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DOE/SC-ARM-TR-250

Ultra-High-Sensitivity Aerosol Spectrometer Aboard Aircraft (UHSAS-AIR) Instrument Handbook

J Uin L Goldberger

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Ultra-High-Sensitivity Aerosol Spectrometer Aboard Aircraft (UHSAS-AIR) Instrument Handbook

J Uin, Brookhaven National Laboratory
L Goldberger, Pacific Northwest National Laboratory

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Acronyms and Abbreviations

AAF	ARM Aerial Facility
AMF	ARM Mobile Facility
ARM	Atmospheric Radiation Measurement
CACTI	Cloud, Aerosol, and Complex Terrain Interactions
CPC	condensation particle counter
DMA	differential mobility analyzer
DQ	data quality
HEPA	high-efficiency particulate air
HI-SCALE	Holistic Interactions of Shallow Clouds, Aerosols, and Land-Ecosystems
NIST	National Institute of Standards and Technology
PC	personal computer
PCASP	passive cavity aerosol spectrometer
PSL	polystyrene latex
SGP	Southern Great Plains
SMPS	scanning mobility particle sizer
UHSAS	ultra-high-sensitivity aerosol spectrometer
USB	Universal Serial Bus

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1.0 Instrument Title

Ultra-high-sensitivity aerosol spectrometer

2.0 Mentor Contact Information

Jason Tomlinson (lead mentor)
Jason.Tomlinson@pnnl.gov

Mikhail Pekour (associate mentor)
Mikhail.Pekour@pnnl.gov

3.0 Vendor/Developer Contact Information

Droplet Measurement Technologies, Inc.
2545 Central Avenue
Boulder, Colorado, USA 80301-5727
tel: +1 (303) 440-5576
fax: +1 (303) 440-1965
customer-contact@dropletmeasurement.com
www.dropletmeasurement.com

Instrument manual available at http://www.dropletmeasurement.com/resources/manuals-guides

4.0 Instrument Description

The ultra-high-sensitivity aerosol spectrometer (UHSAS) (Figure 1) is an optical-scattering, laser-based aerosol particle spectrometer system for sizing particles in the 60- to 1000-nanometer (nm) range [1–3]. The instrument counts particles in up to 100 user-specified sizing bins. The instrument's laser illuminates particles, which scatter light. The system captures the peak light signals that are generated. These signals are used for particle sizing, since the amount of light scattered correlates strongly with particle size.

For campaigns previous to 2017, the ARM Aerial Facility (AAF) deployed a canister version of this instrument on board the Gulfstream-1 aircraft on the starboard wing. This instrument was replaced for campaigns after 2017 with a bench version of the instrument placed in the cabin with a modified volumetric air flow control to compensate for changing cabin pressure and sampling pressure.

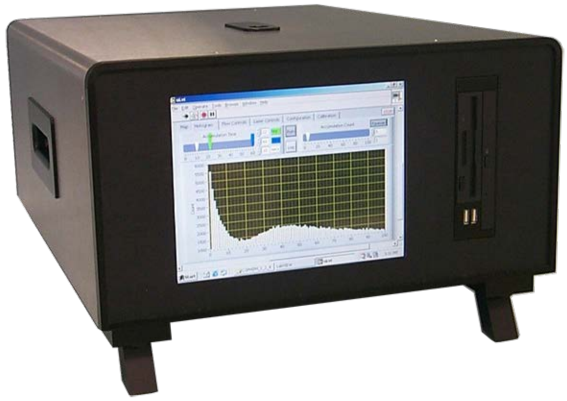

Figure 1. The ultra-high-sensitivity aerosol spectrometer, bench version. Image adapted from the manufacturer's website.

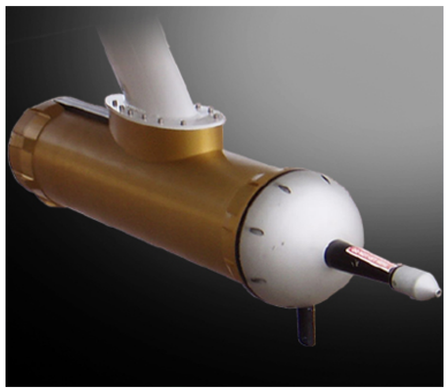

Figure 2. The ultra-high-sensitivity aerosol spectrometer, pylon version. Image adapted from the manufacturer's website.

5.0 Measurements Taken

The primary measurement output of the UHSAS is the equivalent optical diameter distribution as particle number concentrations (in counts or in cm^{-3}) per user-defined size bins. Additional measurements include sample flow rate, sample time, sample air pressure, and sample temperature.

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

Starting in 2018, the UHSAS data were submitted as routine data with the name aafuhsas. These data are available in netcdf format. Previous data sets have the naming structure uhsas-air and are available in icartt format.

These data from the UHSAS are recorded in column format with appropriate headers specifying the data and units of measurement. The data fields recorded include:

Measurement date/time, sample accumulation time, raw light scatter signal, current drawn by the instrument, sample flow, laser reference signal, sample temperature, sheath air flow rate, instrument internal temperature, flow rate of purge air, ambient pressure, boundaries of the size bins of the particle size distribution, and particle concentration in each size bin.

Output data are recorded after every sample, typically every second in flight (1 Hz). A new data file is started at the beginning of each flight.

This data object description is subject to change with future revisions of the instrument software.

6.2 Data Ordering

Data from the UHSAS can be ordered from https://www.arm.gov/capabilities/instruments/uhsas-air. Data are organized by measurement location/campaign.

6.3 Data Plots

Figures 3 and 4 show typical data for the UHSAS. Figure 3 shows measured particle size distributions (particle counts per size bin) as a function of time. Figure 4 shows a comparison between the total particle number concentration (calculated from the measured size distribution) measured by the UHSAS and particle number concentration measured by a condensation particle counter (CPC), as a function of time. Differences in measurements are mainly due to the different detection ranges of the two instruments. These plots were generated using the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) user facility Data Quality Diagnostic Plot Browser (http://plot.dmf.arm.gov/plotbrowser/).

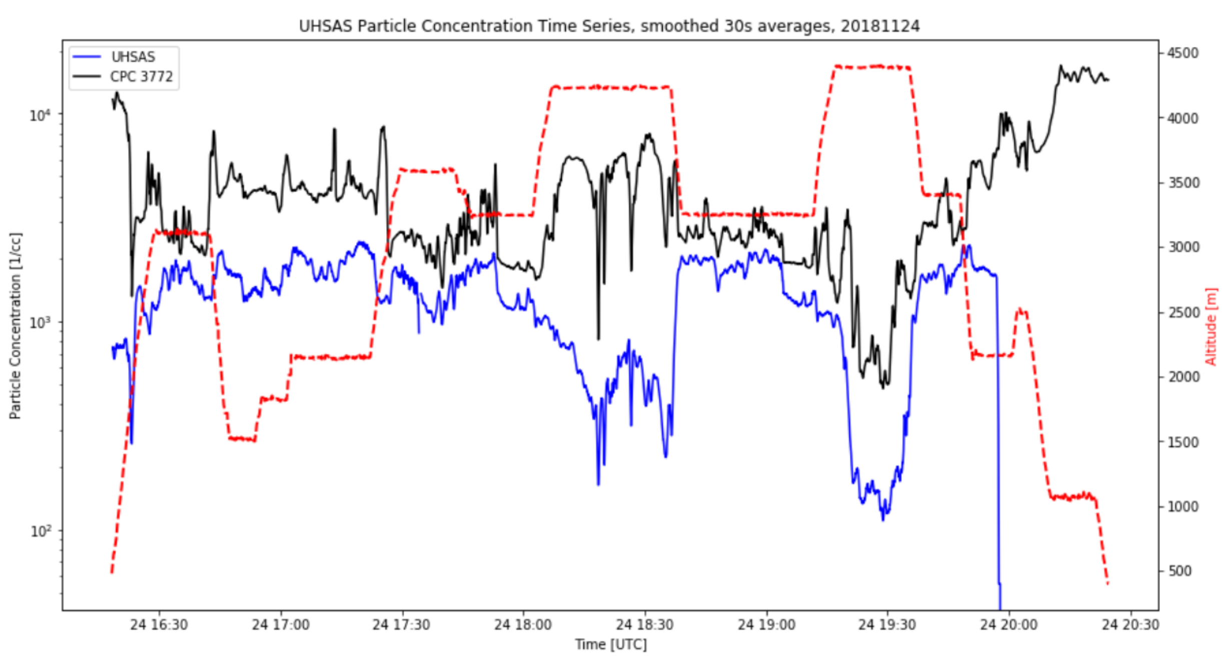

Figure 3. Comparison of total aerosol particle concentrations measured by the UHSAS and by a CPC on 24 November, 2018 during a research flight on the Cloud, Aerosol, and Complex Terrain

Interactions (CACTI) field campaign in the Sierras de Cordoba, Argentina. The UHSAS and CPC sample nearly identical size ranges of aerosol 10^1–10^3 microns. The UHSAS follows the same trend as the CPC at a lower concentration; see section 6.2.

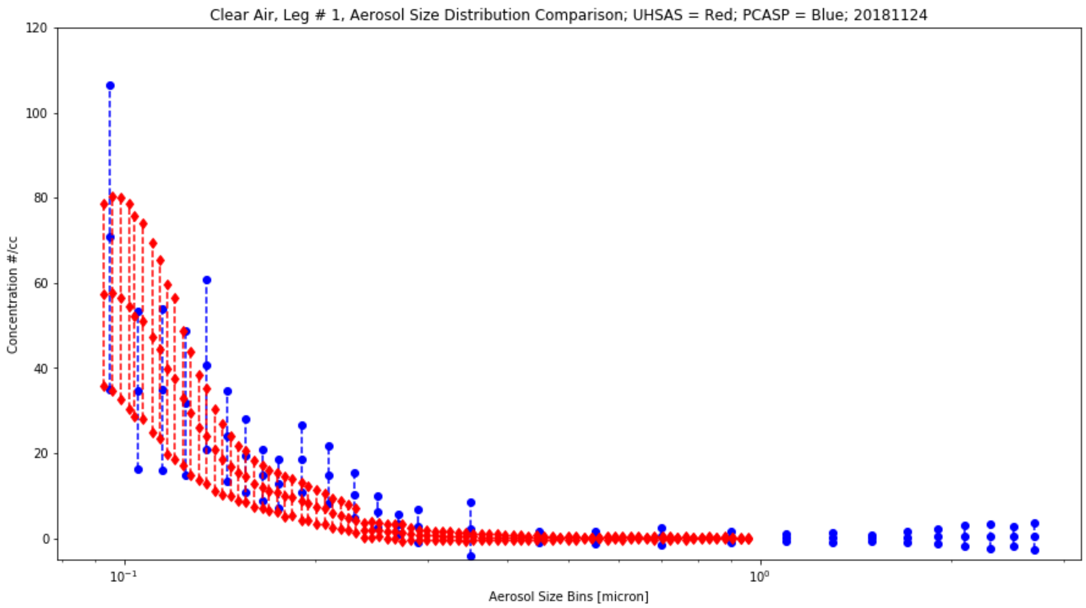

Figure 4. Comparison of aerosol size distribution measured by the UHSAS (in red) and by the passive cavity aerosol spectrometer (PCASP) (in blue) on 24 November, 2018 during a research flight on the CACTI field campaign in the Sierras de Cordoba, Argentina. This comparison was made during the first continuous level portion of flight in clear air. See figure 3, time 1610 UTC. Bin size is the mean value, each line represents a sampled bin size. The mean is the middle point and the points on either end of the line is the standard deviation. Both the UHSAS and PCASP are in situ optical particle counters sampling at 1 Hz, making them good complementary instruments on a fast-moving platform.

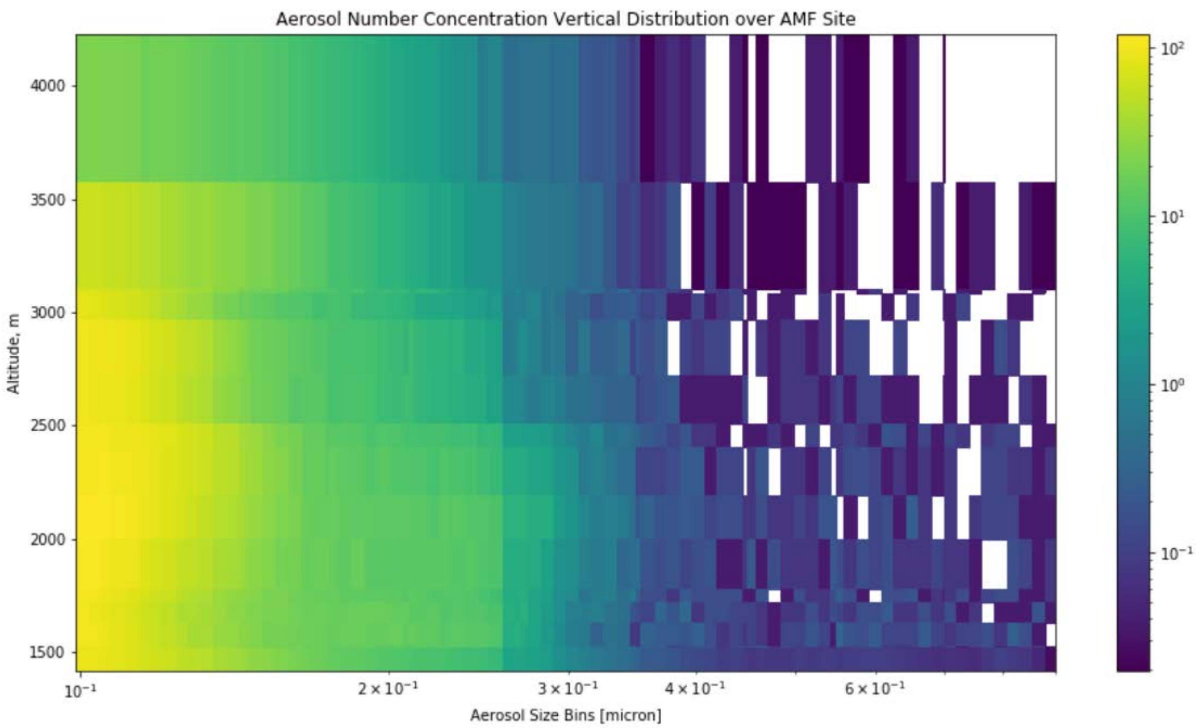

Figure 5. Vertical aerosol size distribution measured by the UHSAS on 24 November, 2018 during a research flight on the CACTI field campaign in the Sierras de Cordoba, Argentina. This profile was made from a spiral taken over the ARM Mobile Facility (AMF) ground site in clear air. See figure 3, time 1640 UTC. Passes over the AMF site at 1730 and 1830 UTC were incorporated to capture the overhead aerosol size distribution above the boundary layer. Bin size is the mean value.

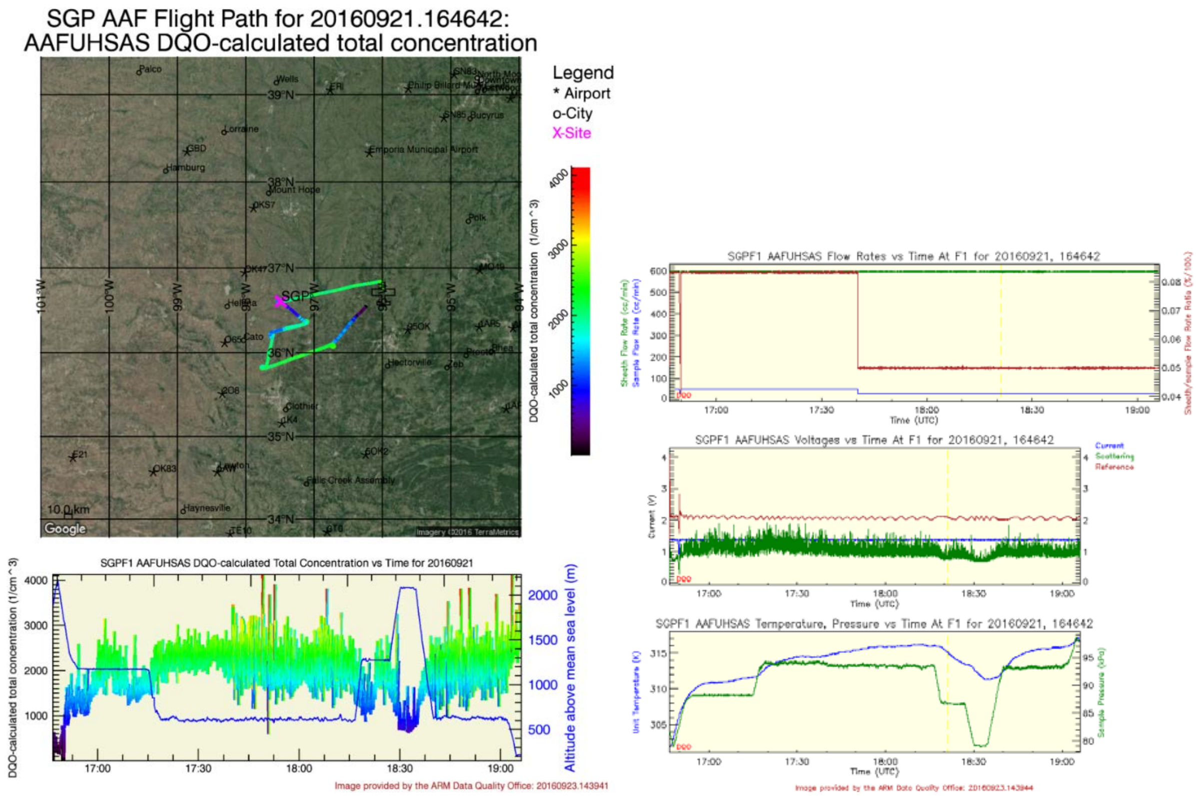

Figure 6. Plots available from the ARM data quality (DQ) plot browser (https://dq.arm.gov/dq-plotbrowser/). UHSAS data from the Holistic Interactions of Shallow Clouds, Aerosols, and Land-Ecosystems (Hi-SCALE) campaign over ARM's Southern Great Plains (SGP) AMF site on 21 September, 2016. Left, UHSAS-derived aerosol concentration presented spatially and temporally. Right, housekeeping data from the instrument.

6.4 Data Quality

Data quality evaluation involves the automatic generation of the following plots in collaboration with the ARM Data Quality Office (see also Figure 6):

- Aerosol particle size distribution as a function of time. Low counts or noisy signal may indicate issues with the UHSAS optics block (misalignment, contamination) or air flows (low or unstable sample flow).
- Comparison of particle number concentration measurements from the UHSAS and from several co-located instruments such as CPC or scanning mobility particle sizer (SMPS). The total concentration as measured by the UHSAS should follow the same general trend as other instruments but show lower concentrations, since the lower particle size limit for the UHSAS is higher than it is for CPC or SMPS.
- Sample flow rate. Low or unstable flow rate indicates a blockage in the sample line or a failing pump.
- Laser reference voltage. A value more than 25% lower than the nominal value of 2.5 volts (V) indicates dirty optics or, less likely, misalignment of optical elements.

- Below 100 nm, counting confidence decreases due to decreased detection efficiency. These values can be treated as a lower bound estimation. We recommend being critical of particles smaller than 100 nm [1].

6.5 Calibration Data Base

During deployment the UHSAS calibration is periodically verified by the instrument mentors. This includes using the UHSAS to measure the size distribution of monodisperse (monomobile) aerosols with a known refractive index mean particle diameter (electrical mobility) generated by a differential mobility analyzer (DMA) and comparing the measured mean particle size to the DMA selection size. Additionally, as particles selected by the DMA include those with more than one elementary charge, the produced aerosol particle size distribution is not strictly monodisperse and includes multiple narrow peaks at well-defined positions corresponding to differently charged aerosol particles. The locations of those peaks, as measured by the UHSAS, are compared to locations theoretically predicted by the Millikan formula, which relates particle electrical mobility and diameter.

Calibration verification data are collected and maintained by the instrument mentors. No corrections to the data are derived from calibration checks. The main purpose of these checks is to assess the instrument state and health. True calibrations are performed by the vendor as part of servicing or by the mentor when the calibration check fails.

7.0 Technical Specification

7.1 Units

Units include aerosol particle size, nanometers (nm), aerosol particle number concentration, particles per cubic centimeter (cm^3), or raw number of counts (dimensionless).

7.2 Range

Particle size can be measured from 60 to 1000 nm. Total particle number concentration (per unit time) can be measured from 0 to 3000^{s-1} (3600 cm^{-3} for 50-ccm sample flow—the maximum number of particles per unit volume depends on the instrument’s sample flow rate).

7.3 Accuracy

Accuracy of particle sizing depends mainly on the accuracy of the particle size look-up table that is calculated during instrument calibration with monodisperse calibration aerosols. The look-up table relates particle size to pulse height of scattered light for a calibration aerosol used, which is usually polystyrene latex (PSL). Ambient aerosol particles with a non-spherical shape or refractive index different from PSL can be thus sized incorrectly. In general, the instrument sizing accuracy is within 5% as seen from comparison experiments with an SMPS [1]. The above applies to the instrument’s normal operating mode where the total particle counts are below 3000 $^{s-1}$ and no significant particle coincidence occurs.

7.4 Repeatability

Repeatability of particle sizing mainly depends on the inherent noise in the response of the electronics that measure the pulse height of the scattered light. In general, the repeatability is within 1% [1]. This applies to the instrument's normal operating mode where the total particle counts are below 3000 $^{s-1}$ and no significant particle coincidence occurs.

7.5 Sensitivity

Aerosol particle size and concentration measurement is sensitive to particle concentration (due to particle coincidence during counting at higher concentrations). The operating speed of the detector electronics sets the upper limit of total particle counts for reliable single-particle detection at around 3000 $^{s-1}$ (3600 $^{cm-3}$ for 50-ccm sample flow). No corrections for particle coincidence are made by the instrument and a dilution system should be used when sampling aerosol particles at concentrations higher than the upper limit specified above.

Particle sizing is also sensitive to the particle refractive index if it differs from that of the calibration aerosol particles (PSL). If the ambient particle refractive index is known, corrections can be applied to the measurement data [1, 4].

7.6 Uncertainty

Uncertainty for particle sizing is largely determined by the sizing resolution of the instrument, which depends on the geometry of the optics system, i.e., the diameters of the laser beam and the particle jet. The manufacturer specifies the uncertainty of particle sizing as within 2.5% of particle size.

7.7 Input Values

Parameters set by the user include measurement range, number of size bins, upper and lower boundaries of each size bin, sample flow rate, sample accumulation time, and number of samples.

7.8 Output Values

The recorded data include measurement date/time, sample accumulation time, raw light scatter signal, current drawn by the instrument, sample flow rate, laser reference signal, sample temperature, sheath air flow rate, instrument internal temperature, flow rate of purge air, ambient pressure, boundaries of the size bins of the particle size distribution, and particle concentration in each size bin.

8.0 Instrument System Functional Diagram

The entire system can be divided into five separate subsystems (See Figure 7):

1. Main optical subsystem. Generates the laser light, detects the light scattered by particles, and provides a mechanical enclosure for the optical system and for delivery of the sample aerosol.

2. Flow system. Brings the sample aerosol through the optical interaction region, and controls and measures the flows.
3. Analog electronics system. Amplifies and processes the particle signals.
4. Digital electronics system. Analyzes particle signals, bins signals according to user-specified bin mappings, generates a histogram of particles in the specified bins, and communicates with the personal computer (PC) and system monitor/control functions.
5. Onboard PC. Allows the user to control the instrument and collect and report data.

See the manufacturer's manual for detailed description of the instrument's subsystems.

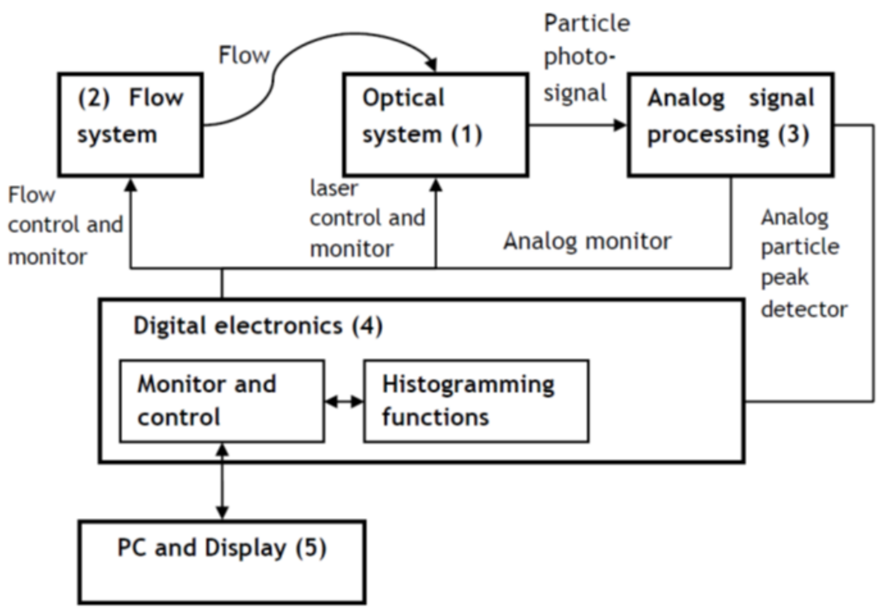

Figure 7. UHSAS block diagram. Adapted from the manufacturer's manual.

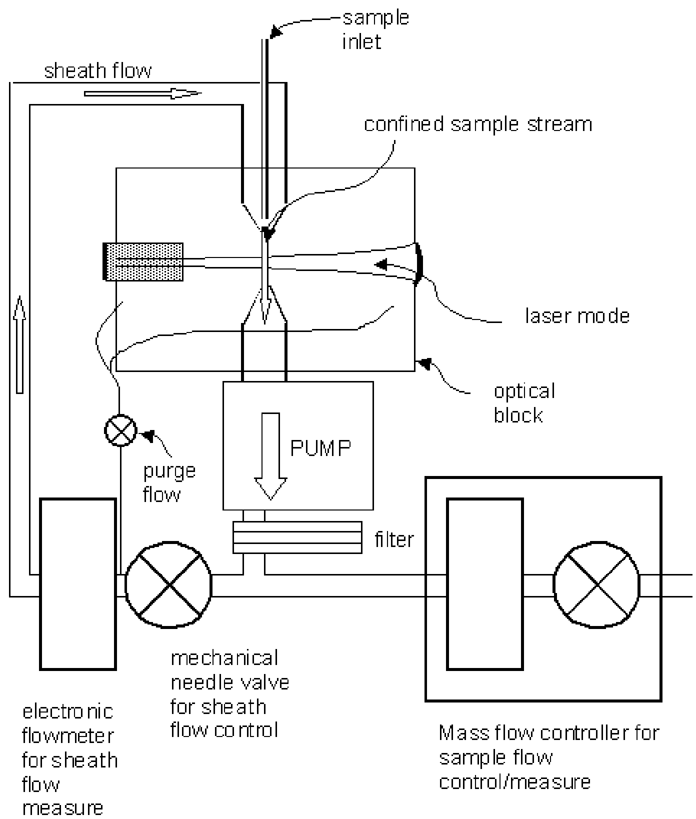

Figure 8. Schematic diagram of the UHSAS flow system. Adapted from the manufacturer's manual. The UHSAS deployed during the CACTI campaign was modified as described in Brock et al. 2011 and Kupic et al. 2018: to correct for changing outside pressure the mechanical needle valve for sheath flow control was replaced by a volumetric flow controller.

9.0 Instrument/Measurement Theory

The aerosol particles are drawn into the instrument's optical chamber and pass in front of a laser beam (see Figure 8). The instrument's infrared (1054-nm) laser illuminates the particles, which scatter light. Four optical detectors capture the light signals generated by particles passing through the laser beam. These signals are used in calculations for particle sizing, since the amount of light scattered correlates strongly with particle size. Scattered light is collected in a direction perpendicular to both the particle flow and the laser beam.

The internal mass flow controller of the sheath flow inside the UHSAS instrument is ill equipped to maintain proper flow rate on airborne platforms due to the inverse relationship between volumetric flow rate and changes in air density. This affect biases the pulse width measured by changing the particle velocity through the laser beam [5]. Furthermore, the original design uses a needle valve for sheath flow control by splitting the sampling and sheath flows. Changing pressures varies the sheath-sample flow ratio because the pressure drop through the valve is Reynolds number-dependent [5,6].

This has been corrected in multiple flight campaigns by replacing the sheath flow valve with a volumetric flow controller to directly monitor and control sheath flow. The modified UHSAS is operated at ~ 0.06 L min^{-1} total inlet flow and 0.7 L min^{-1} sheath flow [5]. The original UHSAS LabView software was modified to accommodate these changes [5]. AAF incorporated this modification for the UHSAS aboard the Gulfstream-159 for the CACTI campaign.

10.0 Setup and Operation of Instrument

1. Connect a keyboard and a mouse to the Universal Serial Bus (USB) ports on the instruments (for initial setup only).
2. Switch on the instrument and wait for the internal computer to boot up.
3. Start the measurement software by double-clicking on the “Spectrometer” icon on the computer desktop screen. The software may be configured to start automatically, in which case skip this step.
4. Switch to the “Histogram” tab in the software main window. Click on “Run” and “Record” buttons in the upper left corner of the software window. If the software was started automatically, these buttons are likely to be already active, in which case skip this step.
5. The instrument is now ready to operate automatically.

For further details, consult the manufacturer’s manual.

11.0 Software

Instrument control and data acquisition is performed by NI LabView-based software written by the manufacturer. Additional LabView-based software, written by Pacific Northwest National Laboratory, reformats and relocates the data files saved by the manufacturer’s software.

12.0 Calibration

The UHSAS system is calibrated by the manufacturer before delivery to the user and during instrument maintenance at the manufacturer’s facilities. The instrument mentors perform calibration verification that checks for conditions requiring a full calibration, typically once every 12 months or as needed, e.g., before deployment. No corrections to the data are derived from calibration verifications. In case of verification failure, the instrument would be size-calibrated by the mentors or sent to the manufacturer for maintenance.

The manufacturer’s calibration includes:

- Measuring the size distribution of National Institute of Standards and Technology (NIST)-traceable calibration aerosols PSL with known mean particle sizes.
- Calibrating the gain of the four internal pulse-height measurement ranges, i.e., recording the responses of the light detector electronics to aerosols with known particle sizes. Calibration values are recorded in the software and applied automatically.

- Calibrating the inlet flow rate with a precision flow meter. Calibration values are recorded in the software and applied automatically.
- Zero counts verification by operating the instrument with a high-efficiency particulate air (HEPA) filter attached to the inlet.

Calibration verification done by instrument mentors includes using the UHSAS to measure the size distribution of monodisperse (monomobile) aerosols with a known mean particle diameter (electrical mobility) generated by a DMA and comparing the measured mean particle size to the DMA selection size. Additionally, as particles selected by the DMA include those with more than one elementary charge, the produced aerosol particle size distribution is not strictly monodisperse and includes multiple narrow peaks at well-defined positions corresponding to differently charged aerosol particles. The locations of those peaks, as measured by the UHSAS, are compared to locations theoretically predicted by the Millikan formula, which relates particle electrical mobility and diameter.

13.0 Maintenance

For action when cleaning the laser optics (when laser reference voltage falls below ~1.9 V): consult the manufacturer's manual.

14.0 Safety

The UHSAS is a Class I Laser Product. During normal operation, the user is not exposed to laser radiation.

15.0 Citable References

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