NCAR-ACD Scanning Mobility Particle Sizer (SMPS) Instrument for aircraft applications
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Instrument Description and Background:

The ACD aircraft Scanning Mobility Particle Sizer (SMPS) measures the particle size distribution over the approximate mobility diameter range of 8 to 500 nm (pressure-dependent, see discussion below). It consists of two components: an electrostatic classifier (EC) that size selects the particles from an original polydispersed distribution, and a condensation particle counter (CPC), which counts the particles within each of these particle size bins. The EC brings in ambient air through either a HIML or SMAI inlet, uses a diffusion dryer to remove excess water vapor, and passes the aerosol-containing air through a Po210 source which, places a well-defined charge distribution on the particles. A Differential Mobility Analyzer (DMA[1]) uses a combination of particle-free sheath air and time-varying high voltage applied to its center rod to select a single "mobility diameter" (proportional to its cross-sectional area-to-charge ratio) to exit and be counted. This selected diameter is determined by a time-varying high voltage applied to the DMA and particle-free sheath air flow rate; following this, particles are counted by the CPC. The total scan time and the number of counting intervals, the latter of which determines the number of diameter bins in the size distribution, are selected based on ambient particle concentrations and altitude. The raw data (particle counts over each counting interval as a function elapsed time during the linear diameter scan) is mathematically inverted during post-processing to obtain the particle size distribution (approximately one size distribution per minute)

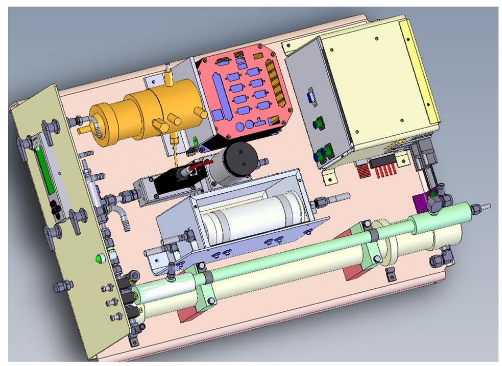

Figure 1. The EC (tubing and filter cover removed for clarity).

Hardware:

The SMPS system consists of the following equipment:

- Electrostatic Classifier (EC) mounted on a standard HIAPER shelf, using 115 VAC 60 Hz @ ~1 A. The EC using a generally licensed, sealed radioactive source (NRD, LLC model P-2021; material: Po210; activity: 10 mCi = 370 MBq). The EC is pictured in Figure 1.
- A commercial Condensation Particle Counter (CPC), manufactured by TSI, Inc (model 3010). The instrument uses n-butanol as the working fluid, which is completely enclosed within the instrument. The CPC has been modified by replacing the original 1.0 L min $^{-1}$ critical orifice with one that allows a CPC aerosol flow rate of 0.6 L/min. The internal pressure taps used to indicate flow (via RS232 communication) are routed outside of the counter and this measurement is used to calculate the sample flow rate. The instrument has also been partially re-plumbed to reduce pressure fluctuations within the instrument during pressure changes. This helps to prevent butanol from entering the optics block.
- Vacuum pump plate, which is required for both the EC and the CPC. The pump plate consists of 3 KNF diaphragm pumps that operate on 28 VDC.

Configuration:

The SMPS has flown successfully on both the NSF-C130 and the NSF-GV and the same configuration, with different operating parameters, is used for each aircraft. The particle size range is dependent on altitude (inlet pressure), DMA voltage range, and the detection limits of the CPC. This relationship is plotted in Figure 2. For the TSI model 3010 CPC the standard limit for particle detection is nominally 10 nm in diameter. By adjusting the difference in saturator and condenser temperature within the CPC, we are able to reduce the minimum detectable size to ~8 nm, which is the minimum reported diameter in the particle size distributions. The maximum diameter shown in Figure 2 corresponds to a DMA voltage of 3000VDC, which is prevents corona discharge at the lowest expected pressures for that aircraft. Thus the diameter range for this instrument for use the GV will typically range from 10 – 70 nm at sea level to 10 – 155 nm at the highest expected altitudes . These ranges will overlap well with the UHSAS instrument (Droplet Measurement Technologies), which measures particle size distributions with a diameter range of 60 nm to 1 µm. Because the C130 typically stays below 30,000 ft. altitude, it is possible to increase the DMA voltage to 5000V, thus slightly extending the size range. The stand-alone CN counter and SMPS are typically used together, which is valuable to compare total particle counts to the particle size distribution.

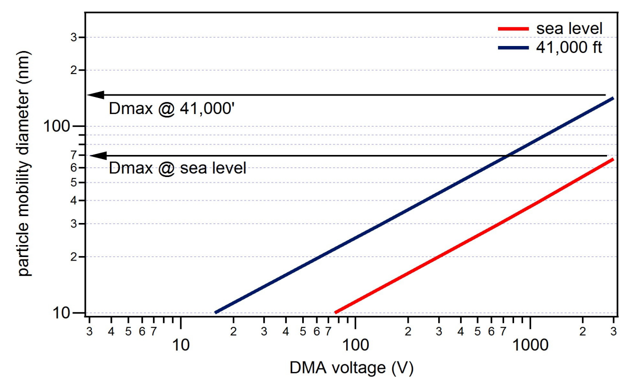

Figure 2. Nano-SMPS particle size/voltage relationship

Data:

The SMPS raw data are recorded on an on-board (PC/104) computer and critical data are also fed into the aircraft data system (ADS) using UDP so that they can be viewed from the ground using Aeros software. Since these critical data are fed into the ADS, a data back-up is automatically generated for each measurement. Flight parameters including inlet temperature, inlet pressure, relative humidity and altitude are read from the ADS (also using UDP) and are also saved locally. The combination of these stored parameters (including raw CPC particle counts, DMA voltage, volumetric sheath flow rate, temperature, and pressure) are used to calculate the final particle size distribution for each up/down scan combination. The SMPS control and data acquisition computer's clock is synchronized with the ADS so that particle data accurately reflect the exact conditions of the rest of the measurements. In most operations, a one-way diameter scan is performed over 15 size bins every 60 seconds. Instrument conditions can be changed during flight (either from on-board the aircraft or remotely from a ground operator) to change operating conditions such as faster time scans or different diameter ranges.

References:

1. Flagan, R.C., *Electrical mobility methods for submicrometer particle characterization*, in *Aerosol measurement: Principles, techniques, and applications*, P. Kulkarni, P.A. Baron, and K. Willeke, Editors. 2011, John Wiley & Sons: Hoboken.