Dependence of Aircraft Smoke Number on Black Carbon Size Distribution

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Current methods used to estimate aircraft black carbon (BC) emissions for the purposes of air quality and climate impact studies rely on an outdated correlation and underestimate by a factor of 2-3. In this study, we show that the correlation between the BC mass concentration and smoke number is strongly dependent on the geometric mean of the particle size distribution. To test the correlation a new method to produce BC particles with a variable geometric mean diameter on the range 20-60 nm is employed to simulate BC particles emitted by aircraft gas turbine engines.

Aircraft engine exhaust is currently regulated on the basis of a filter smoke number (SN) – the observed change in reflectance of the filter after sampling a specified mass of exhaust. Estimates of aircraft BC emissions rely on an empirical correlation between SN and BC mass concentration (C_{BC}) derived using BC particles with geometric mean diameter (GMD) between 80-100 nm (Girling et al., 1990). Recent measurements of BC particles in aircraft exhaust have shown that aircraft soot can be characterized as having lognormal particle size distribution with a GMD between 20-40 nm (Kinsey et al., 2010).

A co-flow inverse diffusion flame provides a steady source of BC particles with variable GMD in the range 20-60 nm and geometric standard deviation between 1.5-1.7. The particle size distribution is characterised with a Scanning Mobility Particle Sizer (SMPS) and particle mass as a function of mobility diameter (d_m) is measured using a Centrifugal Particle Mass Analyser. Calculated BC mass concentrations are verified with gravimetric analysis. SN measurements are taken according to the standard aircraft test procedure (SAE, 1997). Correlations between SN and BC concentration are derived for 20, 30 and 60 nm GMD. Filtration efficiency of the specified SN filter as a function of d_m is measured.

In Fig. 1, the particle mass distributions for GMD~20 nm, GMD~30 nm and GMD~60 nm are superimposed on the filtration efficiency, indicating that filtration efficiency increases with d_m such that a smaller proportion of the BC mass is collected on the filter for a smaller GMD.

In Fig. 2 the correlation between SN and BC mass concentration is shown to be a function of d_m – for a smaller GMD a greater C_{BC} is required to produce the same SN, suggesting that current estimates underestimate aircraft BC mass emissions by up to a factor 2-3. These revised correlations improve estimates of aircraft BC emissions compared to measurements but do not account for uncertainty in the regulatory SNs.

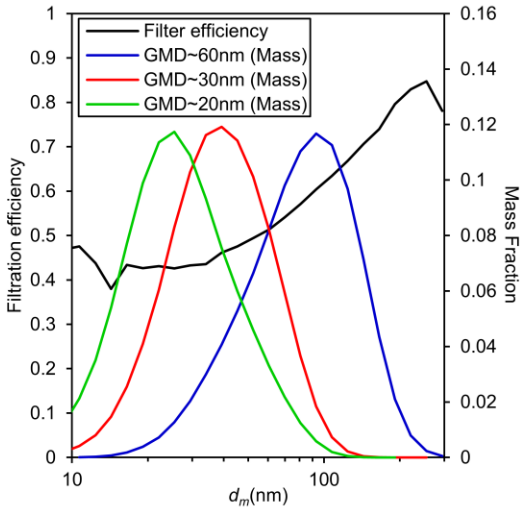

Figure 1. Filtration efficiency of the SN filter with mass distributions for GMD~20, GMD~30 and GMD~ 60 nm soot.

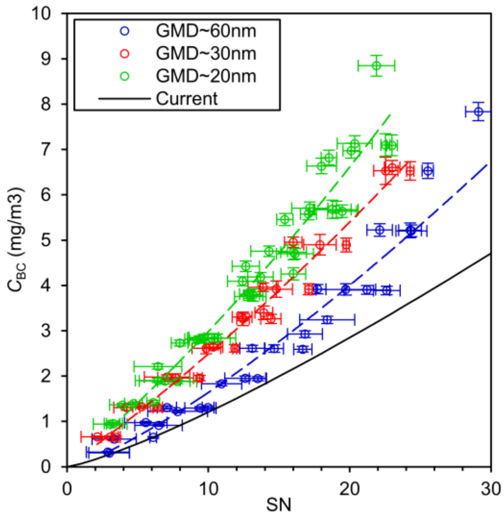

Figure 2. Correlation between C_{BC} and SN.

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