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Airborne Condensation Nucleus Counter User's Guide

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PREFACE

Small particles in the atmosphere are produced by many different sources and may be indicators of air mass history. They are also important as sites for chemical reactions and cloud droplet formation. In response to an increased interest in aerosol and chemical measurements, the Research Aviation Facility (RAF) at the National Center for Atmospheric Research (NCAR) has modified a TSI Inc. Model 3760 condensation nucleus counter to measure a wide range of particle sizes and concentrations at altitudes up to about 11 km. The counter has been flown successfully on the NCAR Sabreliner as a stand-alone device, but may also be used downstream of various instruments (e.g., a counterflow virtual impactor or differential mobility analyzer) to measure particle concentrations. This note describes the basic operating principles of the instrument, the modifications necessary for high altitude, reduced pressure operation, and data reduction procedures. It is intended both as a technical guide for RAF staff and as an aid to users in understanding and interpreting the acquired data.

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AIRBORNE CONDENSATION NUCLEUS COUNTER USER'S GUIDE

1. Principles of operation

1.1 *Basic description of measurement physics*

The TSI Model 3760 condensation nucleus (CN) counter measures the number concentration of particles from about 0.01 to 3 micrometers in diameter. The particles are detected by condensing n-butyl alcohol (butanol) on the particles, which allows them to grow to a size that can be detected optically. Air containing particles is initially drawn into a sponge-like alcohol reservoir, where it is saturated with butanol vapor (see Figure 1). The sample is then cooled in a condenser tube, where the vapor supersaturates to a few hundred percent and condenses on the particles. The condenser is cooled by a thermoelectric device which is sandwiched between the condenser and a heatsink. After the particles have grown, they are passed through a laser-diode optical detector, which counts individual particles.

1.2 *Technical details of operation*

The original TSI instruction manual for the instrument contains information on its basic operation and electronics. Several additions and modifications have been made to the factory instrument for operation on NCAR aircraft. The following have been added: an isokinetic sampling inlet, a charcoal filter to trap butanol vapor, two flow meters, a vacuum pump, and an external exhaust port (see Figure 2). Inside the instrument, the "purge" airflow (necessary only for clean room operation) has been closed off. The internal filter between the inlet line and saturator has been replaced with one with a smaller pressure drop, allowing the internal pressure to equalize more easily at high altitudes. More information on some of these modifications is given in the subsequent text.

Flow through the CN counter is maintained by an external vacuum source (1/8 hp Gast diaphragm pump) and controlled by a critical orifice inside the instrument. The sample flow is monitored by a Sierra 830 mass flow meter, which has a range of 0–2 standard liters per minute (slpm). Since the conditions at the CN inlet are generally not the same as the standard calibration pressure and temperature (1013 mb and 21°C), the flow meter output (FCN) is corrected to volumetric liters per minute (vlpm). In order for the instrument to function properly, it is critical that the volumetric flow rate is maintained between about 1.2 and 1.7 vlpm under all operating conditions. This flow rate (FCNC) is calculated by the onboard software from flow, temperature, and pressure inputs.

The flow system for sampling air from outside the cabin is shown in Figure 2. It is known that particles may stick in sharp bends, valves, and any kind of plastic tubing. Because air flows to the CN counter through a stainless steel line that is as short as possible and that has no sharp ($>$ 45 degree) angles, particle loss is minimized. A Heise Model 623 pressure transducer measures the counter inlet pressure (PCN) in order to convert from mass to volumetric flow rate. An AD590 temperature sensor, FCBADS, is attached to the sample line immediately ahead of the CN counter with insulating tape. (A dedicated in-line temperature sensor is planned for the future.) The exhaust line from the instrument

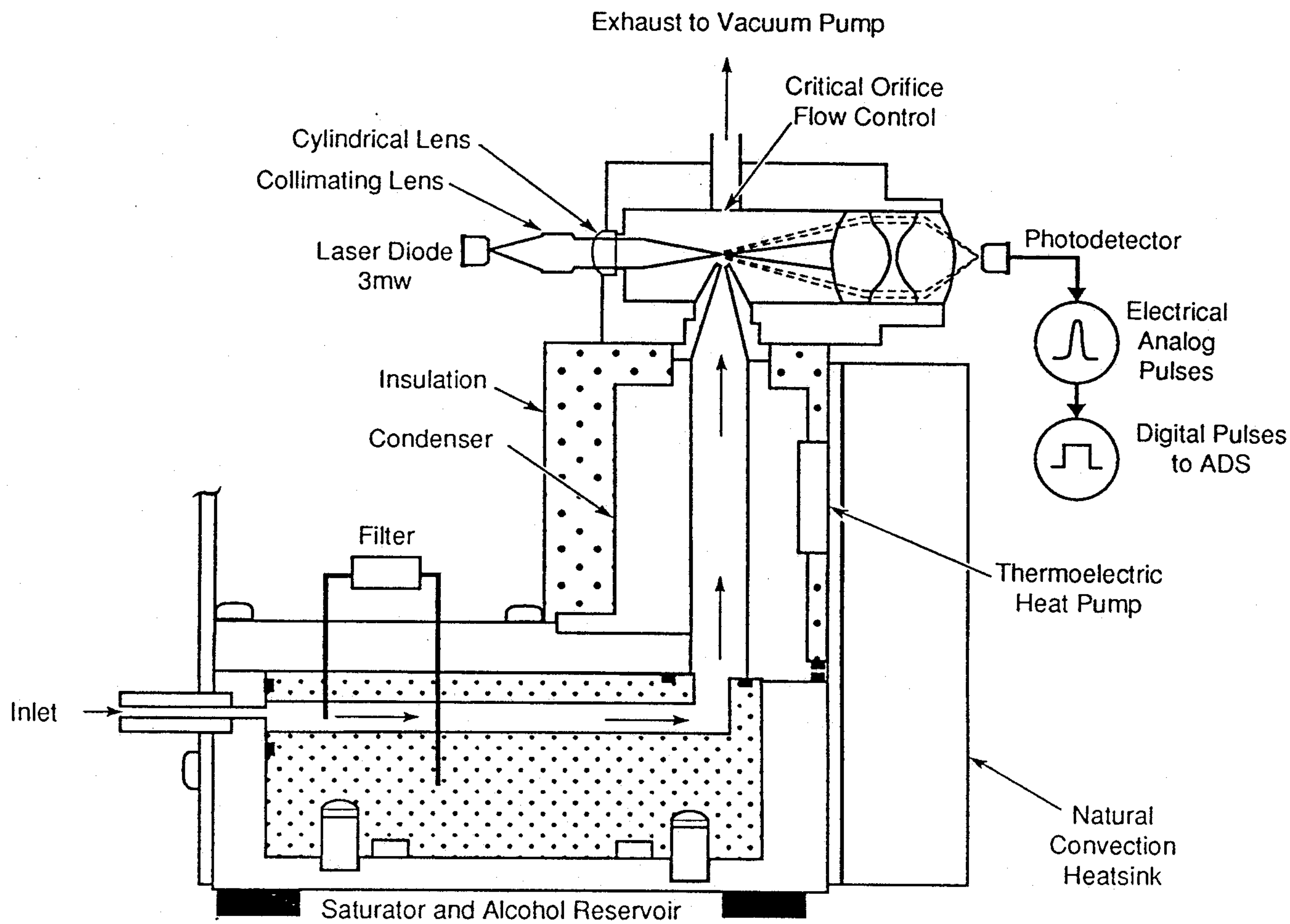


FIGURE 1. Internal schematic of the TSI 3760 CN counter

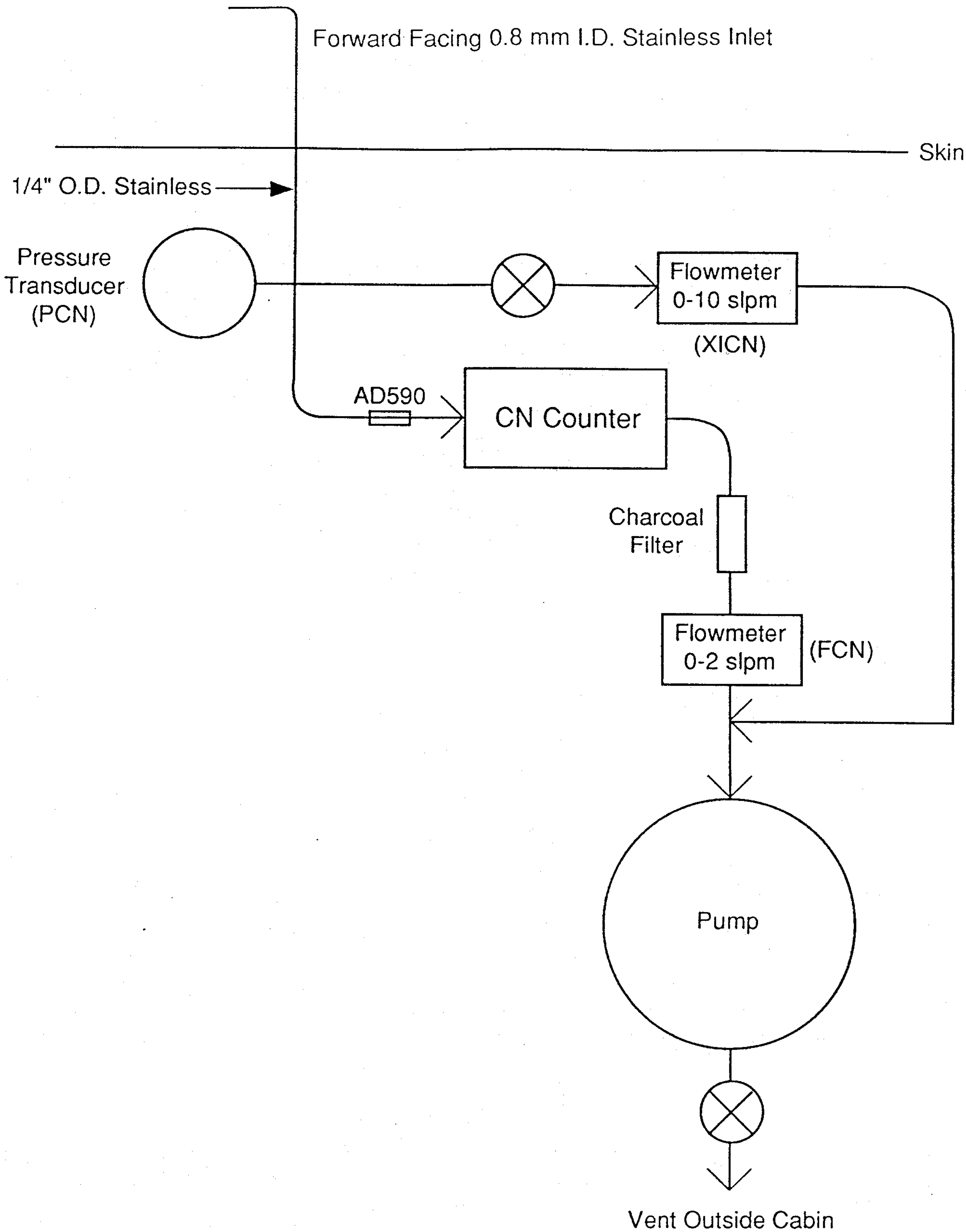


FIGURE 2. CN counter flow system used on the NCAR Sabreliner

consists of flexible tubing (teflon or polyethylene) and may contain angles as long as they do not restrict the flow. A charcoal filter removes most of the butanol vapor before it reaches the flow meter and pump. The exhaust line is dumped outside the aircraft for two reasons: to remove any excess butanol vapor from the cabin and to improve the pump efficiency at low atmospheric pressures. A stainless steel "T" valve, which is closed manually during takeoff and before landing, prevents contamination of the instrument and sample lines.

The CN counter inlet is designed to be "isokinetic," meaning that the flow speed just inside the inlet tip should equal the airstream speed. This is desirable in order to obtain a representative sample and is especially important in the sampling of large particles (> 1 micrometer in diameter). The high speed needed inside the inlet tip requires a very small tip inside diameter (ID) and/or a very large sample flow rate. The stainless steel Sabreliner inlet has a 0.8 mm ID tip that is matched to the remainder of the inlet (5.0 mm ID) with a 7 degree half-angle. Also, some additional capacity from the vacuum pump supplements the CN sample flow. A side flow (XICN, corrected volumetric value XICNC) in parallel with the sample flow brings the *total* flow at the inlet approximately up to the flow rate required for isokineticity. At Sabreliner research speeds and altitudes, the Reynold's number inside the 5.0 mm tubing is below 2000; thus turbulent losses downstream of the tip should be small. This side flow is measured by a 0–10 slpm Sierra 830 mass flow meter. Both flow meters run off the same power supply, which fits in a standard rack and has a digital flow readout in fraction of full scale (e.g., a reading of 0.60 for a flow meter with a range of 0–2 slpm means the flow rate is 1.20 slpm).

Appendix A provides a listing and plot of total volumetric flow rates required for isokinetic sampling at various research airspeeds using the 0.8 mm ID inlet designed for the Sabreliner. Assuming the flow speed at the inlet location approximately equals the aircraft true airspeed (TAS), the general relationship between TAS in m/s and total flow rate through the system in vlpm is:

$$\text{Total Flow (FCNC} + \text{XICNC)} = 0.0311 \times \text{TAS}$$

The side flow valve should be adjusted during a project test flight to bring the total flow rate to within 10% of isokinetic (at the typical research airspeed and altitude for each project). Of greater importance, however, is the sample flow, FCNC, which must always be maintained at a minimum of 1.2 vlpm. Once adjusted correctly, the volumetric flow rate through both the sample and side flow lines should remain approximately constant with altitude up to about 9 km, but this should be verified every few flights.

1.3 *Data analysis and interpretation*

CN concentration, CONCN, in particles per cubic centimeter (cm^{-3}) is calculated from the raw counts, CNTS, and the sample flow rate as described in Appendix B. Because particles are grown inside the counter before they are counted, this instrument can detect much smaller particle sizes than an instrument which measures particles directly by optical means. Therefore, concentrations measured by the CN counter are typically much higher than those measured by an instrument such as Particle Measuring Systems Inc.'s Active Scattering Aerosol Spectrometer Probe (PMS ASASP). Since all particles are grown to about the same size in the condenser, however, the CN counter does not resolve particle concentration by size. Particle concentration varies substantially with environmental conditions and air mass history, and the true signal may appear noisy. Normal values range from less than a few hundred per cubic centimeter in clean air (high altitude or marine environments) to greater than 10^4 cm^{-3} in more polluted environments.

An example of particle concentration measured by the CN counter as a function of altitude in September in northeastern Colorado is shown in Figure 3. Well-defined particle layers are seen where the air is stably stratified and mixing is inhibited, such as near the tropopause (here, at about 9 km). Rapid increases in concentration may be caused by industrial emissions at low altitudes or aircraft at high altitudes. (Since particle concentration is derived in part from pressure and flow signals, disturbances in these measurements may occasionally affect final concentration.)

1.4 *References*

Model 3760 Condensation Nucleus Counter Instruction Manual, TSI P/N 1933760, TSI Inc., St. Paul, MN, 19 pp.

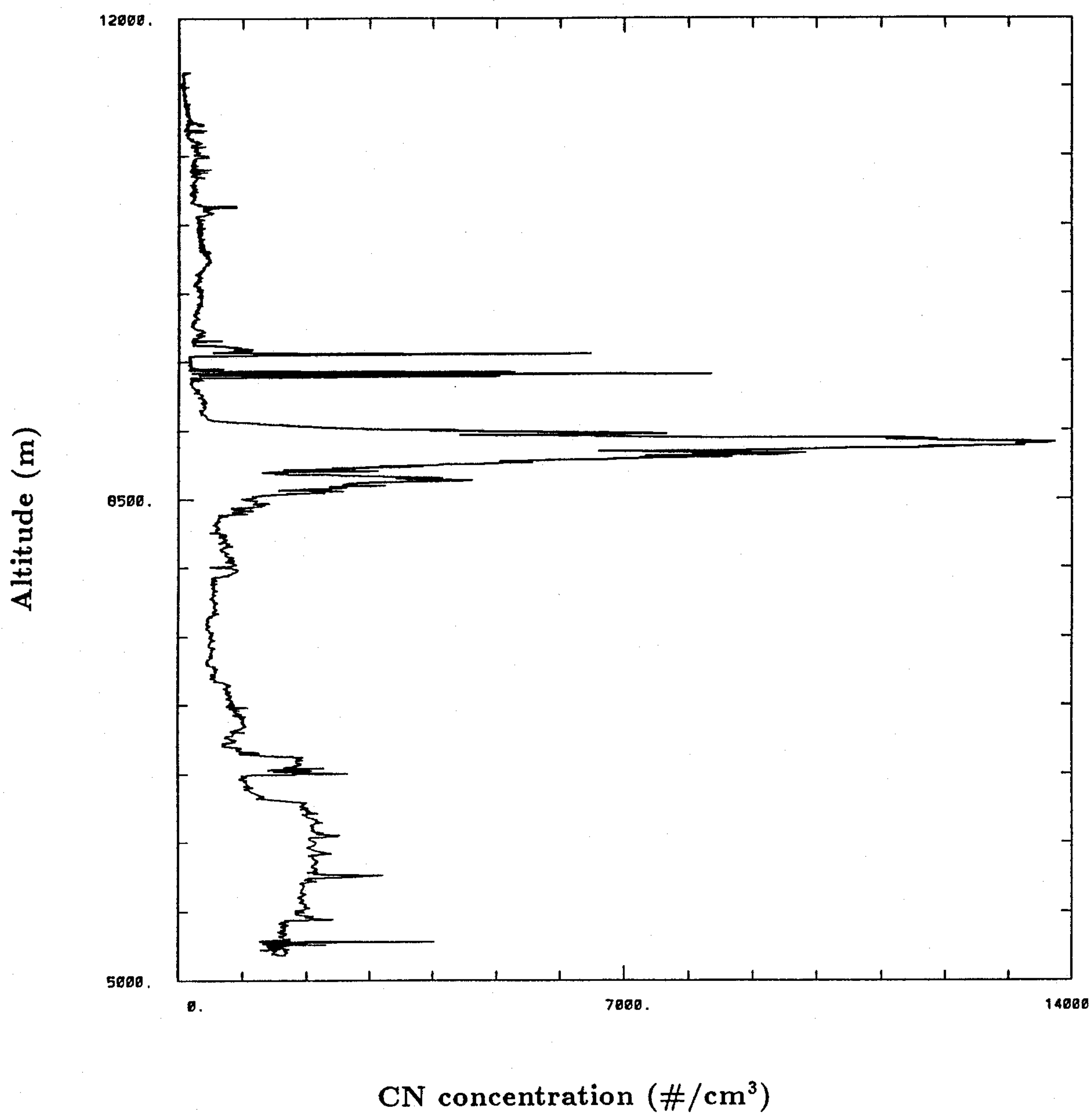


FIGURE 3. Example of particle concentration as a function of altitude

2. Measurement limitations and uncertainties

2.1 *Factors limiting accuracy*

The counting efficiency of the Model 3760 at standard pressure as a function of particle size is shown in Figure 4 (Zhang, 1988). Most particles smaller than 0.01 micrometers in diameter either do not grow large enough to be counted or are lost by diffusion inside the instrument. Particles greater than about 3 micrometers may also be lost in the instrument by other mechanisms.

At lower operating pressures, the counting efficiency for smaller particles decreases. This is partly a consequence of increased diffusional losses at lower air densities. Figure 5 shows the response of the CN counter at reduced pressures measured by Zhang (1988). This shows that at pressures of approximately 200 mb (11.5 km), the unit is no longer counting 0.01 micrometer particles very efficiently, but most particles larger than about 0.025 micrometers in diameter are still being detected. At pressures less than 200 mb, counting efficiency for all particles smaller than 0.1 micrometers in diameter drops off dramatically. The overall decrease in counting efficiency at reduced pressures has been verified at NCAR, although no size dependence was investigated in these lab experiments.

At high concentrations, two or more particles may be present in the viewing volume at once and still produce a single pulse from the photodetector. This "coincidence" error, which is statistically corrected for in post-processing, increases from about 0.6% at 10^3 particles cm^{-3} to 6% at 10^4 cm^{-3}. Even with the coincidence correction, the output should not be considered accurate at concentrations greater than 2×10^4 cm^{-3}.

Because the CN inlet is small and unheated, the instrument is not recommended for use in clouds, especially under icing conditions. Flow into the inlet is affected by attack and yaw angle; therefore particle concentrations will not be as accurate during moderate to steep climbs, descents, and turns as during straight and level flight. Even during straight and level flight, some particle losses will inevitably occur inside the inlet and sample line due to turbulence, particle impaction, and deviations from isokineticity and isoaxiality (alignment with air streamlines). These effects have yet to be quantified but are expected to be dominated by losses of large (> 1 micrometers in diameter) particles. In most cases these comprise less than 10% of the total number of particles.

2.2 *Tabulation of measurement uncertainties*

Based on the various sources of error estimated for measurements made by the CN system, the following uncertainty factors have been calculated. S represents the precision index (random error), and B is the bias limit (fixed error). Sources of each type of error as well as the final integrated root-sum-square uncertainty for derived parameters were combined by methods following Abernethy et al. (1980) and Bevington (1969). When data were not available for error sources, estimates have been made. No attempt has yet been made to account for inlet losses, which will vary with the particle size distribution and may be significant. Errors not listed are assumed to be negligible relative to those for which values are listed, and the sample size is assumed to be > 30 in all cases. All values are for straight and level flight in clear air.

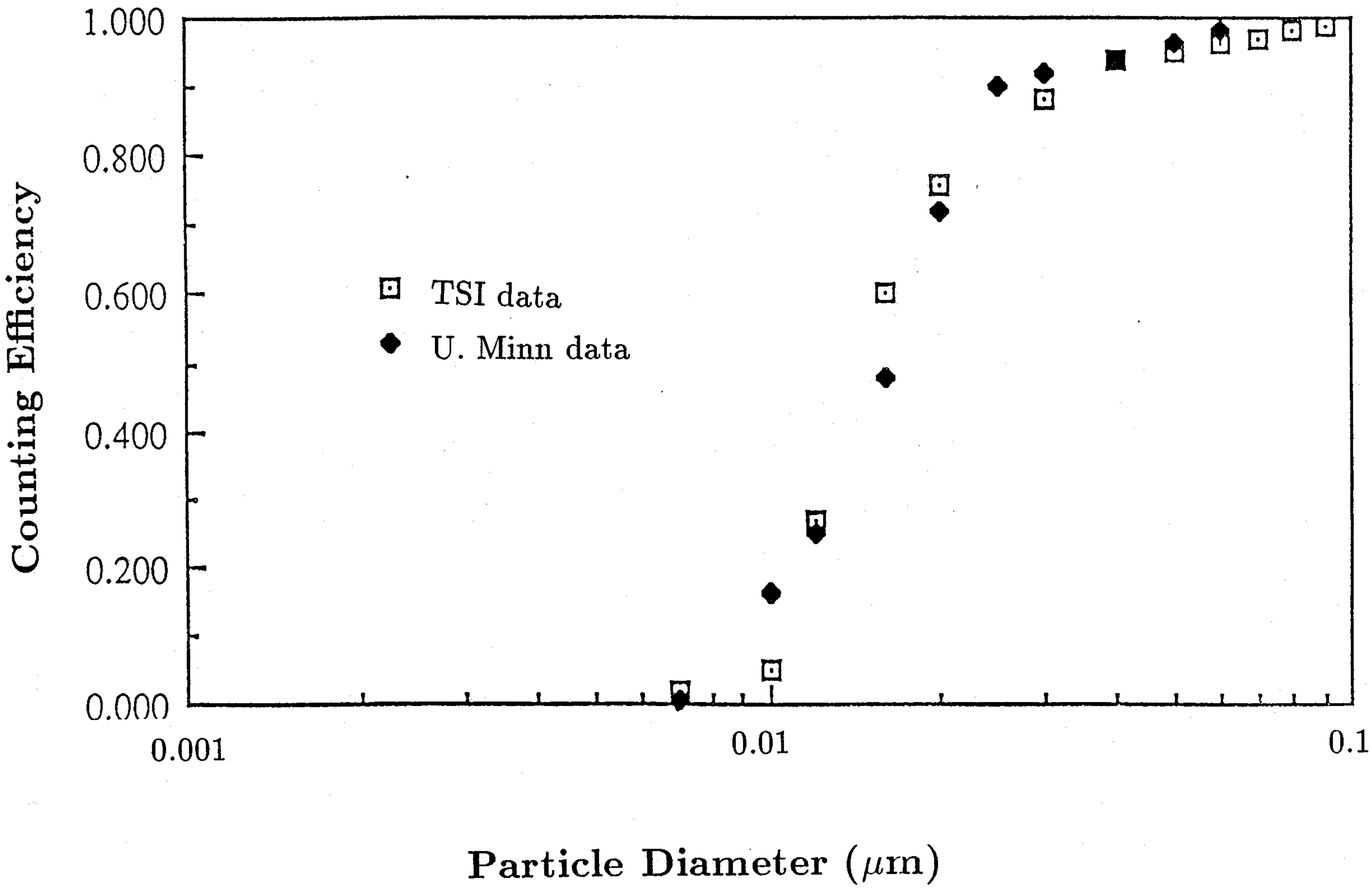


FIGURE 4. Counting efficiency of the Model 3760 at standard pressure as a function of particle size (Zhang, 1988).

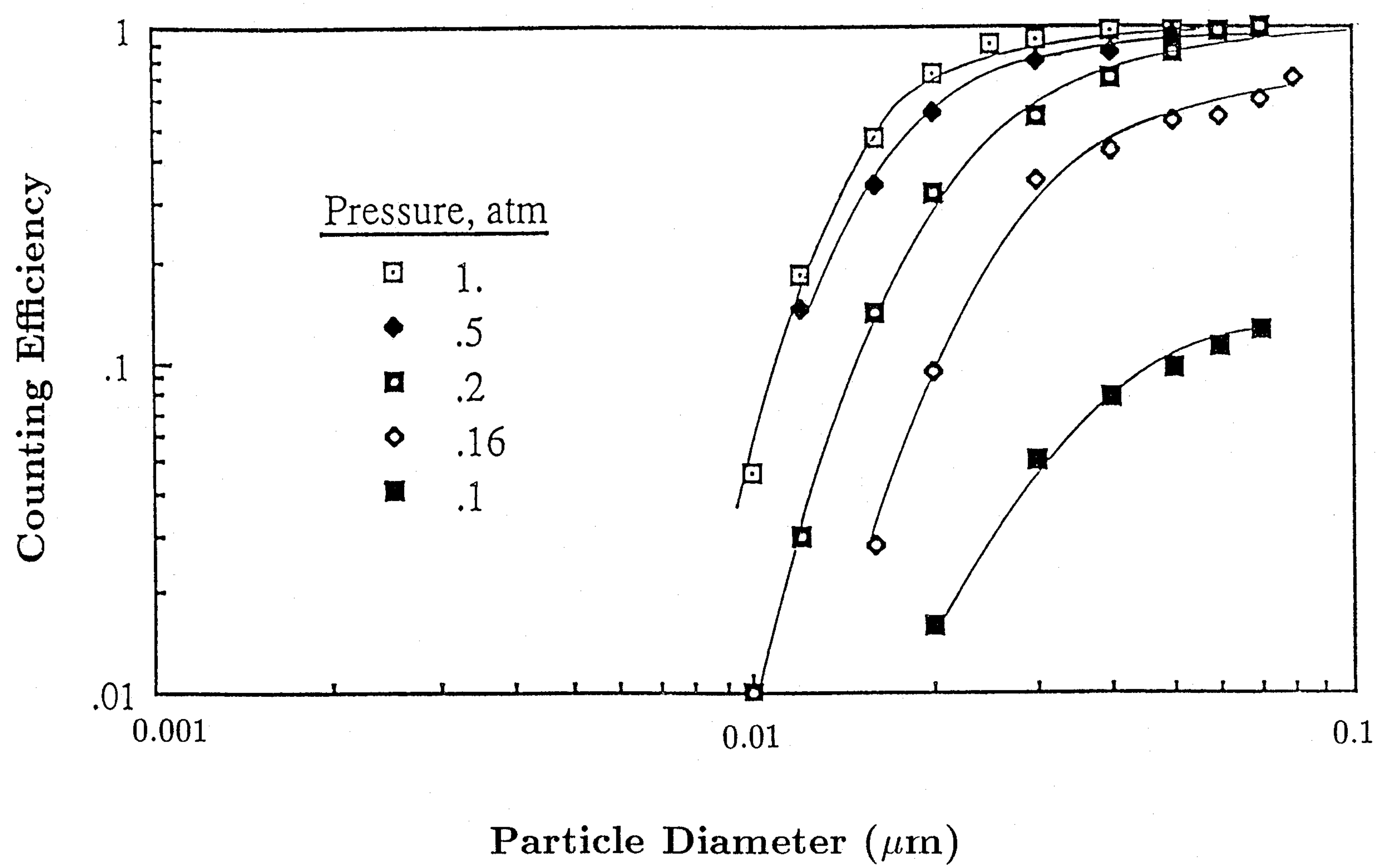


FIGURE 5. Counting efficiency of the Model 3760 as a function of pressure (Zhang, 1988).

	$2S$	B	Source
PCN (Inlet pressure in mb)			
Calibration	—	3.0	Manufacturer
Data Acquisition			
Sensor Placement	—	0.06	Calculated[a]
Data System error and drift	0.17	0.18	Calculated[b]
Data Analysis	—	—	
	0.17	3.24	
FCN (Sample Flow Rate in slpm)			
Factory Calibration	0.004	0.04	Manufacturer
Data Acquisition			
Data System error and drift	0.0002	0.0002	Calculated[b]
Data Analysis	—	—	
	0.0042	0.0402	
FCBADS (Inlet temperature in °C)			
Calibration of AD590K	2.5	—	Manufacturer[c]
Data Acquisition			
Sensor Placement	—	5.0	Estimated[d]
Data System error and drift	—	—	
Data Analysis	—	—	
	2.5	5.0	
CNTS (Counts per 0.2 s ÷ 16)			
Calibration	—	—	
Data Acquisition			
Data System error and drift	1.0	—	
Data Analysis	—	—	
	1.0	—	

[a]Based on potential error due to flow speed differences between transducer location and entry to CN instrument.

[b]Calculated from overall data system uncertainty as determined by Knowlton et al., 1985.

[c]Calibration bias errors are assumed to be small relative to random error.

[d]Due to external placement of sensor; will be reduced substantially with dedicated in-line sensor.

The following errors in derived parameters have been calculated:

FCNC:

$$B^2_{\mathrm{FCNC}} \cong \left(\frac{\partial\mathrm{FCNC}}{\partial\mathrm{PCN}} B_{\mathrm{PCN}}\right)^2 + \left(\frac{\partial\mathrm{FCNC}}{\partial\mathrm{FCN}} B_{\mathrm{FCN}}\right)^2 + \left(\frac{\partial\mathrm{FCNC}}{\partial\mathrm{FCBADS}} B_{\mathrm{FCBADS}}\right)^2$$

Using values of PCN = 500 mb, FCBADS = 15°C, FCN = 0.75 slpm:

$$\frac{\partial\mathrm{FCNC}}{\partial\mathrm{PCN}} = 3.0 \times 10^{-3}$$

$$\frac{\partial\mathrm{FCNC}}{\partial\mathrm{FCN}} = 2.0$$

$$\frac{\partial\mathrm{FCNC}}{\partial\mathrm{FCBADS}} = 5.2 \times 10^{-3}$$

$$B^2_{\mathrm{FCNC}} \cong 7.2 \times 10^{-3}$$

Similarly, $(2S)^2_{\mathrm{FCNC}} \cong 2.4 \times 10^{-4}$

$U_{\mathrm{RSS,\ FCNC}} = 0.086$ vlpm (5.7% for FCNC = 1.5)

CONCN:

$$B^2_{\mathrm{CONCN}} \cong \left(\frac{\partial\mathrm{CONCN}}{\partial\mathrm{CNTS}} B_{\mathrm{CNTS}}\right)^2 + \left(\frac{\partial\mathrm{CONCN}}{\partial\mathrm{FCNC}} B_{\mathrm{FCNC}}\right)^2$$

Using values of FCNC = 1.5 vlpm, CNTS = 1000:

$$\frac{\partial\mathrm{CONCN}}{\partial\mathrm{CNTS}} = 3.3$$

$$\frac{\partial\mathrm{CONCN}}{\partial\mathrm{FCNC}} = 2.2 \times 10^{3}$$

$$B^2_{\mathrm{CONCN}} \cong 3.4 \times 10^{4}$$

Similarly, $(2S)^2_{\mathrm{FCNC}} \cong 1.1 \times 10^{3}$

$U_{\mathrm{RSS,CONCN}} = 187$ (5.7% for CONCN = 3265)

2.3 *References*

Abernethy, R.B., and J.W. Thompson, Jr., 1980: *Measurement Uncertainty Handbook*, Instrument Society of America, Research Triangle Park, NC 27709, 1–172.

Bevington, P.R., 1969: *Data Reduction and Error Analysis for the Physical Sciences*, McGraw-Hill, New York, 336 pp.

Knowlton, D., S. Skinner, and C. Walther, 1985: Aircraft Data System (ADS), NCAR Hardware Manual 003-41ADS-003, National Center for Atmospheric Research, Boulder, CO.

Zhang, Z.Q., 1988: *Fundamental studies of aerosol filtration by fibrous filters in the transition region*, Ph.D. Thesis, University of Minnesota Mechanical Engineering Dept., Chap. 3.

3. Data acquisition and processing

3.1 *Frequency response of instrument*

Due to particle transit through the sample line and electronic response, there is a one to two second delay between the time when particles enter the inlet and the time they are recorded on the data system. The instrument responds to concentration increases faster than this, requiring less than 1/3 second to indicate a large increase (a factor of 100) and less than 1/6 second to shift from 10% to 90% of the maximum value. Because of turbulent mixing inside the sample line, however, the instrument may take as long as two seconds to return to a low baseline value after measuring very large particle concentrations.

3.2 *Data format, sampling rate, and recommended filtering and conditioning*

The CNC has been enabled for high concentration measurement by setting the toggle switch on the main circuit board (shown in Figure 6a) to "OTHER." One 15 V, 0.25 microsecond digital pulse is emitted from the BNC connector on the back of the counter for each particle detected. (These pulses have been converted inside the instrument from 200 mV analog pulses.) The digital pulses are transmitted to a counter card (Revision B) in the Aircraft Data System (ADS). The card is terminated with a 51 ohm resistor and usually employs a prescale factor of 16 in order to detect high concentrations. A sample rate of 5 samples per second (sps) is standard for the unfiltered digital signal (CNTS).

The analog pressure (PCN) and flow (FCN and XICN) signals are 0-5 V and employ a gain of two and no offset in the ADS. Calibration coefficients convert the raw signals to engineering units of mb and slpm, respectively. They are all sampled at 5 sps and filtered to 1 sps. Housekeeping variable FCBADS, the CN inlet temperature, is recorded at 1 sps.

3.3 *Algorithms for conversion of data bits to scientific values*

Particle concentration (CONCN) is calculated from the raw digital output (CNTS) and corrected sample flow rate (FCNC). FCNC and the corrected isokinetic side flow (XICNC) are calculated from the mass flow rates (FCN and XICN) and inlet temperature and pressure (FCBADS and PCN, respectively). A listing of these parameters and the associated calculations is given in Appendix B. These calculations are included in the onboard as well as the final output software. Note that the CNTS sample rate and prescale factor are included in the software, which must be modified if a different rate or prescale factor is used. The final CONCN output rate is 5 sps for high rate data sets.

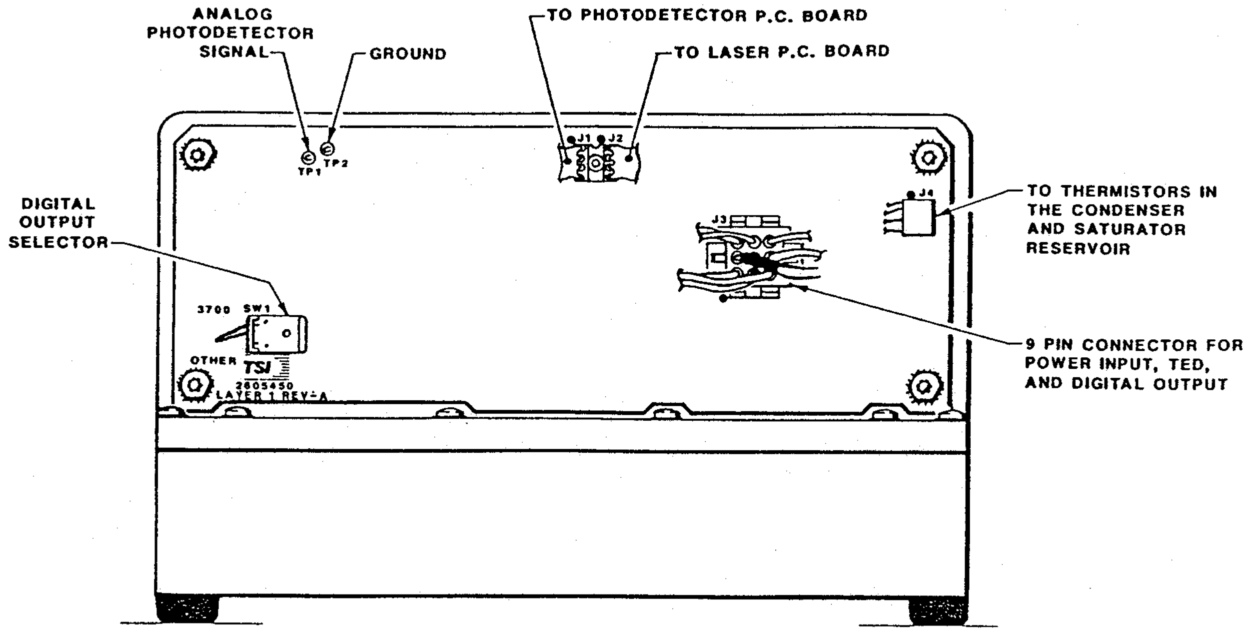


FIGURE 6a. Main circuit board of the Model 3760, viewed from the rear of the instrument

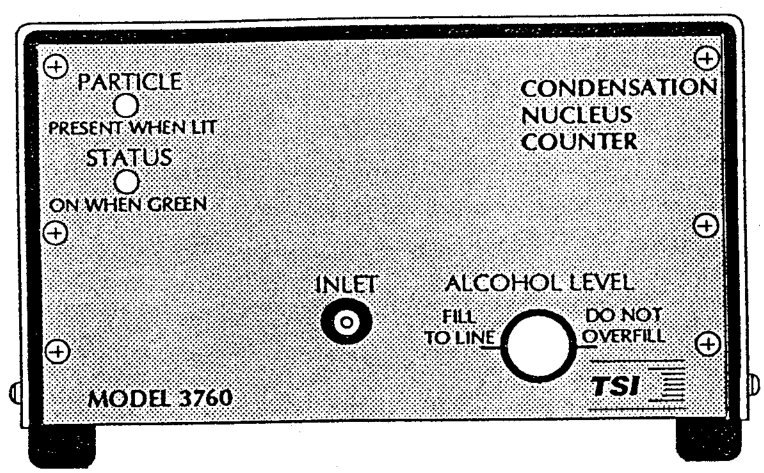


FIGURE 6b. Front panel of the Model 3760

4. Operation, calibration, maintenance, and troubleshooting

4.1 *Installation in aircraft*

The inlet for the CN counter is located on top of the aircraft, where the airflow is relatively undisturbed, and points into the airstream (parallel to the aircraft fuselage and the centerline until actual airflow measurements become available). As mentioned before, to minimize particle losses, the instrument and inlet are connected by stainless steel tubing which is as short and straight as possible. The back of the instrument is exposed to cabin air for cooling. On the Sabreliner, the CNC, flow meters, and pressure transducer are all mounted on a plate on top of a standard rack, and the pump is installed on the seat rails. (Refer to Section 1.2 for more details on installation and plumbing of this instrument.)

IMPORTANT: The CN counter itself should always be carried and mounted upright. Any prolonged or severe tipping of the instrument from the horizontal position could contaminate the optics with butanol, resulting in failure to detect particles.

4.2 *Operation and maintenance*

The CNC has no power switch, so the unit and flow meter power supply are plugged in directly and powered up with the aircraft. The valve downstream of the pump is closed and the pump is off until after takeoff. Depending on cabin temperature, the instrument and flow meters will require 10–20 minutes to warm up, which is usually accomplished during alignment of the Inertial Navigation System (INS) and runup. The STATUS light on the front panel will turn from red to green when the instrument is at operating temperature. Every few flights, check the digital flow meter readouts after the warmup period with no flow through the system—if they are more than 2% off from zero (a digital reading of ± 0.020), they may require zero adjustment. See a Sierra flow meter manual for instructions.

After takeoff, completely open the pump valve and plug in the pump. The corrected sample and isokinetic side flow rates will increase to the desired values and the PARTICLE light on the front of the instrument will be solid red when particles are being counted. Every few flights, check the flow rates again (FCNC and XICNC) at altitude to make sure they are being maintained (see Section 1.2). Just before landing, unplug the pump and close the pump valve.

The CN counter requires little routine maintenance. Before each project, the inlet and lines upstream of the counter should be thoroughly cleaned. After the initial installation, fittings should be tightened and the unit should be run on the ground with an absolute filter attached to the inlet to test for leaks in the inlet line. The butanol should also be filled before and drained after each project (see below).

Fresh butanol (reagent grade) and bottles with special fittings for filling and draining the instrument are kept in the flameproof materials cabinet in the hangar storage room at RAF. Before each project, fill the "CLEAN BUTANOL" bottle with about 50 mls of fresh butanol and attach it to the special fitting on the back of the CN counter. (If the instrument has two fittings, the top one is for filling and the bottom is for draining.) First, loosen the bottle cap as an airlock, then raise the bottle and slowly gravity feed the instrument with butanol. **IMPORTANT: Do not fill to the "FILL" line indicated**

in the window on the front of the instrument (Figure 6b)! In flight, the excess butanol may enter the optical block and temporarily cause low particle counts.

After the butanol is added, it should be visible at the fill line only when the instrument is tilted forward at a 15 to 30 degree angle. (With the current setup, this requires that the instrument be unbolted from the mounting plate.) Under normal conditions, add another 50 mls of butanol after about 25 hours of operation. After each project, drain any excess butanol into the designated "USED BUTANOL" bottle by loosening the cap, lowering the bottle below the counter, and attaching it to the drain port on the back. Tip the instrument back to evacuate as much alcohol as possible. Do not reuse or pour down a drain. The used butanol is periodically disposed of by the NCAR Safety Officer. **IMPORTANT: Handle butanol in a well-ventilated location and avoid spillage as the vapor can cause nausea or headaches when inhaled and is potentially toxic at high concentrations.**

The charcoal filter has a long life under these conditions, but it should be replaced about once a year as a precaution. With prolonged operation in very humid environments, water may be ingested into the butanol reservoir, lowering the instrument's efficiency. Under such circumstances, the butanol should be drained and replaced after about every ten hours of operation.

No routine cleaning of the optical block is required. However, with prolonged sampling of polluted air, the critical orifice and aerosol-focussing nozzle inside the CN counter may become dirty, causing low flow rates or internal losses of particles. As a precaution, these components should be removed and cleaned after each project which routinely samples dirty air. This procedure is described in Appendix C.

4.3 *Calibration, including techniques and recalibration intervals*

No direct calibration of the CNC is required, since particle pulses are well above the electronic noise level and each one corresponds to exactly one particle (except at high concentrations; see Section 2.1). Counting efficiency for different sizes of particles has been measured by TSI and verified by independent researchers at the University of Minnesota (Figure 4). For each project, the pressure transducer, PCN, should be calibrated in the 200 to 1000 mb range by usual RAF procedures. Flow meter calibration is verified with a bubble flow meter (done periodically by the RAF chemistry group).

4.4 *Assessment of operation*

Corrected sample flow rate (FCNC) should range between about 1.2 and 1.7 vlpm at all times to ensure proper particle detection. Total flow rate (sample flow rate + isokinetic side flow rate) should satisfy isokinetic requirements given in Appendix A within $\pm 10\%$. Both flow rate measurements are subject to VHF radio interference. At Sabreliner speeds, inlet pressure (PCN) should be approximately 60 mb greater than the ambient outside pressure. Concentration (CONCN) should be roughly three times the raw counts per 1/5th second with a prescale factor of 16 (CNTS). Calculated concentrations should be near the values given in the following section.

4.5 *Diagnosis and repair*

The main problems that can occur with the CN counter are caused by either inadequate flow, improper butanol levels, leaks, or counter card problems. When sampling, the particle concentration should be greater than 10^4 cm^{-3} in relatively dirty air and $< 10^3$ in relatively clean air. Without flow through the system, CNTS and CONCN should both equal 0. If the CN counter and pump are on but CNTS is still 0, make sure the CN counter is warmed up (green status light), the pump and flow meters are on, and the valve by the pump is open. Check that the sample flow (FCNC) is not blocked anywhere and is between 1.2 and 1.7 vlpm. If all the above checks out and the particle light on the front of the instrument is lit, look for problems with the counter card in the ADS or the connection to it.

CN concentrations may be greater than zero but low for the following reasons:

1. Incorrect sample rate, prescale factor, or software
2. Inadequate flow rate
3. Overfilling of butanol and/or tipping of the instrument
4. Inadequate butanol supply
5. Dirty optics

First verify that the software and counter card setup is correct. If so, check the sample flow rate (FCNC). If it is low, the critical orifice or one of the lines may be blocked. Remove the orifice and clean it if necessary (Appendix C). If the flow is high, there may be a leak in the vacuum line between the back of the instrument and the flow meter. Leak check this part of the system. **IMPORTANT: When leaks are suspected, leak check system components other than the CNC first. If the instrument itself is suspect and must be checked, bring the internal pressure up or down very gradually, so that the pressure-equalizing filter does not become clogged with butanol.** If the flow rate is adequate, check the butanol level and fill if necessary. If overfilling or tipping is suspected, drain the excess butanol and run the instrument normally on the ground until the problem corrects itself (the butanol inside the optics will eventually dry out). If CNTS is still low, verify with an oscilloscope that the pulses are of the correct amplitude and duration using the procedure described in the TSI CN manual. If not, contact TSI technical service for assistance.

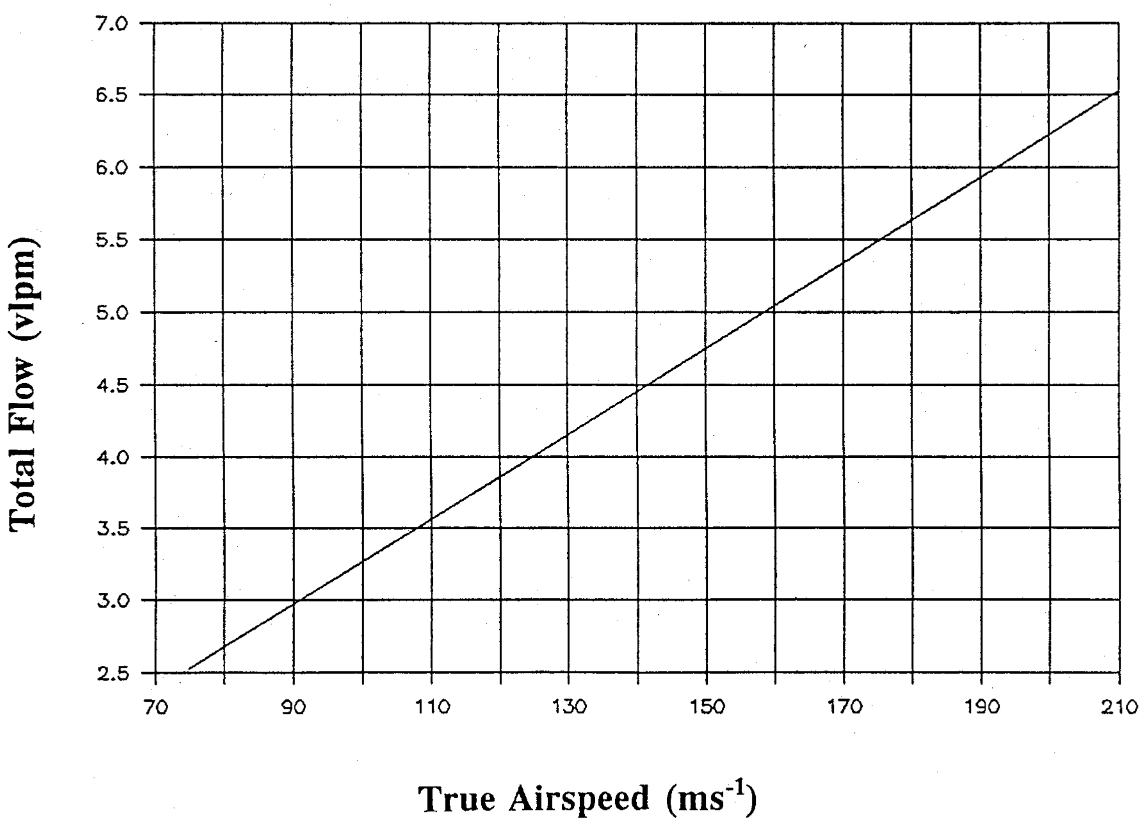
A complete listing of parts specifications and suppliers is given in Appendix D. Electrical schematics are contained in the TSI instruction manual.

APPENDIX A

Isokinetic flow rate as a function of true airspeed

True Airspeed, m/s	Total Flow Rate (FCNC+XICNC), vlpm
75	2.3
90	2.8
105	3.3
120	3.7
135	4.2
150	4.7
165	5.1
180	5.6
195	6.1
210	6.5

General Equation: Total Flow (vlpm) = 0.0311×TAS (m/s)



APPENDIX B

CN counter software

(Revised 9/90)

MODE 1 VARIABLES:		**Rate**	**Filter**
PCN:	Inlet pressure (0–5 V, Gain 2)	5	1
FCN:	Sample flow rate (0–5 V, Gain 2)	5	1
XICN:	"Isokinetic" side flow (0–5 V, Gain 2)	5	1
CNTS:	Particle count (digital)	5	none

MODE 2 VARIABLES:

PCN: Inlet pressure in mb
FCN: Sample flow rate in slpm*
XICN: "Isokinetic" side flow in slpm*
FCBADS: Inlet temperature in °C

DERIVED PARAMETERS (using Mode 2 variables except CNTS)

```
C     FCNC:     Corrected sample flow rate in vlpm**
C               1013.25 = standard pressure in mb
C               273.15 = standard temperature in K
C               21.11 = calibration temperature in °C
      FCNC = FCN*(1013.25/PCN)*((FCBADS+273.15)/(21.11+273.15))
C
C     XICNC:    Corrected side flow rate in vlpm**
      XICNC = XICN*(1013.25/PCN)*((FCBADS+273.15)/(21.11+273.15))
C
C     CONCN:    Particle concentration in #/cm^3
C               SR = CNTS rate (samples per second)
C               DIV = counter card prescale factor
                SR = 5.
                DIV = 16.
C     Protect CONCN from division by zero before pump is turned on
                IF (FCNC.LE.0.0) FCNC = 0.01
                CONCN = CNTS*SR*DIV/(FCNC*1000./60.)
C     Particle concentration corrected for coincidence:
C     4.167E-6 is time in view volume (.25 microseconds)
                CONCN = CONCN*EXP(4.167E-6*CONCN*FCNC)
C
```

*   slpm = standard liters per minute
**   vlpm = volumetric liters per minute

APPENDIX C

Instructions for cleaning the critical orifice and nozzle

1. Remove the CN counter cover. Then remove the optics module (block containing "Danger" warning label) by unscrewing the four screws (two inside on top and two outside on back). (Do not disconnect any electrical cables.)
2. To clean the critical orifice: Tip the optics block up; on the back are two orifices with white nylon O-rings. Pull out the top orifice (CN sample line) and clean it. (Blow out any foreign material and flush with alcohol or acetone.)
3. To clean the aerosol-focussing nozzle: Turn the optics block over; on the bottom is one end of the nozzle (a black Delrin piece about 15 mm in diameter). Pull the nozzle straight out (using a razor blade, small screwdriver, or your fingernail for leverage). Gently clean the nozzle by flushing with alcohol or acetone. Be careful not to deform or damage the narrow end of the nozzle (which may cause stray particle counts). Replace it in the bottom of the optical block.
4. Replace the optics and carefully replace all four screws with equal pressure to avoid leaks; replace the instrument cover.
5. Check the sample flow rate to make sure no leaks have been introduced.

APPENDIX D
Specifications and suppliers

1. CN Counter
   TSI Model 3760
   Digital Output: 15 V, 0.25 μs square pulse
   Weight: 8 lbs.
   Power: 110 VAC, 60 Hz
   Supplier: TSI Inc., P.O. Box 64394, St. Paul, MN 55164, (612) 483-0900
   Technical Contacts at TSI: Patricia Keady, Maynard Havlicek, Rob Caldow
2. Flow Meters
   Sierra Model 830, 0–2 slpm and 0–10 slpm
   Analog Output: 0–5 VDC
   Power Supply: 110 VAC, 60 Hz, 50 W.
   Weight: 5 lbs. total for 2 meters; 10 lbs. for power supply
   Supplier: Sierra Instruments, P.O. Box 909, Carmel Valley, CA 93924, (800) 345-8725
   Technical Contact at Sierra: Corey Merritt
3. Pressure Transducer
   Heise Model 623
   Analog Output: 0–5 VDC for 0-1500 mb range
   Weight: 2 lbs.
   Power: 28 VDC, 50 mA max
   Supplier: Dresser Industries, Newtown, CT 06470, (203) 426-3115
4. Vacuum Pump
   Gast Model DOA-V191-AA, 1/8 HP
   Weight: 15 lbs.
   Power: 110 VAC, 60 Hz, 90 W continuous
   Supplier: Fiero Fluid Power Inc., 10515 E. 40th Avenue, Denver, CO 80239, (303) 373-2600
5. Charcoal Filter
   Analabs Charcoal Drier Cat. #HGC–147
   1/4″ Swagelock Fittings
   Supplier: Analabs, 140 Water St., Norwalk, CT 06850, (800) 243-4398
6. Pressure Equalizing Filter
   Balston 9922-05-DQ disposable filter tube
   Supplier: Webster Associates, 7300 So. Alton Way, Ste. L, Englewood, CO 80112, (303) 773-8989
7. Quick-Disconnect Fitting for Butanol Bottles
   Colder plastic male insert (shutoff) #PMCD-22-02
   Supplier: Fluid Power Tech, 6850 N. Broadway, Suite B, Denver, CO 80221, (303) 650-1500