Bulletin No. 21

PRESSURE MEASUREMENT FROM NCAR AIRCRAFT

rev. 10/91

General

This Bulletin describes the types of pressure measurements and the sensors and transducers used to make them. Performance specifications and information on transducer accuracy are also included.

Pressure Measurements

Both static (absolute) and differential pressure measurements are made at various locations on the RAF aircraft. Table I summarizes the measurements, their location, and the type of transducer used.

The static pressure measurements are made through a static pressure port, flush on the side of the fuselage or on the side of a pitot-static tube. This port is connected to either a Rosemount Model 1201 capacitive-type absolute pressure transducer or a Rosemount Model 1501 digital absolute pressure transducer. The Rosemount Model 1201F series absolute pressure transducer uses a diaphragm-driven capacitance-measuring circuit. The Rosemount Model 1501 high-accuracy digital absolute pressure transducer outputs a pressure-dependent frequency signal.

Differential pressure measurements are made with either a pitot-static tube or a pitot tube referenced to a static port. The differential pressure measurements are used to determine aircraft dynamic pressure and flow angle (angles of attack and sideslip of the aircraft). Dynamic pressure (Q_c) is the difference between the total pitot pressure (P_t) and the static pressure (P_s).

$$Q_c = P_t - P_s$$

The true airspeed of the aircraft (TAS) is calculated from measurements of this pitot-static difference, the static pressure, and the total air temperature using Bernoulli's equation. (See RAF Bulletin No. 9.)

Flow-angle measurements are made with either a Rosemount Model 858AJ flow-angle sensor of a nose radome flow-angle pressure-sensing configuration. In flow-angle measurements, differential pressures are measured in the horizontal and vertical axes, relative to the aircraft, at or near the nose of the aircraft. These pressure differentials are used with the dynamic pressure at the aircraft nose or boom to determine the angles of attack and sideslip of the aircraft.

The RAF currently uses an electrically-deiced flow-angle sensing probe (Rosemount Model 858AJ) that can be interchangeably mounted on any of the aircraft. This flow angle sensor is hemispheric, capping a cylindrical tube, as shown in Figure 1.

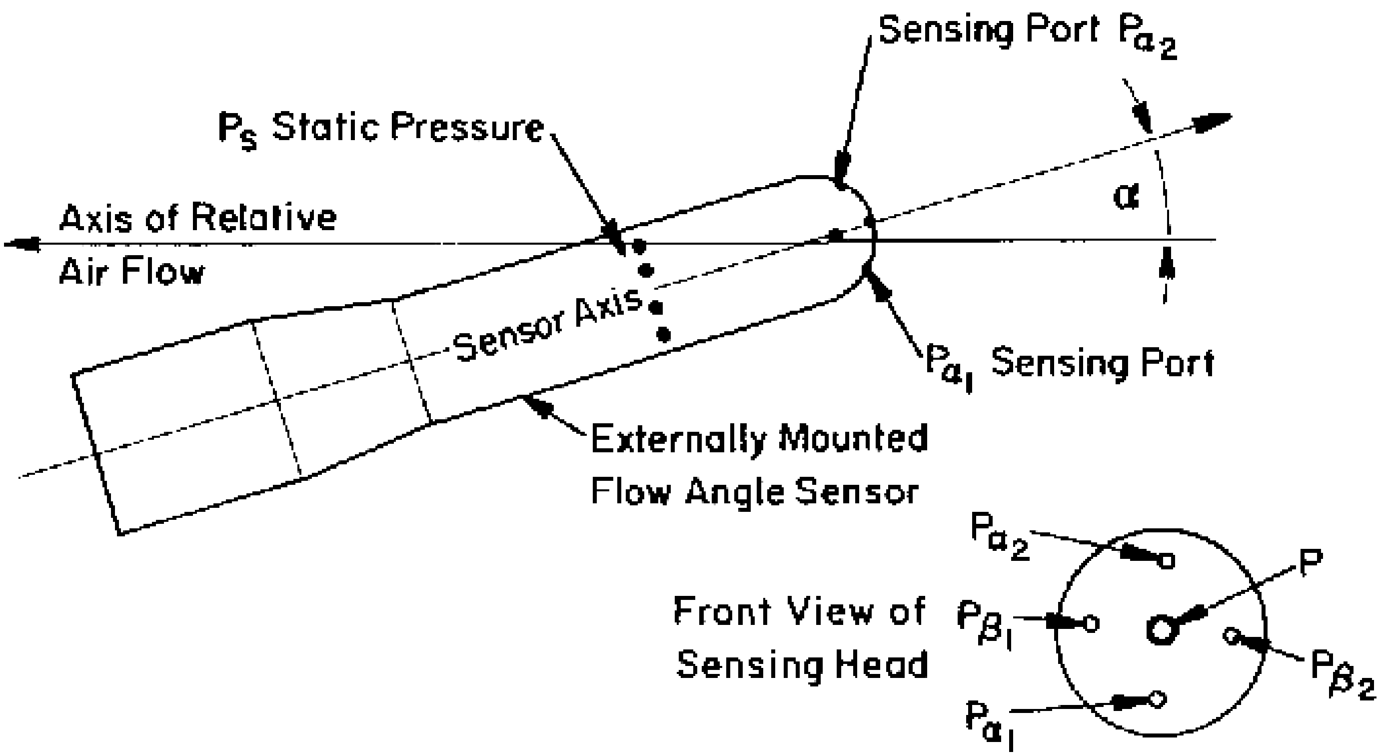

Figure 1. Schematic Representation of the Rosemount 858AJ Flow-Angle Sensor

The attack and sideslip angles of the aircraft are determined from the Rosemount Model 858AJ flow-angle sensor by the following equations:

ATTACK = ADIF / (GR * QCB)

SIDESLIP = BDIF / (GR * QCB)

Here ADIF is the differential pressure across the vertical axis of the probe. BDIF is the differential pressure across the horizontal axis of the probe. QCB is the dynamic pressure at the probe tip. GR is the normalized sensitivity coefficient, which for Rosemount 858AJ probe is 0.079 for Mach numbers below 0.51.

The radome technique for flow-angle sensing is similar, in principle, to that used with the Rosemount Model 858AJ probe. The major difference is that the nose of the airplane itself is used as a probe instead of the separate flow-angle sensor, as shown in Figure 2. *In-situ* calibration techniques are used for each aircraft to determine the normalized sensitivity coefficients. Details of the radome technique are discussed by Brown, et al., 1983.

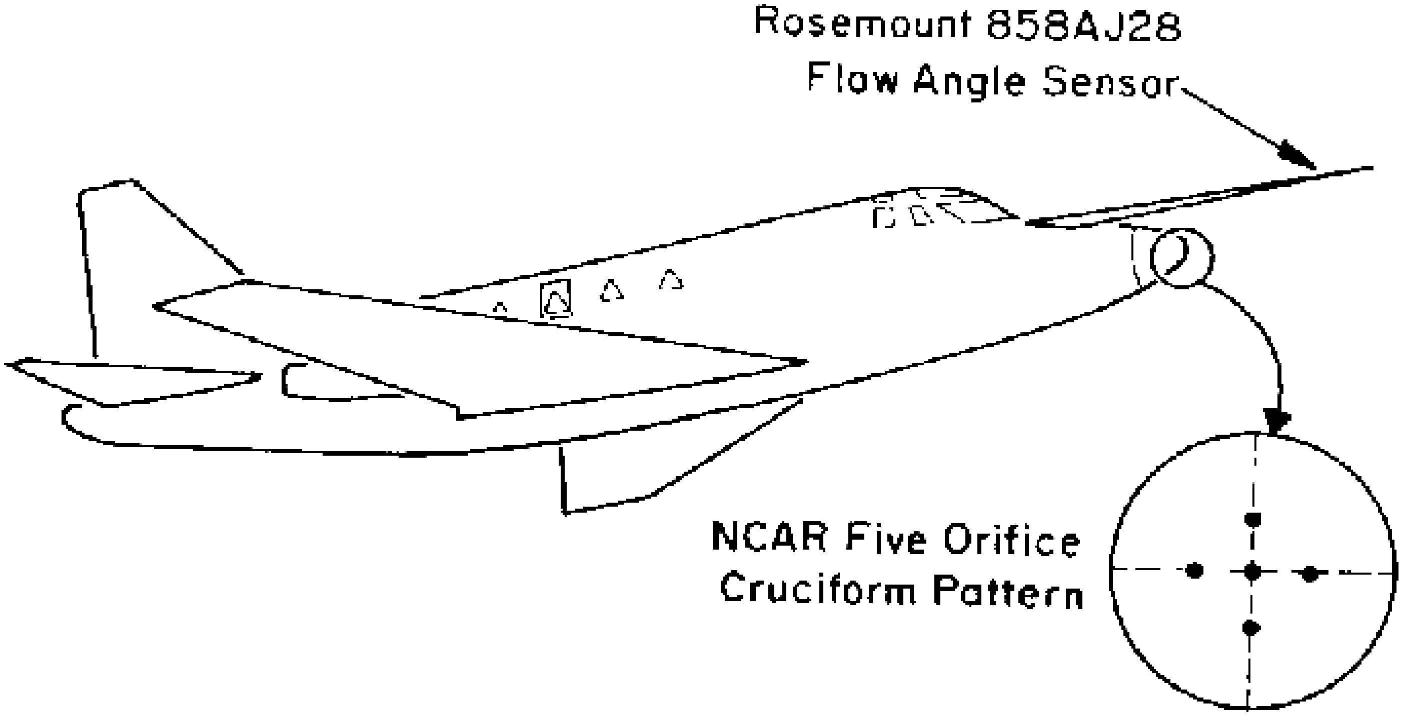

Figure 2. Sketch of Nose Radome Flow-Sensing Configuration on the NCAR Sabreliner and Detail of Pressure Taps in the Radome

At present the radome flow-angle sensing configuration is available on the King Air N312D, the Sabreliner (N307D), and the Electra (N308D) aircraft. The King Air and the Electra radomes are heated and will function well under most atmospheric conditions. The Sabreliner radome is unheated; thus, the range of atmospheric conditions in which it will function properly is somewhat limited. (Icing conditions and liquid water will adversely affect radome performance on the Sabreliner.)

The Rosemount Model 1221F series differential pressure transducer is used for differential pressure measurement for determining high-rate winds in the gust probe dynamic pressure measurement on RAF aircraft. The 1332 series transducer is used in this application, because it can be located out in the boom closer to the Q_c measuring point. (The size of the 1221 transducer does not allow this. See the line-length tabluation in Table I.) Both types of differential-pressure transducers us a diaphragm-driven capacitive pressure-sensing capsule. {Obsolete: For high-rate winds and turbulence studies, the gust-probe dynamic pressure is used with flow-angle measurements obtained from fixed vanes rather than with the Rosemount Model 858AJ differential pressure flow-angle sensor. (The vanes use strain gauges to measure the force, which is proportional to the flow angle.)}

TABLE I: Pressure Measurements

Measurement	Description	Transducer Used (Rosemount Model)	Nominal Line Length Sensor to Transducer (M)		
			N307D	N308D	N312D
PSW	Static pressure at the wing tip	1201		3.6	1.2
PSB	Static Pressure at the boom	1201	5.4		
PSF	Static pressure at the fuselage	1201	4.9		

PSFD	Static pressure at the fuselage (digital)	1501	5.2	12.2	2.4
PCAB	Static pressure in the aircraft cabin	1205			
QCW	Dynamic pressure at the wing tip	1221		3.6	1.5
QCB	Dynamic pressure at the boom	1221	5.4		
QCF	Dynamic pressure at the fuselage	1221	2.9 4.9*	2.0	
QCR	Dynamic pressure at the radome	1221	2.1 5.5*	1.7	
ADIF	Differential pressure in the vertical plane on the boom w/Rosemount 858AJ	1221	5.4		
BDIF	Differential pressure in the horizontal plane on the boom w/Rosemount 858AJ	1221	5.4		
ADIFR	Differential pressure in the vertical plane on the radome w/radome	1221	2.1	1.7	0.9 0.6*
BDIFR	Differential pressure in the horizontal plane on the radome w/radome	1221	2.1	1.7	0.8 0.6*
All pressure lines are 4.32mm I.D.					
* The high-pressure line lehgth is given first.					

Correction for Static Pressure Defect

Pressure measurements on board an aircraft are affected by local flow-field distortions, and corrections are made for these pressure defects. The corrections are unique to both the aircraft and the position of the measurement on the aircraft.

The correction for static pressure error for a given location on a given aircraft may be determined by flying by an instrumented tower (equipped with a precision barometer) at various air speeds (varying dynamic pressure, Q_c). The pertinent meteorological data (ambient static pressure, etc.) are recorded simultaneously on the aircraft and on the tower. Pressure corrections ("PCORs") are determined from a regression between the static pressure differences measured between the tower reference and the aircraft versus the dynamic pressure, Q_c, measured on the aircraft.

An example of a PCOR calculation follows (In this case QCF is a measurement of uncorrected dynamic pressure; PSF is an uncorrected static pressure measurement.):

$$\mathrm{PCOR(QCF)} = C_1 + C_2 * \mathrm{QCF}$$

Here C_1 and C_2 are coefficients determined from the regression, in this case a first-order regression. Thus, the corrected static pressure would be:

$$\mathrm{PSFC} = \mathrm{PSF} + \mathrm{PCOR\ (QCF)}$$

For dynamic pressure correction, the sign of the PCOR is reversed as shown below.

$$PSFC = PSF + PCOR\ (QCF)$$

$$QCFC = P_{Pitot} - \{P_{Static} + PCOR(QCF)\} = QCF - PCOR(QCF)$$

PCORs have been determined at RAF using both tower flybys and trailing-cone tests. Extensive trailing-cone calibrations have been completed on the RAF aircraft; this procedure and uncertainty analysis are discussed by Brown, 1988.

Table II lists the "PCORs" for each RAF aircraft.

Table II: PCOR Tabulation (not avaliable)

Transducer Specifications

Performance and environmental specifications for the pressure transducers used on NCAR aircraft are shown in Table III. This information was obtained from "Product Data Sheets" provided by the manufacturer, Rosemount, Inc.

TABLE III: Specifications for Rosemount Pressure Transducer Models

	1501 Digital Absolute (FSP=1000 mbar)	**1201F Absolute (FSP=1034 mbar)**	**1221 Differential (FSP=±? mbar)**	**1332 Differential (FSP=±172.4 mbar)**
Operating Accuracy	±0.042% FSP (±0.42mbar)*	±0.30% FSP (±3.0 mbar)**	Refer to Table IV	±0.20% FSP (±0.35 mbar)***
Static Error The static error is the root sum square of the errors due to nonlinearity, repeatability, hysteresis and resolution.	±0.026% FSP (±0.26 mbar)	±0.10% FSP (±1.0 mbar)	±0.10% FSP	±0.10% FSP (±0.2 mbar)
Long-Term Stability Change in output over period indicated	±0.025% FSP (12 months)	±0.15% FSP (6 months)	±0.15% FSP (6 months)	±0.15% FSP (6 months)
Response Time (63% response)	75 milliseconds	15 milliseconds	10 milliseconds	10 milliseconds
Operating Temperature Range	-55C to +81C	-55 to +71C	-55C to +71C (Electronically compensated range)	-18C to +65C (Electronically compensated range)

* This is the root sum square error, which includes dynamic error (stated by Rosemount as ±0.021% FSP), the static error, and the long-term stability.

** The reported operating accuracy includes the effect of ambient temperature on the transducer. Laboratory tests at RAF indicate that ambient temperature changes on the order of 2°C per minute produce static pressure errors of 1.0 to 1.5 mbar in the 1201 series transducer. Thus, if the ambient temperature around the transducer is controlled, by locating the transducer in the aircraft cabin for

instance, the operating accuracy is greatly improved.
*** This value is an estimated root sum square error obtained from errors (stated by Rosemount) caused by various environmental factors. This value includes the static error in the root sum square calculation.

TABLE IV: Differential Pressure Measurements and the Operating Accuracies of the Rosemount 1221 Transducer used for each Measurement (-55C to +71C)			
Aircraft	**Measurement**	**Transducer Pressure Range Used**	**Accuracy***
Electra N308D	QCRC	±206.8 mbar ±275.8 mbar	±0.27% FSP (±0.6 mbar) ±0.23% FSP (±0.6 mbar)
Electra N308D	ADIFR, BDIFR	±68.9 mbar ±51.7 mbar	±0.27% FSP (±0.2 mbar) ±0.37% FSP (±0.2 mbar)
* The operating accuracy includes the static accuracy as well as calibration tolerance and the effect of ambient temperature over the compensated range (-55C to +71C).			

Error Propagation

Pressure measurement error, either static of differential, will propagate into parameters derived from those pressure measurements. Errors propagated to selected derived measurements are shown in Table V. For illustration purposes, the errors shown are those that would result for each 1.0 mbar error in the corresponding measured pressure. Details of the measurement uncertainty of true air speed, angle of attack, and sideslip applicable to RAF aircraft are discussed in Brown, 1991.

TABLE V: Error Propagation						
Measurement (1.0 mbar error)	**Conditions**	**Derived measurement to which error is propagated**				
		TAS (M/s)	**Wind speed (M/s)***	**W (M/s)**	**Attack (deg)**	**Sideslip (deg)**
Static Pressure	750 mbar (Q_c=35 mbar)	0.05	0.05			
	540 mbar (Q_c=81 mbar)	0.05	0.13			
	760 mbar (Q_c=93 mbar)	0.09	0.09			
Dynamic Pressure	750 mbar (Q_c=35 mbar)	1.18	1.18	0.14	0.09	
	540 mbar (Q_c=81	0.78	0.78	0.05	0.05	

	mbar)					
	760 mbar (Q_c=93 mbar)	0.65	0.65	0.10	0.4	
Attack Differential Pressure	750 mbar (Q_c=35 mbar)			0.48	0.37	
	540 mbar (Q_c=81 mbar)			0.42	0.16	
	760 mbar (Q_c=93 mbar)			0.35	0.14	
Sideslip Differential Pressure	750 mbar (Q_c=35 mbar)					0.37
	540 mbar (Q_c=81 mbar)					0.16
	760 mbar (Q_c=93 mbar)					0.14
* Assumes wind is along the longitudinal axis (worst case for error attributable to the pressure measurement)						

References

1. Rosemount Engineering Co., Post Office Box 35129, Minneapolis, MN 55435

2. Brown, E.N., C.A. Friehe, and D.H. Lenschow, 1983: The use of pressure fluctuations on the nose of aircraft for measuring air motion, *J. Clim. Appl. Meteorol.*, **22**, 171-180.

3. Brown, E.N., 1988: Position Error Calibration of a Pressure Survey Aircraft Using a Trailing Cone. NCAR Tech. Note (NCAR/TN-313+STR). NCAR, Boulder, Colo., 29 pp.

4. Brown, E.N., 1991: The Uncertainty Analysis of a Radome Flush Orifice Air Motion System for the Measurement of Aircraft Incident Angles. NCAR Tech. Note (NCAR/TN-359+STR). NCAR, Boulder, Colo., 27 pp.

Last update: Thu Nov 30 15:40:05 MST 2000