Final Technical Report

For

Cooperative Agreement NCC 2-894:

# Highly Resolved Aerosol Measurements from High Altitude Platforms

Report Submitted to the United States National Aeronautics and Space Administration by the University of Denver

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Project Objective:

The University of Denver agreed to develop and fabricate two instruments for the characterization of submicron aerosol. The instruments were to be light weight for use on remotely-piloted aircraft or balloons. The instruments were to provide accurate size measurements of size distributions in the size range from 0.07 μm to 2 μm in diameter and concentration measurements in the size range from ~0.01 μm to 2 μm in diamter.

The instruments have been constructed and one has been used in tropospheric studies. The second instrument will be used in stratospheric studies in January 2000. This report describes the instruments and outlines the performance observed to date.

Instrument Description:

We will refer to the instruments constructed under this cooperative agreement as CNC/FCAS. Each CNC/FCAS constructed under this cooperative agreement includes a passive, focused cavity aerosol spectrometer able to size particles in the diameter range from 0.08 μm to 1 μm and two condensation nucleus counters able to count particles in the diameter range from 0.006 μm to 2 μm. The instrument package weighs 55 lbs and consumes approximately 220 watts of 28 V DC power and 50 watts of 112 V AC power (60 to 400 Hz).

Unique aspects of the instrument design include the strategies for providing structural integrity and thermal management. The main objectives of the instrument development include building lightweight instruments while meeting requirements for integration onto aircraft. These requirements include the ability to withstand significant accelerations, up to 9 g's, without breaking up. In previous generations of instruments that performed similar tasks on aircraft, the required cooling and structural integrity were obtained by using thick pieces of aluminum in the construction to conduct heat and provide the structure.

In the CNC/FCAS, the structural backbone of the instrument is a duct of rectangular cross section which runs the length of the instrument. Elements which generate heat are anchored to the duct. Air from outside the aircraft is brought into the plane using a small scope and the air flows through the instrument. A butterfly valve is controlled to maintain the flow in a range compatible with the cooling requirements. The CNC/FCAS performs functions similar to those performed by two instruments whose total weight exceeded 110 lbs. Thus the weight required to obtain size distributions and measure CN concentrations has been halved as a result of this development.

FCAS Instrument Performance:

Figure 1 shows the layout of the optical bench used in the optical counter. The bench was purchased from PMS Inc in Boulder. The light scattered by particles out of the laser beam into coaxial cones of 45° half angle oriented perpendicularly to the laser and aerosol beam is collected and measured by two array photodiodes. The bench is sensitive to particles in the diameter range from 74nm to 1050 nm. The introduction of monodisperse aerosol into the viewing volume results in a population of pulses of many sizes as shown in Figure 2. Design trade-offs that allowed the bench to be useful for measurements made at 200m/s in the stratosphere resulted in this behavior.

Adapting the bench for use in the troposphere involved installation of a sheath air system that recirculates approximately 27 $cm^3/s$ of filtered air and draws 1.1 $cm^3/s$ of sample flow. This relative modest sample flow prevented coincidences between particles in the viewing volume and the large amount of filtered sheath air prevented recirculation of particles through the laser beam. The data acquisition rate was adjusted to permit adequate statistical samples to be collected without filling up the disk.

This optical bench had not been used prior to this application and it represents a new type. Therefore, it is not as well understood as its predecessor in spite of shared geometry.

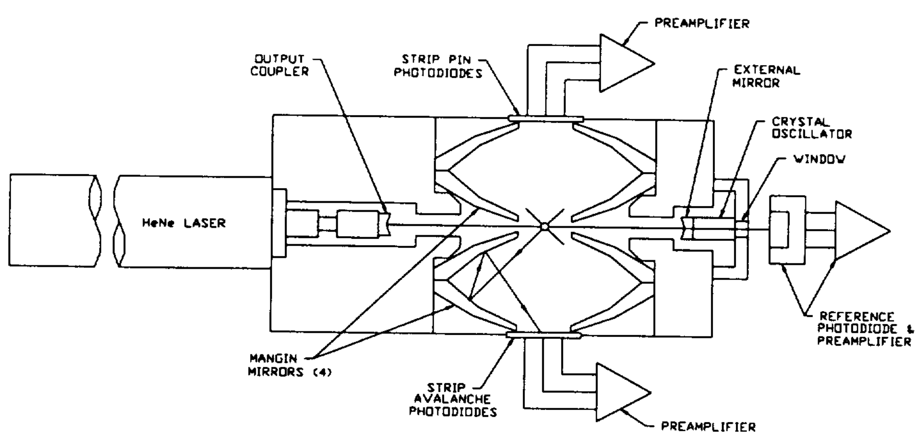


*Figure 1. Schematic of optical bench used in Phase I. The bench is sensitive to particles in the 74 to 1050 nm diameter range and is low resolution in the sense illustrated by Figure 2.*

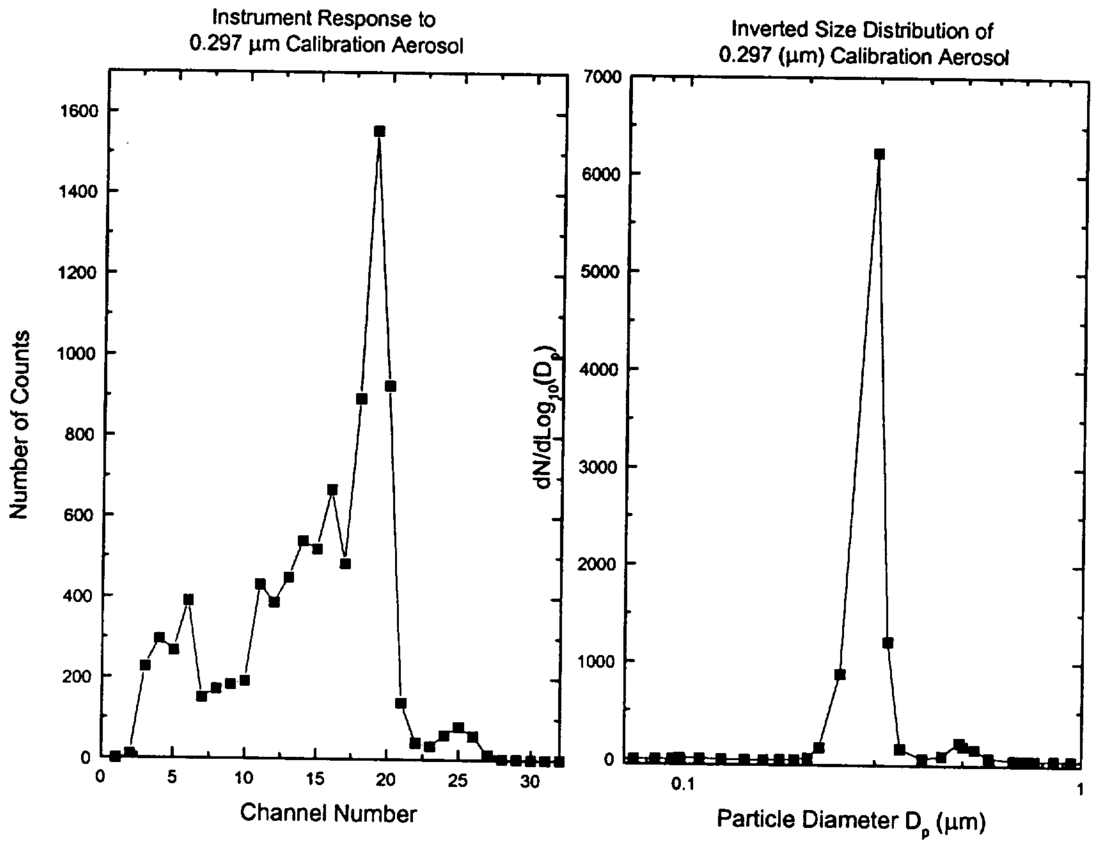


*Figure 2. Left Panel: Pulse height distribution for a calibration with particles having a diameter of 0.297 µm. Approximately half of the particles fall outside of the main peak seen in channels 18-20. The Peak around channel 25 includes the doubly charged particles having the same mobility as the main peak. Right panel : Size distribution resulting after inversion with the Twomey technique. The average diameter obtained by averaging the size distribution from the lower bound to the beginning of the doublets peak is within two percent of the diameter provided by the differential mobility analyzer.*

*Calibration of the FCAS Optical Bench*

Twenty-eight, monodisperse calibration aerosols consisting of di(2-ethylhexyl) sebacate were generated using an atomizer and a differential mobility analyzer. The resulting pulse height distributions were modified to remove the impact of the doublets seen in Figure 7. Then the 28 normalized distributions were placed into a matrix describing the instrument response. Simultaneous measurements with a CNC counter permitted the detection efficiency of the optical bench to be determined as a function of particle size.

*FCAS Data Reduction*

A smoothed Twomey data inversion technique was used (Markowski,1987). The detection efficiencies were then applied to the inverted distributions to obtain the measured size distribution. The convergence criterion was altered slightly and additional smoothing was performed using a 3 channel boxcar average.

*Field Comparisons of FCAS with Nephelometer: Marshall, CO:*
Scattering predicted from the size distributions measured using the optical spectrometer is compared to nephelometer readings in Figures 3 and 4 The nephelometer was measuring submicron aerosol and data were supplied by John Ogren of NOAA CMDL.

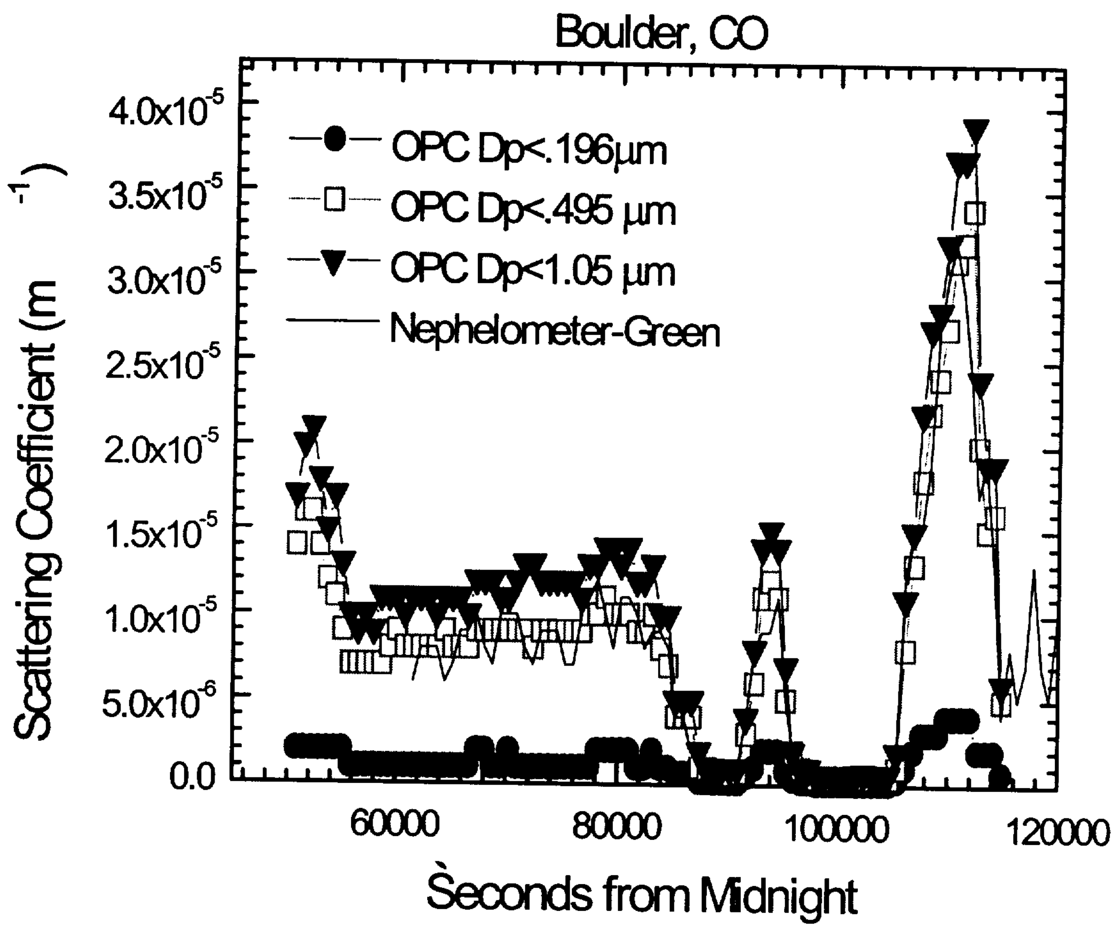


*Figure 3. Scattering coefficient predicted from the size distributions determined using the aerosol spectrometer (OPC) and measured using a nephelometer. Note that particles smaller than 0.2 micron did not contribute much to the scattering and the dominant contribution is made by particles in the 0.2 to 0.5 µm diameter range.*

The scatter plots shown in Figure 4 show that the scattering for the blue, green and red light predicted from the aerosol spectrometer size distributions exceeded that measured by the nephelometer by 10%, 20% and 25% respectively. The value of $R^2$ for the regressions all exceeded 0.93. The scatter plot of aerosol mass determined by an ICVI against the volume predicted by the aerosol spectrometer also demonstrates an impressive correlation.

The aerosol spectrometer was calibrated at the site in Marshall and the nephelometer was checked with span gas shortly before the comparison. The aerosol sample for the spectrometer was drawn from the tube through which the nephelometer sample was drawn. The sampling arrangement was not isokinetic but corrections were calculated using the known flow rates and the geometry of the sampling configuration. The discrepancy between the nephelometer and the scattering predicted by from the spectrometer size distributions could be reduced by correcting the nephelometer reading for angular nonidealities (Anderson and Ogren, 1998). These nonidealities will be less than 10% in the case of the Marshall data since the scattering is dominated by small particles. But the corrections are in the right direction to reduce the small discrepancies and move the slopes of the scatter plots closer to one.

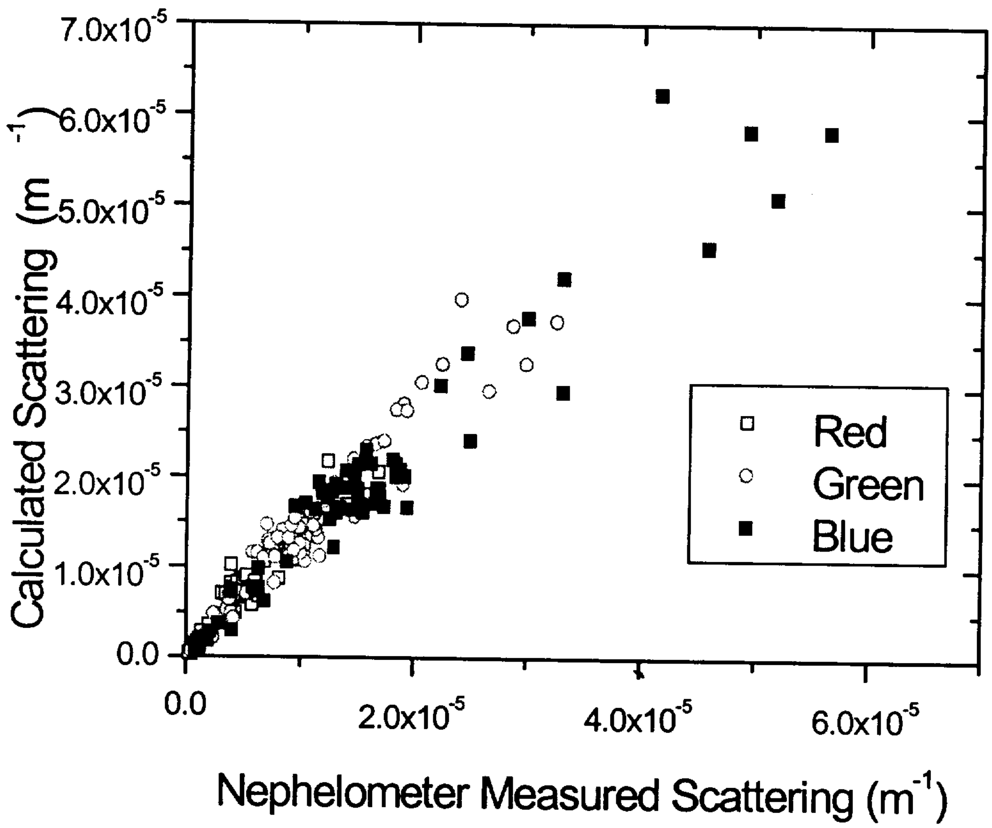


*Figure 4. Scattering calculated from aerosol spectrometer measurements plotted against simultaneous nephelometer measurements. Values of $R^2$ exceed 0.93 for the three curves. The slopes of the best-fit curves are 1.24,1.19 and 1.09 for Red, Green and Blue respectively.*

*Use of FCAS in the Southern Oxidant Study*

The first airborne application of the CNC/FCAS occurred in the Southern Oxidant Study. The instrument was integrated onto the NOAA P-3 and flown in a pollution study that occurred mostly in the boundary layer. Initial thermal difficulties were overcome and the CNC/FCAS performed flawlessly in the last seven flights. This demonstrated the robustness of the instrument and box design. Figure 5 shows sampling in the plume of the Thomas Hill power plant. Each line shows the mixing ratio of particles larger than the given size. The curves representing Dp>100 nm, Dp>150 nm and Dp>225 nm were taken from CNC/FCAS data. In this application, the CNC's on the CNC/FCAS were not used since these CNC's were designed for operation at pressures below 400 mb and those pressures were not reached in the experiment.

The Plume crossings are identified in the figure. The top 5 curves in the figure represent concentrations determined with the NMASS (Nuclei Mode Size Spectrometer). The plume was intersected six times at increasing distances downwind from the stack. The figure also shows $O_3$ and $SO_2$. The aerosol behavior shows new particles formed in the plume and the growth of the background aerosol in the plume as well as the expected behavior of the gas phase species as the plume ages. The FCAS has successfully captured the aerosol behavior in the plume.

CNC Instrument Performance:
The CN counters in the CNC/FCAS are very similar to CN counters in the NMASS and in the ER-2 CNC II.

<u>Conclusions:</u>
The instruments constructed under this cooperative agreement respond quite nearly as expected and meet the objective of being light and compact. One has been used for ground based and low altitude studies and the other will be deployed in high altitude studies this winter.

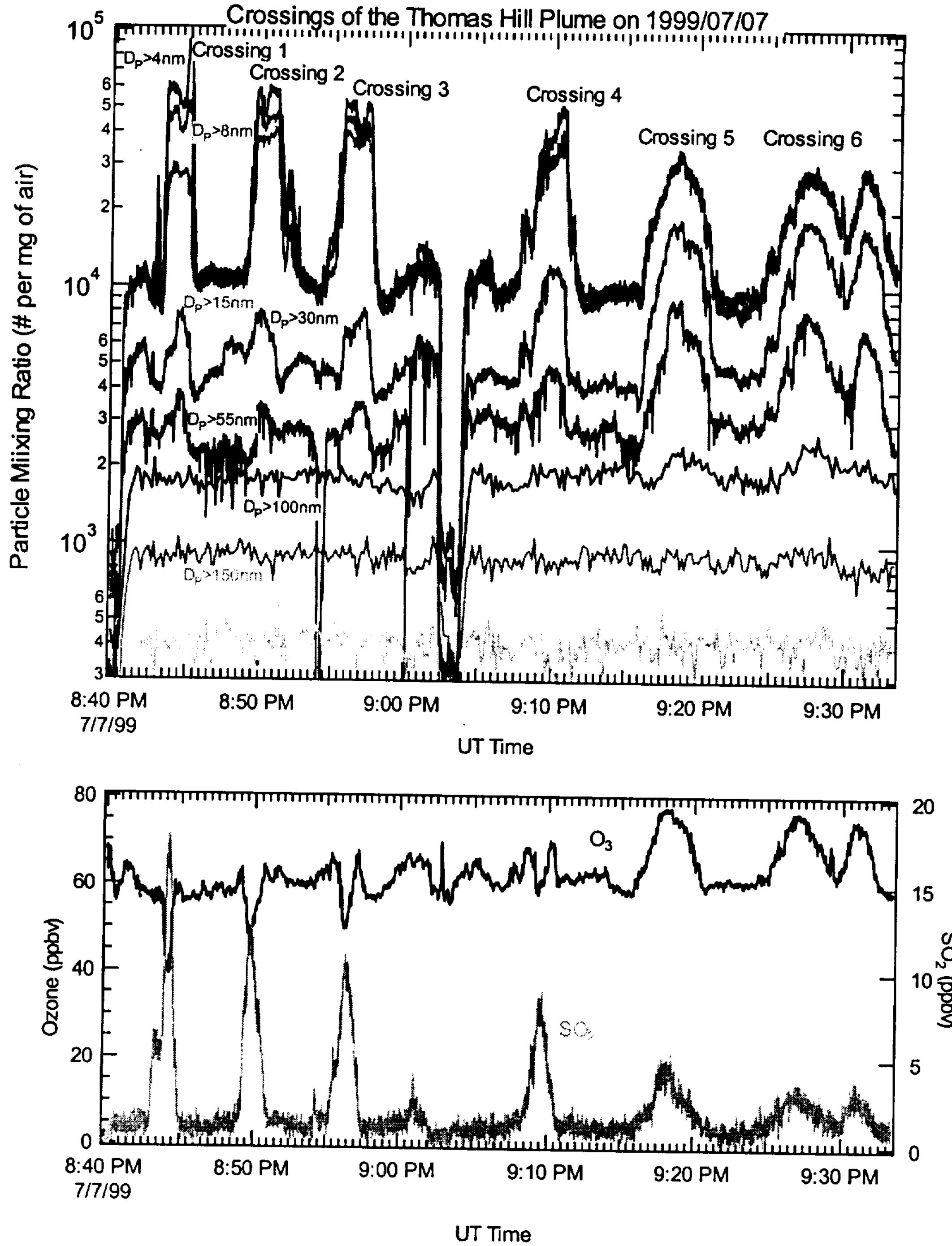


*Figure 5. Aerosol and gas concentrations in a power plant plume. The CNC/FCAS data are displayed in the bottom 3 traces of the upper graph. The growth of the particles in the plume is observed in the concentration of particles larger than 100 nm in crossings 5 and 6.*