NOAA Technical Memorandum OAO 1

CALIBRATION OF METEOROLOGICAL MEASUREMENTS MADE BY NOAA WP3D AIRCRAFT - 1983

Office of Aircraft Operations
Miami, Fla.
November 1983

U.S. DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / Office of Aircraft Operations

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UNITED STATES
DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and
Atmospheric Administration
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Office of Aircraft Operations
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Director

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ABSTRACT. Techniques used by the Office of Aircraft Operations (OAO) to calibrate its airborne meteorological measurements are described and results for fiscal year 1983 are presented. Appendices describe the facilities used for calibration and list calibrations done since 1979.

I. INTRODUCTION

The Office of Aircraft Operations (OAO) operates two WP3D research aircraft in support of a variety of programs of the National Oceanic and Atmospheric Administration (NOAA) and other agencies. These airborne research platforms provide state of the art measurements of atmospheric and oceanographic variables. An important part of maintaining the accuracy of the measurements is an ongoing calibration program. This report describes the calibration program and some of its current results.

The variables of concern to the calibration program are the principal state variables (pressure, temperature, and humidity), the winds, and certain specialty measurements (including quantities significant to investigations in cloud physics, air-sea interaction, and radar meteorology). Much of the instrumentation used aboard the aircraft is described in Merceret and Davis (1981) where error estimates and a discussion of each instrument's operating principles may be found. The scope of this paper is limited to calibration per se and does not encompass an analysis of instrument lifetime, reliability, or failure modes.

While this report deals exclusively with calibration, it presupposes some knowledge of the calculation of corrected results from raw aircraft measurements. Such matters are discussed in detail in Merceret (1982) and Merceret and Davis (1981) which may be useful references to have at hand. There are some notational differences between those papers and these which should be kept in mind. Table 1 presents the notation used in this report. Merceret *et al.* (1980) describes some calibrations done prior to the period covered *in this* report and may be useful for comparison purposes.

II. STATE VARIABLES

A. Pressure

There are two fundamental kinds of pressure sensors we calibrate: absolute and differential. Absolute pressure is required for static (ambient environmental) pressure which is used to estimate surface pressure and compute

Table 1: Symbol Definitions

Symbol	Meaning
Δ	Difference
ρ	Correlation coefficient
A/C	Aircraft
AA	Attack angle
ALT CON	Altitude correction to pressure
AP	Attack pressure
BP	Sideslip pressure
DA	Drift angle
DAP	Dynamic attack pressure
DAPC	Correction to DAP
DAPM	Measured DAP before correction
DBP	Dynamic sideslip pressure
DBPC	Correction to DBP
DBPM	Measured DBP before correction
GS	Ground speed
HD	Heading
HDC	Correction to heading
I	Intecept
INE	Inertial navigation equipment
KIAS	Knots indicated airspeed
LVDT	Linear variable differential transformer
PC	Pitch
PQ	Dynamic pressure
PQC	Correction to PQ
PQM	Measured PQ before correction
PRT*	Platinum resistance thermometer
PS	Static pressure
PSC	Correction to PS
PSM	Measured PS before correction
S	Slope
SA	Angle of sideslip
SEE	Standard error of estimate
SST	Sea surface temperature
TA	Air temperature
TD	Dewpoint temperature
TK	Track angle
TS	True airspeed
TWR	Tower
W	Wind

*Not to be confused with the "PRT" designation used by Barnes for its "PRT-5" series of radiation thermometers.

"D-values" and the height of standard pressure surfaces. Differential pressure is necessary for dynamic pressure (a function of air speed and air density), angle of attack, and angle of sideslip measurements. In each case, both laboratory and in-flight calibrations are used. The laboratory calibrations will be described first.

The system used for pressure calibration is presently configured for measurements in both modes: absolute pressure from near vacuum to one atmosphere, and differential pressure for similar limits at any reference pressure between near vacuum and one atmosphere. The modes of operation are diagrammed in Figure 1. The constraints on the pressure limits are due to the limits on the capability of the vacuum pump used during calibrations. According to the manufacturer, it has an ultimate capacity of 0.1 millitorr (1.333E-4 mb) when operated in a closed system. The main components of the pressure system are:

(1) a Calibration Pressure Controller Type 6-003-002, manufactured by CEC Division of Bell and Howell Electronics and Instruments Group,

(2) a Direct Reading Differential Pressure Gauge, Model DDR 6000, manufactured by Ruska Instrument Corporation,

(3) two, eleven-port manifolds with purge valves and quick-connect fittings,

(4) interconnecting tubing using quick-connect fittings and adapters, and

(5) a data controller and processor, Model 9845T, manufactured by Hewlett-Packard.

The Ruska differential gauge is the laboratory's secondary pressure standard. It is calibrated every six months or less with our primary standard, a dead-weight piston gauge, also manufactured by Bell and Howell. Corrections for local gravity and air buoyancy (temperature) are applied to the primary standard during calibrations. The secondary standard, when used in conjunction with the pressure controller, simplifies pressure measurements by allowing direct reading of actual pressure, manual selection of any pressure desired within limits, reasonable repeatability, drift, and ease in configuring the test equipment. The secondary gauge outputs an analog signal (0 to 11 vdc) which is interfaced to the data controller with the responses from a maximum of three sensors utilizing specialized electronic equipment.

By connecting the secondary standard's reference port to a vacuum source, it becomes, in essence, an absolute pressure gauge with respect to the ultimate vacuum of the source. In order to measure the vacuum source capability, an MKS Baratron Pressure Transducer, Type 220B, is connected directly to the low pressure (vacuum) manifold, as is the vacuum source and the reference port of the Ruska gauge (see Figure 1). The zero setting of the MKS transducer is periodically checked or adjusted by connecting the transducer port directly to the vacuum pump and allowing it to run to its ultimate capacity, which is the same order of magnitude as the resolution of the MKS. The use of this instrument as a vacuum reference is considered in excellent agreement with the secondary standard. The pressure system resolution is .01 mb with a combined accuracy of less than 0.1 mb.

CALIBRATION LAB PRESSURE SYSTEM

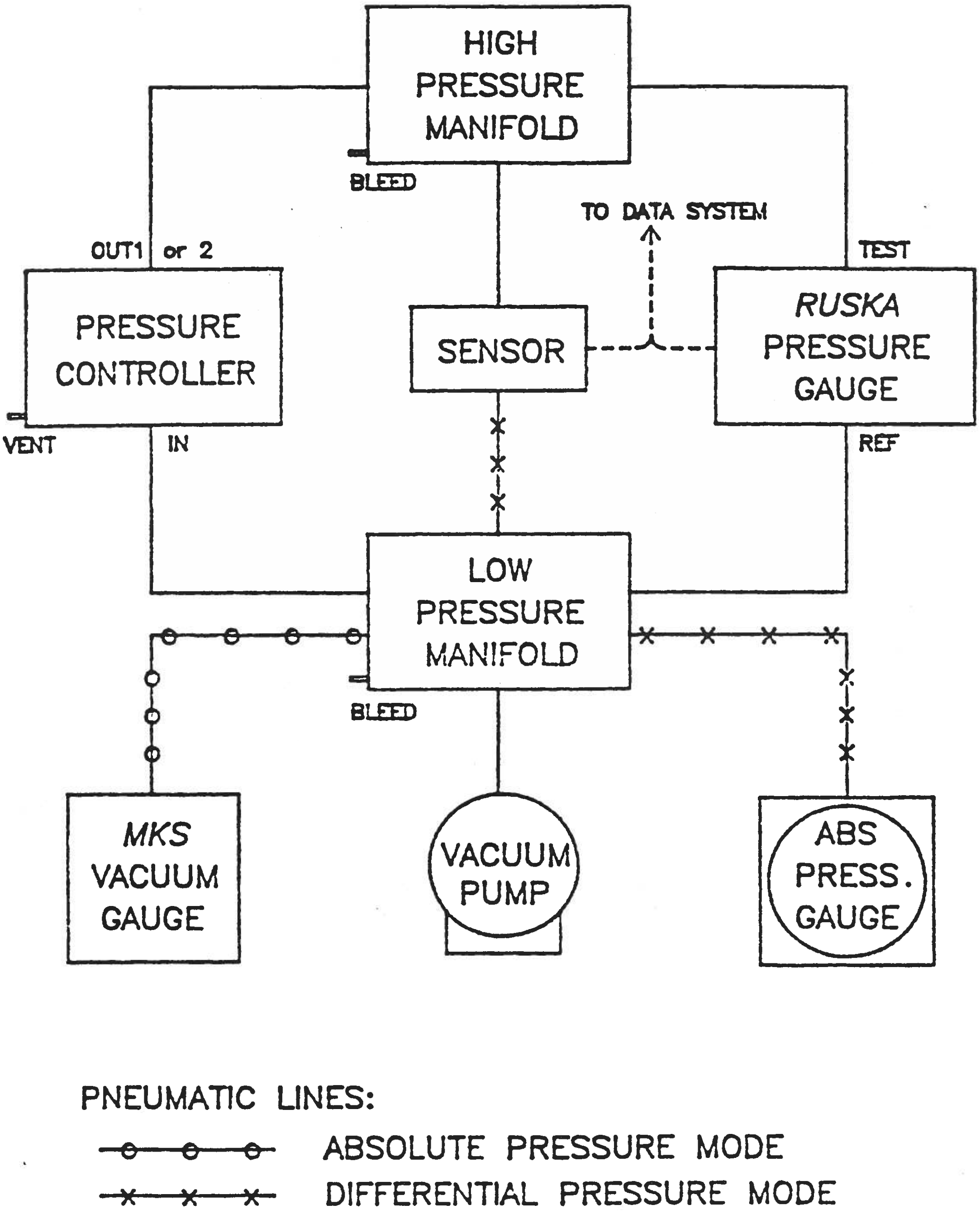


Figure 1

The use of 3/8" O.D. polyethylene tubing with quick-connect, swaged ferrule fittings provides a practically leak-free system and a relatively fast response to changing pressure or step change of the measurand. The response time is on the order of a few seconds depending on the total system volume including the transducers under test. The response time of the system itself has not been determined but times as low as 8 to 10 ms have been measured for LVDT type transducers. Pressure transducers are connected to the pressure system for calibration or testing using quick-connect adapters assembled for various port sizes. With the adapters attached, the configuration can be easily changed as is necessary for bidirectional differential transducers. These type of transducers output a positive or negative pressure depending on the relative pressure difference between ports. Of course, the unidirectional transducers only provide positive pressures with respect to a referenced port. Since the secondary pressure standard is unidirectional, the calibration of bidirectional sensors is conducted in two parts. The first is conducted as would a unidirectional transducer's calibration. The second part is accomplished by reversing the port connections at the sensor and the pressure standards output voltage leads. This provides the negative pressures at the sensor ports and the corresponding input to the data system. Both ports of the transducer and the pressure system are at equilibrium with ambient room pressure whenever any connections are made or changed.

A typical pressure calibration will provide staggered measurements ascending and descending throughout the working range of the transducer. For example, the bidirectional capacitance type sensors are nominally calibrated at the following approximate settings: 0, 20, 40, 60, 80, 100, 90, 70, 50, 30, and 10 mb, the port connections reversed, and the same readings repeated. During the subsequent analysis of the calibration data, one of the two zero pressure readings is deleted unless they are noticeably different; thus providing equal weight to all readings. The staggered readings provide a measure of the hysteresis inherent in the sensor and its associated electronics.

The LVDT and capacitance type pressure transducers put out an analog voltage which is interfaced to the data controller as previously described. The quartz type sensor preprocesses its information and provides digital data and, therefore, requires a multiprogrammer to convert the data to an acceptable form for reading by the data controller. This limits the number of sensors that can be calibrated at one time. The manifolds allow several sensors or gauges to be interconnected and, therefore, comparative tests can be performed on up to three sensors.

The pressure calibration software has undergone extensive upgrading to provide as much automation of a calibration as possible. The pressure controller, with its associated valving and volume regulator, can provide coarse and fine pressure control but only by manual operation. Thus, a calibration official must perform the pressure setting adjustments, but all data recording is under control of the HP9845T processor and the specific software. After each pressure setting is established, a nominal stabilization period of at least one minute is allowed before signaling the data controller to begin a measurement sequence. Statistics are computed and displayed for the official who determines whether to accept or reject the data after comparing it with previously displayed data. This technique allows careful scrutiny by the calibration official and quickly identifies problems with the pressure connections on the sensors. The laboratory calibrations described above provide data for the conversion of the sensors' electrical outputs to sensed pressures. Additional corrections must be made before the sensed pressures can be properly interpreted in terms of meteorological variables.

In-flight calibration of pressure is used to account for dynamic effects including effects of air compressibility and sensor placement. For static pressure, measurements are made during fly-by's of the Dade-Collier airport control tower. Aircraft height above ground is measured to about 1 meter by photographing the aircraft against the horizon from the tower during each pass. Secondary standards accurate to ± 0.3 mb are deployed at a known height on the tower (see Appendix One, section V). Several passes are made by each aircraft at each of three indicated air speeds: 180, 210 and 240 KIAS. The difference between the aircraft and reference pressure is computed for each pass and corrected for the altitude difference between the aircraft and the reference barometer. A least squares fit relates the dynamic correction for static pressure to the dynamic pressure. The data from the calibration flight of 23 June 1983 presented in Table 2 and Figure 2 are typical. The quantity labeled ES1 is of the form ES1 = ES1I + ES1S * PQ where ES1I and ES1S on the constants mentioned on page 11 of Merceret (1982) and on page 5 of Merceret and Davis (1981). Aircraft to aircraft intercomparison data confirm the corrections (see Table 4). In-flight calibration of the differential pressure measurements is discussed under the wind calibration heading.

B. Temperature

Because of the lack of proper facilities, we have not yet begun a regular program of bath calibrations of the primary aircraft temperature sensors. Instead, we have relied on the factory calibrations, room temperature spot checks and in-flight calibrations. The electronics package is checked using a PRT simulator and digital voltammetry.

In-flight calibrations to determine dynamic effects are made during the tower fly-by's described above. ASTM mercury-in-glass thermometers are pre-calibrated in the controlled temperature bath for use as a field reference. Radiation shielding and adequate ventilation are provided. Typical results are shown in Table 3 from the same flight as the data in Table 1. The intercomparison data are shown in Table 4.

C. Humidity

As with temperature, complete humidity calibrations are not possible, but the thermometers in the dew pointers are checked as described in B above. Tower fly-by data are compared with measurements from an Assman psychrometer made at the time of each pass. The thermometers in the psychrometer are pre-calibrated as described under temperature above. Results from the flight of 23 June 1983 are presented in Table 3 with intercomparisons shown in Table 4.

Table 2: Pressure Calibration.

830623I: PSC vs. PQ Regression (ES1)

Run	A/C PSM	ALT CQN	A/C PSM	TWR PS	Δ	PQ
1	12.0	0.0	12.0	14.9	+2.9	53.4
2	12.8	-0.4	12.4	15.0	+2.6	51.0
3	12.4	-0.1	12.3	15.1	+2.8	54.1
4	13.1	-0.5	12.6	15.2	+2.6	52.4
5	12.8	-0.4	12.4	15.3	+2.9	72.5
6	12.9	-0.4	12.5	15.5	+3.0	72.5
7	13.1	-0.5	12.6	15.6	+3.0	67.9
8	12.9	-0.2	12.7	15.5	+2.8	68.9
9	11.9	+0.1	12.0	15.5	+3.5	94.5
10	12.4	-0.2	12.2	15.6	+3.4	92.7
11	12.2	-0.2	12.0	15.6	+3.6	95.3
12	12.4	-0.4	12.0	15.6	+3.6	97.3

$ES1 = +1.630 + 0.0194*PQ$; $\rho = 0.95$; SEE = 0.12

Table 3

830623I: Temperature-Dewpoint

Run	TWR TA	A/C TA	Δ	TWR TD	A/C TD	Δ
1	25.1	25.8	-0.7	24.2	23.7	+0.5
2	25.4	26.3	-0.9	24.3	23.7	+0.6
3	25.3	26.5	-1.2	24.2	23.9	+0.3
4	25.3	26.2	-0.9	24.3	23.7	+0.6
5	25.6	26.5	-0.9	24.5	24.0	+0.5
6	25.8	26.8	-1.0	24.4	24.1	+0.3
7	26.3	27.0	-0.7	24.5	24.0	+0.5
8	26.7	27.1	-0.4	24.6	24.1	+0.5
9	26.8	27.2	-0.4	24.6	24.3	+0.3
10	26.7	27.5	-0.8	24.6	24.3	+0.3
11	27.2	27.8	-0.6	24.7	24.2	+0.5
12	27.4	27.8	-0.4	25.0	24.6	+0.4
Avg. Δ			-0.7			+0.4

Table 4

830623H&I: Aircraft Comparison Data

Run		GS	Δ	TS	Δ	TK	Δ	HD	Δ	PS	Δ	PQ	Δ	TA	Δ	TD	Δ
1	42	135.6	---	132.6	---	097.7	---	097.8	---	712.0	---	79.8	---	9.6	---	1.8	---
	43	134.4	+1.2	132.6	0.0	097.8	-0.1	097.8	0.0	712.1	-0.1	79.8	0.0	9.8	-0.2	1.3	0.5
2	42	136.5	---	133.1	---	098.5	---	097.8	---	712.0	---	80.5	---	9.8	---	-0.7	---
	43	135.2	+1.3	133.1	0.0	098.5	0.0	097.8	0.0	712.1	-0.1	80.4	0.1	10.0	-0.2	-0.8	-0.1

	RA42	RA43	Δ
1	3073	(3064)	
2	(3073)	3064	+9

Data are three minute averages; both A/C INE1 (N43RF INE unaided)

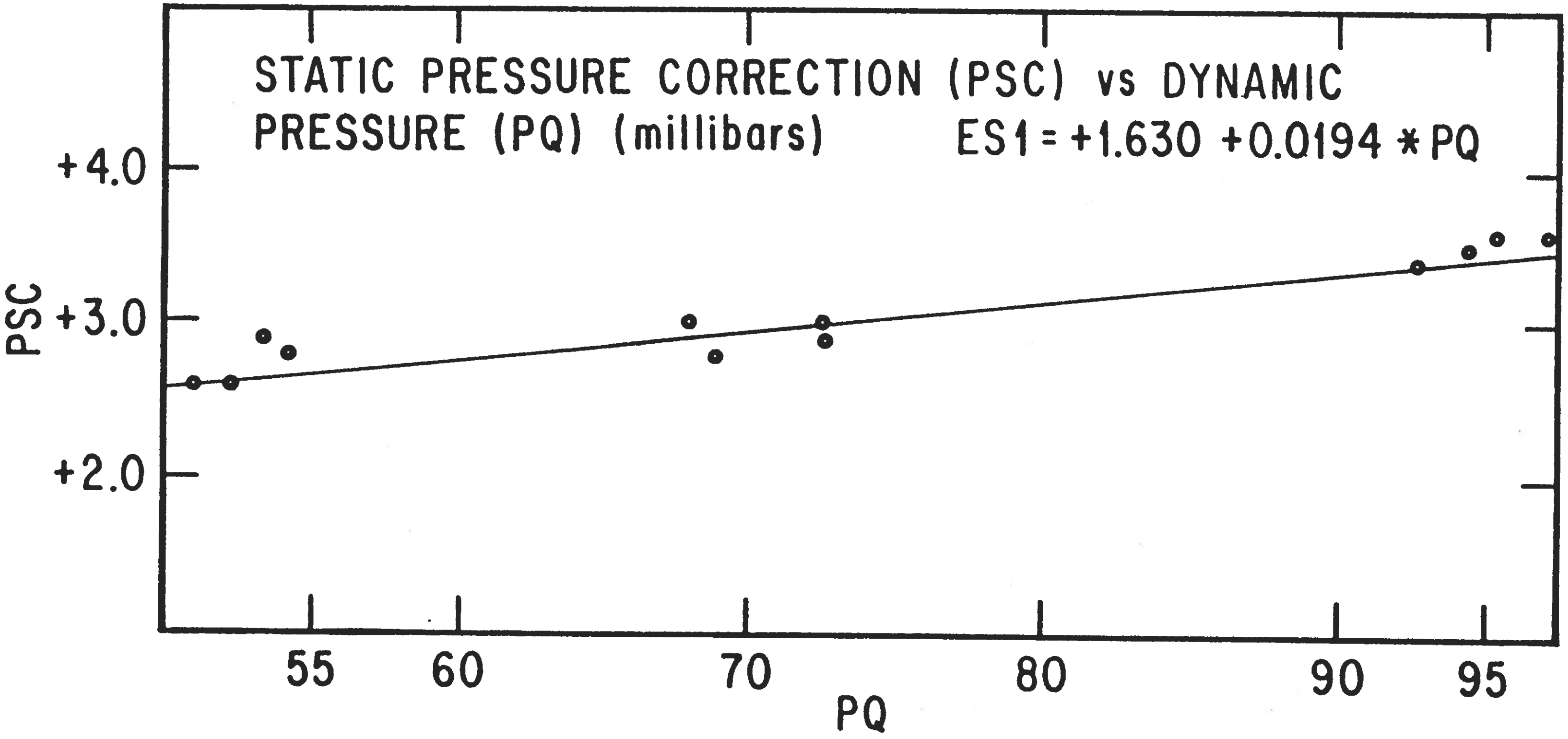

STATIC PRESSURE CORRECTION (PSC) vs DYNAMIC
PRESSURE (PQ) (millibars)
ES1 = +1.630 +0.0194 * PQ
PSC
+4.0
+3.0
+2.0
55
60
70
80
90
95
PQ

Figure 2

III. WINDS

Wind calibration is the most complex calibration which we undertake. Of necessity, these data are collected in-flight. The critical variables include true air speed (from PQ, PS and TA), angles of attack and sideslip (from differential pressure measurements), ground speed, vertical acceleration, roll, pitch, and heading. The last five items listed above are supplied by the inertial navigation equipment (INE) and are not "calibrated" in any strict sense but are checked for adherence to accepted tolerances and a heading correction is obtained. Actual calibration and derivation of dynamic corrections is undertaken for dynamic pressure (hence TS), sideslip, and angle of attack. These procedures are described here.

The wind vector $\underline{W}$ is given by the difference between the ground speed vector $\underline{G}$ and the air speed vector $\underline{A}$, thus $\underline{W} = \underline{G} - \underline{A}$. If $\underline{G}$ from the INE is error free, then any error in $\underline{W}$ comes from $\underline{A}$ whose magnitude is the true air speed and whose direction is the heading. Systematic errors in either TS or HD show up as changes in the sensed wind when the aircraft changes heading. These apparent wind shifts are maximum for a 180° aircraft heading change. One can determine the TS and HD errors from pairs of flight legs at reciprocal headings if the wind field remains constant over the time and space in which the calibration maneuvers are being performed. Because of this limitation, it is not an absolute calibration procedure and not much reliance can be placed on a single case. In order to establish validity, a sufficient number of cases must be collected so that the variance of the errors is sufficiently small that from a statistical viewpoint the results are acceptable. The manuevers required for the completion of a set of data for one case are as follows: in an area of light to moderate winds ($<$ 25 kts) fly straight and level for approximately two minutes, then change heading (preferably 180°) and again fly straight and level for approximately two minutes. These two segments will be denoted by flight legs 1 and 2 in the analysis below. Since the inertial navigation system measures GS east/west and GS north/south directly, further information is available if the sets of runs are oriented north/south and east/west. This technique won't detect east/west or north/south bias in INE ground speed. Our experience is that the unaided INE can drift, but Omega update cures that bias. The equations used to reduce these observations are presented in Merceret and Davis (1981).

Typical results are shown in Table 5 and Figure 3. The quantity ES2 is of the form ES2 = ES2I + ES2S*PQM where ES2I and ES2S are the constants referred to on page 6 of Merceret (1982) and page 5 of Merceret and Davis (1981). TAS errors have been converted to dynamic pressure (PQ) errors.

The actual flight pattern used is a set of reciprocal "ELLS" so that pairs of reciprocal runs are made at right angles to each other, thus providing additional checks on heading dependent vectors. The measured values are based on the laboratory calibrations; the corrections sought here account for dynamic effects. The reference dynamic pressures DAP and DBP are obtained in the same manner as PQ (which they should equal if all effects of probe installation and calibration are accounted for) during these manuevers. A correction of the form DAPC = I + S*ℓn (PS) is used. Results are shown in Tables 6 and 7 and Figures 4 and 5.

Table 5

230512I: PQ Calibration, ES2 = 0.0, INE1

Run	HDC	PQC	PQM	ES2	Δ
Alt: 18 K					
1	+0.01	-1.85	53.0	-1.73	-0.12
2	-0.03	-1.79	53.2	-1.74	-0.05
3	-0.04	-2.11	74.1	-2.35	+0.24
4	-0.04	-1.86	73.4	-2.33	+0.47
5	-0.04	-3.64	98.9	-3.08	-0.56
6	+0.12	-3.21	96.7	-3.08	-0.13
Alt: 10 K					
12	+0.18	-1.34	52.7	-1.72	+0.38
11	+0.17	-1.99	53.8	-1.76	-0.23
10	+0.09	-2.76	74.4	-2.36	-0.40
9	+0.01	-2.16	75.2	-2.38	+0.22
8	+0.11	-2.94	98.3	-3.06	+0.12
7	-0.13	-3.02	98.4	-3.07	+0.05
18	-0.02	-1.86	53.2	-1.74	-0.12
17	+0.33	-1.75	53.5	-1.75	0.00
16	+0.27	-2.61	74.1	-2.35	-0.26
15	+0.01	-2.38	74.6	-2.37	-0.01
14	-0.18	-2.89	98.4	-3.07	+0.18
13	-0.11	-2.81	99.4	-3.10	+0.29

ES2 = -0.174 - 0.0294*PQM
SEE = 0.26

ES1 = +0.82 + 0.0245*PQ
SA = +0.26 - 7.28*BP/DBP

Table 6

830512I: DAP Calibration, INE1

Run	DAPC	LN (PS)	DAPM	($10^4/\text{DAPM}^2$)	I	S
1	-1.35	6.185	52.4	3.494	10.175	-1.864
2	-1.31	6.185	52.7	---	---	---
11	-2.43	6.546	54.2	---	---	---
12	-1.73	6.546	53.1	---	---	---
17	-2.57	6.891	54.3	---	---	---
18	-2.72	6.891	54.1	---	---	---
			53.5			
3	-1.21	6.185	73.2	1.802	19.962	-3.435
4	-1.08	6.185	72.6	---	---	---
9	-2.52	6.546	75.6	---	---	---
10	-3.11	6.546	74.7	---	---	---
15	-3.40	6.890	75.7	---	---	---
16	-3.72	6.890	75.2	---	---	---
			74.5			
5	-1.66	6.185	96.7	1.039	21.154	-3.679
6	-1.38	6.185	94.7	---	---	---
7	-3.11	6.545	98.4	---	---	---
8	-3.05	6.545	98.4	---	---	---
13	-4.06	6.890	100.6	---	---	---
14	4.16	6.890	99.7	---	---	---
			98.1			

DAPC = I + S*LN (PS)
I = 27.000 - 4.690*($10^4/\text{DAPM}^2$)
S = -4.620 + 0.771*($10^4/\text{DAPM}^2$)
SEE = 0.24

Table 7

830512I: DBP Calibration, INE1

Run	DBPC	LN (PS)	DBPM	$(10^4/\text{DBPM}^2)$	I	S
1	-4.43	6.185	55.6	3.133	5.399	-1.588
2	-4.36	6.185	55.8	---	---	---
11	-5.44	6.546	57.3	---	---	---
12	-4.68	6.546	56.1	---	---	---
17	-5.43	6.891	57.2	---	---	---
18	-5.60	6.891	57.0	---	---	---
			56.5			
3	-3.92	6.185	76.0	1.665	22.101	-4.204
4	-3.73	6.185	75.3	---	---	---
9	-5.26	6.546	78.4	---	---	---
10	-5.88	6.546	77.6	---	---	---
15	-6.63	6.890	79.0	---	---	---
16	-6.94	6.890	78.5	---	---	---
			77.5			
5	-3.70	6.185	98.9	0.948	26.977	-4.934
6	-3.45	6.185	96.9	---	---	---
7	-5.30	6.545	100.7	---	---	---
8	-5.19	6.545	100.6	---	---	---
13	-6.96	6.890	103.6	---	---	---
14	-7.15	6.890	102.7	---	---	---

ES2 = I + S*LN (PS)
I = 37.500 - 10.098*$(10^4/\text{DBPM}^2)$
S = -6.580 + 1.569*$(10^4/\text{DBPM}^2)$
SEE = 0.23

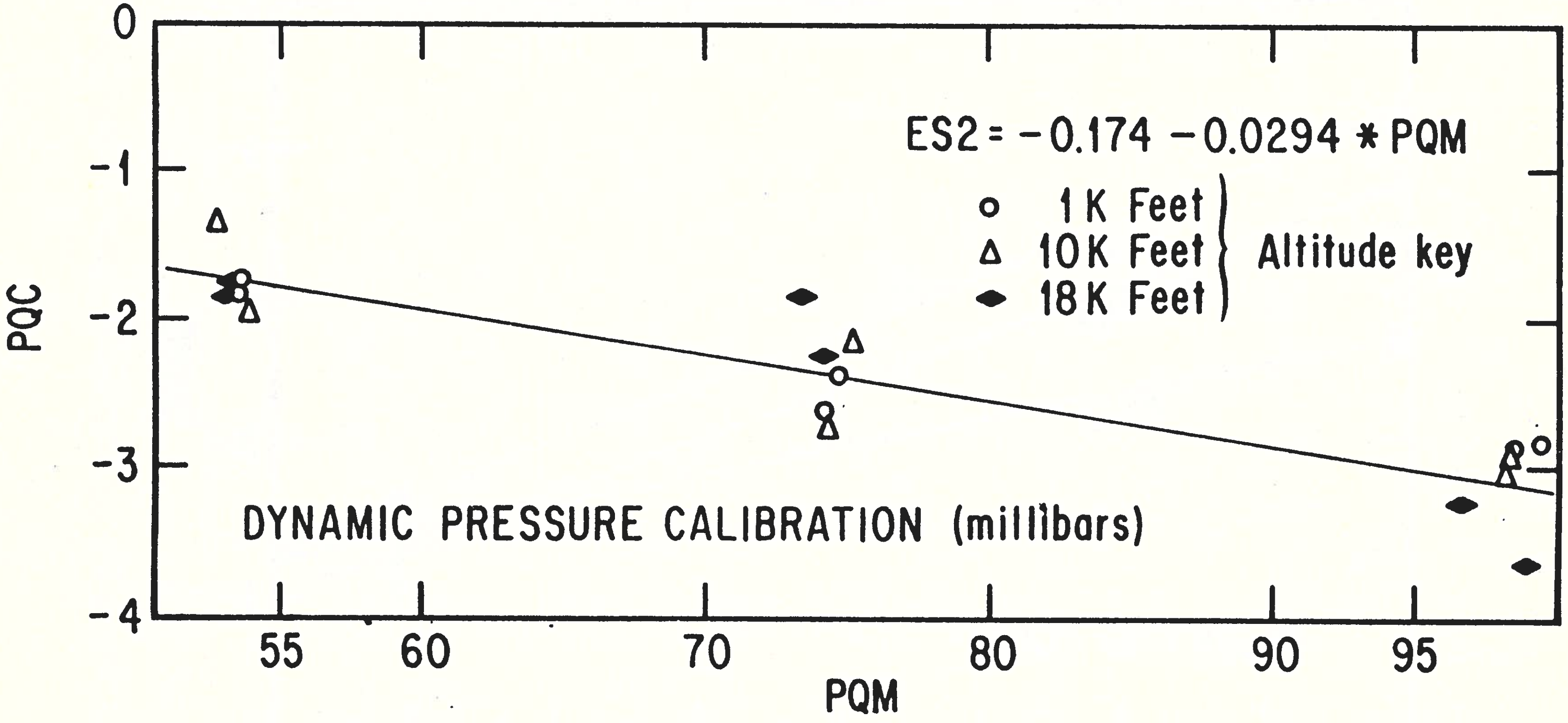

ES2 = -0.174 -0.0294 * PQM
○ 1K Feet
△ 10K Feet
◆ 18K Feet
Altitude key
DYNAMIC PRESSURE CALIBRATION (millibars)
PQC
0
-1
-2
-3
-4
55
60
70
80
90
95
PQM

Figure 3

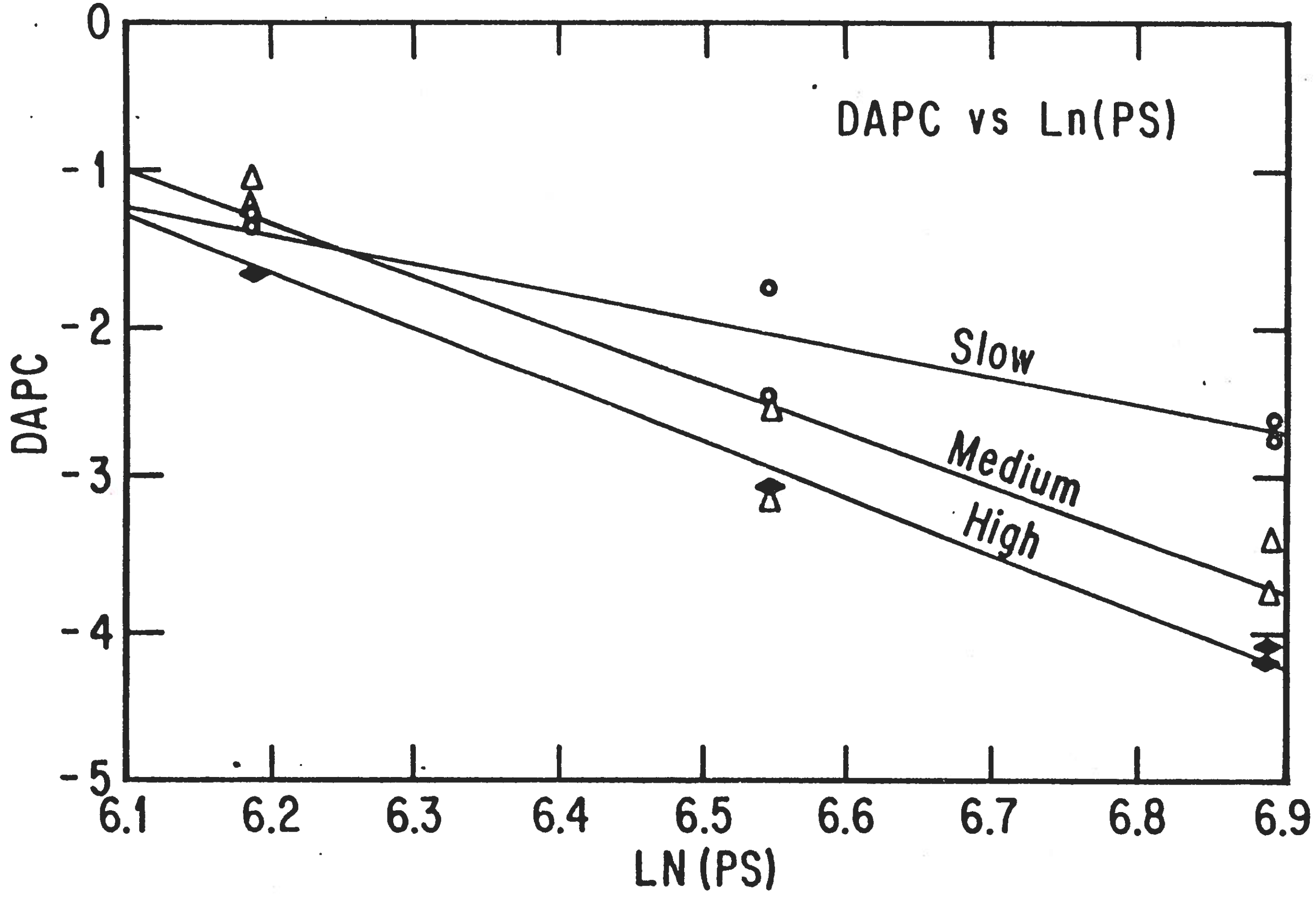

DAPC vs Ln(PS)
Slow
Medium
High
DAPC
0
-1
-2
-3
-4
-5
LN (PS)
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9

Figure 4a

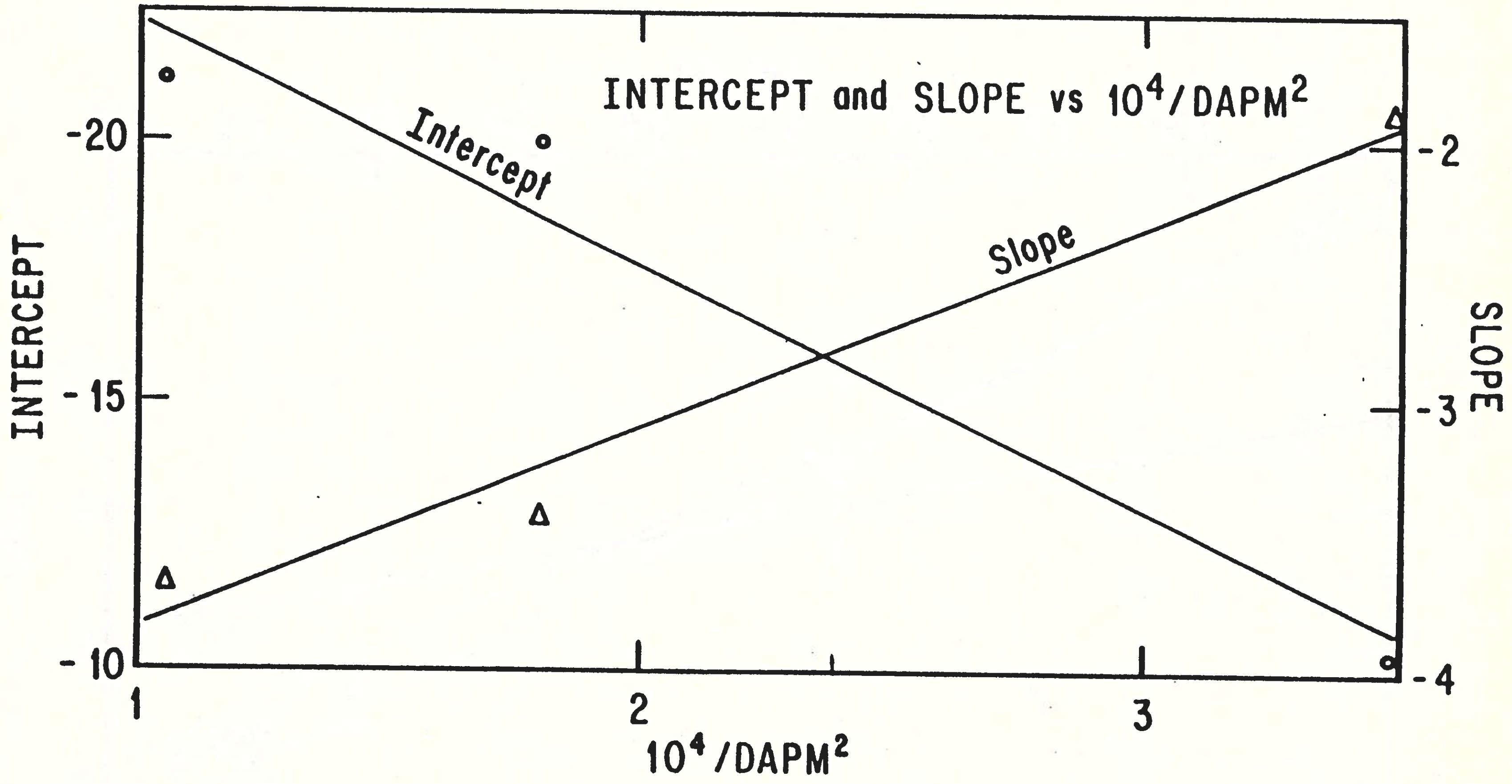
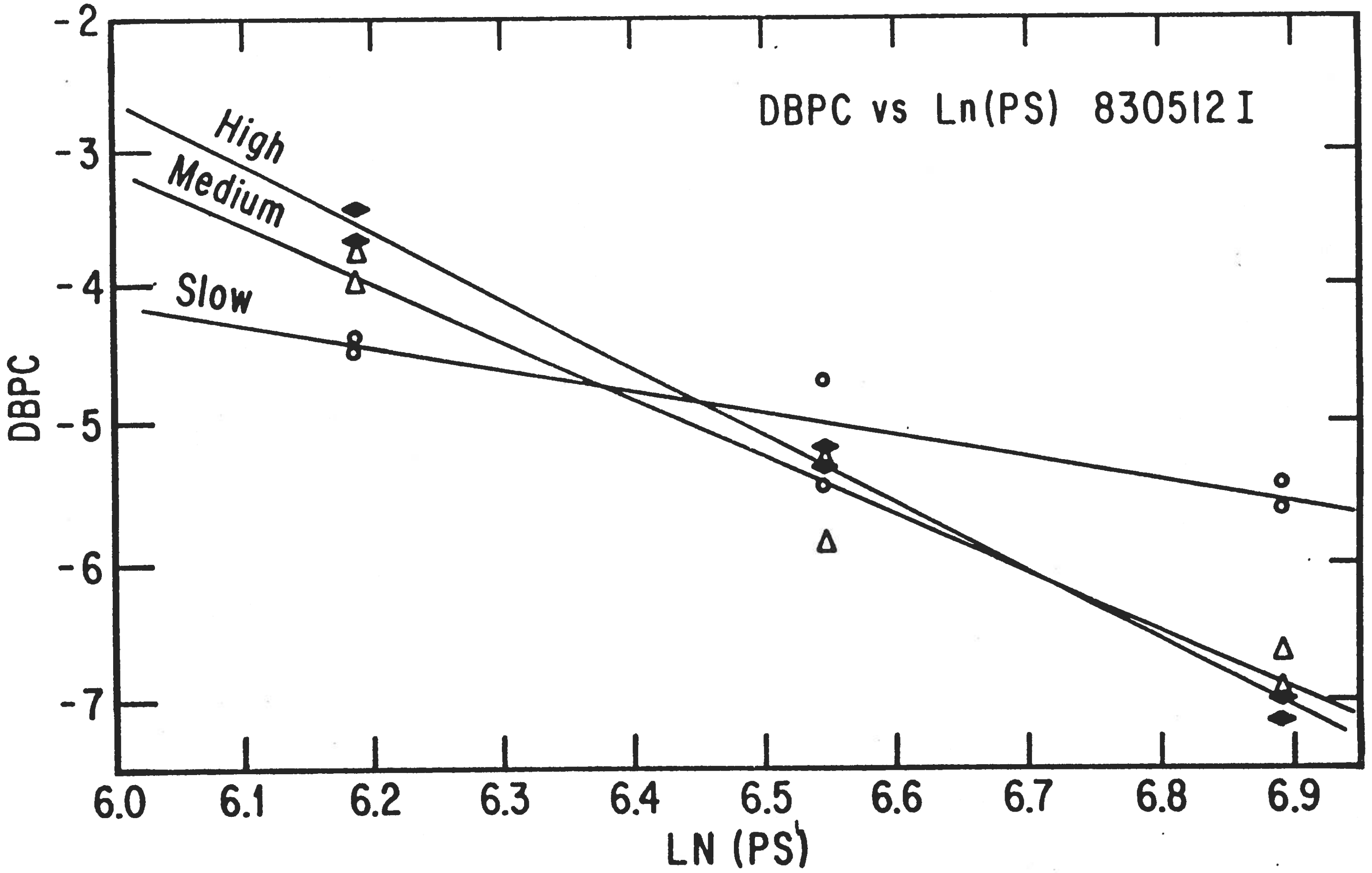

INTERCEPT and SLOPE vs $10^4/DAPM^2$
Intercept
Slope
INTERCEPT
-20
-15
-10
SLOPE
-2
-3
-4
1
2
3
$10^4/DAPM^2$

Figure 4b


DBPC vs Ln(PS) 830512 I
High
Medium
Slow
DBPC
-2
-3
-4
-5
-6
-7
6.0
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6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
LN (PS)

Figure 5a

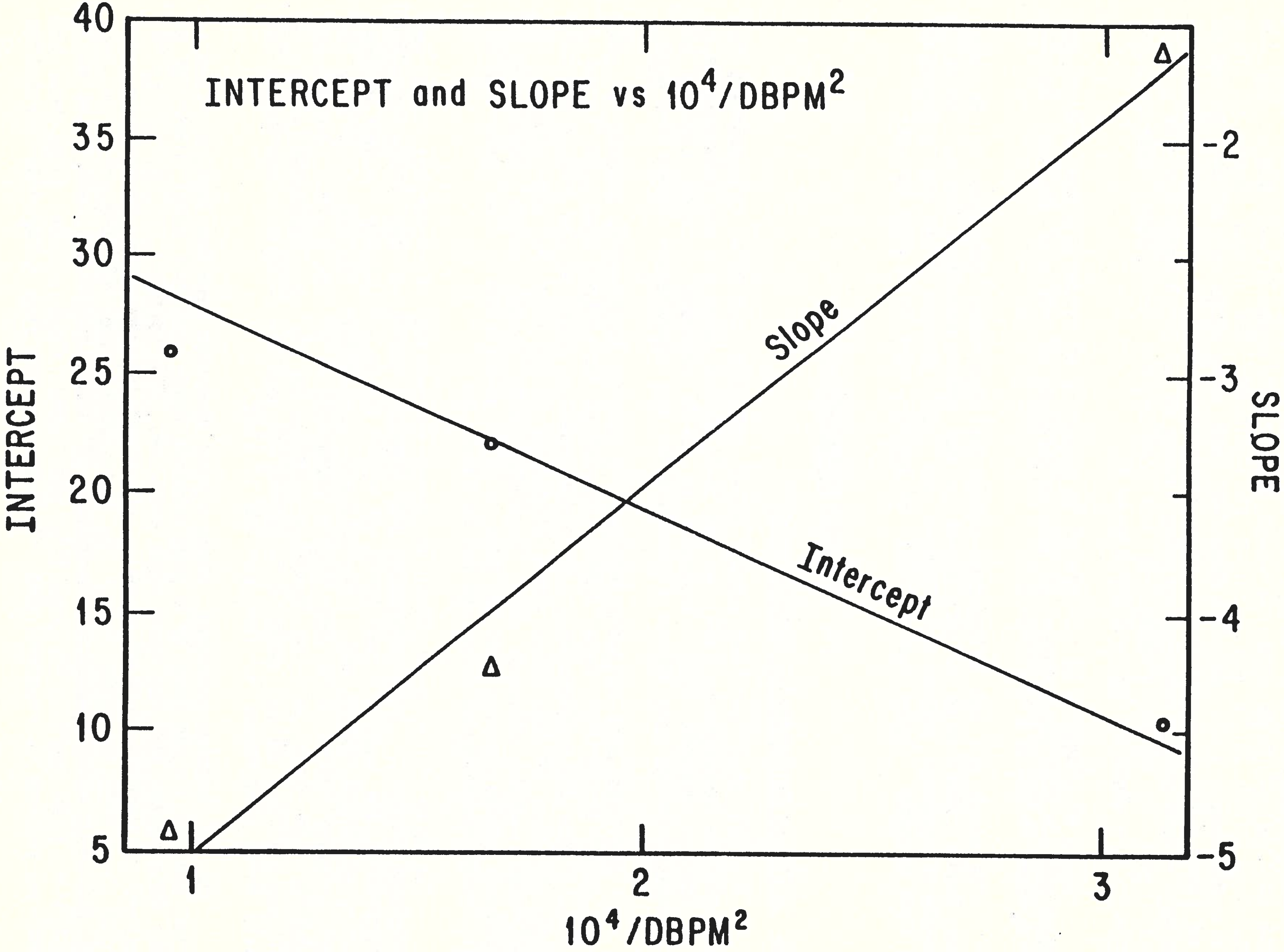
INTERCEPT and SLOPE vs $10^4/DBPM^2$
INTERCEPT
40
35
30
25
20
15
10
5
SLOPE
-2
-3
-4
-5
Slope
Intercept
1
2
3
$10^4/DBPM^2$

Figure 5b

Angle of attack and angle of sideslip are calibrated in a series of attitude maneuvers in a region of stable air and negligible winds. Since if the vertical wind is zero the pitch angle equals the attack angle, the INE measured pitch angle can be used to calibrate the attack angle in these circumstances. A run at high speed and near zero pitch is followed by one at low speed and pitch near +5 degrees, with the change in air speed being made slowly enough to use the intermediate values as well. Negative values are not obtainable in level flight, so the calibration is simply extrapolated. Results are shown in Table 8 and Figure 6.

Angle of sideslip is calibrated by a series of rudder/aileron induced yaw maneuvers in the same manner as the calibration of angle of attack. Results are shown in Table 9 and Figure 7.

The winds are now calculated using the algorithms described in Merceret and Davis (1981) with results shown in the intercomparison table. Table 10 presents dynamic correction factors for 1983 derived from the calibration flight program. These numbers will, of course, vary from year to year.

IV. SPECIALITY MEASUREMENTS

A. Infrared Radiometric Temperatures

The RFC uses modified Barnes PRT-5 infrared radiation thermometers for sea surface temperature (SST) in the 9-11 micron band and air temperature in the carbon dioxide (CO_2) waveband of 14-16 microns. Both systems are calibrated in the same manner although different temperature ranges are used.

A modified cone assembly designed by Barnes Engineering Company is used in a Forma Scientific, Model 2095, Temperature Bath/Circulator (see Figure 8) to calibrate the radiometers. The cone assembly rests on the rim of the bath with the tips of two brass cones extending 28 cm into the bath fluid. The interior surface of each cone is coated with "black velvet" paint, a 3M product, which is claimed to have a 0.99 emissivity. This provides the blackbody temperatures required for calibration.

The bath fluid is a 50/50 mixture, by weight, of distilled water and ethylene glycol. This depresses the freezing point of the fluid to -38°C permitting the bath's lower limit of -20°C to be ultimately reached without icing or slush conditions. The mixture also allows heating to +70°C, the bath's upper limit, with very little vaporization of the fluid. Heating and cooling the bath may be manually controlled by a thermoregulator, or automatically. Manual control is primarily used to initially condition the bath while unattended for long periods of time.

For calibration purposes, however, the standard bath has been modified so that control is provided by a programmable relay actuator under direction of the data system and its associated software. The software, in fact, runs the entire calibration procedure by: (1) obtaining real-time temperature data from the quartz thermometer and its associated probe; (2) comparing the data to the programmed temperature settings; (3) activating/deactivating the relay actuator accordingly; (4) providing sufficient stabilization time once the desired setting is reached; and (5) computing and displaying data statistics

Table 8

830623I: Attack Angle Calibration

Time	No.	AP/DAPM	PC (AA)	I	S
132545	1	.03	.65	0.00	0.000
132550	6	-.02	1.09	0.00	0.000
132555	11	-.07	1.28	.75	-4.876
132600	16	-.11	1.21	.75	-5.594
132605	21	-.17	1.57	.76	-5.731
132610	26	-.23	2.28	.73	-6.307
132615	31	-.29	2.69	.72	-6.549
132620	36	-.36	2.98	.72	-6.531
132625	41	-.44	3.53	.72	-6.575
132630	46	-.52	4.17	.71	-6.658
132635	51	-.62	5.03	.71	-6.663
132640	56	-.73	5.13	.74	-6.475
132645	61	-.87	6.34	.76	-6.401
132650	66	-1.02	7.60	.73	-6.489
132655	71	-.82	7.24	.66	-6.868
132700	76	-.66	4.86	.65	-6.929
132705	81	-.57	4.34	.64	-6.875
132710	86	-.50	3.76	.63	-6.855
132715	91	-.44	3.76	.62	-6.854
132720	96	-.37	3.23	.61	-6.857
132725	101	-.32	2.43	.60	-6.865
132730	106	-.26	2.37	.59	-6.876
132735	111	-.21	1.99	.59	-6.877
132740	116	-.17	1.92	.58	-6.883
132745	121	-.13	1.51	.58	-6.888
132750	126	-.09	1.29	.57	-6.897
132755	131	-.07	1.32	.57	-6.892
132800	136	-.04	.88	.57	-6.903
132805	141	-.02	.75	.58	-6.890
132810	146	.00	.48	.59	-6.871
132815	151	.02	.81	.60	-6.843

AA = +0.60 - 6.84*AP/DAPM

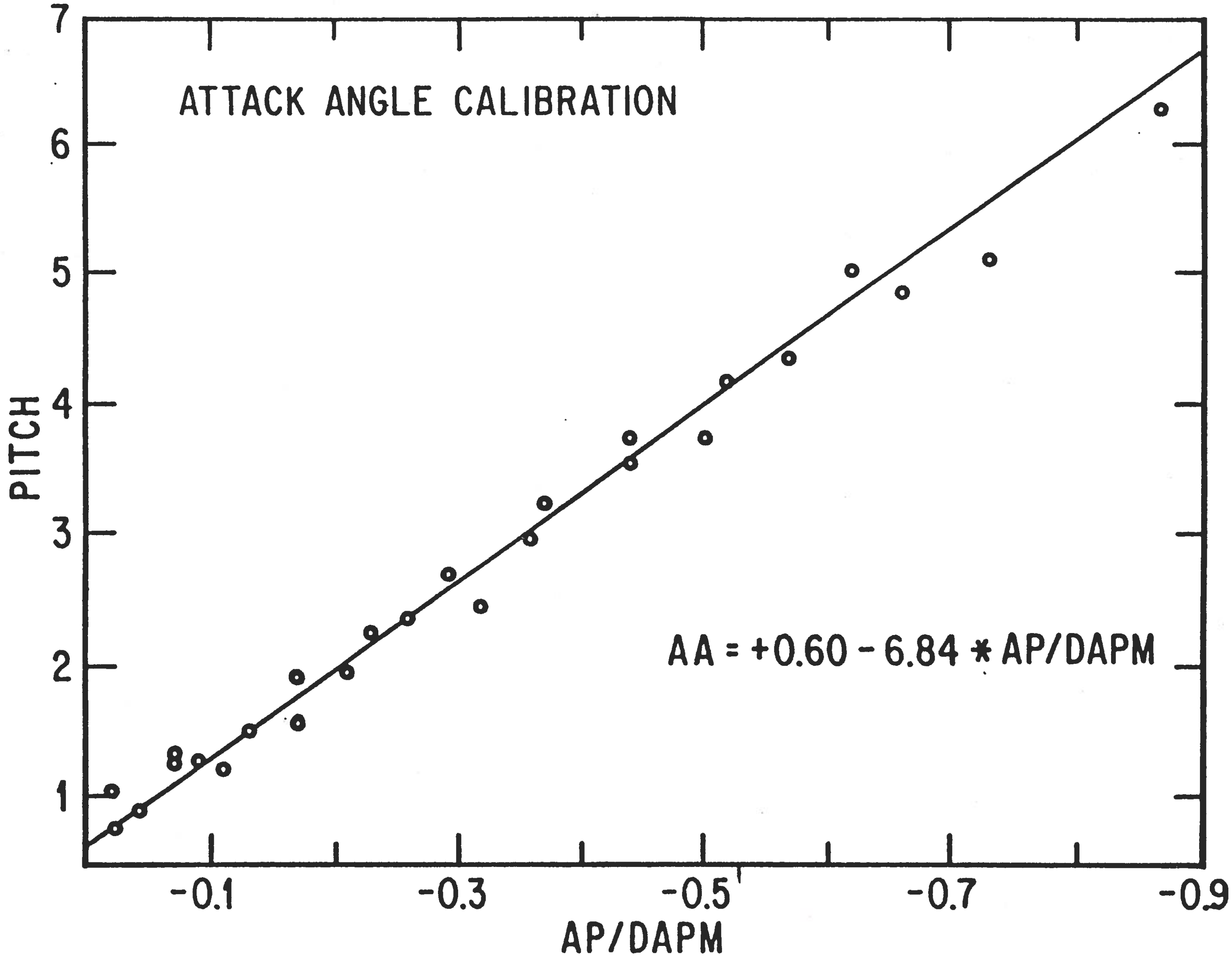
ATTACK ANGLE CALIBRATION
AA = +0.60 - 6.84 * AP/DAPM
PITCH
7
6
5
4
3
2
1
-0.1
-0.3
-0.5
-0.7
-0.9
AP/DAPM

Figure 6

Table 9

830623I: Slip Angle Calibration

Time	No.	BP/DBP	DA	I	S
133020	1	.21	-2.54	0.00	0.000
133025	6	.69	-5.99	0.00	0.000
133030	11	.38	-1.94	-.91	-6.980
133035	16	-.41	2.62	-.43	-7.720
133040	21	-.54	3.33	-.57	-7.437
133045	26	.13	-2.85	-.78	-7.212
133050	31	.72	-6.09	-.85	-7.336
133055	36	.05	.75	-.73	-7.237
133100	41	-.70	4.21	-.68	-7.317
133105	46	-.67	4.05	-.69	-7.297
133110	51	.27	-3.58	-.80	-7.229
133115	56	.76	-6.66	-.83	-7.292
133120	61	.74	-4.72	-.81	-7.235
133125	66	-.37	3.04	-.72	-7.250
133130	71	-.70	4.19	-.70	-7.278
133135	76	.08	-2.49	-.77	-7.219
133140	81	.83	-7.41	-.81	-7.287
133145	86	.69	-3.91	-.78	-7.234
133150	91	-.52	3.92	-.71	-7.267
133155	96	-.66	4.02	-.71	-7.278
133200	101	.26	-3.20	-.76	-7.240
133205	106	.97	-8.33	-.79	-7.303
133210	111	.49	-2.50	-.76	-7.238
133215	116	-.52	3.92	-.71	-7.272
133220	121	-.68	4.14	-.70	-7.284
133225	126	-.11	.29	-.72	-7.270
133230	131	.16	-.95	-.71	-7.268

SA = +0.30 - 7.27*BP/DBPM

Intercept from wind ELLS (i.e., HDC)

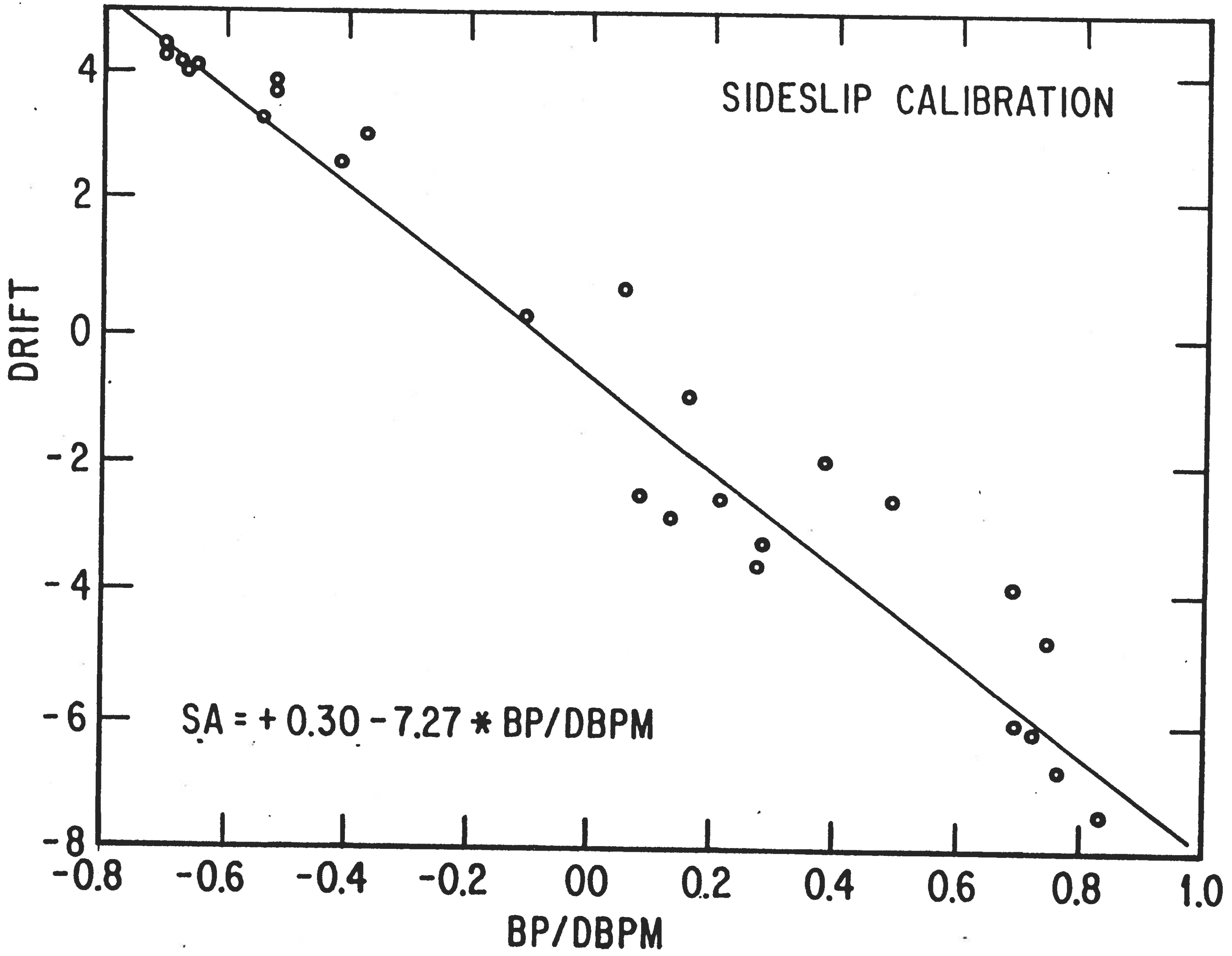
SIDESLIP CALIBRATION
SA = + 0.30 - 7.27 * BP/DBPM
DRIFT
4
2
0
-2
-4
-6
-8
-0.8
-0.6
-0.4
-0.2
00
0.2
0.4
0.6
0.8
1.0
BP/DBPM

Figure 7

Table 10

1983 Dynamic Correction Factors

Quantity	Page Reference Merceret (1982)	Page Reference Merceret and Davis (1981)	N42RF	N43RF
ES1 (I)	11	5	0.64	1.63
ES1 (S)	11	5	0.0309	0.0194
ES2 (I)	6	5	-0.59	-0.17
ES2 (S)	6	5	-0.0223	-0.0294
AA (I)	9	8	2.13	0.60
AA (S)	9	8	6.57	-6.84
SA (I)	9	10	0.03	0.30
SA (S)	9	10	7.30	-7.27
HDC	--	--	0.03	0.04
TAC	--	--	-0.8	-0.7
TDC	--	--	0.1	0.4
DAPC (I)	--	--	-21.985+0.4202*DAPM	$27-4.69*10^4/DAPM^2$
DAPC (S)	--	--	+2.809-0.0660*DAPM	$-4.62+0.771*10^4/DAPM^2$
DBPC (I)	--	--	-31.671+0.575*DBPM	$37.5-10.098*10^4/DBPM^2$
DBPC (S)	--	--	3.821-0.088*DBPM	$-6.58+1.569*10^4/BDPM^2$

CALIBRATION LAB TEMPERATURE SYSTEM
(RADIATION THERMOMETER CONFIGURATION)

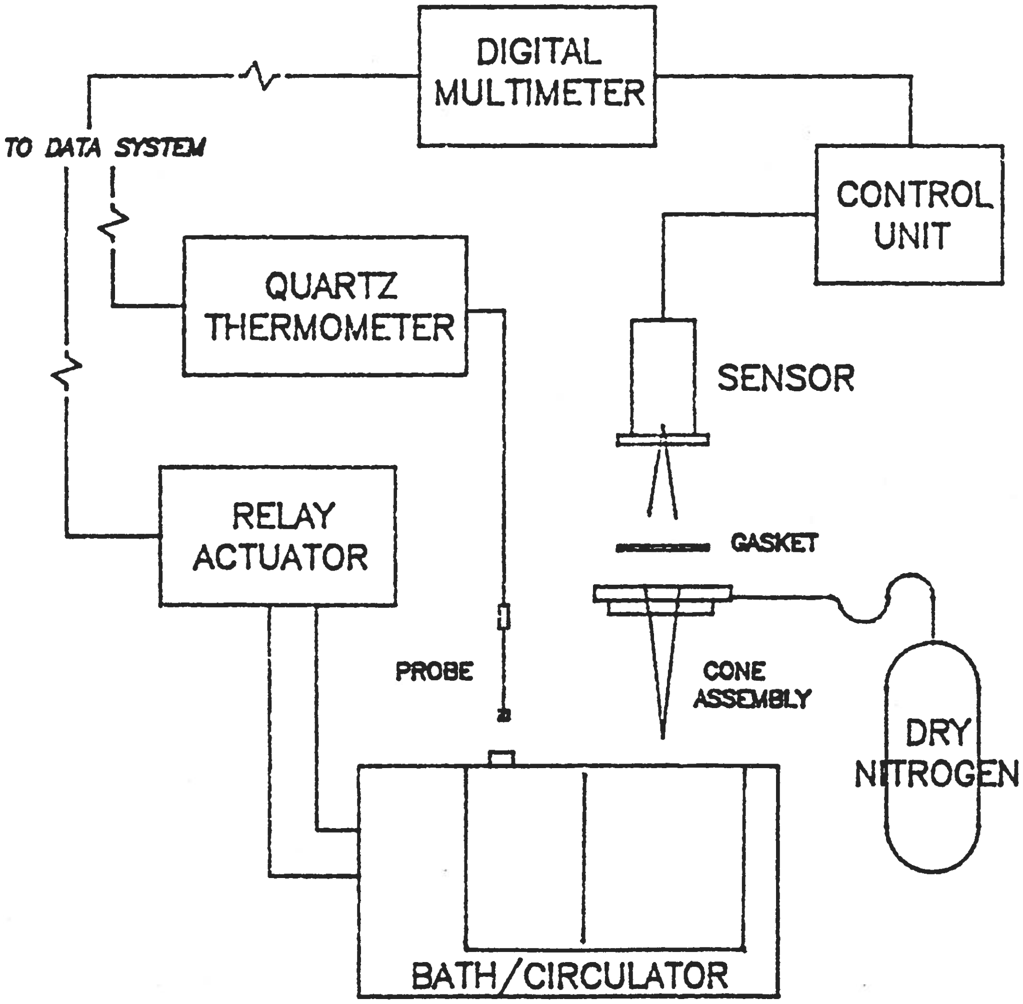

Figure 8.

of temperature and sensor output for each programmed setting. The radiation thermometer data (in analog form) is input to the data controller via a programmable digital multimeter. The calibration software also provides quick-look analyses for accepting or rejecting measurements made at any temperature setting. The accuracies associated with bath control and temperature measurement are on the order of .05°C or less, which is more than sufficient for the radiometer calibrations. However, the degree to which the interior cone temperature (i.e., the blackbody temperature) represents the bath temperature has not been quantitatively verified.

Whether controlled manually or automatically, the heating and cooling rates are governed by the temperature characteristics of the bath fluid and the amount of refrigerant flow, baffled or otherwise. The heating rate may be increased by a factor of two by turning off the compressor and eliminating all cooling effects. This may only be done during heating periods between temperature settings since cooling is required for control at a temperature setting. Until recently, continuous monitoring of this procedure was required. The bath's electrical circuitry has also been modified to turn the compressor off or on via the relay actuator under program control. Thus, the calibration of the radiation thermometers is totally automated and requires minimal monitoring by the calibration official. The automating process has also increased the efficiency of calibrations with regard to time and provides more meaningful calibration records than the manual format previously employed.

Before calibrating the radiation thermometers, the sensor must be correctly mounted on the cone assembly. This mainly requires centering the radiometer head over one of the cones to ensure the sensor's 2° field of view is looking at the deepest submerged portion of the cone. A lightly silicone-greased gasket is placed between the sensor and the cone assembly to minimize horizontal movement of the sensor due to vibration of the temperature bath. The gasket also provides a seal when flushing the cone with dry nitrogen gas for subzero temperature settings.

A SST radiometer is nominally calibrated from -10 to + 38°C in 3°C increments. The CO_2 radiometer's calibration range is from -20 to + 28°C in 3° increments. If ambient air were allowed in the cone during subzero temperatures, the build-up of frost on the interior surface would alter the blackbody temperature toward a warmer than required reading. To prevent this, dry nitrogen is flushed through the cone assembly with the sensor mounted on the greased gasket for approximately five minutes at a near zero temperature. For colder temperatures more time is required to flush the cone. By means of specially mounted purge and check valves installed on the cone assembly, a slightly positive gas pressure is retained in the cone during calibration, which cools or heats accordingly with the bath. After securing the gas flushing, the bath is cooled to its initial setting of -10°C or -20°C depending on the type of radiometer, then heated through the remaining settings, stabilizing for periods of three to five minutes before obtaining readings at each setting.

This technique showed a marked improvement over a previous method of slow, continuous flushing using a special adapter which raised the sensor approximately 5 cm above the cone assembly. The earlier method probably biased the sensor reading in two ways: (1) changing the interior blackbody temperature since the nitrogen gas is usually near room temperature; and (2) raising the field of view of the sensor to higher levels on the cone. For subzero temperatures, the improvement in readings was nearly 1°C.

The use of statistics computed for each measurement has also proved worthwhile. By monitoring the variation of a statistic from one measurement to the next, problems with interface equipment, the sensor, or their configuration can be easily checked, corrected, and the measurement retaken using available software options.

B. AXBT Measurements

We do not currently calibrate AXBT's because of their size (they won't fit in our baths) and the need to dismantle them to calibrate them. Manufacturers' calibrations are relied on and checked periodically by sending randomly selected batches of units to other facilities. The manufacturers' calibrations appear to be correct within specifications during these tests. Comparison with SST radiometer data suggests errors are on the order of 0.2°C in the tropics.

C. ODW Measurements

The Omega dropwindsondes are supplied by the manufacturer with a calibration tape which is fed to the onboard computer during baselining of each sonde. A reference unit compares the indicated cabin temperature and pressure with that measured by the sonde. Any deviation beyond specification causes an operator flag and the sonde is not launched, but is returned to the manufacturer for refurbishment. No in-house calibrations are presently undertaken.

D. Hot-Film Anemometer System

The operating principles and calibration techniques for airborne hot-film anemometers (HFA) are presented in Merceret (1976) and will not be repeated here. Temperature-resistance calibrations of the sensors are presently performed in the Rosemount precision bath with the quartz thermometer and Datron DVM as temperature and resistance standards respectively.

Since the HFA system has just been installed for engineering checkout late this year (after a six-year interlude in which significant improvements were made), we have not undertaken any wind tunnel calibrations during the period covered by this report.

E. Cloud Physics Measurements

The only cloud physics instrument which we calibrate in any reasonable sense of the word is the Knollenberg two dimensional droplet spectrometer. The Knollenberg units are factory calibrated using glass beads of known size. Because of their construction, any change in calibration is unlikely unless physical damage is done to the equipment; nonetheless, we check the calibration before and after each program and each repair. The check is performed by passing a wire of known size through the instrument's field of view and confirming that the size is correctly measured.

We do not presently have the capability to calibrate Johnson-Williams or other hot-wire type liquid water sensors. We also have no means to calibrate impactor-type or air/water/nuclei collection devices.

F. Pyranometers

The Eppley pyranometers, used for upward and downward radiation measurements, are calibrated at the Solar Radiation Facility of NOAA/ERL in Boulder, Colorado. Calibrations are performed annually or on request by principal investigators.

G. Radar Receivers

The radar receiver is calibrated using a precision signal source. A Hewlett-Packard model 8672A signal generator provides a source of precisely known amplitude and selectable frequency. Cable losses are measured using a Hewlett-Packard model 432A power meter. The reference signal is fed to the RF input of the receiver and the frequency is adjusted to the center of the receiver's bandpass by peaking the output from the remote digital scan converted (RDSC) which measures the amplitude of the received signal. The amplitude of the reference signal is stepped from 0.0 to -110.0 dBm and the RDSC output is recorded. The resulting curve (see Figure 9 for example) is compared with previous calibrations to detect any significant changes in receiver sensitivity or linearity.

ACKNOWLEDGMENTS

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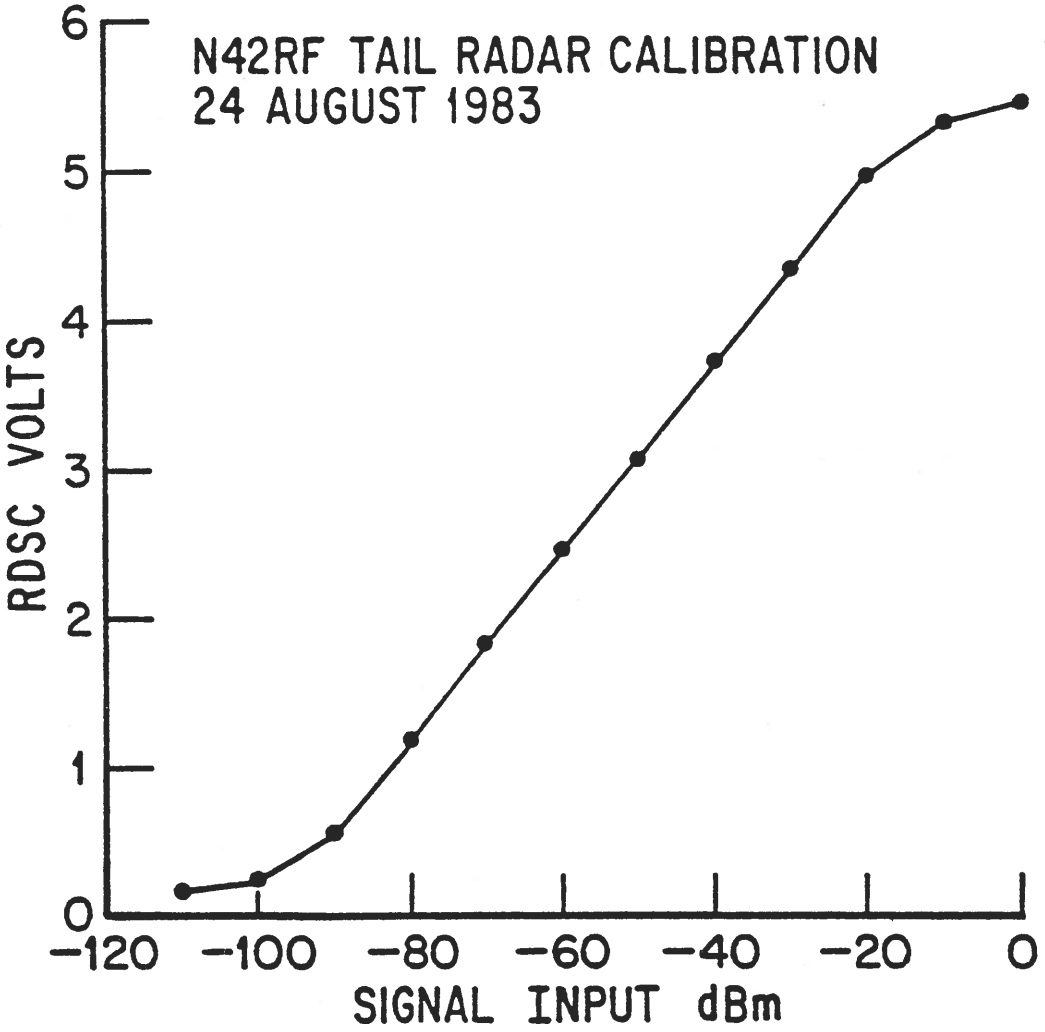
N42RF TAIL RADAR CALIBRATION
24 AUGUST 1983
RDSC VOLTS
0
1
2
3
4
5
6
−120
−100
−80
−60
−40
−20
0
SIGNAL INPUT dBm

Figure 9

REFERENCES

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Merceret, F. J. (1982). The sensitivity of variables computed from RFC WP3D flight data to fluctuations in the raw data inputs. NOAA Tech. Memo. ERL-RFC-8, NOAA/ERL/RFC, Miami, FL, 43 pp.

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Merceret, F. J., H. Davis, R. DeVivo, W. M. Lewis, W. M. Mallinger, and J. A. Zysko (1980). In-flight calibration of the NOAA/RFC meteorological research aircraft instruments at the Air Force Eastern Test Range: 1977-1978. NOAA Tech. Memo. ERL-RFC-6, NOAA/ERL/RFC, Miami, FL, 64 pp.

APPENDIX ONE

Calibration Laboratory Facilities and Equipment

I. Introduction

The Calibration Laboratory at the RFC presently occupies about 550 square feet of clean, air-conditioned laboratory space on the ground floor of the building housing RFC. It contains primary or secondary standards for pressure, temperatures, voltage, and resistance, and has access to secondary standards for time and frequency. Additional equipment for precision measurement of humidity, electronic current, capacitance, and inductance is also maintained.

Data collection and analysis is facilitated through the use of an eight-bit desktop computer with A to D and D to A conversion, parallel and serial digital interfaces, and the IEEE 488 bus. Figure A.1 presents a block diagram of the system. A real-time two channel Fourier analyzer is used for transfer function and spectral analysis. Various counters, oscilloscopes and meters are also available.

Systems for the generation and maintenance of known controlled temperatures and pressures are presently employed.

This appendix provides a detailed catalog of the principal physical resources of the Calibration Laboratory in use as of the end of FY-1983. Equipment on hand but not yet usable has not been included.

II. Resources Used Principally for Pressure Calibration

A. Primary Standard - Bell and Howell dead-weight piston gauge, model 6-201, serial number 3399.

B. Secondary Standards

1. Direct reading differential pressure gauge, Ruska Instrument Corp., model DDR 6000, serial number 24009.
2. Differential pressure gauge, Mensor Corp., serial number 192.
3. Low absolute pressure transducer, MKS Baratron model 220B, serial number 37688.

C. Additional Equipment

1. Calibration pressure controller, Bell and Howell CEC Division Type 6-003-002, serial number 2155.
2. Two, eleven port manifolds with purge values.
3. Vacuum pump, Ley Bold - Heraeus model 4810, serial number 91049.
4. Assorted tubing and fittings.

CALIBRATION LAB DATA CONTROLLER
DIGITAL INTERFACES

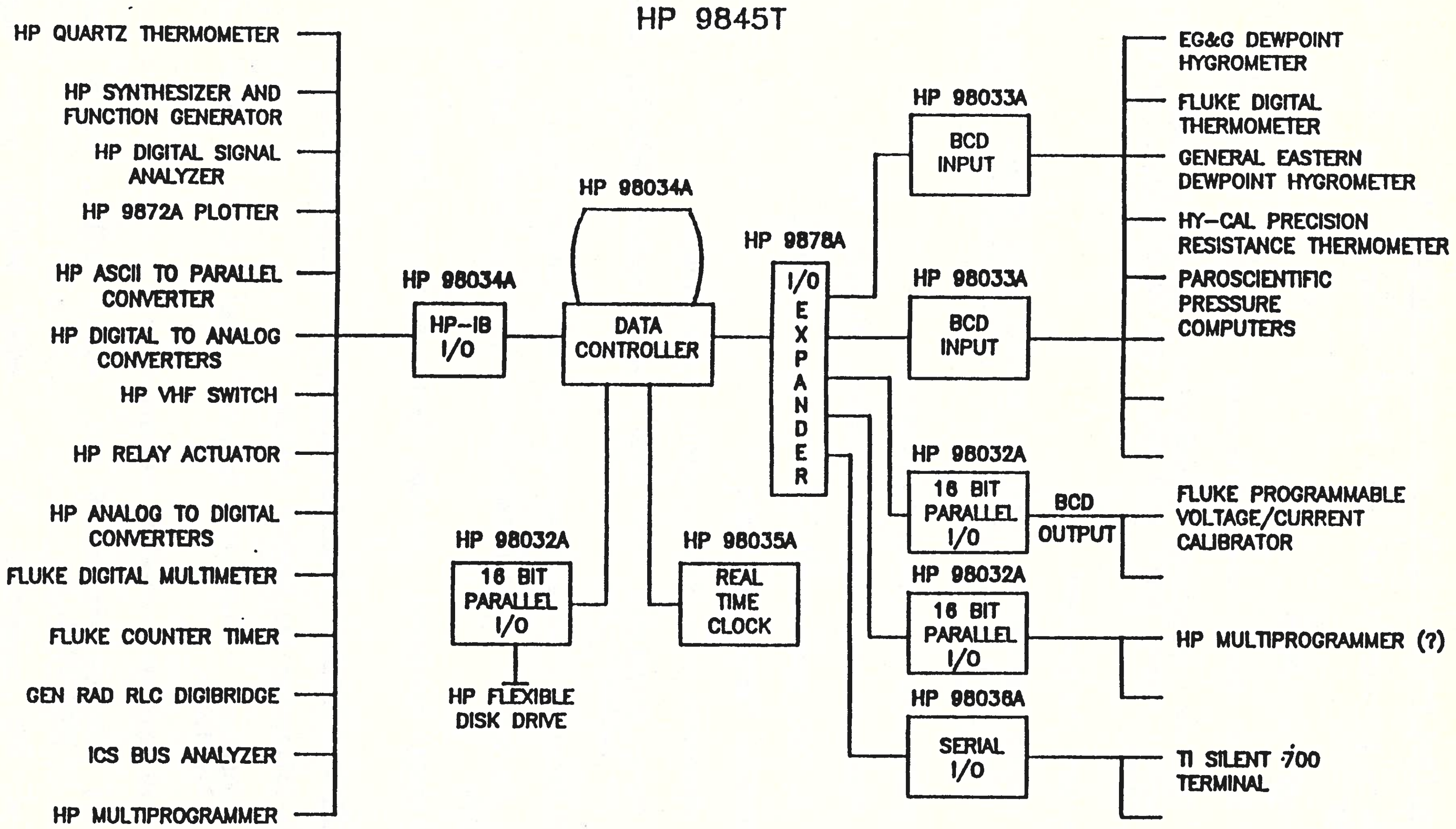

Figure A.1

III. Resources Used Principally for Temperature Calibration

A. Primary Standard - Ice point bath, Rosemount model 911A2, serial number 356.

B. Secondary Standards

   1. Gallium point standard, YSI model 60, serial number 120.

   2. Platinum resistance thermometer, Rosemount model 162N100B, serial number 2020, with model 414L3AGG1 bridge, serial number S2403.

C. Precision Thermometers

   1. Quartz thermometer, Hewlett Packard model 2804A, serial number 1744A00439, with two probes, serial numbers 1731A00980 and 1731A00769.

   2. ASTM mercury-in-glass thermometers.

   3. Platinum resistance thermometers, YSI model 703.

   4. J. Fluke model 2100A, serial number 0925011.

D. Controlled Temperature Baths

   1. Rosemount model 910AC1, serial number 1304.

   2. Forma Scientific model 2095, serial number 20955-73, modified for automatic computer control.

E. Cone Assembly - Barnes model 16-120, serial number 116.

F. RTD indicator - Hy-Cal Engineering model SA-740-A, serial number 73978.

G. Additional Equipment - various clamps, stands and fittings.

IV. Resources Used for Both Pressure and Temperature Calibrations

A. Data Collection and Control System

   1. Computer - Hewlett Packard model 9845T, serial number 1742A01417.

   2. I/O equipment - Hewlett Packard

      a) A/D converters, 8 bit, model 59313A, serial numbers 1908A01252, 3.

      b) D/A converters, 8 bit, model 59303A, serial numbers 1720A01088, 98.

c) Serial interface model 98036A.

d) Parallel interface model 98032A.

e) IEEE 488 bus card model 98034A.

f) I/O expander, model 9878A, serial number 1625A02543.

g) ASCII to parallel converter model 49301A, serial number 1928A017777.

h) Multiprogrammer interface model 59500A, serial number 1927A01565.

i) BCD interface model 98033A.

j) Relay actuator model 59306A, serial number 1920A02239.

k) Multi-programmer model 6940B, serial number 1923A03579.

3. Peripherals - Hewlett Packard

a) 8 inch floppy disk drives, model 9855M.

b) Four pen graphics plotter model 9872A, serial number 1810A02748.

c) VHF switch model 59307A, serial number 1920A01993.

d) Relay actuator model 59306A, serial number 1920A02239.

e) X-Y recorder model 7045A, serial number 1701A01522.

f) Strip chart recorder model 7132A, serial number 1606A00495.

g) Oscillographic recorder model 7402A, serial number 1451A1243.

B. Electronic Measurements

1. Resistance, voltage, and current

a) Datron model 1071, serial number 7291, with IEEE 488 bus.

b) J. Fluke Manufacturing Company, model 8500A, serial number 725040, with IEEE 488 bus.

c) Keithley model 198 with true rms option, serial numbers 19855, 64.

d) Line monitor, Cole-Parmer model 293, serial number A274381.

e) High Z voltmeter, J. Fluke model 845AR, serial number 710010.

f) Programmable voltage/current source, J. Fluke model 3330B, serial number 610012.

2. Time frequency, and waveform

   a) Hewlett Packard model 5820A two-channel, real-time Fourier analyzer with IEEE 488 bus, serial number 1936A00547.

   b) Hewlett Packard frequency counter model 5342A, serial number 1916A01644.

   c) Oscilloscope, Tektronix model 7704A, serial number B216733.

   d) Counter-Timer, J. Fluke model 1953A, serial number 685003.

   e) Function generator - Hewlett-Packard model 3325A, serial number 1748A01638.

V. Resources Used as Field Standards for Tower Fly-Bys

A. Pressure

1. Wallace and Tiernman model 61A-1A-0015E, serial number AD13395.

2. Paroscientific model 600B, serial number 753-36B.

B. Temperature and Humidity

1. Assman Psychrometer, Weathertronics model 5230, serial number 132.

2. Bendix psychrometer, model 566, serial number 405.

VI. Additional Laboratory Standards and Sensors

A. Humidity

1. EG&G dewpointer model 660, serial number 458.

2. General Eastern dewpointer model 1200APS serial number 92820.

B. Voltage, Eppley Laboratory Standard Cell model 100, serial number 864805.

C. Resistance

1. Vishay precision reference resistors.

2. PRT simulator, General Resistance Instruments model RTD-100, serial number 187.

3. Precision decade resistors, General Resistance Instruments models RDS 564A and RDS 567A.

D. Reactance-General Radio model 1658, serial number 259002.

E. Capacitance Decade - IET model CS-301.

VII. Miscellaneous Equipment

A. IEEE 488 Bus Fault Analyzer, ICS model 4810, serial number 91049.

B. Precision Balance, Ohaus model 20 Kg.

C. Spectrum Analyzer, Spectral Dynamics model SD330A, serial number 433.

D. Analog Tape Recorder, 7 channel, RACAL model store 7, serial number 8020.

E. Dry nitrogen bottle.

F. Refrigerator.

G. Distilled de-ionized water.

H. Microscope, binocular, American Optical model 40.

I. Digitally tuned variable filter - Krohn-Hite model 3342, serial number 1191.

APPENDIX TWO

Table of Laboratory Calibrations, 1979-1983

Title	Date	Instrument Description	Serial Number	Reference Systems
SST Radiometer Calibration	82/11/29	Barnes PRT-5	588	Quartz Thermometer
Absolute Pressure	80/04/21	Garret Model #2100776-2-2	48-D66	Ruska DDR
Differential Pressure	80/04/21	Garret Model #2100774-1-1	34-D1	Ruska DDR
Absolute Pressure	80/04/22	Garret Model #2100776-2-2	48-D66	Ruska DDR
Absolute Pressure	80/04/22	Garret Model #2100776-2-2	75-D39	Ruska DDR
Differential Pressure	80/04/22	Garret Model #2100774-1-1	34-D1	Ruska DDR
Absolute Pressure	80/05/08	Garret Model #2100776-2-2	48-D66	Ruska DDR
Absolute Pressure	80/05/08	Garret Model #2100776-1-1	34-D1	Ruska DR
Differential Pressure	80/05/08	Garret Model #2100774-2-2	125-D37	Ruska DDR
Absolute Pressure	80/05/09	Garret Model #2100776-2-2	48-D66	Ruska DDR
Absolute Pressure	80/05/09	Garret Model #2100776-1-1	34-D1	Ruska DDR
Absolute Pressure	80/05/14	Garret Model #2100776-1-1	34-D1	Ruska DDR
Differential Pressure	80/05/15	Garret Model #2100774-2-2	125-D37	Ruska DDR
Differential Pressure	80/05/16	Garret Model #2100776-2-2	48-D66	Ruska DDR
Differential Pressure	80/09/22	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	80/09/22	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	80/09/22	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	80/09/30	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	80/09/30	Garret Model #2100774-1-1	34-D1	Ruska DDR

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
Differential Pressure	80/09/30	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	81/04/07	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	81/04/07	Garret Model #2100774-2-2	125-D37	Ruska DDR
Absolute Pressure	81/04/07	Garret Model #2100776-1-1	34-D1	Ruska DDR
Absolute Pressure	81/04/07	Garret Model #2100776-2-2	75-D39	Ruska DDR
Absolute Pressure	81/04/15	Garret Model #2100776-2-2	488-D66	Ruska DDR
Absolute Pressure	82/05/26	Garret Model #2100776-1-1	34-D1	Ruska DDR
Absolute Pressure	82/05/26	Garret Model #2100776-2-2	75-D39	Ruska DDR
Differential Pressure	82/05/27	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	82/05/27	Garret Model #2100774-2-2	125-D37	Ruska DDR
Differential Pressure	82/05/28	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	82/05/28	Garret Model #2100774-2-2	125-D37	Ruska DDR
Differential Pressure	82/05/28	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	82/05/28	Garret Model #2100774-2-2	125-D37	Ruska DDR
Differential Pressure	80/06/23	Rosemount Model #1301BB11B	312	Ruska DDR
Differential PRessure	80/06/23	Rosemount Model #1301BB11B	297	Ruska DDR
Differential Pressure	80/06/25	Rosemount Model #1301BB11B	169	Ruska DDR
Differential Pressure	80/06/25	Rosemount Model #1301BB11B	170	Ruska DDR
Differential Pressure	80/06/26	Rosemount Model #1301BB11B	169	Ruska DDR
Differential Pressure	80/06/26	Rosemount Model #1301BB11B	170	Ruska DDR
Differential Pressure	80/06/27	Rosemount Model #1301BB11B	312	Ruska DDR

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
Differential Pressure	80/06/30	Rosemount Model #1301BB11B	118	Ruska DDR
Differential Pressure	80/06/30	Rosemount Model #1301BB11B	119	Ruska DDR
Differential Pressure	80/06/30	Rosemount Model #1301DB13B	85	Ruska DDR
Differential Pressure	80/06/30	Rosemount Model #1301DB13B	313	Ruska DDR
Differential Pressure	80/07/01	Rosemount Model #1301DB13B	171	Ruska DDR
Differential Pressure	80/01/01	Rosemount Model #1301DB13B	314	Ruska DDR
Differential Pressure	80/07/01	Rosemount Model #1301DB13B	294	Ruska DDR
Differential Pressure	80/07/01	Rosemount Model #1301DB13B	295	Ruska DDR
Differential Pressure	80/07/02	Rosemount Model #1301BB11B	296	Ruska DDR
Differential Pressure	80/07/02	Rosemount Model #1301BB11B	311	Ruska DDR
Differential Pressure	81/04/08	Rosemount Model #1301DB13B	314	Ruska DDR
Differential Pressure	81/04/08	Rosemount Model #1301DB13B	295	Ruska DDR
Differential Pressure	80/04/09	Rosemount Model #1301DB13B	314	Ruska DDR
Differential Pressure	81/04/09	Rosemount Model #1301DB13B	295	Ruska DDR
Differential Pressure	81/04/09	Rosemount Model #1301DB13B	294	Ruska DDR
Differential Pressure	81/04/09	Rosemount Model #1301DB13B	313	Ruska DDR
Differential Pressure	81/04/09	Rosemount Model #1301DB13B	85	Ruska DDR
Differential Pressure	81/04/09	Rosemount Model #1301DB12B	119	Ruska DDR
Differential Pressure	81/04/10	Rosemount Model #1301BB11B	296	Ruska DDR
Differential Pressure	81/04/10	Rosemount Model #1301BB11B	311	Ruska DDR
Differential Pressure	81/04/10	Rosemount Model #1301BB11B	312	Ruska DDR

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
Differential Pressure	81/04/10	Rosemount Model #1301BB11B	118	Ruska DDR
Differential Pressure	81/04/24	Rosemount Model #1301BB11B	296	Ruska DDR
Differential Pressure	82/06/21	Rosemount Model #1301DB13B	314	Ruska DDR
Differential Pressure	82/06/21	Rosemount Model #1301BB11B	311	Ruska DDR
Differential Pressure	82/06/22	Rosemount Model #1301DB13B	294	Ruska DDR
Differential Pressure	82/06/22	Rosemount Model #1301DB13b	295	Ruska DDR
Differential Pressure	81/08/21	CIC Model #8600-6	07652-7	Ruska DDR
Differential Pressure	81/08/21	CIC Model #8600-6	07652-8	Ruska DDR
Differential Pressure	81/08/21	CIC Model #8600-6	07652-5	Ruska DDR
Differential Pressure	81/08/21	CIC Model #8600-6	07652-6	Ruska DDR
Differential Pressure	81/08/28	CIC Model #8600-5	07652-1	Ruska DDR
Differential Pressure	81/08/28	CIC Model #8600-5	07652-2	Ruska DDR
Differential Pressure	81/08/29	CIC Model #8600-5	07652-3	Ruska DDR
Differential Pressure	81/08/29	CIC Model #8600-5	07652-4	Ruska DDR
Differential Pressure	82/06/07	CIC Model #8600-5	07652-2	Ruska DDR
Differential Pressure	82/06/07	CIC Model #8600-5	0765204	Ruska DDR
Differential Pressure	82/06/08	CIC Model #8600-5	07652-5	Ruska DDR
Differential Pressure	82/06/08	CIC Model #8600-5	07652-6	Ruska DDR
Differential Pressure	82/06/09	CIC Model #8600-5	07652-8	Ruska DDR
Differential Pressure	82/06/09	CIC Model #8600-5	07652-7	Ruska DDR
Differential Pressure	82/06/09	CIC Model #8600-5	07652-1	Ruska DDR

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
Differential Pressure	82/06/09	CIC Model #8600-5	07652-3	Ruska DDR
Differential Pressure	82/06/07	CIC Model #8600-5	07652-4	Ruska DDR
Differential Pressure	82/06/08	CIC Model #8600-5	07652-5	Ruska DDR
Differential Pressure	82/06/08	CIC Model #8600-5	07652-6	Ruska DDR
Differential Pressure	82/06/09	CIC Model #8600-5	07652-8	Ruska DDR
Differential Pressure	82/06/09	CIC Model #8600-5	07652-7	Ruska DDR
Differential Pressure	82/06/09	CIC Model #8600-5	07652-1	Ruska DDR
Differential Pressure	82/06/09	CIC Model #8600-5	07652-3	Ruska DDR
Differential Pressure	82/06/10	CIC Model #8600-5	07652-1	Ruska DDR
Differential Pressure	82/06/10	CIC Model #8600-5	07652-3	Ruska DDR
CO2 Radiometer	80/05/29	Barnes PRT-5	469	———
SST Radiometer	80/06/04	Barnes PRT-5	472	HP Quartz Thermometer
SST Radiometer	80/06/05	Barnes PRT-5	589	HP Quartz Thermometer
CO2 Radiometer	80/07/07	Barnes PRT-5	469	HP Quartz Thermometer
SST Radiometer	80/07/10	Barnes PRT-5	589	HP Quartz Thermometer
SST Radiometer	80/07/11	Barnes PRT-5	588	HP Quartz Thermometer
SST Radiometer	81/06/12	Barnes PRT-5	469	HP Quartz Thermometer
CO2 Radiometer	81/06/23	Barnes PRT-5	590	HP Quartz Thermometer
SST Radiometer	81/07/15	Barnes PRT-5	589	HP Quartz Thermometer
CO2 Radiometer	81/07/16	Barnes PRT-5	590	HP Quartz Thermometer

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
SST Radiometer	80/06/04	Barnes PRT-5	472	HP Quartz Thermometer
SST Radiometer	80/06/05	Barnes PRT-5	589	HP Quartz Thermometer
SST Radiometer	81/08/04	Barnes PRT-5	589	HP Quartz Thermometer
SST Radiometer	81/07/24	Barnes PRT-5	589	HP Quartz Thermometer
SST Radiometer	81/07/24	Barnes PRT-5	589	HP Quartz Thermometer
SST Radiometer	81/07/27	Barnes PRT-5	588	HP Quartz Thermometer
SST Radiometer	81/07/27	Barnes PRT-5	588	HP Quartz Thermometer
SST Radiometer	81/08/12	Barnes PRT-5	588	HP Quartz Thermometer
SST Radiometer	81/10/13	Barnes PRT-5	588	HP Quartz Thermometer
SST Radiometer	81/12/24	Barnes PRT-5	588	HP Quartz Thermometer
SST Radiometer	81/12/31	Barnes PRT-5	469	HP Quartz Thermometer
CO2 Radiometer	82/01/05	Barnes PRT-5	590	HP Quartz Thermometer
SST Radiometer	82/02/23	Barnes PRT-5	589	HP Quartz Thermometer
CO2 Radiometer	82/02/24	Barnes PRT-5	590	HP Quartz Thermometer
SST Radiometer	82/02/26	Barnes PRT-5	588	HP Quartz Thermometer
CO2 Radiometer	82/05/12	Barnes PRT-5	590	HP Quartz Thermometer
SST Radiometer	82/05/13	Barnes PRT-5	589	HP Quartz Thermometer
SST Radiometer	80/02/07	Barnes PRT-5	---	-----
CO2 Radiometer	80/03/03	Barnes PRT-5	469	-----
SST Radiometer	80/04/11	Barnes PRT-5	472	-----
CO2 Radiometer	80/05/06	Barnes PRT-5	469	-----

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
SST Radiometer	82/07/09	Barnes PRT-5	588	Quartz Thermometer
SST Radiometer	82/07/09	Barnes PRT-5	588	Quartz Thermometer
SST Radiometer	82/07/09	Barnes PRT-5	588	Quartz Thermometer
SST Radiometer	82/07/09	Barnes PRT-5	588	Quartz Thermometer
Analog Devices	82/07/06	Blue Label	AD590JF	Quartz Thermometer
Analog Devices	82/07/08	Yellow Label	AD590JF	Quartz Thermometer
CO2 Radiometer	82/07/13	Barnes PRT-5	590	Quartz Thermometer
Temperature Comparison	82/07/12	Rosemount Total Temp. Probe	35555	Quartz Thermometer
Differential Pressure	82/07/15	Rosemount Model #1301DB13B	171	Ruska DDR
Differential Pressure	82/07/15	Rosemount Model #1301DB13B	313	Ruska DDR
Differential Pressure	82/07/15	Rosemount Model #1301DB13B	85	Ruska DDR
Differential Pressure	82/07/15	Rosemount Model #1301BB11B	312	Ruska DDR
Differential Pressure	82/07/15	Rosemount Model #1301BB11B	170	Ruska DDR
Differential Pressure	82/07/16	Rosemount Model #1301BB11B	169	Ruska DDR
Absolute Pressure	82/07/26	Garret Model #2100776-2-2	75-D39	Ruska DDR
Differential Pressure	82/07/27	Garret Model #2100774-1-1	34-D1	Ruska DDR
Absolute/Post Switch Settings	82/07/28	Garret Model #2100776-2-2	75-D39	Ruska DDR
Absolute Pressure	82/10/29	Garret Model #2100776-2-2	48-D66	Ruska DDR
SST Radiometer Calibration	82/08/02	Barnes PRT-5	589	Quartz Thermometer
CO2 Radiometer	82/08/04	Barnes PRT-5	590	Quartz Thermometer

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
Differential Pressure	82/07/30	Rosemount Model #1301BB11B	118	Ruska DDR
Differential Pressure	82/10/08	Garret Model #2100776-1-1	34-D1	Ruska DDR
Differential Pressure	82/10/21	Garret Model #2100774-2-1	34-D1	Ruska DDR
Differential Pressure	82/10/21	Garret Model #2100774-2-1	48-D51	Ruska DDR
Differential Pressure	82/10/21	Garret Model #2100774-2-1	48-D51	Ruska DDR
Differential Pressure	83/01/14	CIC Model #8600-5	07652-2	Ruska DDR
Differential Pressure	83/01/14	CIC Model #8600-5	07652-1	Ruska DDR
Differential Pressure	83/01/20	CIC Model #8600-5	07652-5	Ruska DDR
CO2 Radiometer Calibration	82/12/15	Barnes PRT-5	590	Quartz Thermometer
SST Radiometer Calibration	82/12/16	Barnes PRT-5	589	Quartz Thermometer
CO2 Radiometer	83/07/21	Barnes PRT-5	590	Quartz Thermometer
CO2 Radiometer	83/04/23	Barnes PRT-5	590	Quartz Thermometer
SST Radiometer	83/04/19	Barnes PRT-5	589	Quartz Thermometer
CO2 Radiometer	82/04/20	Barnes PRT-5	590	Quartz Thermometer
SST Radiometer	83/08/10	Barnes PRT-5	589	Quartz Thermometer
SST Radiometer	83/08/11	Barnes PRT-5	588	Quartz Thermometer
CO2 Radiometer	83/08/31	Barnes PRT-5	590	Quartz Thermometer
SST Radiometer	83/09/01	Barnes PRT-5	589	Quartz Thermometer
SST Radiometer	83/05/02	Barnes PRT-5	588	Quartz Thermometer
Temperature Transducer	82/09/07	Analog Devices, AD590JF	Blue	Quartz Thermometer
Temperature Transducer	82/09/09	Analog Devices, AD590JF	Yellow	Quartz Thermometer

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
Temperature Transducer	83/05/31	Analog devices, AD590JF	(C02 590)	Quartz Thermometer
Temperature Transducer	83/05/10	Analog Devices, AD590JF	(C02 642)	Quartz Thermometer
Differential Pressure	82/06/17	CIC Model #8600-5	07652-5	Ruska DDR
Differential Pressure	82/06/17	CIC Model #8600-5	07652-6	Ruska DDR
Differential Pressure	83/06/22	CIC Model #8600-5	07652-1	Ruska DDR
Differential Pressure	83/06/22	CIC Model #8600-5	07652-3	Ruska DDR
Differential Pressure	83/06/22	CIC Model #8600-5	07652-4	Ruska DDR
Differential Pressure	83/06/22	CIC Model #8600-5	07652-7	Ruska DDR
Differential Pressure	83/06/22	CIC Model #8600-5	07652-8	Ruska DDR
Differential Pressure	83/06/20	Garret Model #2100774-2-1	48-DS1	Ruska DDR
Differential Pressure	82/10/21	Garret Model #2100774-2-1	48-DS1	Ruska DDR
Differential Pressure	83/06/20	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	83/07/13	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	83/07/12	Garret Model #2100774-1-1	34-D1	Ruska DDR
Differential Pressure	83/06/21	Garret Model #2100774-2-2	125-D37	Ruska DDR
Differential Pressure	83/07/12	Garret Model #2100774-2-2	125-D37	Ruska DDR
Differential Pressure	83/07/13	Garret Model #2100774-2-2	125-D37	Ruska DDR
Absolute Pressure	83/06/17	Garret Model #2100776-2-2	75-D39	Ruska DDR
Absolute Pressure	83/06/21	Garret Model #2100776-1-1	34-D1	Ruska DDR
Absolute Pressure	83/07/21	Rosemount Model #542K2	123	Ruska DDR
Impact Pressure	83/07/21	Rosemount Model #542K2	123	Ruska DDR

APPENDIX TWO (Continued)

Title	Date	Instrument Description	Serial Number	Reference Systems
KIAS	83/07/21	Rosemount Model #542K2	123	Ruska DDR
Differential Pressure	83/06/21	Rosemount Model #1301DB13B	314	Ruska DDR
Differential Pressure	83/06/21	Rosemount Model #1301DB13B	295	Ruska DDR
Differential Pressure	83/06/22	Rosemount Model #1301BB11B	170	Ruska DDR
Differential Pressure	83/07/18	Rosemount Model #1221F1AF1B1B	286	Ruska DDR
Differential Pressure	83/07/18	Rosemount Model #1221F1AF1B1B	287	Ruska DDR
Differential Pressure	83/09/13	Rosemount Model #1221F1AF1B1B	658	Ruska DDR
Differential Pressure	83/09/13	Rosemount Model #1221F1AF1B1B	288	Ruska DDR

APPENDIX THREE

Tower Fly-By, Wind Calibration and Intercomparison Flights, 1979-1983

I. Tower Fly-By's

Date	Aircraft	Location
6 June 1980	42	Dade-Collier
11 September 1980	43	Dade-Collier
4 June 1981	42	Dade-Collier
28 July 1981	43	Dade-Collier
19 January 1982	42	Denver
19 July 1982	42	Dade-Collier
3 August 1982	43	Dade-Collier
23 June 1983	42, 43	Dade-Collier

II. Wind Calibrations

N42RF	N43RF
12 April 1979	26 October 1979
3 June 1980	31 October 1980
4 June 1981	3 September 1981
19 January 1982	3 August 1982
19 July 1982	-----
23 June 1983	12 May 1983

III. N42RF - N43RF Intercomparisons

4 August 1980
3 September 1981
25 September 1981
4 September 1982
23 June 1983

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