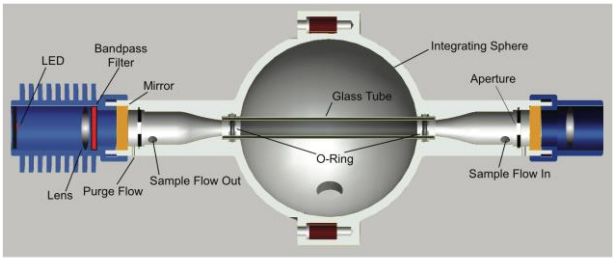

Fig. 1 Schematic of CAPS PMssa Monitor

A correlation plot of the soot concentrations (μg m^{-3}) measured by the instruments operating at 630 nm and 660 nm is shown below in Fig.2 ; each monitor was attached to a different sampling line. Note the excellent agreement between the two monitors even at extremely low soot concentrations. The two monitors also showed excellent agreement with concentrations determined using a Sunset Laboratories EC/OC (Elemental Carbon/Organic Carbon) Analyzer.

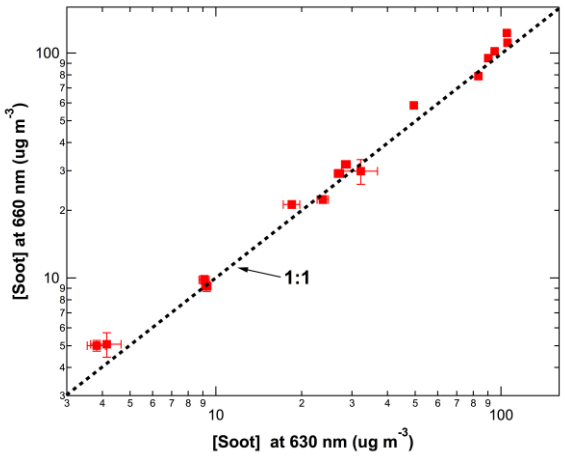

Fig. 2 Correlation plot of concentrations emitted by a jet engine measured using two different CAPS PMssa monitors attached to two different sampling lines.

Aerodyne's participation in the VARIAnT2 campaign was sponsored by funding from Arnold Engineering Development Center of the U.S. Air Force. NRC Canada was funded by Transport Canada under the Clean Transportation Initiative.

[1] Onasch, T.B., et al. (2015) *Aerosol Sci. Technol.* 49:267-278
[2] Petzold, A., Kramer, H., and Schönlinner, M. (2002) *Environ. Sci. Poll. Res.* 4:78–82.