QLD CLOUD SEEDING RESEARCH PROJECT

MANUAL FOR ZS-JRA

A guide to the operation of instruments aboard the SAWS AEROCOMMANDER 690A

Draft updated on 1st December 2008 by Ian P. Craig

Contents

1 Introduction

Due to increasing demands on water supplies and the negative effects of climate variability and change, south east Queensland frequently suffers severe water shortages. Based on recent scientific advances in cloud seeding techniques, a research project was commissioned by the Queensland Government in 2007. The aim of the project is to investigate the potential for cloud seeding technologies in the Somerset and Wivenhoe catchments of south east Queensland as part of the solution to the regions water shortages. The ongoing project has involved over 40 dedicated personnel, research aircraft and the Bureau of Meteorology's advanced weather radar facilities located at Redbank Plains and Mt Stapylton. During the first season, which took place from December 2007 to March 2008, randomised seeding experiments were carried out to quantify the effect of hygroscopic seeding using pyrotechnic flares which release small particles of potassium chloride at the base of convective clouds (Bruintjes, 1999). Research into the climatological characteristics of precipitation in the target area including the frequency of cumulus clouds suitable for seeding has also been undertaken. The CP2 polarimetric radar at Redbank Plains and the local Bureau of Meteorology radar network are used to evaluate the effects of seeding on precipitation flux, duration and storm dynamics including secondary cell initiation. Radar estimates of precipitation are calibrated using a ground-based video disdrometer. Cloud microphysical data was collected by the research aircraft which was equipped with over 20 microphysical recording instruments. The program has been highly successful in providing cloud statistical data for the target area in addition to evaluating aircraft based hygroscopic seeding activities. Sub-tropical maritime warm shallow convective clouds rather than the more potentially suitable deep convective cloud systems were a feature of the first seasons weather. Although positive trends in terms of increased cell duration are apparent in the data, the number of randomised cases (27) is not sufficient to draw statistically significant conclusions regarding the efficacy of hygroscopic seeding of these clouds. This important scientific research program has continued into the 2008-2009 season. Based on results to date there is strong incentive for further research into the hygroscopic seeding of deep convective clouds throughout south east Queensland and its potential for inland catchments.

1.1 Objectives of the QCSRP

The overall objective of the CSRP was to provide an assessment of the potential for cloud seeding to enhance rainfall in Southeast Queensland. The scientific objectives were to make preliminary assessments of:

(1) The climatological characteristics of precipitation and, in particular, the frequency of clouds potentially suitable for seeding.
(2) The approaches necessary to obtain robust estimates of precipitation amount and retrieve microphysical properties of the clouds.
(3) The effect of cloud seeding on storm microphysics and dynamics. This includes precipitation particle types, number and size of precipitation particles, and horizontal and vertical air motions.
(4) Evidence from cloud seeding of increased secondary convective storm initiation.

(5) Evidence of precipitation enhancement from cloud seeding.

The operational objectives of Phase I (and potentially Phase II) of the Rainfall Enhancement Assessment Program in Southeast Queensland are to:

(a) Understand the natural characteristics of SE Queensland clouds and their environment.
(b) Make quantitative measurements of radar-derived storm-based rainfall for assessing potential effects from hygroscopic and glaciogenic seeding.
(c) If an effect is found, understand the time history of such effect and the probable cause.
(d) Test the concepts of the South African and Mexican hygroscopic seeding experimental approach in Southeast Queensland.
(e) Collect physical measurements in natural and seeded clouds and provide substantiation for the physical hypothesis.
(f) Conduct preliminary theoretical studies on the logistics and feasibility to extend storm-scale effects to an area wide effect.

1.2 QCSRP PARTICIPANTS

The project is managed by the Research Applications Laboratory (RAL), National Centre for Atmospheric Research (NCAR) Boulder Colorado. The project is sponsored by the Queensland Government. The University of Southern Queensland (USQ), Monash University (Monash), the Bureau of Meteorology (BoM) and the Commonwealth Scientific Industrial Research Organisation (CSIRO) also have various roles in the research project.

- Queensland Government, Climate Change Centre of Excellence (QCCCE), initially through the Department of Natural Resources and Water but subsequently through the Department of Sustainability, Climate Change, and Innovation.
- Bureau of Meteorology (BOM) and Bureau of Meteorology Research Centre (BMRC)
- Monash University
- CSIRO Australia
- University of Southern Queensland (USQ)
- Witwatersrand University (WITS)
- South African Weather Service (SAWS)
- Orsmond Aerial Spray
- National Center for Atmospheric Research (NCAR), Boulder, Colorado
- MIPD
- WMI

1.3 AEROCOMMANDER AIRCRAFT

The aircraft is an Aerocommander 690A twin fitted with TPE331 Garrett 700 horse power turbine engines. It is owned by the South African Weather Service (SAWS) and operated by Orsmond Aviation Ltd South Africa. The cruise speed of the aircraft is approximately 150 knots and the aircraft is well suited to weather research applications.

Figure 1 **SAWS Aerocommander 690A (ZS-JRA) carrying out ground tests following a successful full turboprop engine replacement which took less than two weeks to complete.**
Engineer : Harry McGarry. Pilots :- Ret Orsmond, Hans Krugar, Gary Wiggins and John Hingst.

The aircraft was built in the mid 1970s and has been operated for meteorological research purposes by staff the South African Weather Service (SAWS) and the University of Witswatersrand for approximately twenty years.

1.4 SCIENTIFIC INSTRUMENTATION

Scientific instrumentation described in this manual are the instruments which have been mounted aboard the SAWS Aerocommander 690A. The aircraft has a registration ZS-JRA and whilst in operation during the Queensland Government Cloud Seeding Research Project (QCSRP) has a designated call sign "SEEDA1".

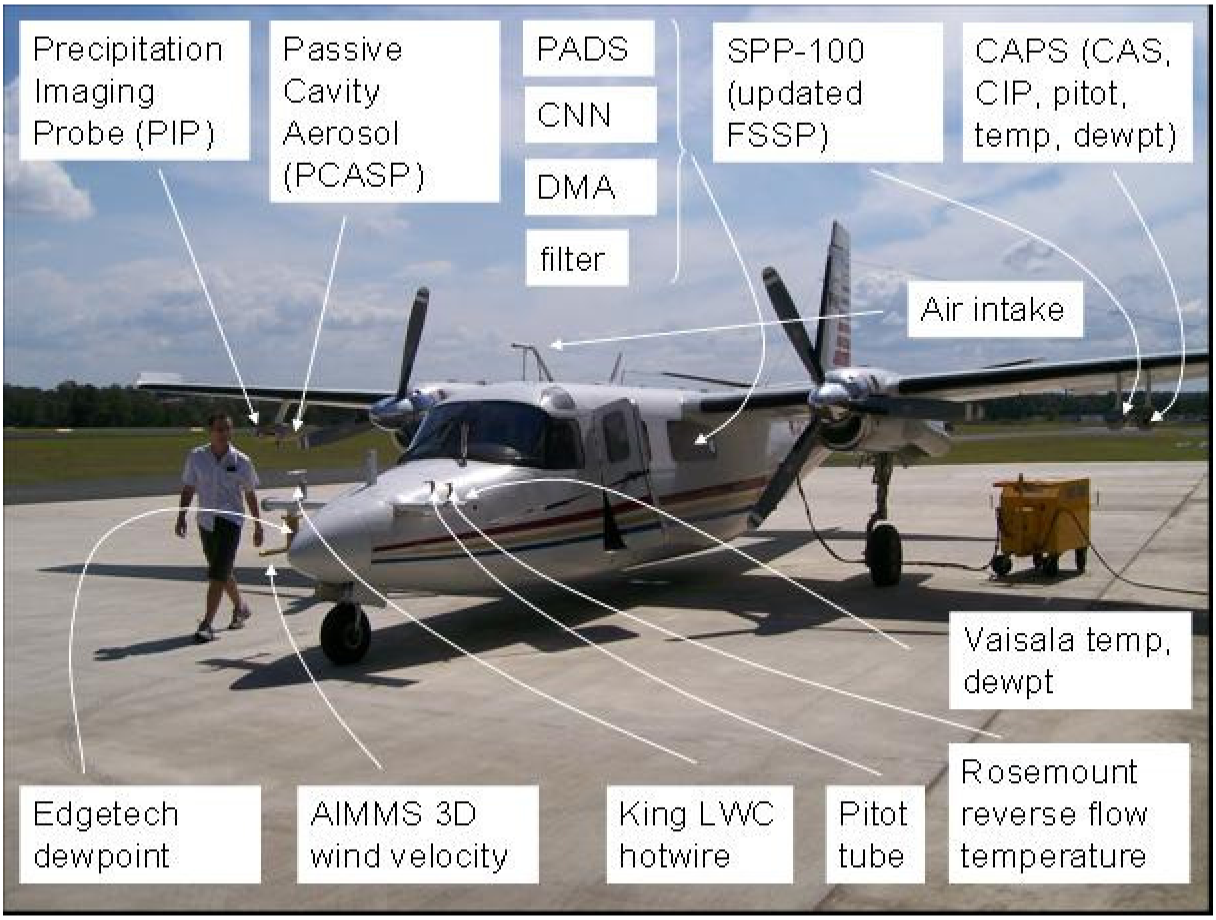


Figure 2 Mounting positions of the various scientific instruments on ZS-JRA

The scientific instrumentation aboard ZS-JRA underwent an extensive upgrade between the 2007/8 and 2008/9 field campaigns. This included a completely new data aquisition system (DMT PADS), an integrated cloud physics probe (DMT CAPS), a three dimensional wind velocity probe (Aventech AIMMS) and a cooled mirror fast response dewpoint sensor (Edgetech VIGILANT).

Table 1 List of instrumentation on SEEDA1 (ZS-JRA Aerocommander).

Instrument	Purpose/Comment	Range
	State Variables	
Rosemount Temperature, Static and Dynamic Pressure, and GPS	Temperature, pressure, altitude, TAS, lat-long - recorded on telemetry box and PADS data system	*multiple*
Edgetech Cooled Mirror	Dewpoint	-40 to 60 C
Vaisala Temperature and Relative Humidity	Secondary temperature and moisture content	-50 to 50 C, 0-100%
	Cloud Physics	
SPP-100	Cloud droplet spectra	3-47 µm
CIP	Cloud Imaging Probe	25-1500 µm
PIP	Precipitation Imaging Probe	100-6200 µm
King Hotwire	Liquid water content	0.01 – 3 g m^{-3}
CAPS probe	Cloud and Aerosol Probe ~ CAS, CIP, LWC; static and dynamic pressure; temperature	*multiple*
	Aerosols	
CCN Counter	Cloud condensation nuclei concentration and spectra	Depends on Supersaturation
DMA	Fine mode aerosol spectra and concentration	0.01 to 1 µm
PCASP	Aerosol concentration and spectra	0.1 to 3 µm
	Trace Gases	
TECO SO_2 (43c)	Sulphur dioxide	0-100 ppb
TECO CO (48c)	Carbon monoxide	0-10,000 ppb
TECO O_3 (49i)	Ozone	0-200 ppb
TECO NO_y (42c)	Nitrogen oxides	0-1000 ppb
	Cloud and Situation Imagery	
Digital still camera	To show development of clouds and treatment situations for historical purposes	N/A

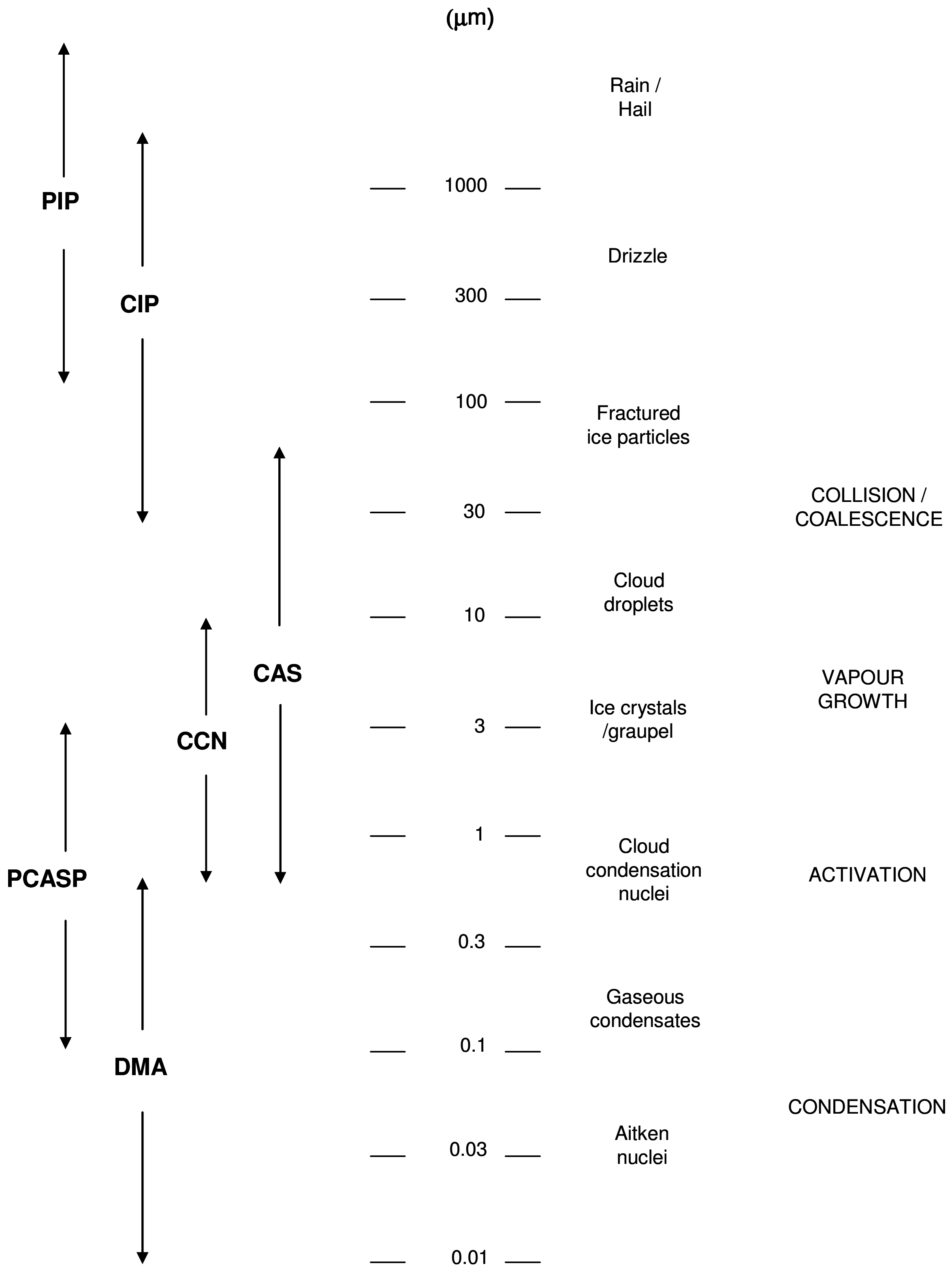


Figure 3 **Range of particle sizes measured by the instruments aboard ZS-JRA**

2 DMT Particle Analysis and Display System (PADS)

PADS proprietry software is a copyrighted commercially available product available from Droplet Measurement Technologies (DMT) located at 5710 Flatiron Parkway, Unit B, Boulder, CO 80301 USA. The following paragraph is taken from the latest current version of the DMT PADS Operator Manual (DOC-0116 Revision F).

The Particle Analysis Data System (PADS) is a software package designed to interface with all the instruments produced by Droplet Measurement Technologies (DMT) and other leading instruments used in the atmospheric sciences. The program is designed using LabView 8.0, combining ease of instrument connectivity and powerful graphical displays. PADS uses a tab based structure to display information about individual instruments and the overall program. The system will sample real time information from the instruments, record data to the files, and read files for graphical analysis. The data file format is comma delimited so that the data can be imported into spreadsheet programs for additional analysis. The program is configurable to use any combination of instruments and has the ability to sample up to 10Hz.

The tabs are arranged from left to right as follows :-

1) PIP
2) CIP
3) CAS
4) Hotwire-LWC
5) CAPS Summary
6) CCN
7) SPP_200
8) AIMMS20
9) Dewpoint
10) Collective 1
11) Setup
12) Debug

3 DMT CAPS Probe

The DMT Cloud, Aerosol and Precipitation Spectrometer (CAPS) is a combination probe consisting of four instruments to characterise cloud parameters. These include the following :-

1) Cloud Imaging Probe (CIP)
2) Cloud and Aerosol Spectrometer (CAS)
3) Liquid Water Content (LWC)
4) Pitot tube

The probe's combined measuring range is from 0.3um to 1.55um particle diameter and from 0.01 to 3 gm^{3}. liquid water content. The data displaying software is the Particle Analysis and Collection System (PACS) which facilitates real time size distributions and derived parameters to be viewed

Figure 4 **CAPS probe (on right) incorporating four cloud physics measuring instruments including - Cloud Imaging Probe (CIP), Cloud and Aerosol Spectrometer (CAS), Liquid Water Content (LWC) hot wire instrument in addition to a pitot pressure tube**

4 Aventech AIMMS Probe

AIMMS	*Aircraft Integrated Meteorological Measurement System*	*Three dimensional position, velocity, acceleration,*	*pitch, yaw, roll, windspeed, temperature, pressure and humidity*	

description description

description description

description description

description description

description description

5 Static Pressure

5.1 ROSEMOUNT STATIC PRESSURE

Rosemount Static Pressure	*static ports located along the fuselage*	*transducer*	*pressure*	

5.2 AIMMS STATIC PRESSURE

AIMMS Static Pressure	*static port in AIMMS probe*	*transducer*	*pressure*	

5.3 PRESSURE ALTITUDE CALCULATION

According to RAF /NCAR documentation (Bulletin 9, Appendix B), pressure determined altitude of the aircraft is defined as :-

$$P_{ALT} = (T_{ref}/\text{lapse})\ (1-(P_{stat}/P_{ref})^{x} \qquad (8)$$

where P_{ALT} is the pressure altitude
T_{ref} is the reference temperature for the standard atmosphere (288.15K)
lapse is the standard lapse rate (0.0065 K/m)
P_{stat} is the measured static pressure
P_{ref} is the reference pressure for the standard atmosphere (1013.246 mbar)
x is R_o lapse / (M_w g) = R lapse/g = 0.190284
Ro is the universal gas constant
Mw is the molecular dry weight of air, g
g is the acceleration due to gravity, ms^{-2}
R is the gas constant for dry air

Comparison with "calc.c" code

```
alt1 = (3.2808*(1.0-pow(stpl/1013.25, 0.190284)*288.15))/0.0065;
```

Notes
i) 3.2808 is the metres to feet conversion factor
ii) 0.190284 is the value R.lapse / g
iii) 288.15 is the standard atm temp
iv) 0.0065 the standard atm moist lapse rate

6 Dynamic Pressure

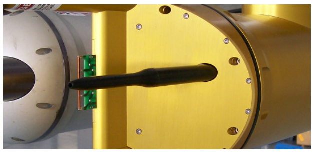
6.1 Nose Pitot

Dynamic Pressure	*Pitot tube located at on the left (port) nose boom*	*pressure transducer*	*range*	

6.2 AIMMS Pitot

AIMMS Pitot Pressure	*dynamic ports in AIMMS pitot*	*pressure transducer*	*range*	

6.3 CAPS Pitot

Caps Pitot	*dynamic port in pitot tube*	*pressure transducer*	0-500 knots	

6.4 BERNOULLI'S THEOREM

The pitot tube is a pressure measuring instrument used to measure fluid flow velocity, and more specifically, used to determine the airspeed of an aircraft. The Pitot tube was invented by Italian-born French engineer Henri Pitot in the early 1700s, and was modified to its modern form in the mid 1800s by French scientist Henry Darcy. It consists of a basic tube pointing directly into the fluid flow. As this tube contains air, a pressure can be measured as the moving air is brought to rest. This pressure is the stagnation pressure of the air, also known as the total pressure, or sometimes (particularly in aviation circles) the pitot pressure. This pressure is compared to the static pressure to obtain airspeed.

Bernoulli's equation along a stagnation streamline gives :-

$$p_e + \frac{1}{2}\rho V_e^2 = p_0 + \frac{1}{2}\rho V_0^2 \qquad 1.$$

where the point e is far upstream and point 0 is at the stagnation point. Since the velocity at the stagnation point is zero,

$$p_e + \frac{1}{2}\rho V_e^2 = p_0$$

static pressure + dynamic pressure = stagnation pressure 2.

6.5 TRUE AIRSPEED (TAS) CALCULATION

According to RAF /NCAR documentation (Bulletin 9, Appendix B), true airspeed of the aircraft is

$$TAS = M\left(\gamma R T_{amb}\right)^{0.5} \qquad 4$$

where Mach Number M (ie. the speed of sound in air) is :-

$$M = \left(2\frac{c_v}{R}\left[\left(\frac{P_{dyn}}{P_{stat}}+1\right)^{R/c_p} - 1\right]\right)^{1/2} \qquad 5$$

As $\gamma = c_p / c_v$ and $R = c_p - c_v$, and bringing M^2 inside the square root bracket :-

$$TAS = \left(2\frac{c_v}{R}\left[\left(\frac{P_{dyn}}{P_{stat}}+1\right)^{R/c_p} - 1\right]\gamma R T_{amb}\right)^{1/2} \qquad 6$$

cancelling R,

$$TAS = \left(2 c_v \gamma T_{amb}\left[\left(\frac{P_{dyn}}{P_{stat}}+1\right)^{R/c_p} - 1\right]\right)^{1/2} \qquad 7$$

substituting γ

$$TAS = \left(2 c_p T_{amb}\left[\left(\frac{P_{dyn}}{P_{stat}}+1\right)^{R/c_p} - 1\right]\right)^{1/2} \qquad 8$$

Comparison with “calc.c” code

```
tas1 = sqrt (2009.6 * rmt2 *(pow (1.0 + dfpl/stpl, 0.2856541) – 1.0));
```

Notes

i) 2009.6 is equal to the value of $2c_p$ when the units are J kg^{-1} K^{-1}

ii) dfpl/stpl are the differential or dynamic / static pressure readings, P_{dyn} / P_{stat} from the Pitot

iii) 0.2856541 is equal to the value of R / c_p

iv) table of gas constants for air :-

	cal/g/K	J/kg/K
c_p	0.240	1004.8
c_v	0.171	717.8
R	0.069	287
γ	1.4	1.4

7 Temperature

7.1 ROSEMOUNT TEMPERATURE

Rosemount Total Temperature	*Pitot tube located at on the left (port) nose boom*	*resistance of a platinum wound ceramic core*	range	

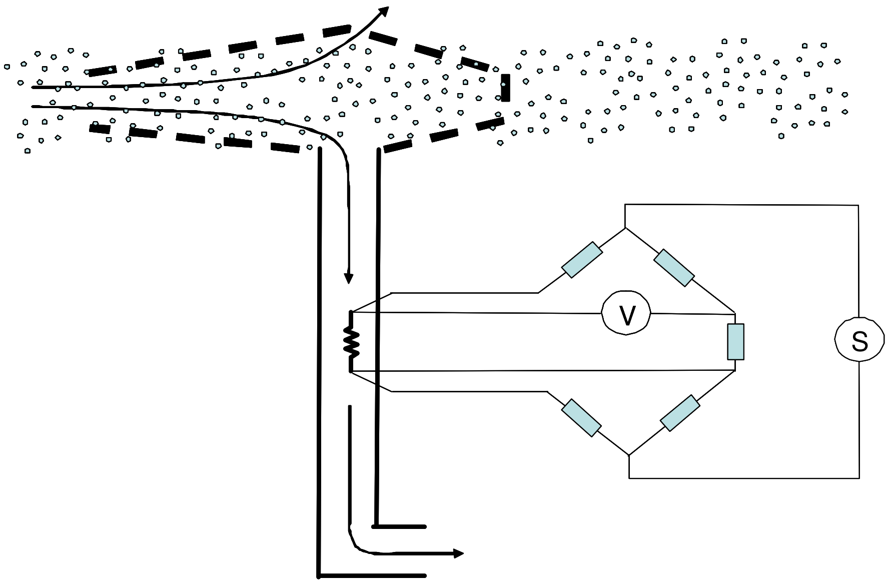
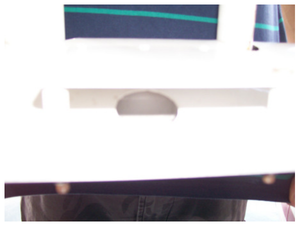


Figure 5 Principle of operation of the Rosemount Temperature Sensor – air is decelerated with a diffuser and separated from large particles by means of a right angle bend. The change in resistance of a platinum wire wound sensor with a ceramic core is measured using a Wheatstone bridge circuit.

7.2 VAISALA TEMPERATURE

Vaisala Total Temperature	*Located under a cover on left (port) nose boom*	*transducer ~ resistance of a platinum wound ceramic core*	-50 to +50 C	

7.3 AIMMS TEMPERATURE

AIMMS Total Temperature	*Aircraft Integrated Meteorological Measurement System*	*transducer ~ resistance of a platinum wound ceramic core*	-50 to +50 C	

7.4 AMBIENT TEMPERATURE CALCULATION

According to RAF/NCAR documentation (Bulletin 9, Appendix B), ambient temperature may be calculated as follows :-

$$T_{amb} = T_{tot} \Big/ \left(1 + \left(\frac{\gamma - 1}{2}\right) r M^2\right) \qquad 3.$$

where T_{amb} is the static or ambient temperature

T_{tot} is the total temperature recorded by the Rosemount or Vaisala instrument

γ is the ratio of specific heats c_p / c_v = 1.4 for air

r is the recovery ratio recorded for the instrument (for most aircraft temperature sensors between 0.8 and 0.95

M is the Mach number ie. aircraft speed as a proportion of the speed of sound, $\sqrt{\gamma RT}$

Mach number may be defined as :-

$$M = \left(\frac{2}{\gamma - 1}\left[\left(\frac{P_{dyn}}{P_{stat}} + 1\right)^{\frac{\gamma - 1}{\gamma}} - 1\right]\right)^{\frac{1}{2}} \qquad 4.$$

Inserting M^2 into eqn (1), the term in the inner bracket of eqn 1 disappears, and the expression for T_{amb} then becomes as described in the "Calculations for JRA" :-

$$T_{amb} = T_{tot} \Bigg/ \left(1 + r \left[\left(\frac{P_{dyn}}{P_{stat}} + 1 \right)^{\frac{\gamma-1}{\gamma}} - 1 \right] \right) \qquad 5.$$

<u>Comparison with "calc.c" code</u>

rmt2 = (rmt1 + 273.15)/1.0 + 0.847 * (pow(1.0 + dfpl/stpl, 0.2856541) – 1.0))

<u>Notes</u>

i) 273.15 is the conversion of raw signal rmt1 into degrees kelvin giving rmt2 also in kelvin
ii) the value 0.847 is the assumed value for r
iii) dfpl/stpl are the differential or dynamic / static pressure readings from the Pitot
iv) 0.2856541 is close to the value of (1.4-1)/1.4 or 2/7

7.5 Sounding Comparison Procedure

Compare a JRA ascent sounding with a balloon sonde sounding released from an airport.

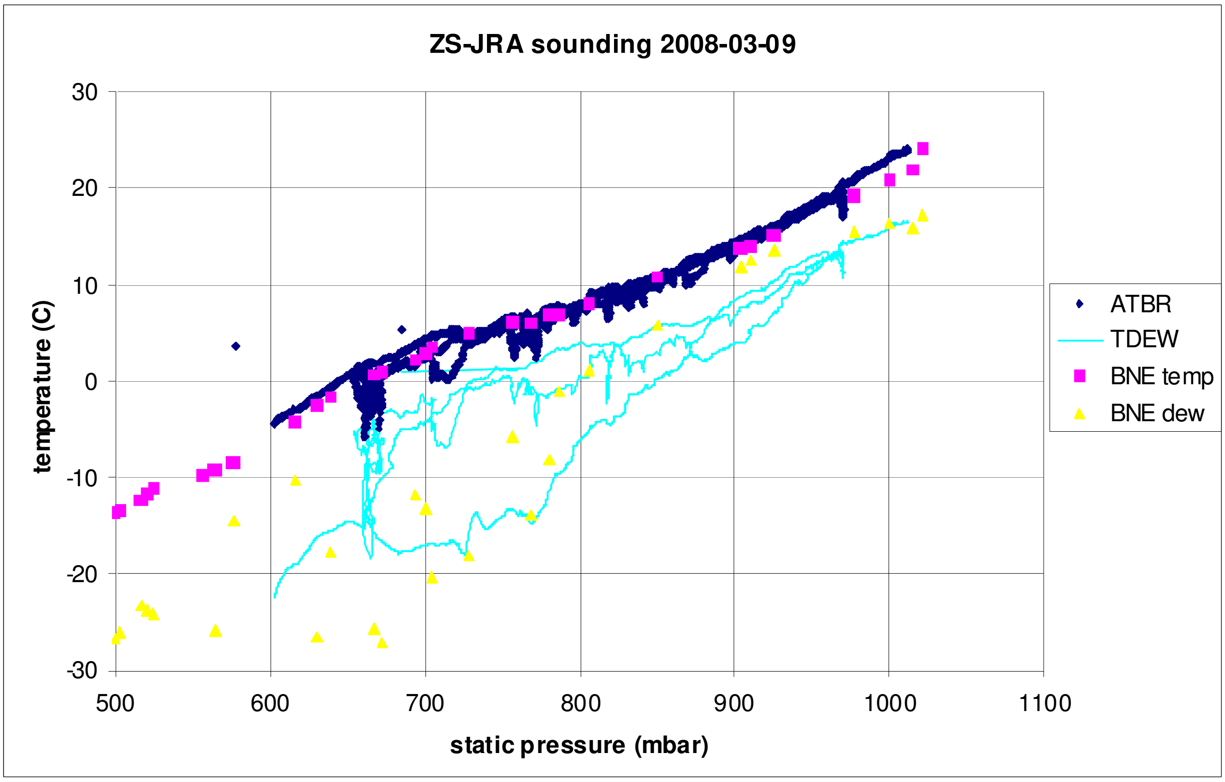


Figure 6 Comparison of Rosemount temperature with a Brisbane airport balloon sounding

8 Dewpoint

8.1 EDGETECH COOLED MIRROR

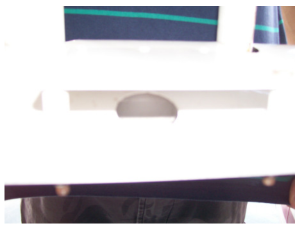
EdgeTech	*137 Vigilant Dew Point Hygrometer*	*cooled mirror*	-40 to +60 C	

The EdgeTech V1 (137 Vigilant™ Dewpoint Hygrometer) is a microprocessor based, programmable humidity measurement instrument which uses an Optical Chilled Mirror (OCM) as primary measurement technique. This instrument was specifically designed for continuous unattended operation and is well suited to aircraft based research operations. The mirror is electronically chilled using Thermo-Electric Cooler (TEC) technology and the temperature of the mirror surface is measured with a Platinum Resistance Thermometer (PRT). A control loop operates continuously just forming and then drying a mist on the mirror which is detected optically.. The current required to maintain an even film of dew on the mirror provides and accurate measurement of the dewpoint temperature ie. the average temperature of the mirror at that point is the dewpoint. The Vigilant can also enter Automatic Balance Cycle (ABC) mode which is a calibration feature to take account of wear on the mirror surface.

8.2 AIMMS HUMICAP

AIMMS Humicap	*Aircraft Integrated Meteorological Measurement System*	*humicap ~ platinum wound ceramic core*	*insert range*	

8.3 VERSAILA HUMICAP

Vaisala Humicap	*Aircraft Integrated Meteorological Measurement System*	*humicap ~ platinum wound ceramic core*	*insert range*	

8.4 DEWPOINT CALCULATION

The Magnus-Tetans formula can be used to calculate dewpoint from ambient temperature and relative humidity readings provided by solid state sensors (Vaisala and AIMMS instruments). To within a few percent, the expression is valid for 0°C < T < 60°C, 1% < RH < 100%, 0°C < TDEW < 50°C. With a = 17.27 and b = 237.7

$$T_{DEW} = \frac{b\gamma(T,RH)}{a-\gamma(T,RH)} \qquad 6.$$

where

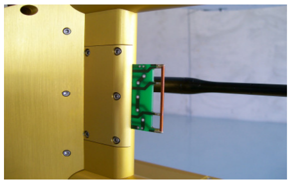
$$\lambda(T,RH) = \frac{aT}{b+T} + \ln(RH/100) \qquad 7.$$

science.c code

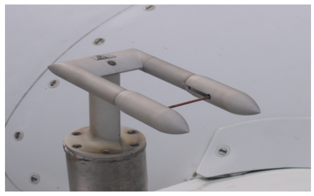
```
float tdew(float T,float RH)
{
	float es, e, de, x, y, Td, rv, dT, dewpt;
	int j;

	es=esw(T);
	e=0.01*RH*es;
	de=es-e

	Td=T

	for (j=0; j<10; j++){
		de = esw(Td)-e;
		x = Rv*(pow(Td,2))*de
		y = 597.3*pow((Tzero/Td),((0.167+(3.67*pow(10,-4))*Td)))*4186;
		dT = x/(y*es);
		Td = Td-dT;
	}

	dewpt=Td

	return(dewpt);
}
/*-----------------------------------------------------------------------------------------------------------------------------------------*/
float ew(float T, float Ps)
{
	float x, ew

if (T >= Tzero)
	x = 23.832241 – 5.02808 * log10(T) – 1.3816*pow(10,-7) * ( 10 * (11.334
	- 0.0303998*T)) + 8.1328*pow(10,2) * (10 * (3.49149 – 1302.8844/T))
else
	x = 3.56654*log10(T) - 0.0032098 * T - 2484.956/T + 2.0702294;

ew = pow(10,x);
return(ew)
```

9 Liquid Water Content

9.1 CAPS-LWC

Caps LWC	*Caps Liquid Water Content*	*Hot wire*	0.01 – 3 gm^{-3}	

9.2 KING-LWC

King LWC	*King Liquid Water Content*	*Hot wire*	0 – 5gm^{-3}	

This is a hot wire instrument consisting of 0.1mm diameter varnished copper wire tightly wound in a single layer on a nickel-silver tube. The coil thus formed has a diameter of 1.8mm and a length of 20mm long. Slave coils are situated either side of the main sensing coil to reduce end losses. The electrical power required to keep the temperature constant at 125 degC is monitored, and this is related to cloud liquid water content as follows :-.

9.3 LIQUID WATER CONTENT CALCULATION

LWC $=$ $\rho \frac{\pi}{6} \sum (c_1 x_1^{\ 3} + c_2 x_2^{\ 3} + c_3 x_3^{\ 3} \ldots\ldots\ldots\ldots c_{15} x_{15}^{\ 3})$

To obtain LWC in g/cc, the LWC value has to be divided by the sample volume per second of the instrument, which is the cross-sectional area of the heated element multiplied by the true airspeed (TAS) in cm/s.

King liquid water content, with respect to the heated element, is defined as :-

$$LWC = \frac{P - P_{dry}}{ld\left(\lambda_v + c_p (T_b - T_a)\right)v}$$ 9

where

LWC is the liquid water content (g/m^3)

P	total power consumed by the probe (W)
P_{dry}	is the dry power loss (W)
l	is the length of the master element (m)
d	is the diameter of the master element (m)
λ_v	is the latent heat of vaporization (J kg^{-1})
c_p	is the specific heat capacity of water (J kg^{-1} K^{-1})
T_b	is the boiling point of water
T_a	is the ambient air temperature
v	is the true airspeed ie. TAS (m)

The dry power loss, P_{dry}, is the power dissipated by cooling effect of dry air alone flowing over the probe element and is defined by Zukauskas and Ziugzda (1985) as follows :-

$$P_{dry} = A_o \pi k (T_s - T_a) \mathrm{Re}^x \mathrm{Pr}^y \qquad 10$$

where

A_o, x, y	are constants for the heated cylinder at high Reynolds Number
k	thermal conductivity of dry air (0.025 $Wm^{-1}K^{-1}$)
T_s	temperature of the sensor (K)
T_a	air temperature, or T_{amb} (K)
Re	*Reynolds Number* ratio of inertial to viscous forces, $\mathrm{Re} = \rho V d / \mu$
Pr	*Prandtl Number* ratio of viscous to thermal diffusion rate $\mathrm{Pr} = c_p \mu / k$
Nu	*Nusselt Number* ratio of convective to conductive heat transfer $Nu = hL / k_f$
ρ	density of air (1.292 kg m^{-3} at sea level)
μ	viscosity of air (1.8 x 10^{-5} kg m^{-1} s^{-1} at sea level)
h	convective heat transfer coefficient
L	characteristic length (m)
k_f	thermal conductivity of the fluid

Inorder to calculate P_{dry},, the following sequence of pre-calculations needs to be performed :-

1. calculate water thin film temperature

TFLM = (TWK + TK) / 2

2. calculate thermal conductivity

CND = 5.8 * 10^{-5} * (398/(125+TFLM)) * (TFLM/273)^1.5
CNDW = 5.8 * 10^{-5} * (398/(125+TWK)) * (TWK/273)^1.5

3. calculate viscosity

VISC = 1.718 * 10^{-4} * (393/(120 + TFLM)) * (TFLM/273)^1.5
VISW = 1.718 * 10^{-4} * (393/(120 + TWK)) * (TWK/273)^1.5

4. calculate density

DENS = PMB/(2870.5*TFLM)
FCT = 3.14159 * L * CND * (TWK-TK)

5. calculate Re

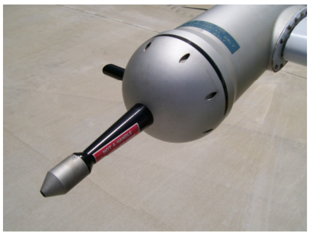
RE = 100 * DENS * TAS D / VISC

6. calculate Pr

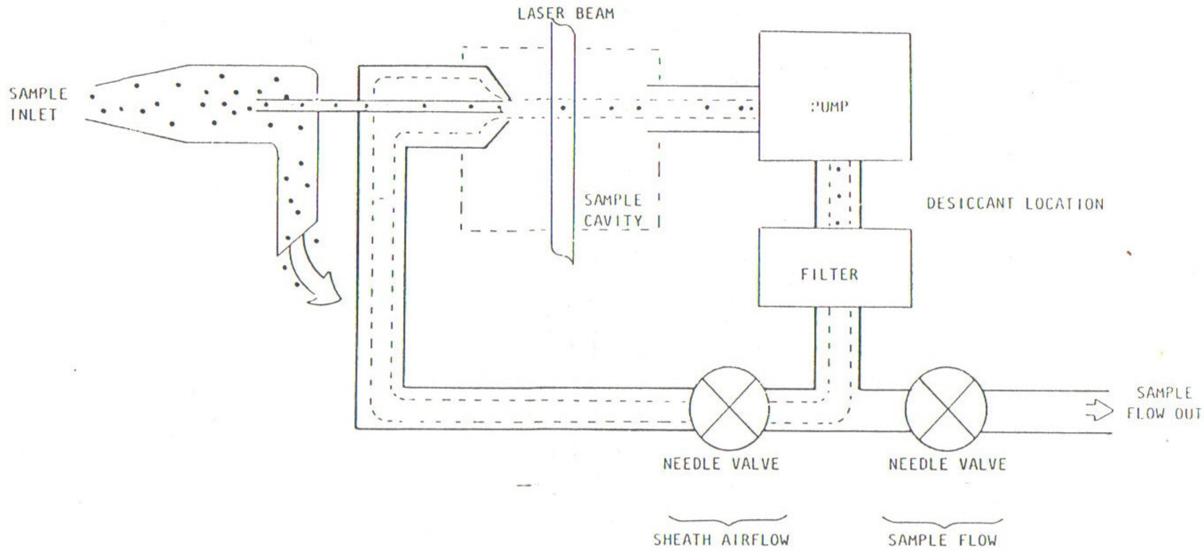
PRF = 0.24 * VISC / CND
PRW = 0.24 * VISC / CNDW

10 Light Scattering Probes (PCASP, and CAS and SPP-100)

10.1 PCASP

PCASP	*Passive Cavity Aerosol Spectrometer probe*	*Light scattering within an enclosed cavity*	0.1um – 3um (15 bins)	

The Passive Cavity Aerosol (PCASP) instrument (now called the SPP-200) measures aerosol particles in the size range 0.1 to 3 µm. Air enters the probe through an intake tube with conical end, and is decelerated to approximately one tenth of the flight speed. Pumped and filtered air is supplied to a sheath flow nozzle forming a fine jet of the particles which are projected into a cavity which contains the laser beam. A parabolic mirror and a plane mirror form the walls of the cavity. Forward scattered light is first reflected by a the parabolic mirror, then the plane mirror, and then passes through a aspheric collecting lens before striking a photodetector module.



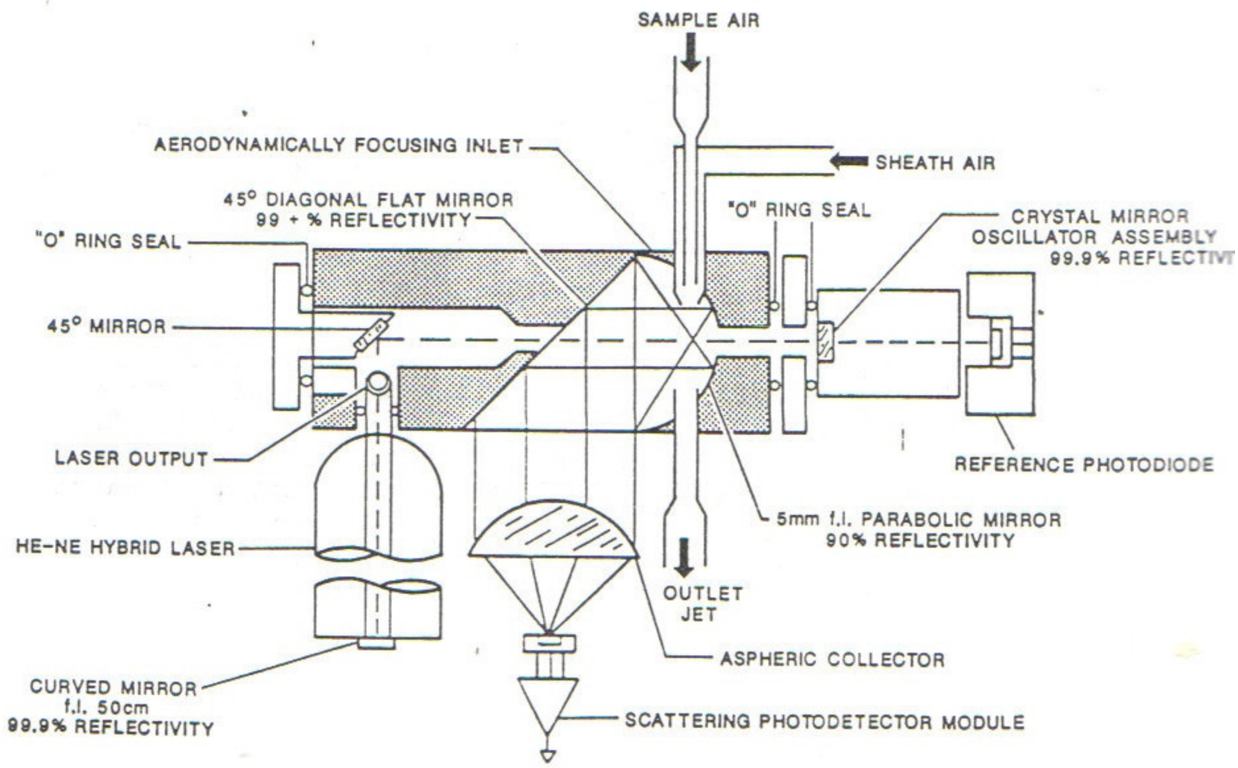


Figure 7 Airflow path and optical system diagram for the PCASP probe

10.2 CAS

Caps CAS	*Caps Cloud Aerosol Spectrometer*	*Forward and back scatter Mie Theory*	0.6um – 50um	

CAS stands for CLOUD AND AEROSOL SPECTROMETER (CAS). This is the latest generation probe which uses light scattering according to Mie Theory to characterise cloud droplets. The probe utilises forward and back scattering of light and effectively replaces the previous FSSP (forward scatter only) instrument. It forms part of the CAPS probe. The size range is 0.3 to 28.5um (or 0.6 to 50um). CAS is similar to the old FSSP probe except that an additional back scatter sensor is used in combination with the conventional forward scatter sensor. The light from a 50mW laser diode is scattered by particles and the collecting optics guide forward scattered light from 5° to 14°, and backward scattered light from 168° to 172°, into a masked qualifying photodetector. The latter allows determination of refractive index for spherical particles.

10.3 SPP-100

SPP-100	*Spectrometer probe*	*Forward scatter Mie Theory*	0.5 to 47um (15 bins)	

SPP-100 is similar to the previous Forward Scattering Spectrometer Probe (FSSP) except that is has updated and faster electronics. A 2mW He-Ne hybrid laser beam (wavelength of 680nm) is generated inside the pod and proceeds along one of the arms where it negotiates a condensing lens and heated 45° angle mirror. The beam is therefore reflected perpendicular to the airflow and is focused to a diameter of approximately 0.2mm at the centre of focus. The sampling area either side of the centre of focus has a dimension of approximately 2.5mm in the direction of the beam referred to as the Depth of Field (DOF). Most of the laser beam which is not diffracted by the particles, is then dumped onto a dump spot (Figure 8) to prevent the beam from entering the collection optics.

The probe works similar to the previous FSSP, except it has improved electronics which executes the data capture.

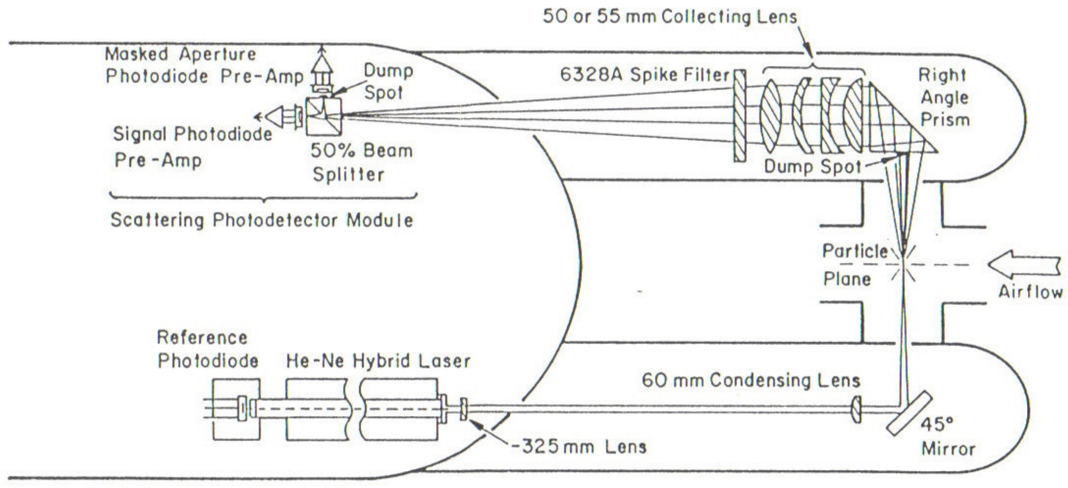


Figure 8 Optical system diagram for the SPP-100 probe

The dump spot is 2mm in diameter and situated on the front face of a right angled prism. Laser light which is scattered in a forward direction with respect to the direction of laser beam travel (which is perpendicular to the airflow) is then reflected off the back face of a prism, and returns (now in the direction of the airflow) back inside the probe. Here the light negotiates a splitting prism whereby 33% of the light does not have this direction altered and proceeds to a signal photodiode. The remaining 67% of the light is reflected through 90º onto a diode referred to as the annulus photodiode. The laser and optics are aligned to ensure concentricity of the annulus voltage output around the reference voltage output, which should be normal in shape and positioned at the centre of the annulus.

Particles that encounter this beam scatter light in all directions and some of that scattered in the forward direction is directed by a right angle prism though a condensing lens and onto a beam splitter. The "dump spot" on the prism and aperture of the condensing lens define a collection angle from about 4° - 12°. The beam splitter divides the scattered light into two components, each of which impinge on a photodetector. One of these detectors, however, is optically masked to receive only scattered light when the particles pass through the laser beam displaced greater than approximately 1.5 mm either side of the Centre of Focus (COF). Particles that fall in that region are rejected when the signal from the masked detector exceeds that from the unmasked detector. This defines the sample volume needed to calculate particle concentrations.

10.3.1 Depth of Field determination

The FSSP laser beam Depth of Field (DOF) is the area around the Centre of Focus which has an elevated light intensity, because the laser beam has been brought to a focus. In practice, this is determined electronically. The extent of the DOF either side of the centre of focus is defined where the signal and annulus voltages are equal. Regular measurement of this in addition to the beam diameter at the centre of focus is required for accurate sample area determination. This multiplied by True Airspeed (TAS) is in turn required for an accurate calculation of FSSP sample volume, and thus particle number concentration measured through the cloud

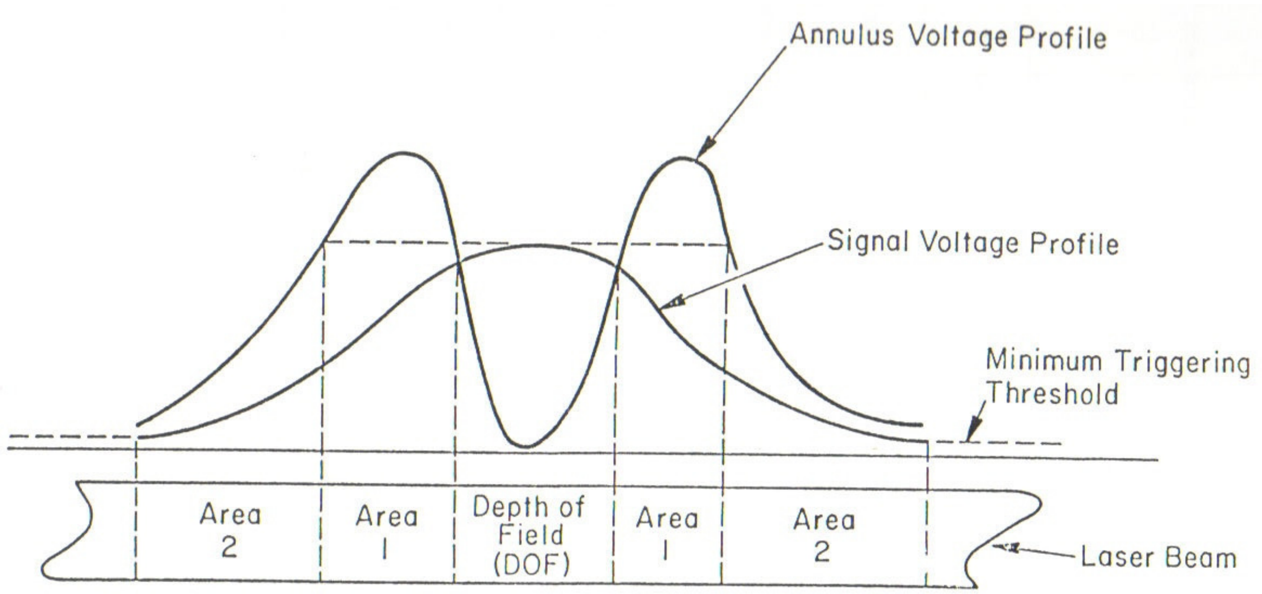


Figure 9 Definition of the FSSP Depth of Field which has to be determined electronically. The extent of the DOF either side of the centre of focus is defined where the signal and annulus voltages are equal. Regular measurement of this in addition to the beam diameter at the centre of focus is required for accurate sample area determination. This multiplied by True Airspeed (TAS) is in turn required for an accurate calculation of FSSP sample volume, and thus particle number concentration measured through the cloud.

additional FSSP sample volume diagram here (scan)

10.3.2 Mie Scattering Theory

Particles smaller than about 25µm do not form distinct shadows, but diffract (or scatter) light quite well, and this principle, known as Mie Scattering theory is the principle used here. The PMS FSSP probe measures particles in the range 0.5 to 47µm and needs a number concentration of these particles greater than 1000 cm^{-3} inorder to work satisfactorily. Particles of this size range are mainly seen due to their light diffracting properties. The size of these particles can be determined by measuring the light scattering intensity and using Mie scattering theory to relate this intensity to the particle size. Figure 10 illustrates how the scattered light varies with particle diameter given that the particle is spherical and that the refractive index is known.

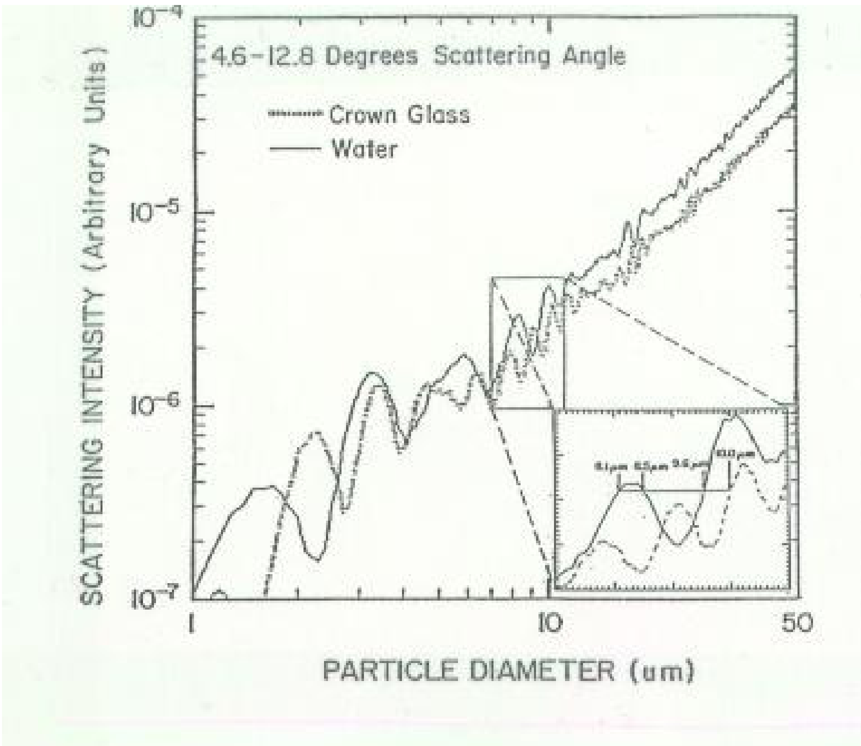


Figure 10 **Variation in light scattering intensity with particle diameter according to Mie Theory**

10.3.3 SPP-100 calculations

According the RAF / NCAR convention :-

$$CONCF = \sum_{i=1}^{i=15} \frac{n_i}{V} \; ; \; PLWCF = \frac{\pi}{6} \rho \sum_{i=1}^{i=15} \frac{n_i d_i^3}{V} \; ;\_ \; DBARF = \frac{\sum_{i=1}^{i=15} n_i d_i}{\sum_{i=1}^{i=15} n_i}$$

where :-

CONCF is the concentration # of droplets per unit volume - number per cubic centimeter
PLWCF is the Liquid Water Content Total droplet mass - grams per cubic meter
DBARF is the Average Diameter Arithmetic average of droplet size - micrometers
n_i is the number of droplets detected in size channel i
d_i is the diameter represented by channel i
V is the sample volume measured in a given sample period

Sauter Mean Diameter (SMD), also known as Effective Diameter, is the ratio of droplet volume to surface area as follows :

$$SMD = \bar{d_{32}} = \sum_i \frac{d_v^3}{d_s^2}$$

10.3.4 Caution on SPP-100 LWC determination

The FSSP-100 was developed as a cloud droplet measurement instrument. The size that is determined by the FSSP assumes that the scattered light detected is from a spherical, liquid droplet of refractive index 1.33. The size distributions produced from these measurements must be viewed with great caution when in clouds containing mixtures of water and ice, since ice particles will not be correctly sized due to their different refractive index and non-spherical shapes. A secondary caution is when looking at size distributions when precipitation sized drops are presents. These are suspected of colliding with the sample inlet and causing spurious satellite droplets. The probability of more than a single particle coinciding in the beam or being missed during the electronic reset time increases with concentration from about 5% losses at 300 cm-3 to greater than 30% at 1000 cm-3. Corrections are applied to account for these losses but still lead to concentration uncertainties. The FSSP is a droplet sizing instrument, not a liquid water content probe. Since the liquid water content is derived by integrating the size distribution, uncertainties in the size measurement lead to root sum squared accuracies in liquid water content a factor of three higher.

11 Imaging probes (CIP and PIP)

The Cloud Imaging Probe (CIP) and Precipitation Imaging Probe (PIP) are laser shadowing probes ie. they utilise shadowing rather than light scattering. As the particles these instruments measure are larger (>25um) they can form a distinct shadow on a linear photodiode array. Previous versions of these probes used to be referred to as 2D because image slices are taken and stored to obtain the shape of particles as they pass through the laser beam. This, in addition to particle size and velocity information is stored in PADS

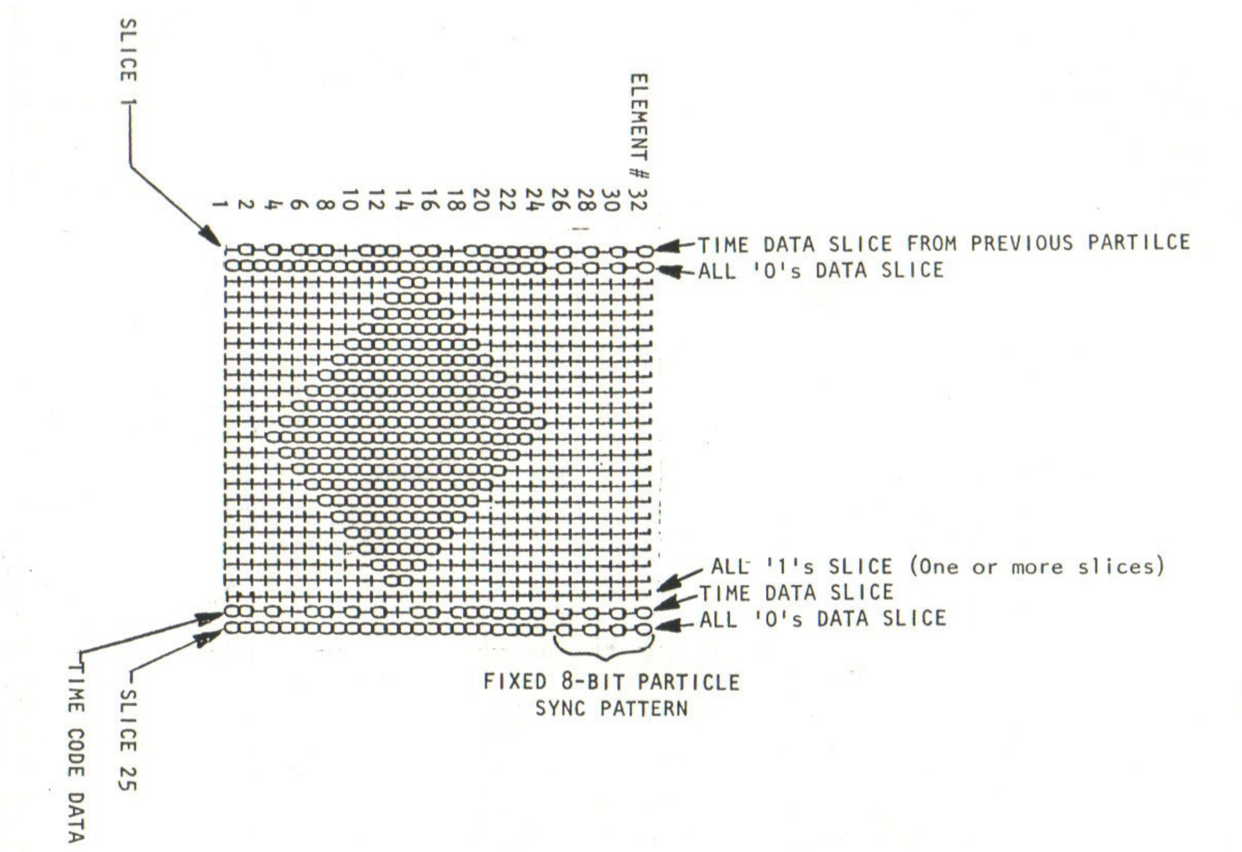
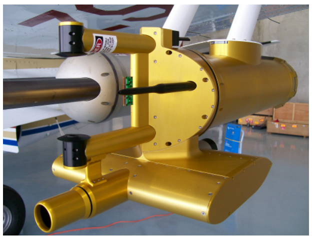


Figure 11 Cncept of time slice imaging of a theoretical square shaped particle performed by 2D probes

11.1 CLOUD IMAGING PROBE (CIP)

Caps CIP	*Caps Cloud Imaging Probe*	*Laser shadow on photodiode array*	25 – 1550 um (64 bins)	

The CAPS Cloud Imaging Probe (CIP) is similar to the previous PMS 2D-C, except that the electronics are vastly improved (on-board digital processor, fast front end analoge circuits and synchronous RS-422 data channel). There are 64 elements instead of 32 elements as with the 2D-C instrument. A 50mW diode laser illuminates the array with optics which provide x8 magnification. As each end element is used for particle rejection circuitry, the available 25um and 1550um is divided into 62 recordable size bins.

The 2D-C measures precipitation sized particles in the range 25um to 800um or 50um to 1600um depending upon optics magnification used (x5 to x10 available). ZS-JRA utilised 50um to 1600um for this project. At the heart of the instrument lies a 32 element photodiode array. Each photodiode is approximately 25um in size and is situated upon 200um centres along the array. The array is illuminated by means of a 2mW He-Ne laser. The laser beam is generated inside the pod and travels through one of the protruding arms. It is reflected at right angles by a 45° mirror and travels across to the other protruding arm

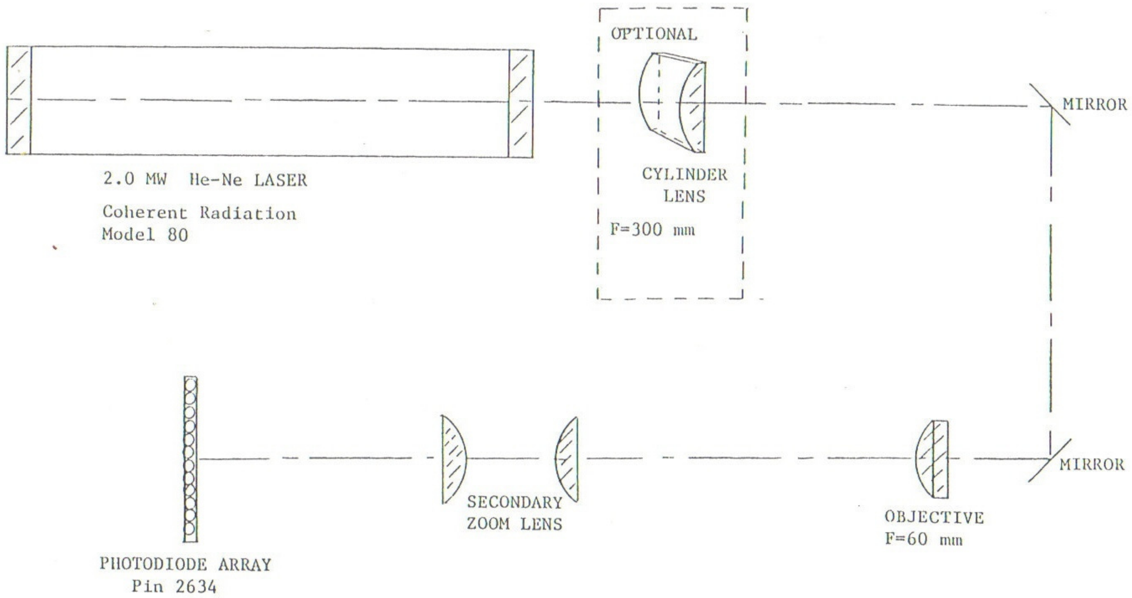


Figure 12 Optical system diagram for the OAP 2D-C probe

Table 2 OAP 2D-C - sampling area chart for size resolution 25um to 800um

CHANNEL NUMBER	NOMINAL DIAMETER MEASURE µm	ACTUAL RANGE OF DIAMETERS MEASURED µm Low	High	AVERAGE ACTUAL DIAMETER µm	DEPTH OF FIELD mm	EFFECTIVE ARRAY WIDTH mm	IDEAL SAMPLE AREA mm²
1	25	17.75	42.50	30.13	1.56	0.8	1.25
2	50	42.50	67.25	54.88	6.25		5.00
3	75	67.25	92.00	79.63	14.06		11.25
4	100	92.00	116.75	104.36	25.00		20.00
5	125	116.75	141.50	129.13	39.06		31.25
6	150	141.50	166.00	153.75	56.25		45.00
7	175	166.00	190.50	178.25	*61.00		48.00
8	200	190.50	215.25	202.88			
9	225	215.25	242.00	228.63			
10	250	242.00	264.75	253.38			
11	275	264.75	289.00	276.88			
12	300	289.00	313.75	301.38			
13	325	313.75	338.25	326.00			
14	350	338.25	363.00	350.63			
15	375	363.00	387.50	375.25			
16	400	387.50	412.50	400.00			
17	425	412.50	437.50	425.00			
18	450	437.50	462.50	450.00			
19	475	462.50	487.50	475.00			
20	500	487.50	512.50	500.00			
21	525	512.50	537.50	525.00			
22	550	537.50	562.50	550.00			
23	575	562.50	587.50	575.00			
24	600	587.50	612.50	600.00			
25	625	612.50	637.50	625.00			
26	650	637.50	662.50	650.00			
27	675	662.50	687.50	675.00			
28	700	687.50	712.50	700.00			
29	725	712.50	737.50	725.00			
30	750	737.50	762.50	750.00			
31	775	762.50	787.50	775.00			
32	800	787.50	812.50	800.00	*61.00	0.8	48.00

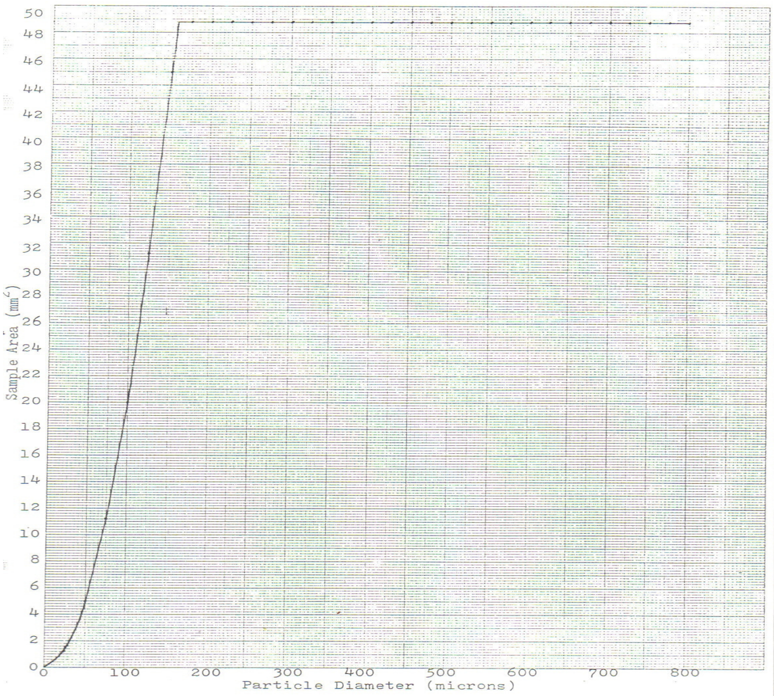


Figure 13 OAP 2D-C - sampling area

11.2 PRECIPITATION IMAGING PROBE (PIP)

The now effectively combines two previous laser shadowing instruments (the 2D-P and the 2D-C) into one convenient instrument. The appearance of the PIP instrument takes the form of the the previous 2D-P. The size ranges of the instrument is 100um to 6mm.

PIP	*Two dimensional probe – precipitation*	*Laser shadow on photodiode array*	100um – 6200um (64 bins)	

11.2.1 Basic description of the PMS 2D-P

The 2D-P measures precipitation sized particles in the range 240um to 6000um (ie. up to 6mm, the maximum size of a raindrop). At the heart of the instrument lies a 32 element photodiode array. Each photodiode is approximately 25um in size and is situated upon 200um centres along the array. The array is illuminated by means of a 2mW He-Ne laser. The laser beam is generated inside the pod and travels through one of the protruding arms, is reflected by a mirror, and then travels across to the other protruding arm and back through a series of optics into the instrument.

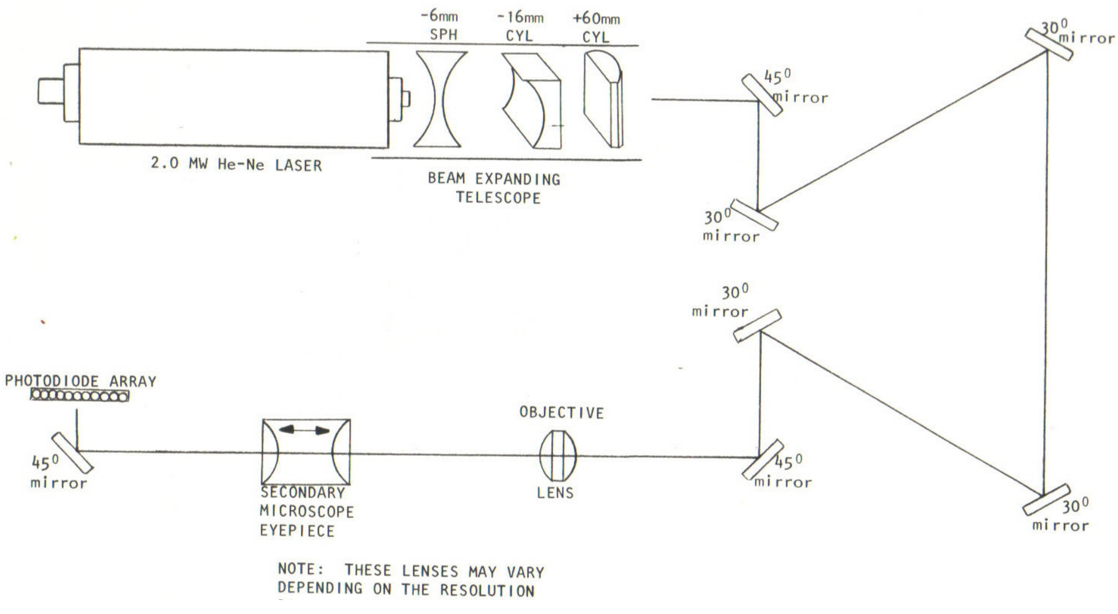


Figure 14 Optical system diagram for the OAP 2D-P probe

CHANNEL	ACTUAL RANGE OF DIAMETERS MEASURED LOW µm	AVERAGE µm	HIGH µm	DEPTH OF FIELD mm	EFFECTIVE ARRAY WIDTH mm	ACTUAL SAMPLE AREA mm^2
1	71.000	120.000	170.000	9.438	3.000	28.314
2	170.000	219.500	269.000	74.679	2.900	216.570
3	269.000	318.500	368.000	225.709	2.800	631.985
4	368.000	417.500	467.000	*261.000	2.700	704.700
5	467.000	516.500	566.000		2.600	678.600
6	566.000	615.000	664.000		2.500	652.500
7	664.000	713.000	762.000		2.400	626.400
8	762.000	811.500	861.000		2.300	600.300
9	861.000	914.500	968.000		2.200	574.200
10	968.000	1013.500	1059.000		2.100	548.100
11	1059.000	1107.500	1156.000		2.000	522.000
12	1156.000	1205.500	1255.000		1.900	495.900
13	1255.000	1304.000	1353.000		1.800	469.800
14	1353.000	1402.500	1452.000		1.700	443.700
15	1452.000	1501.000	1550.000		1.600	417.600
16	1550.000	1600.000	1650.000		1.500	391.500
17	1650.000	1700.000	1750.000		1.400	365.400
18	1750.000	1800.000	1850.000		1.300	339.300
19	1850.000	1900.000	1950.000		1.200	313.200
20	1950.000	2000.000	2050.000		1.100	287.100
21	2050.000	2100.000	2150.000		1.000	261.000
22	2150.000	2200.000	2250.000		0.900	234.900
23	2250.000	2300.000	2350.000		0.800	208.800
24	2350.000	2400.000	2450.000		0.700	182.700
25	2450.000	2500.000	2550.000		0.600	156.600
26	2550.000	2600.000	2650.000		0.500	130.500
27	2650.000	2700.000	2750.000		0.400	104.400
28	2750.000	2800.000	2850.000		0.300	78.300
29	2850.000	2900.000	2950.000		0.200	52.200
30	2950.000	3000.000	3050.000	*261.000	0.100	26.100

*Maximum Depth-of-Field Limited By Probe Aperture

Table 3 OAP 2D-P - sampling area chart for size resolution 100um to 3200um

The two variants of the 2D probe are the 2D-P model (for measuring precipitation sized particles - 240µm – 6000µm) and the 2D-C model (for measuring cloud sized particles - 50µm – 1600µm). These probes are similar, except that the laser portion perpendicular to the airflow forming the sample volume is longer and wider than for the 2D-P probe. Hence, the forward extending arms which contain heated laser reflecting mirrors are divergent away from the pod body with the 2D-P probe, and are parallel to the airflow with the 2D-C probe. Both probes feature a 2mW He-Ne laser beam with a wavelength of 680nm. Particles passing through the open path sample volume portion beam cast a shadow on a photodiode array (PDA). The laser illuminates a PDA consisting of 32 active photodiodes. Optics focus the laser beam so that it has an oval cross section and illuminates the PDA evenly. At regular intervals, typically once per week, the 2D optics have to be aligned to ensure even illumination of the PDA. Each photodiode element is approximately 25 across, and each is placed at 200µm centres across the array. Each photodiode element is supplied with approximately 0.1 to 0.5 microamps. The signals from each of the photodiode elements are processed and amplified on 32 separate cards, known as the photodetection electronics. With an assumed airspeed of 100m/s, 250nanoseconds is the approximate passage time of a particle and 25µm is therefore the approximate size resolution of the instrument. This information is then temporarily stored in a high speed front end data storage register located at the back end of the probe. Each photodetector element transmits 1024 bits of shadow information and thus image slices are recorded to develop the two dimensional image shapes. The image slice rate is approximately 4 million per second. With 32 photodiodes, particle image information is therefore collected at the rate of 128 million bits per second. A static MOS shift register acts as a buffer operating in a “ping-pong” fashion to prevent “indigestion” ie. no loss of data during the writing process.

12 Cloud Condensation Nuclei (CCN)

CCN	*Cloud Condensation Nuclei counter(Univ Wyoming)*	*Super-Saturation column measures activation*	0.75um to 10um (20 bins) ~ depends on supersaturation	

12.1.1 Brief description

The CCN counter operates on the principle that the diffusion of heat in air is slower than the diffusion of water vapour (Roberts and Nenes, 2005). The cloud chamber or column is mounted vertically with the ambient aerosol entering at the top, and the flow progressively becomes super-saturated with water vapour as it traverses down the column. The aerosol sample is placed at the centre of the column where supersaturation is maximum. Filtered, humidified sheath air surrounds the sample. The flow is typically 1 part sample to 10 parts sheath air to ensure that the aerosol is exposed to a uniform saturation profile. The vertical mounting, cylindrical geometry and porous alumina bisque liner (which provides the wetted surface down the column wall) minimise bouyancy effects and helps droplets grow to detectable size.

The base of the column is heated and the centreline supersaturation level depends upon the temperature difference between the top and the bottom of the column, the flowrate and the absolute pressure in the column. There are three heat settings which give three different supersaturation (SS) levels between 0.1% and 2%. A few minutes is required for a shift from one SS level to another. Activated droplet counting is done with an Optical Particle Counter (OPC) which uses side scattering with a 660nm diode laser in the range 0.75 to 10um in 20 bins. When mounted in an aircraft the supersaturation column is held at a pressure of 600mbar which is equivalent to an atmospheric pressure of 14000 feet (ie. the maximum likely altitude of the aircraft). Supersaturation temperature is only a very weak function of air pressure (0.028% per 100 mbar decrease) and so this correction can be ignored. Reduced pressure in the column is achieved by means of a pump and a variable flow restrictor at the inlet. Column pressure is held constant by means of a feedback loop between the control box and internal pressure transducer.

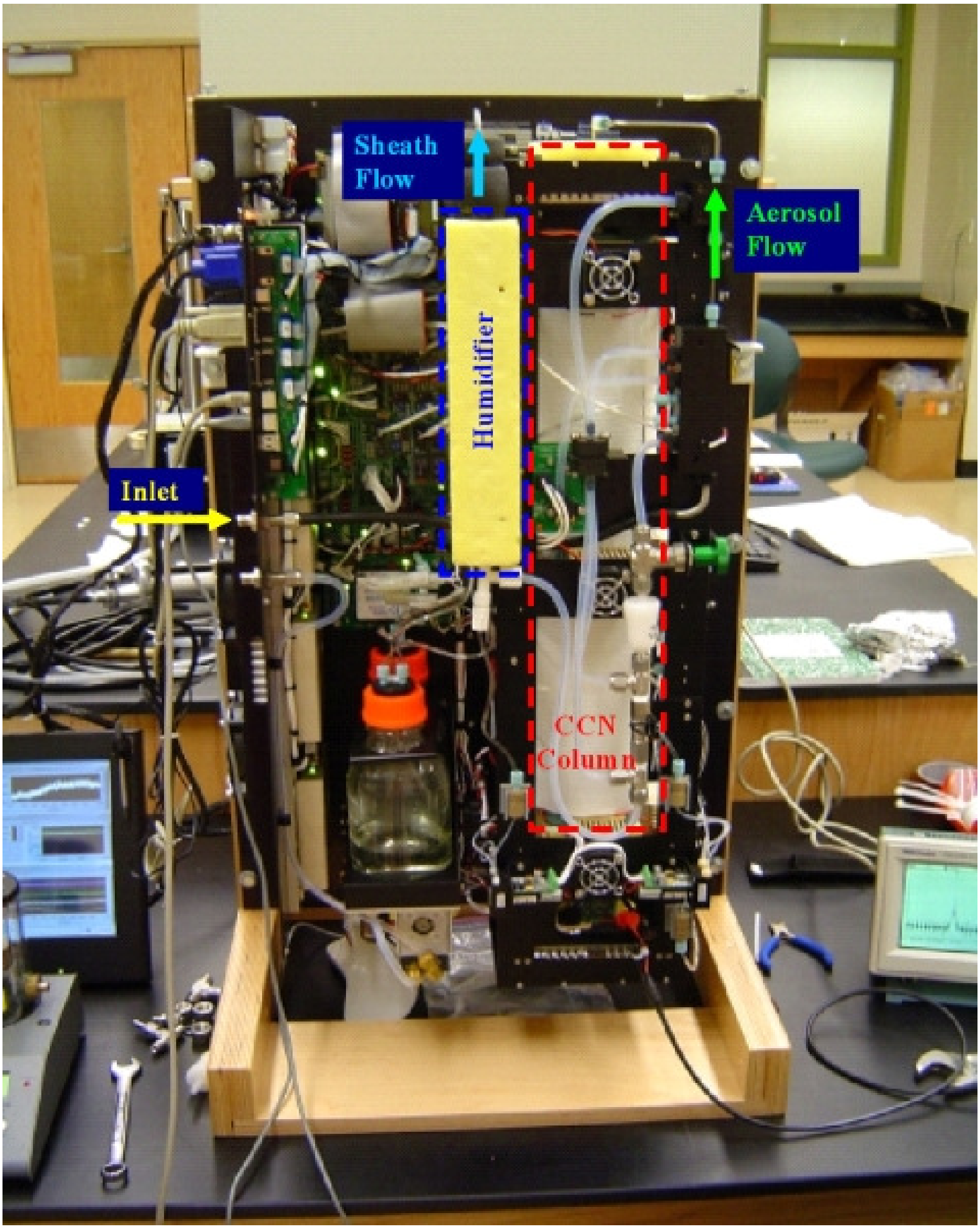


Figure 15 The CCN instrument – the ambient inlet air is split into aerosol and sheath flow. The sheath flow is filtered, humidified and heated. The two flows meet at the top of the CCN column. The CCN column is where supersaturation is generated and particles grow to become droplets, which are then large enough to be detected by an Optical Particle Counter (OPC). The inner walls of the CCN column are maintained moist. The aerosol flow is directed through the centerline of the column, and is surrounded by an annular flow of particle free sheath air

12.1.2 Theory of operation

The Cloud Condensation Nuclei (CCN) instrument essentially measures the hygroscopicity of particles within an aerosol sample , ie how an aerosol distribution responds to a change in relative humidity. A particle's response to a change in humidity say from 10 to 90% is a function of it's size and chemical composition. Soluble particles take on water and grow with increasing humidity, while particles composed of hydrophobic material do not. The amount of growth which takes place also depends on size according to the Kelvin effect, so small particles grow less than larger ones. The ratio of the wet and dry diameters is referred to as the particle's growth factor.

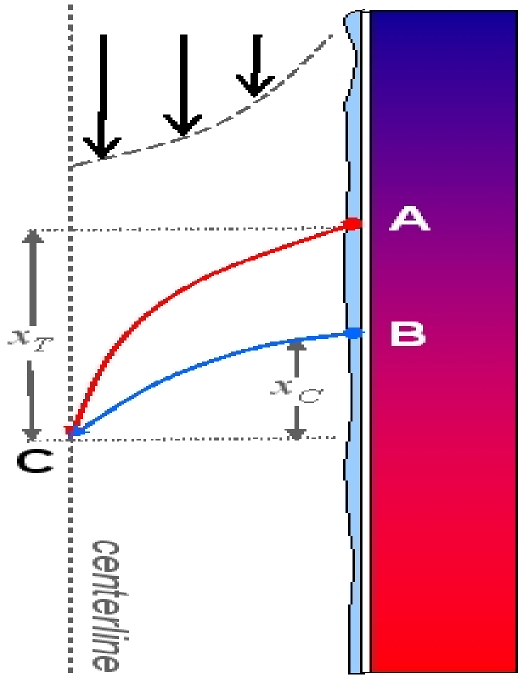


Figure 16 Principle of operation of the CCN – with laminar flow, heat and water vapor are transported to the centerline of the column from the walls only by diffusion. Since molecular diffusivity is greater than thermal diffusivity, the distance downstream that a water molecule travels before reaching the centerline is less than the distance the temperature travels downstream before reaching the centerline. If you pick a point at the centerline, the heat originated from a greater distance upstream than the water vapor.

A particle's response to changing relative humidity (assuming it responds at all) is generally somewhat non-linear. For example, most inorganic salts grow very little with increasing relative humidity until their deliquescence point is reached (the RH at which the particle changes from crystaline to liquid form) after which significant growth with increased RH takes place. However, when RH is decreased below the delequescence point, most salts exhibit hysterisis, that is they do not immediately re-crystalise, but continue to shrink, remaining as supersaturated liquid drops until their effervescence point is reached.

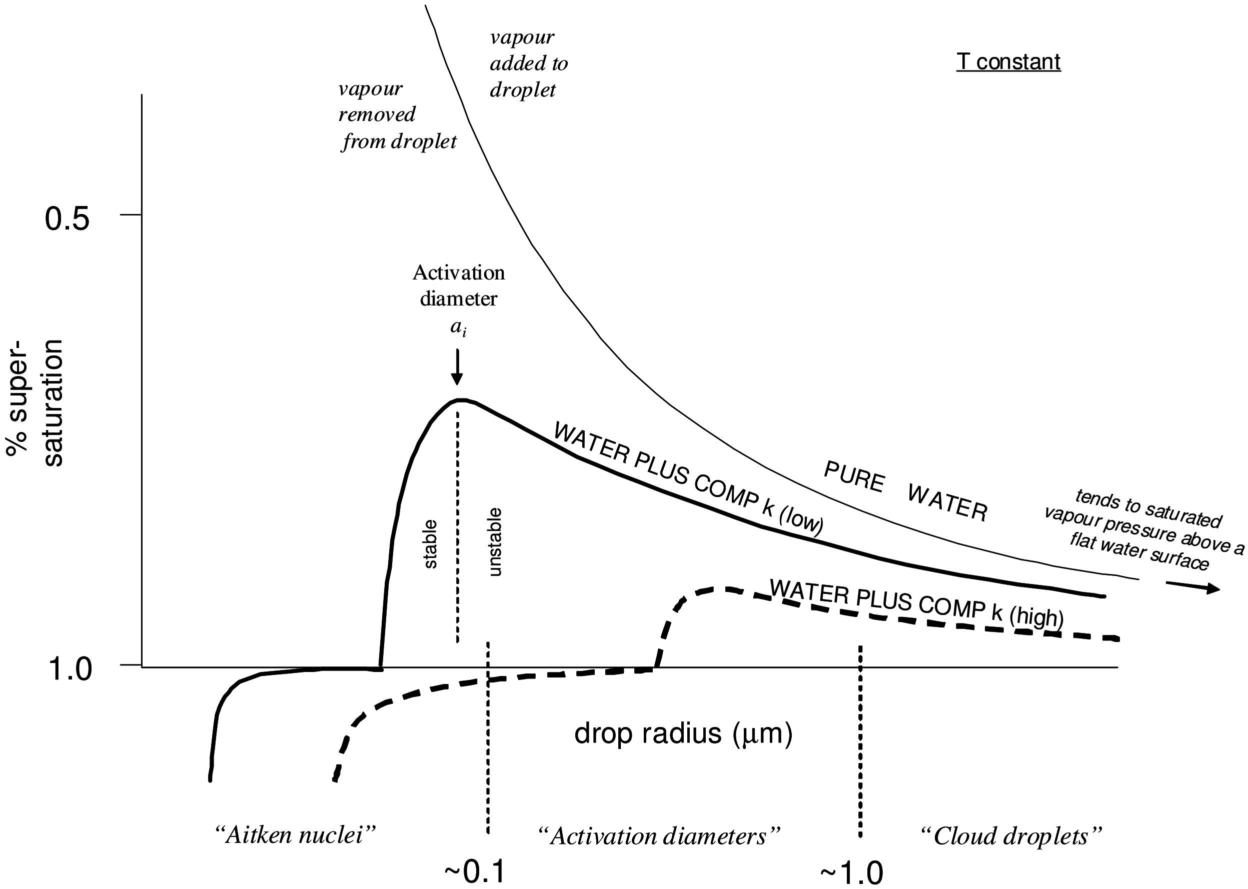
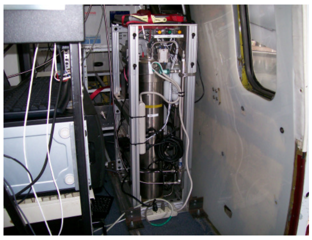


Figure 17 Kohler Theory explains how aerosol particles become activated into cloud droplets. The higher the hygroscopic salt component, the less is the degree of supersaturation required to achieve activation. Prior to activation, growth of the particle is via diffusion / condensation processes only and is slow. Once activation of the particle is achieved by reaching the critical supersaturation level, growth of the particle is significantly more rapid.

13 Differential Mobility Analyser (DMA)

DMA	*Differential Mobility Analyser(Texas A&M)*	*Particle path altered by voltage*	0.01 to 1um (20 bins)	

13.1.1 Brief description

The Differential Mobility Analyser (DMA) consists of a cylinder with a negatively charged rod at the centre. The instrument works on the principle that in the presence of an electric field, particles in motion move along different curved paths according to their charge characteristics. Particles entering at the top of the instrument are first neutralized (using a radioactive source) such that they have a Fuchs equilibrium charge distribution (Liu and Pui, 1974). A particle laden airstream is then injected at the outside edge of the DMA cylinder. The main air flow through the DMA cylinder is particle free 'sheath' air. It is important that this flow is laminar because particles with a positive charge move across the sheath flow towards the central rod, at a rate determined by their electrical mobility. Particles with a narrow range of mobility exit through the sample slit while all other particles exit with the exhaust flow. The size of particle exiting through the slit being determined by the particles size, charge, central rod voltage, and flow within the DMA. This now monodisperse distribution then goes to a Condensation Nuclei Counter (CNC) which determines the particle concentration at that size.

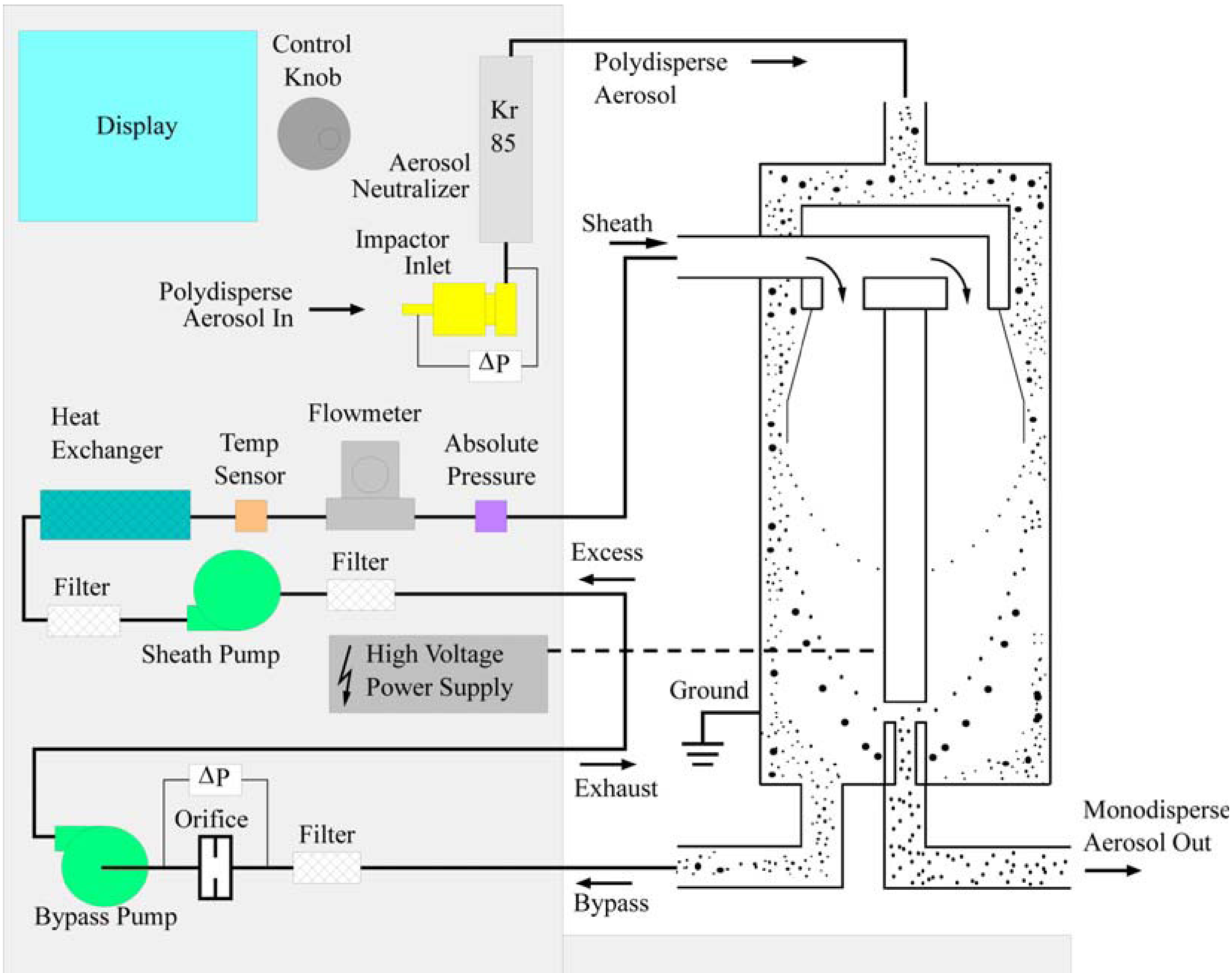


Figure 18 Diagram illustrating operation of a DMA (taken from SPMS Spectrometer Operation Manual)

13.1.2 Theory of Operation

An aerosol particle in an electric field, E, carrying n electric charges experiences an electrical force causing it to move through the gas in which it is suspended. It very quickly reaches its terminal velocity, v. The resulting drag force on the particle is given by Stokes Law and can be equated to the electrical force to determine the electrical mobility of a particle. The electrical mobility, then, is a measure of the particle's ability to move in an electric field, and is defined as

$$Zp = \frac{neC}{3\pi\mu d_p} \qquad 8.$$

where

n is the number of elementary charges on the particle
e is the elementary charge (1.6 x 10^{-19} Coulomb)
C is the Cunningham slip correction $= 1 + Kn[\alpha + \beta \exp(-\gamma / Kn)]$ (Cunningham, 1910)
$\alpha = 1.142$, $\beta = 0.558$, $\gamma = 0.999$ (Allen and Raabe, 1985)
Kn is the Knudsen Number $= 2\lambda / d_p$ (Knutsen, 1975)
λ is the gas mean free path $= \lambda_r (P_r/P)(T/T_r)[(1+S/T_r)/(1+S/T)]$
μ is the gas viscosity $= \mu_r [(Tr+S)/(T+S)(T/Tr)^{3/2}$
d_p is the particle diameter
S is the Sutherland constant
T is the temperature (K)
T_r is the reference temperature

An explanation of the gas equations can be found in Willeke and Baron (1993) and Radar (1990). Knutsen (1975) determined the following :-

$$Z_p = \frac{q_{sh}}{2\pi V L} \ln\left(\frac{r_2}{r_1}\right) \qquad 9.$$

where

Zp is the set mobility and $\Delta Z_p = (q_a / q_{sh}) Z_p$ is the mobility bandwidth
q_a aerosol flowrate through the DMA
$q_a = q_s = q_p$ for a closed-loop setup of sheath and excess flowrate
q_s monodisperse flowrate
q_p polydisperse flowrate
q_{sh} sheath air flowrate (equal to excess air flowrate)
r_2 outer radius of annulus space
r_1 inner radius of annulus space
$\overline{V}$ average voltage on the inner centre rod (volts)
L length between exit slit and polydisperse aerosol inlet

Combining equations 17 and 18, an expression can be derived which describes the relationship between particle diameter and centre rod voltage

$$d_p = \frac{2Cne\overline{V}L}{3\mu q_{sh}\ln(r_2/r_1)} \qquad 10.$$

13.1.3 <u>DMA Condensation Nuclei Counter (DCNC)</u>

The mechanism used to grow particles in the DCNC is heterogeneous condensation, whereby particle growth is promoted by the presence of a condensing vapour, but in contrast to the water based CCNC instrument (described in earlier section), the vapour is in this case generated butyl alcohol. The saturation ratio of which determines the smallest particle size detected according to the Kelvin equation :-

$$p / p_s = \exp[4\sigma M / \rho RTd_K] \qquad 11.$$

where

p is the actual vapour partial pressure at a given temperature
p_s is the saturation vapour pressure at a given temperature
σ is the surface tension
M is the molecular weight
ρ is the density of the liquid
d_K is the Kelvin diameter
R is the universal gas constant
T is the absolute temperature

The Kelvin diameter is the droplet diameter that will neither grow nor evaporate at the saturation ratio (p/p_s). For every droplet size, there is a saturation ratio that will exactly maintain that size. If the saturation ratio is too small, the particle evaporates, if it is too great, the particle grows.

14 MPS-3 Cascade Impactor

14.1.1 Brief description of instrument

The California Measurements Microanalysis Particle Sampler (MPS-3) is a three stage cup cascade impactor which collects airborne particles for later analysis, usually using a scanning electron microscope (SEM). Utilising the principle of inertial impaction, the MPS-3 fractionates the particles according to their effective diameter collects them in three segregated groups as follows :-

1) 5um – 10um - "large" sized aerosol particles
2) 1um – 5um - "medium" sized aerosol particles
3) 0.1um – 1um - "small" sized aerosol particles

The particle laden airstream passes through three stacked cup shape collectors as depicted in the diagram below. If one places a number of impactors with successively smaller jets in series (thereby increasing jet velocities), smaller and smaller particles can be captured on the different impactor plates as the airstream flows from one stage to the next – hence the term "cascade impactors". :-

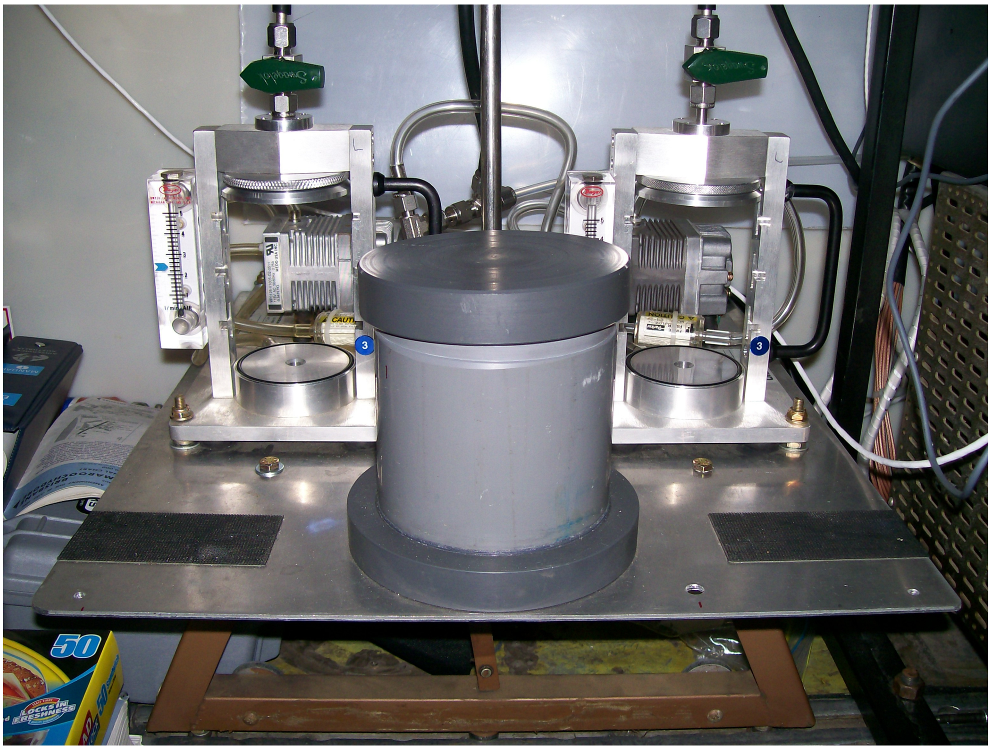


Figure 19 MPS-3 Cascade Impactor Each stage features a nozzle which produces a particle laden jet which impinges upon a perpendicular collection plate, coated in a thin film of grease to enhance particle capture and retention. The plate is able to be stored and later inserted straight into a scanning electron microscope

14.1.2 Inertial Impaction Theory

The ratio of inertial to drag forces is expressed by Stokes Number, St, as follows

$$St = \rho V d^2 / 18 \mu L$$

where ρ particle mass density (1.292 kg m^{-3} at sea level)
V velocity of particle laden airstream exiting jet
μ viscosity of air (1.8 x 10^{-5} kg m^{-1} s^{-1} at sea level)
L a typical dimension ie. jet to plate distance

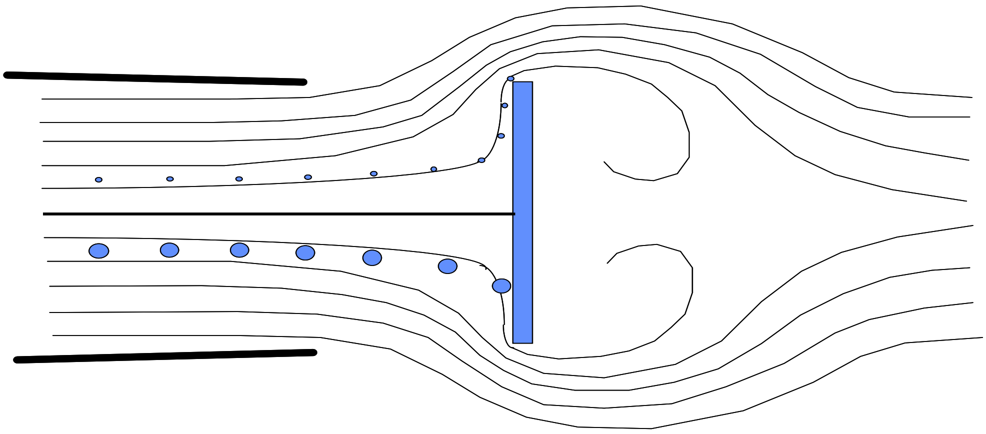


Figure 20 Diagram illustrating path of large and small particles in an airstream approaching a perpendicular flat plate. The smaller particles have less inertia and therefore tend to stay in the airsteam and move around the plate, whereas larger particles have sufficient inertia to impact onto the plate.

It has been found empirically that at a Stokes Number of about 0.2, there is a 50% probability that a particle of diameter d will strike the impactor plate rather than follow the deflected airstream. This diameter, d_{50}, is defined as

$$d_{50} = \left(\frac{\mu L}{\rho V} \right)^{1/2} \quad 12.$$

The d_{50} is described as the "effective" or "aerodynamic" size, because in addition to particle dimension, particle density has an effect on its inertia, and particle shape will also influence its drag characteristics. Equation 17 is only valid for air with normal density. If density or pressure is significantly below standard, the aerodynamic drag force tends to decrease , a phenomenon known as "slip". To correct for this, a correction factor C needs to be introduced :

$$d_{50} = \left(\frac{\mu L}{\rho C V} \right)^{1/2} \quad 13.$$

15 Trace gases

These are standard "off the shelf" instruments.

CO	*Carbon monoxide*	Infrared absorbance	1 – 10 ppm	
O_3	*Ozone*	UV absorbance	0 – 200 ppb	
NO	*Nitrogen monoxide*	Chemo-luminescence	0 – 100 ppm	
NO_2	*Nitrogen dioxide*	Chemo-luminescence	0 – 100 ppm	
NOx	*Total oxides of nitrogen*	Chemo-luminescence	0 – 100 ppm	
SO_2	*Sulfur dioxide*	Electrochemical	0 – 100 ppm	

Table 1 Summary of trace gas instruments aboard ZS-JRA (individual photos to be inserted)

16 References

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17 Appendices

17.1 THERMODYNAMIC VARIABLE CALCULATIONS

Largely taken from RAF/NCAR documentation (Bulletin 9, Appendix B)

17.1.1 Potential Temperature (K) - THETA

Potential air temperature $\boldsymbol{\theta}$ is the temperature which a sample of air would have if brought adiabatically to a standard reference pressure of 1000mbar. Where g is acceleration due to gravity, cp is specific heat capacity at constant pressure, and Δz is the height difference from the 1000mbar level

$$\theta = T + (g / c_p)\Delta z$$

This is a derived variable from the definition of potential temperature.

$$THETA = T_a(1000/P_s)^{R/c_p} \qquad 14.$$

where T_a = ambient temperature, K
P_s = static pressure, mbar
R = gas constant for dry air
c_p = specific heat at constant pressure for dry air

17.1.2 Equivalent Potential Temperature (K) – THETAE

This is a derived variable obtained by the method of Bolton (1980).

$$THETAE = THETA \{[(3.376/T_{lcl}) -0.00254] [q\,(1.0 +0.00081\,q)]\} \qquad 15.$$

where: T_{lcl} = temperature at the lifting condensation level, K
$T_{lcl} = \{[2840./(3.5 \ln\{T_a\} -\ln\{e_w\} -4.805)] +55.\}$
ln = natural logarithm (base e)
T_a = ambient temperature, K
e_w = water vapor pressure, mbar
q = mixing ratio, g/kg

17.1.3 Virtual Temperature (C) – TVIR

Virtual air temperature T_v is the temperature which sample of moist air would have if it were dry, but had the same pressure and density. Where q is the specific humidity (see section)

$$T_v = T(1 + 0.61q)$$

The virtual temperature is the temperature of dry air having the same pressure and density as the air being sampled. It is a measure of the effect of water vapour on air density. The calculation of virtual temperature in RAF output products is taken from page 295 of the Smithsonian Meteorological Tables (1958).

$$T_{vir} = [T_a\ (1.0 + 1.6078\ q)/(1.0 + q)] - 273.16 \qquad 16.$$

where T_{vir} = virtual temperature, C
T_a = ambient temperature, K
1.6078 = the ratio of the molecular weight of dry air to that of water vapor
q = specific humidity, g/g

17.1.4 Virtual Potential Temperature (K) – THETAV

Potential virtual temperature θ_v is

$$\theta_v = (\theta / T) T_v$$

Derived output of potential temperature using virtual temperature as a reference; otherwise it is the same as the derivation of THETA.

$$THETAV = (T_{vir} + 273.16)(1000/Ps)^{R/c_p} \qquad 17.$$

where: T_{vir} = virtual temperature, C
P_s = static pressure, mbar
R = gas constant for dry air
c_p = specific heat at constant pressure for dry air

17.1.5 Relative Humidity (per cent) – RHUM

Derived output of relative humidity from definition:

$$RHUM = 100.\ e_w/e_{ws} \qquad 18.$$

where: e_w = atmospheric water vapor pressure, mbar
e_{ws} = saturation water vapor pressure, mbar

17.1.6 Absolute Humidity (Vapor Density) (g/M^3) – RHOx

Derived output of absolute humidity (water vapor density) computed from its standard definition (equation of state).

$$RHO = 10^6\ e_w\ M_w/(R_o\ T_a) \text{ (multiplied by } 10^6 \text{ to give } g/M^3)$$

$$RHO = 216.68\ e_w/T_a \qquad 19.$$

where: e_w = water vapor pressure over a plane water surface, mbar
M_w = molecular weight of water
R_O = universal gas constant
T_d = dew point temperature, K
T_a = ambient temperature, K

This variable is calculated for a number of moisture sensors.

17.1.7 Specific Humidity (g/kg) – SPHUM

Derived output of specific humidity from definition:

$$SPHUM = 622.\ e_w/(P_s - 0.378\ e_w) \qquad 20.$$

where: e_w = atmospheric water vapor pressure, mbar
P_s = static pressure, mbar
622 = 1,000 times the ratio of the molecular weight of water vapor to that of dry air.

17.1.8 Mixing Ratio (g/kg) - MR

A derived variable that is expressed in terms of grams of water vapor per kilogram of dry air. It differs from specific humidity in that it is related to dry air mass rather than the total of dry air plus water vapor.

$$MR = 622.\ e_w/(P_s - e_w) \qquad 21.$$

where: e_w = water vapor pressure, mbar
P_s = static pressure, mbar
622 = 1,000 times the ratio of the molecular weight of water vapor to that of dry air.

17.1.9 Calculated Surface Pressure (mbar) – PSURF

This value is a calculated surface pressure obtained from HGM, TVIR, PSFDC, and MR using the thickness equation. The average temperature for the layer is obtained by using HGM and a dry-adiabatic lapse rate. Due to the assumptions made in the calculation of this variable, the result is only valid for flight in a well-mixed surface layer or in other conditions in which the temperature lapse rate matches the dry-adiabatic lapse rate.

$$PSURF = P_s \exp[g/R\ (HGM/T_m)] \qquad 22.$$

where: P_s = static pressure, mbar
exp = exponentiation (natural antilogarithm, e = 2.71828...)
g = acceleration of gravity, M/s^2
R = gas constant for dry air
HGM = radio altitude, M
T_m = mean temperature of the layer, K = $(T_{vir}+273.16) + 0.5\ HGM\ (g/c_p)$
T_{vir} = virtual temperature, C
c_p = specific heat at constant pressure for dry air

science.c code

The following symbols are used :-

T	ambient temperature (C)
Td	dew point temperature (C)
RH	relative humidity (%)
Ps	static pressure
theta	potential temperature (K)
thetae	equivalent potential temperature (K)
thetav	virtual potential temperature (K)
Tvir	virtual temperature (K)
q	specific humidity (g/kg)
mr	mixing ratio (g/kg)
rho	vapour density (absolute humidity) (g/m^3)

```
void calc_tdynamics(float T, float RH, float Ps, float *theta, float *thetae,
                    float  *thetav, float *q, float *mr, float *rho, float *Td,
                    float  *Tvir, float missing
{
        float esat, Tlcl, e;

T  += Tzero;

if (T > 0 && T < 400  && Ps < 2000 && RH > 0 && RH < 105){
        *Td = tdew(T,RH)  -  Tzero;
        esat  =  esw(T);
        e  =  esat*RH/100;
        *theta  =  T*pow((1000/Ps), (R/Cp));
        Tlcl  =  ((2840/3.5*log(T)  -  log(e)  -  4.805  +  55);
        mr  =  eps  *  e/(Ps  -  e);
        *q  =  eps  *  e/(Ps  -  0.378*e);
        thetae  =  *theta  *  (((3.376/Tlcl)  -  0.00254)*((*mr)*(1+0.00081*(*mr))));

        Tvir  =  T*(1+1.6078*  (*q))/(1+(*q));
        thetav  =  *Tvir*pow((1000/Ps),(R/Cp));
        rho  =  216.88  *  e/T;
}
else{
        Td  =  missing;
        *theta  =  missing;
        *mr  =  missing;
        *q  = missing;
        *Tvir  =  missing;
        *thetae  =  missing;
        *thetav  =  missing
        *rho  =  missing;
   }
}
```

17.2 DROPLET CALCULATIONS

Mean diameter, D_{BAR} or d_{10} , with size bins from *x_1 to x_{15}*

$$\bar{d} = \frac{\sum d}{n} \quad = \quad \frac{\sum (c_1x_1 + c_2x_2 + c_3x_3 ....c_{15}x_{15})}{n}$$

Standard deviation

$$\sigma = \sqrt{\frac{\sum (d - \bar{d})^2}{n}} \quad = \quad \sqrt{\frac{\sum (c_1x_1 - \overline{\overline{nd}})^2 + (c_2x_2 - \overline{\overline{nd}})^2 + (c_3x_3 - \overline{\overline{nd}})^2 ....c_{15}x_{15} - \overline{\overline{nd}})^2}{n.\overline{\overline{nd}}}}$$

Dispersion coefficient (or Coefficient of Variation)

$$CV = \sigma / \bar{d}$$

Area mean diameter, AMD or d_{20}

$$d_{20} = \left(\frac{\sum d^2}{n} \right)^{1/2} \quad = \quad \left(\frac{\sum (c_1{x_1}^2 + c_2{x_2}^2 + c_3{x_3}^2 ....c_{15}{x_{15}}^2)}{n} \right)^{1/2}$$

Mass mean diameter, MMD or d_{30}

$$d_{30} = \left(\frac{\sum d^3}{n} \right)^{1/3} \quad = \quad \left(\frac{\sum (c_1{x_1}^3 + c_2{x_2}^3 + c_3{x_3}^3 ....c_{15}{x_{15}}^3)}{n} \right)^{1/3}$$

Effective diameter ED, SMD, or d_{32}

$$d_{32} = \left(\frac{\sum d^3}{\sum d^2} \right) \quad = \quad \left(\frac{\sum (c_1{x_1}^3 + c_2{x_2}^3 + c_3{x_3}^3 ....c_{15}{x_{15}}^3)}{\sum (c_1{x_1}^2 + c_2{x_2}^2 + c_3{x_3}^2 ....c_{15}{x_{15}}^2)} \right)$$

Calculated Liquid Water Content, LWC (g/cm^3)

$$\text{LWC} \quad = \quad \rho \frac{\pi}{6} \sum (c_1{x_1}^3 + c_2{x_2}^3 + c_3{x_3}^3 ....c_{15}{x_{15}}^3)$$

17.3 DATA PROCESSING CODE (PREVIOUS)

calc.c code

```
unsigned int adzero = 32767
```

32767 is a binary number assigned to have value zero

```
calc_jrx( )
{

/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE STATIC PRESSURE 1 */

stpl = 1083.64 – ((float)(65535 – analog_7 )/30.235);
```

1083.64 is maximum likely atm pressure ?, 30.235 is stat pressure constant

```
/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE DIFFERENTIAL PRESSURE 1 */
if (analog_3 < adzero) analog_2 = adzero;      /* 32767 */
dfpl =  ((float)  (analog_3 – adzero))/237.63 ;
```

237.63 is a diff pressure constant ?

```
/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE AUX DIFFERENTIAL PRESSURE 1 */
if (analog_3 < adzero) analog_2 = adzero;      /* 32767 */
auxdfp =  ((float)  (analog_2 – adzero))/636.49 ;
```

636.49 is the aux diff pressure constant ?

```
/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE INDICATED AIRSPEED */
ias1 = sqrt(579066.0 * (pow (1.0 + dfpl/1013.25), 0.2856541) – 1.0));
```

1013.25 is standard atmospheric pressure (hPa), 0.2856541 is the value R/c_p ?

```
/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE ROSEMOUNT TEMP 1 AND 2 */
rmt1 = ((float)(analog_0 – adzero/163.84) – 50.0
rmt2 = (rmt1 + 273.15)/(1.0 + 0.847 * (pow (1.0 + dfpl/stpl, 0.2856541) – 1.0));
     /*   rmt1 is raw val   rmt2 is first true value  */
```

273.15 is a kelvin conversion
0.847 is a temperature probe airflow recovery factor

```
/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE TRUE AIR SPEED 1 */
tas1 = sqrt  (2009.6  * rmt2  *(pow (1.0 + dfpl/stpl, 0.2856541) – 1.0));
```

2009.6 is the value 2c_p multiplied by a unit conversion factor ?
specific heat capacity of air, c_p = 1003.5 J kg^{-1} K^{-1} ?

```
/*--------------------------------------------------------------------------------------------------------*/

/* CALCULATE STATIC PRESSURE 2  */
stp2  =  stp1  +0.021856  *  tas1  +  5.3;  /* must use updated correction factor */
```

5.3 is an offset, 0.021856 is a gain

```
/*--------------------------------------------------------------------------------------------------------*/

/* CALCULATE ROSEMOUNT TEMP 3   */

rmt3 = (rmt1 + 273.15)/1.0 + 0.847 * (pow (1.0 + dfpl/stp2, 0.2856541) – 1.0)) – 273.15;
                                                                   /* rmt is in celcius  */
if (dice) == 0)   rmt3  =  rmt3  -  0.5                  /* CORRECT IF DE ICE IS ON  */
```

this recalculates rmt using corrected static pressure stp2

```
/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE TRUE AIR SPEED 2 */

tas2 = sqrt  (2009.6  * (rmt3+273.15) *(pow (1.0 + dfpl/stpl, 0.2856541) – 1.0));
if  (tas2 <10.0)  tas2  =  10.0
tas3  =  tas2
```

this recalculates tas using corrected rosemount temp rmt3
specific heat capacity for air, $c_{p,air}$ is 1003.5 J kg-1 K-1

```
/*--------------------------------------------------------------------------------------------------------*/
/* CALCULATE HUMIDITY  */

if(analog_6 < adzero)analog_6 = adzero;
hum1 = ((analog_6 – adzero)/32.76);
```

32.76 is the humidity probe gain constant

```
/*-----------------------------------------------------------------------------------------------------------------*/
/*  CALCULATE REVERSE FLOW TEMP  */

rft1 = 50.0-((34418-(unsigned int) analog_1 )/32.85);
rft2 = (rft1+273.15)/(1+0.642*(pow(1.0 + dfpl/stpl, 0.2856541) – 1.0));


/*-----------------------------------------------------------------------------------------------------------------*/
/* CALCULATE ALTITUDE  */

/*    alt1  =  (3.2808*(1.0-pow(stp2/1013.25,0.1902)*288.15))/0.0065;  */
```

see subsection

17.4 AIRCRAFT NOMENCLATURE

10micron	*#cm^{-3}*	No of particles counted bigger than 10 microns ie. PM_{10}
AFSSP	*#*	FSSP-100 raw accumulation
AFSSP_LPN	*cnts*	FSSP-100 raw accumulation
ALTF	*feet*	NACA pressure altitude
APCAS_RPN	*#*	PCASP raw accumulation
ATBF	*degC*	Ambient temperature (Boom) - Rosemount
ATBR	*degC*	Ambient temperature (Boom) - Vaisala (reverse flow)
BVAR	*ft/min*	Vertical motion
CASB(1-30)	*counts*	CAS back scatter counts (bins)
CASC(1-30)	*cm^{-3}*	CAS channel concentrations (bins)
CASCONC	*cm^{-3}*	CAS total concentration
CASF(1-30)	*counts*	CAS forward scatter counts (bins)
CASLWC	*gm^{-3}*	CAS liquid water content
CASMED	*gm^{-3}*	CAS effective diameter
CASMVD	*gm^{-3}*	CAS mean volume diameter
CCN_00	*micron*	Bin
CCN_01	*micron*	Bin_1_0.75_micron
CCN_02	*micron*	Bin_2_1.0_micron
CCN_03	*micron*	Bin_2_1.5_micron
CCN_04	*micron*	Bin_2_2.0_micron
CCN_05	*micron*	Bin_2_2.5_micron
CCN_06	*micron*	Bin_2_3.0_micron
CCN_07	*micron*	Bin_2_3.5_micron
CCN_08	*micron*	Bin_2_4.0_micron
CCN_09	*micron*	Bin_2_4.5_micron
CCN_10	*micron*	Bin_2_5.0_micron
CCN_11	*micron*	Bin_2_5.5_micron
CCN_12	*micron*	Bin_2_6.0_micron
CCN_13	*micron*	Bin_2_6.5_micron
CCN_14	*micron*	Bin_2_7.0_micron
CCN_15	*micron*	Bin_2_7.5_micron
CCN_16	*micron*	Bin_2_8.0_micron
CCN_17	*micron*	Bin_2_8.5_micron
CCN_18	*micron*	Bin_2_9.0_micron
CCN_19	*micron*	Bin_2_9.5_micron
CCN_20	*micron*	Bin_2_10.0micron
CCN1SM	*volts*	First stage monitor
CCNAC	*code*	Status systems warning code
CCNBM	*volts*	Baseline monitor
CCNC	*#cm^{-3}*	Cloud condensation nucleii number concentration
CCNDT	*degC*	CCN column temperature gradient
CCNLC	*mA*	Laser driver current
CCNSF	*cm^{-3}/min*	Sample flowrate

CCNSP	*mb*	Sample pressure
CCNSS	%	Current supersaturation
CCNT1R	*degC*	Actual temp top column
CCNT1S	*degC*	Top column temp
CCNT2R	*degC*	Actual temp of column mid point
CCNT2S	*degC*	Mid point column temp
CCNT3R	*degC*	Actual temp bottom column
CCNT3S	*degC*	Bottom column temperature set
CCNTCR	*degC*	Optical particle counter temp
CCNTCS	*degC*	Set optical particle counter temp
CCNTF	*degC*	Sheath flow
CCNTIR	*degC*	Actual particle inlet temp
CCNTIS	*degC*	Set particle inlet temp
CCNTNR	*degC*	Actual nafion temp
CCNTNS	*degC*	Set nafion temp
CCNTS	*degC*	Stabilized temps
CCNTSR	*degC*	Air sample temp
CFSSP_LPN	cm^{-3}	FSSP-100 corrected concentration
CIPC(1-62)	cm^{-3}	CIP channel concentrations (bins)
CIPCONC	cm^{-3}	CIP total concentration
CLWCC	g/m^3	CAPS liquid water content
CLWCMON	*V*	CAPS LWC Mon
CLWCV	*V*	CAPS LWC DryPower
CONCF_LPN	cm^{-3}	FSSP-100 total concentration
CONCP_RPN	cm^{-3}	PCAS-100 total concentration
CPCAS_LPN	cm^{-3}	PCAS-100 corrected concentration
DAY	*UTC*	Raw system date
DBARF_LPN	*um*	FSSP-100 mean particle diameter
DBARP_RPN	*um*	PCAS-100 mean particle diameter
DISPF_LPN	-	FSSP-100 dispersion (sigma/dbarx)
DISPP_RPN	-	PCAS-100 dispersion (sigma/dbarx)
DPBR	*°C*	Dewpoint temperature (Boom)
EDPC	*hPa*	Vapour pressure
FACT_LPN	-	FSSP-100 activity
FRNG_LPN	-	FSSP-100 range
FSTB_LPN	-	FSSP-100 total strobes
GALT	-	NACA pressure altitude
GALT	*m*	GPS altitude
GDATE	*UTC*	GPS date
GGSP	*m/s*	GPS groundspeed
GHDG	*degrees*	GPS heading
GHEAD	*degrees*	GPS heading
GLAT	*degrees*	GPS latitude
GLAT	*degrees*	GPS latitude
GLAT3	*degrees*	GPS latitude
GLON	*degrees*	GPS longitude
GLON	*degrees*	GPS longitude

GLON3	*degrees*	GPS longitude
GSP	*m/s*	GPS groundspeed
GSPD	*m/s*	GPS groundspeed
GSTAT	-	GPS status
GTIME	*UTC*	GPS time
HOUR	*UTC*	Raw system date
KLW	*V*	King liquid water
KLWC	g/m^3	King liquid water content
KMON	*V*	King monitor
LWCF_LPN	g/m^3	FSSP-100 liquid water content
MILSEC	*UTC*	Raw system date
MINUTE	*UTC*	Raw system date
MONTH	*UTC*	Raw system date
MR	g/m^3	Mixing ratio
MR1	g/m^3	Mixing ratio
P2DCH1_RWO	-	OAP-2D-C Housing Number 2
P2DCH2_RWO	-	OAP-2D-C Housing Number 2
P2DCOR_RWO	-	OAP-2D-C shadow OR
P2DPH1_RWI	-	OAP-2D-C Housing Number 2
P2DPH2_RWI	-	OAP-2D-C Housing Number 2
P2DPOR_RWI	-	OAP-2D-C shadow OR
PACT_RPN	-	PCASP-100 activity
PRNG_RPN	-	PCASP-100 range
OA2CC(1-32)	l^{-1}	2DC total concentration (bins)
OA2CCONC	l^{-1}	2DC total concentration
OA2CCONC	l^{-1}	2DC total concentration
OA2CEV	l^{-1}	2DC element 32 voltage
OA2CSO	l^{-1}	2DC shadow OR
OA2CSV	l^{-1}	2DC element 1 voltage
OA2PC(1-32)	l^{-1}	2DP total concentration (bins)
OA2PEV	l^{-1}	2DP element 32 voltage
OA2PMAX	*μm*	2DP maximum size
OA2PSHAD	l^{-1}	2DP shadow or
OAPPSV	l^{-1}	2DP element 1 voltage
PALT	*m*	Pressure altitude
PALTF	*ft*	Pressure altitude
PCASACT	*%*	PCASP activity
PCASC(1-15)	cm^{-3}	PCASP concentration (bins)
PCASCONC	*cm-3*	PCASP concentration (bins)
PCASMDV	*um*	PCASP mean volume diameter
PCASRNG	*none*	PCAS range
PCASV	*V*	PCASP laser volts
PSB	*hPa*	Static air pressure
PSBC	*hPa*	Corrected static pressure
PSTB_RPN	-	PCASP-100 strobes
PSC	*hPa*	CAPS static pressure
PSC	*hPa*	CAPS static pressure

QCB	*hPa*	Dynamic air pressure
QCC	*hPa*	CAPS dynamic pressure
QCC	*hPa*	CAPS dynamic pressure
RH	*%*	relative humidity
RHO	$g\ cm^{-3}$	absolute humidity (vapour density)
RHO1	$g\ cm^{-3}$	absolute humidity (vapour density)
RHUM	*%*	Vaisala relative humidity
SECOND	*UTC*	Raw system time
SIGMF_LPN	-	FSSP-100 standard deviation
SIGMP_RPN	-	PCAS-100 standard deviation
SPHUM	*g/kg*	Specific humidity
SPHUM1	*g/kg*	Specific humidity
TAS	*m/s*	Derived true airspeed
TAS1	*m/s*	Derived true airspeed
TASB	*m/s*	True airspeed
TDEW	*degC*	Dewpoint temperature
TDEW1	*degC*	Dewpoint temperature
THETA	*K*	Potential temperature
THETA1	*K*	Potential temperature
THETAE	*K*	Equivalent potential temperature
THETAE1	*K*	Equivalent potential temperature
THETAV	*K*	Virtual potential temperature
THETAV1	*K*	Virtual potential temperature
THDG	*degrees*	True heading
THETA	*K*	Potential temperature
TTBF	*degC*	Vaisala total air temperature
TTBR	*degC*	Rosemount total air temperature
TTBV	*degC*	Vaisala total air temperature
TTC	*degC*	CAPS total temperature
TTWC	*degC*	CAPS total temperature
TVIR	*K*	Virtual temperature
TVIR1	*K*	Virtual temperature
YEAR	*UTC*	Raw system date
age	*volts*	Set flow regulating valve voltage
case	-	Case number
cell	-	Cell number
event	-	Event number
io	-	In or out of event flag
mode	-	Data acquisition mode -> 0 = 1Hz and 1 => 10Hz
pass	-	Pass number
time_offset	*seconds*	Seconds since base_time (from 0)

calc.c

adzero		binary number assigned equal to zero voltage signal
alt1	m	aircraft altitude
analog_#	V	analogue voltage signal from instrument #
auxdfp	*hPa*	auxilliary differential pressure
dfp1	*hPa*	differential pressure
float		floating decimal integer
hum1	*%*	humidity
ias1	*m/s*	indicated airspeed 1
pow		pow(quantity,x) = quantity raised to power x
rft1	*℃*	reverse flow temp
rft2	*℃*	reverse flow temp
rmt1	*℃*	Rosemount total temperature (in Celcius)
rmt2	*℃*	Rosemount total temperature (in Kelvin)
rmt3	*℃*	Rosemount temperature calculated using stp2
sqrt		square root
stp1	*hPa*	static pressure
stp2	*hPa*	corrected static pressure
tas1	*m/s*	true airspeed
tas2	*m/s*	true airspeed calculated using stp2
vert_accel		vertical acceleration
lwc1		
ice1		Ice Detector liquid water content
pdry		
king1		King liquid water content
king2		King liquid water content
king3		King liquid water content