NCAR/TN-253+EDD
NCAR TECHNICAL NOTE

March 1985

Calibration of the NCAR Sabreliner Research Static Pressure Source with a Trailing Cone Assembly

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Abstract

Trailing cone results verify that pressure corrections for the NCAR Sabreliner derived from tower flyby data can be extrapolated to higher Mach numbers and higher altitudes with valid results. Residual static pressure errors are small, on the order of 0.1-0.3 mb, corresponding to altitude errors of 20-30 ft for altitudes of 15,000-39,000 ft and Mach numbers of 0.59-0.76.

Introduction

Accurate measurement of static pressure from aircraft is required primarily for maintaining safe, vertical separation between aircraft flight levels. Where aircraft are used as platforms for atmospheric research, the static pressure plays an important role with other measured variables.

The static sources on the Model 60 North American Rockwell Sabreliner are flush-mounted, partially compensated, coupled sources located on the forward fuselage at station 82. From past records, the Research Aviation Facility determined the static pressure error for the research system from some 95 tower flybys; this method clearly limits the Mach range to values less than 0.5, which is below the research Mach numbers.

In concert with the Vertical Separation Standards Program of the Federal Aviation Administration (FAA), a trailing cone assembly was installed (Fig. 1) to provide a static error data set extending to

Mach 0.76 and to altitudes of 15,000-39,000 ft. This provided a means to measure the validity of the extrapolation of the static pressure correction (PCOR), derived from previous tower flights, to those conditions.

Test Procedures and Equipment

The trailing cone is the primary test method recommended by the Society of Automotive Engineers [1]. In practice, a static reference is towed far enough behind an aircraft to eliminate the aerodynamic influence of the airframe.

Stated simply, the procedure is to:

1. Determine the trail distance behind the aircraft at which the cone will be deployed for all tests.

2. Determine the error of the cone system by reference to the tower flyby method.

3. Use the cone data to determine the static source position error throughout the altitude and speed range noted and evaluate the validity of extrapolation of PCOR to those flight conditions.

The cone assembly used was a high-speed system manufactured by Douglas Aircraft Company; the static sleeve was located 7 ft ahead of the cone and this static pressure was referenced to the aircraft research system through a Rosemount 1221 0.25-psi differential pressure transducer. For most tests a Rosemount 1501 digital absolute pressure transducer monitored the research system; during the tower calibration (flight R22), this unit measured the absolute pressure from the trailing cone (PTC).

Static pressure on the tower was measured by a Barfield BTS-30 transducer which has specifications similar to the Rosemount 1501. All transducers were calibrated to a Ruska 6000 system; in addition, the Barfield unit was also pre- and post-flight calibrated at the National Bureau of Standards, Washington, D.C.

Trail Length Determination

The trail length is that position determined for zero flap, gear up, constant Mach number, straight and level flight where the pressure field effects diminish to zero; that is said to occur when the pressure from the research system static pressure diminished by the static pressure from the cone sleeve is a constant. In concert with FAA flight R6, tests were conducted at 0.69-0.74 Mach and flight levels of 33,000-39,000 ft. Referring to Table 1 and Fig. 2, the criteria of a constant static pressure error (DPSF/QCF) is satisfied at the 50-ft point.

TABLE 1. Trailing Cone Test 1 - Flight R6 - 20 January 1984

Static Defect $\frac{DPSF}{QCF}$ vs Distance Aft of 307D Reference

ALT. X 1,000 FT	MACH #	TIME PERIOD	T/C EXTENSION (ft)*	DPSF (mb)	QCF (mb)	$\frac{DPSF}{QCF}$
Climb to 20	0.50	18:51:40-18:53:40	100	-3.829	92.34	-.0414
37.0	0.73	19:26:24-19:28:24	90	-4.229	96.94	-.0436
36.9	0.74	19:30:40-19:32:40	70	-4.566	102.14	-.0447
38.9	0.74	19:45:01-19:47:01	50	-3.732	87.81	-.0425
35.2	0.69	19:55:01-19:57:01	40	-3.603	91.93	-.0392
32.8	0.73	20:08:04-20:10:04	30	-6.566	119.21	-.0551

*Trailing static sleeve position = (T/C extension - 13) ft behind station 525

DPSF = (Flush static - T/C pressure) units (mb)

QCF = Uncorrected local q units (mb)

For subsequent flights R8, R22, and R26, we elected to deploy the cone to a reference position of 70 ft, which places the static sleeve 57 ft behind the aft station of the aircraft. The ratio of trail length to wing span is 1.27, which is consistent with recommended practice [2].

Trailing Cone Calibration Verification

The trailing cone method exhibits very little or no static pressure errors. If errors exist, they are a function of (1) cone configuration, (2) the distance aft of the aircraft at which the cone is trailed, and (3) the level of air turbulence at the static sleeve position. Tower flyby calibrations of the cone assembly were accomplished over the speed range of 210-280 knots (Mach 0.33-0.46) at the Boulder Atmospheric Observatory on 2 February 1984. The tower is 300 m in height and was equipped with a Barfield BTS-30 (S/N 6035) digital pressure transducer. The Rosemount 1501 S/N 29 digital pressure transducer on the aircraft was monitoring the absolute pressure from the static sleeve on the cone assembly, thus providing the best-available matched state-of-the-art sensors for this test.

Ten tower passes were flown and the aircraft deviation from tower height was used to hydrostatically ($dP/dz = 0.03$ mb/ft) correct the absolute pressure to the tower observation level; the passes consumed about 37 min, during which the aircraft weight decreased from 16,700 to 15,300 lbs.

Table 2 shows the individual data points taken for the ten passes. The average difference between the corrected cone pressure (PTCC) and the Barfield values is +0.507 mb. The calibrations of the two units for a pressure of 900 mb indicate that the 1501 S/N 29 records values 0.19 mb higher than the Barfield unit, which leaves a residual mean error (D) attributed to the cone assembly of D = +0.31 mb. This correction is applied to the DPSF measurements of tests 3 and 4 to remove the bias allegedly introduced by the cone assembly.

Sabreliner Pressure Calibration

Two trailing cone test flights (R8 and R26) were flown to evaluate the pressure correction function under conditions which more closely represent research flight levels and Mach numbers; the data were obtained by deploying the trailing cone 57 ft behind the aircraft and establishing the aircraft at a constant altitude and Mach number for 2 min. The data presented were based upon computations using one measurement per second; thus 120 points were averaged for the data tabulated in Tables 3 and 4. In reviewing Tables 3 and 4 it must be kept in mind that two different trailing cone assemblies were used for the tests. The corrections obtained from the tower flyby (flight R22) are applied to both R8 and R26. However, after the R8 test the pneumatic line of the cone assembly fractured on retraction; a new line, sleeve, and cone assembly were installed for subsequent flights. The original assembly was not calibrated by a tower flyby.

TABLE 2. **Trailing Cone Test 3 - Flight R22 - 2 February 1984**

Tower Flyby, BAO Tower, Boulder, Colorado

TIME CUT	IAS (Kt)	MACH # (T = 1°C)	ALT. REF. (ft)	PRESS. CORR. (mb)	PTC (mb)	PTCC (mb)	TOWER BTS-30 (mb)	A/C WT (lb)	DPSF / QCF	(PTCC - BTS) T/C - TOWER (mb)
17:48:45	200	--	-25	--	--	--	--	16,700	--	--
17:52:31	210	0.3655	+5	+0.15	811.76	811.91	811.35	16,600	-.0381	0.56
17:56:28	220	0.3745	-20	-0.60	812.36	811.76	811.28	16,500	-.0389	0.48
17:59:58	230	0.3891	-3	-0.09	811.96	811.87	811.30	16,300	-.0413	0.57
18:03:41	240	0.4069	-8	-0.24	811.80	811.56	811.20	16,250	-.0429	0.36
18:07:42	250	0.4197	-20	-0.60	812.00	811.4	811.16	16,150	-.0446	0.24
18:11:57	260	0.4257	-5	-0.15	811.86	811.71	811.07	15,900	-.0446	0.64
18:15:52	270	0.4474	-5	-0.15	811.75	811.60	811.12	15,700	-.0456	0.48
18:20:03	280	0.4618	0	0	811.55	811.55	811.09	15,600	-.0471	0.45
18:24:42	240	0.4037	-3	-0.09	811.55	811.46	811.03	15,400	-.0433	0.43
18:29:06	200	0.3365	0	0	811.90	811.90	811.04	15,300	-.0385	0.86
										Avg. 0.507

dp/dz = 0.03 mb/ft
BTS-30 S/N 6035
PTC absolute pressure from trailing cone measured with Rosemount 1501
PTCC (1501 corrected for altitude variations)

Figure 3 is a comparison of the trailing cone data parameter DPSF/QCF corrected for the cone assembly error of 0.3 mb. The purpose of Fig. 3 is to compare the test results from the two different trailing cone assemblies and to present data from all relevant trailing cone tests, including three data points from test R6 (Table 1). As may be seen from Fig. 3, the data obtained from the different test flights with two different cone assemblies are relatively consistent. It is of interest to note that the two data points at Mach number 0.64 and the one data point at Mach number 0.66, which seem to be inconsistent with the trend of the other data, have an angle of attack (AOA) variation from the other data of approximately one degree. The general AOA of the data from Mach 0.59 to 0.70 varies from approximately 2.9 to 3.2. The two points at Mach 0.64 have an AOA of 3.9-4.0 and the one point at Mach 0.66 has an AOA of 1.8.

With the consistency of data between the three trailing cone flights shown in Fig. 3, it is possible to make the assumption that the residual mean error of +0.31 mb attributed to the cone assembly may be applied to all three sets of data.

Figure 4 illustrates the data from flights R8 and R26 corrected for the cone error of 0.31 mb; this, in effect, references the static pressure error to an errorless cone pressure and the corrected dynamic pressure. Thus Fig. 4 represents the best measure of the static pressure error of the NCAR Sabreliner at the higher Mach numbers.

To test the validity of the tower-derived pressure correction, the parameter RATIO C is used. Figure 5 illustrates the variable RATIO C, which is the static source position error for test instrumentation with the corrections D and PCOR added. (Note that RATIO A and RATIO C use corrected QCFC.) At Mach number 0.70-0.76, the range of interest, RATIO C varies from approximately 0.0017 to -0.0025. For 35,000-40,000 ft pressure altitude at Mach number 0.75, a value of 0.0025 would correspond to an altitude error of approximately 25 ft.

The residual static pressure errors illustrated by Tables 3 and 4 and Figure 5 suggest that PCOR, established only as a function of dynamic pressure, provides an excellent correction for the static source position error of the research instrumentation. The large error at 0.66 Mach is attributed to the large dynamic pressure at 15,000 ft pressure altitude, with PCOR overcorrecting by 1.79 mb. This is a flight condition that is not in the normal operating envelope but is flown especially for this calibration.

The results apply specifically to constant-level, nonmaneuvering flight. A correction function to generally apply for maneuvering flight (i.e., pitching, skids, and a wide angle-of-attack range) would require a more extensive flight program than noted and would correlate the airplane static pressure error DPSF/QCF with the airplane lift coefficient

TABLE 3. **Trailing Cone Test 2 - Flight R8 - 23 January 1984**
Trailing Cone Deployed at 70 Ft

TIME	ALT. X1,000	MACH #	A/C WT. (lbs)	ATTACK ANGLE	$\overline{QCF}$ (mb)	$\overline{QCFC}$ (mb)	$\overline{DPSF}$ (mb)	$\overline{PCOR}$ (mb)	$\overline{RATIO\ A}$	$\overline{RATIO\ C}$	$\overline{RESIDUAL\ ERROR}$ (mb)
16:03:14-16:06:59	29.0	0.64	17,000	3.99	104.2	99.94	-4.784	4.327	-.0448	-.0015	-0.157
16:25:26-16:27:26	39.0	0.76	16,200	3.68	95.3	91.61	-4.1822	3.741	-.0423	-.0015	-0.141
16:31:23-16:33:23	35.0	0.72	16,000	3.61	102.2	98.04	-4.747	4.193	-.0453	-.0025	-0.254
16:37:10-16:39:10	31.0	0.69	15,800	3.32	114.4	109.37	-5.545	5.032	-.0479	-.0019	-0.213
16:42:20-16:44:20	27.0	0.67	15,700	3.05	128.5	122.48	-6.482	6.067	-.0504	-.0009	-0.115
16:47:47-16:49:49	24.0	0.65	15,600	2.94	136.5	129.82	-7.007	6.684	-.0516	-.00017	-0.023
16:54:00-16:56:00	19.0	0.62	15,400	2.57	155.3	147.08	-8.270	8.224	-.0541	.0017	+0.254
16:59:39-17:01:39	15.0	0.66	15,200	1.80	213.8	200.02	-12.305	13.800	-.0600	.0089	+1.795

On T/C retraction, the line severed at 53 ft, after the above data were recorded.

NOTE: Mach runs 120 s statistics.

Ratio A = (DPSF + 0.3)/QCFC; RATIO C = (DPSF + 0.3 + PCOR)/QCFC variables. The present PCOR expression is correlated to the dynamic pressure QCF and is of the form:

PCOR = -0.80179 + QCF*(0.03010 + QCF*0.0001744)

where the units are millibars.

TABLE 4. Trailing Cone Test 4 - Flight R26 - 4 February 1984
Trailing Cone Deployed at 70 Ft

TIME	ALT. X1,000	MACH #	A/C WT. (lbs)	ATTACK ANGLE	$\overline{\text{QCF}}$ (mb)	$\overline{\text{QCFC}}$ (mb)	$\overline{\text{DPSF}}$ (mb)	$\overline{\text{PCOR}}$ (mb)	$\overline{\text{RATIO A}}$	$\overline{\text{RATIO C}}$	$\overline{\text{RESIDUAL ERROR}}$ (mb)
15:32:57-15:34:57	39.0	0.74	16,300	3.90	92.86	89.28	-3.959	3.586	-.0409	-.0008	-.073
15:40:40-15:42:40	35.0	0.73	16,100	3.44	106.76	102.26	-4.863	4.503	-.0446	-.00058	-.060
15:48:55-15:50:55	31.0	0.70	15,800	3.16	118.42	113.10	-5.725	5.323	-.0466	-.0009	-.102
15:55:00-15:57:58	27.0	0.68	15,560	2.91	133.26	126.83	-6.681	6.432	-.0503	.00040	+.0510
16:00:38-16:02:38	24.0	0.64	15,500	2.96	134.45	127.98	-6.763	6.524	-.0505	.00047	+.061
16:09:30-16:11:30	19.0	0.59	15,300	2.84	139.74	132.80	-7.109	6.941	-0.0509	+.0009	+.132

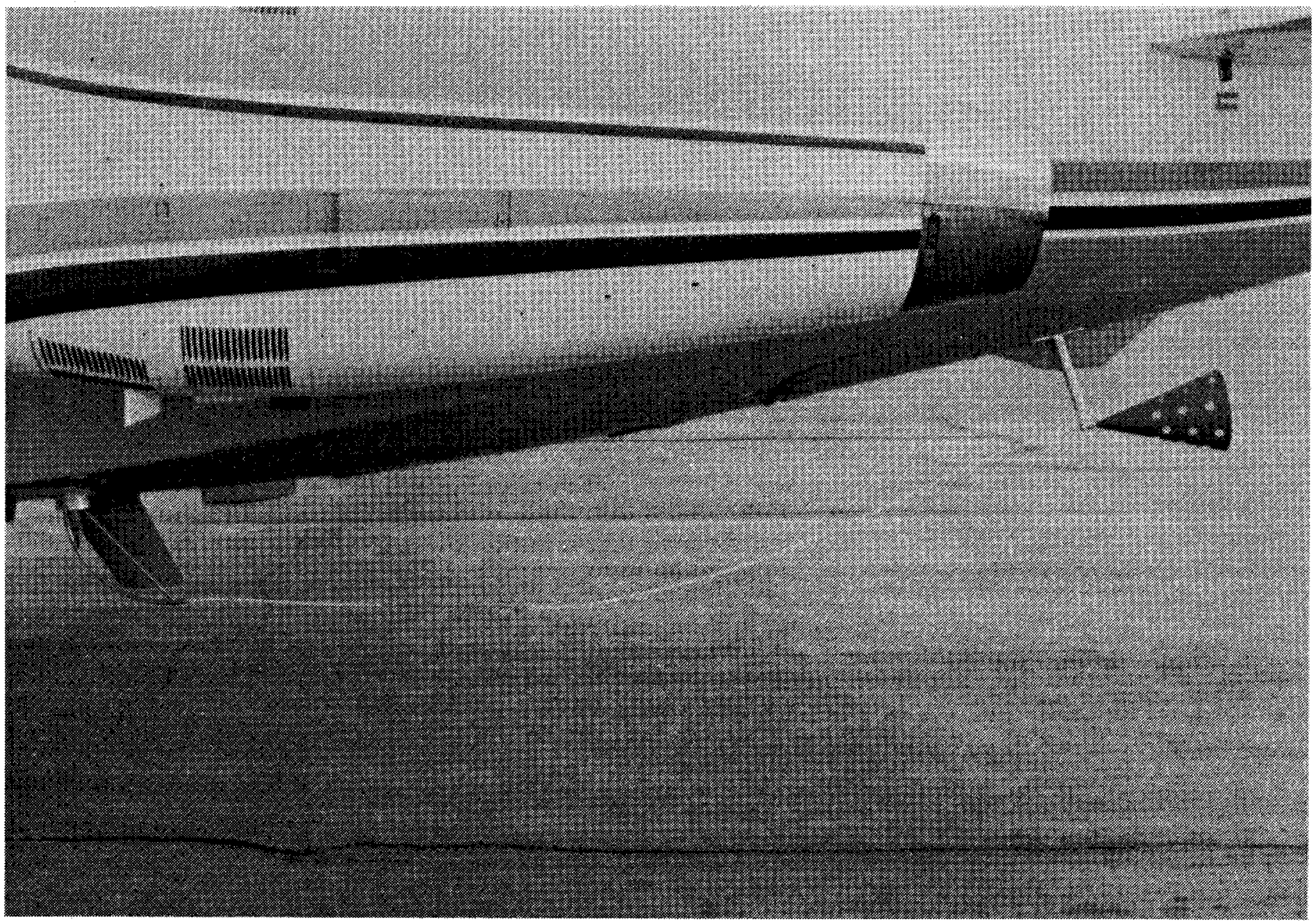

Figure 1 Trailing cone installation on NCAR Sabreliner. Note the static sensing sleeve in the left center of the photograph.

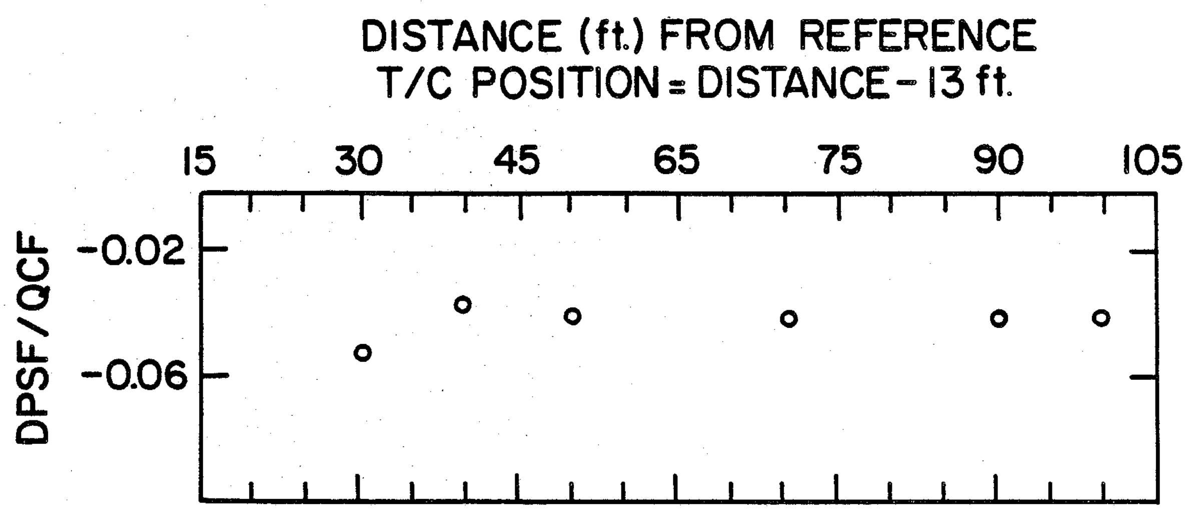

Figure 2 DPSF/QCF vs trail distance from reference

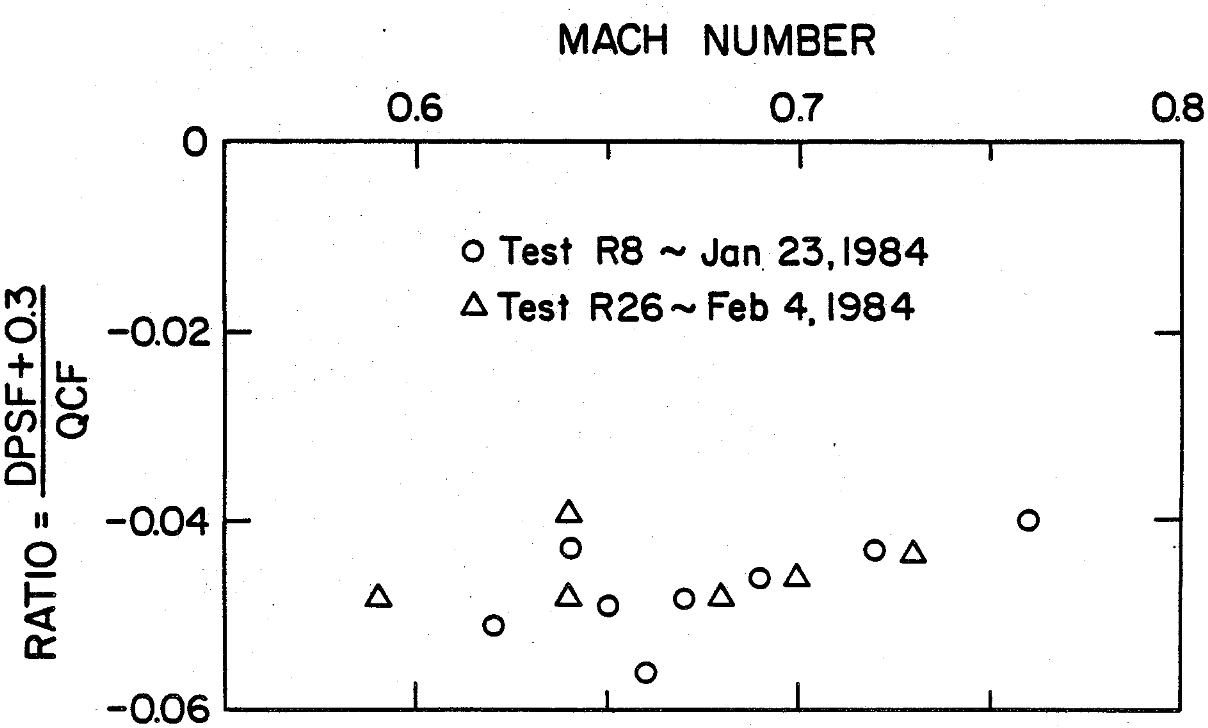

Figure 3 RATIO vs Mach number

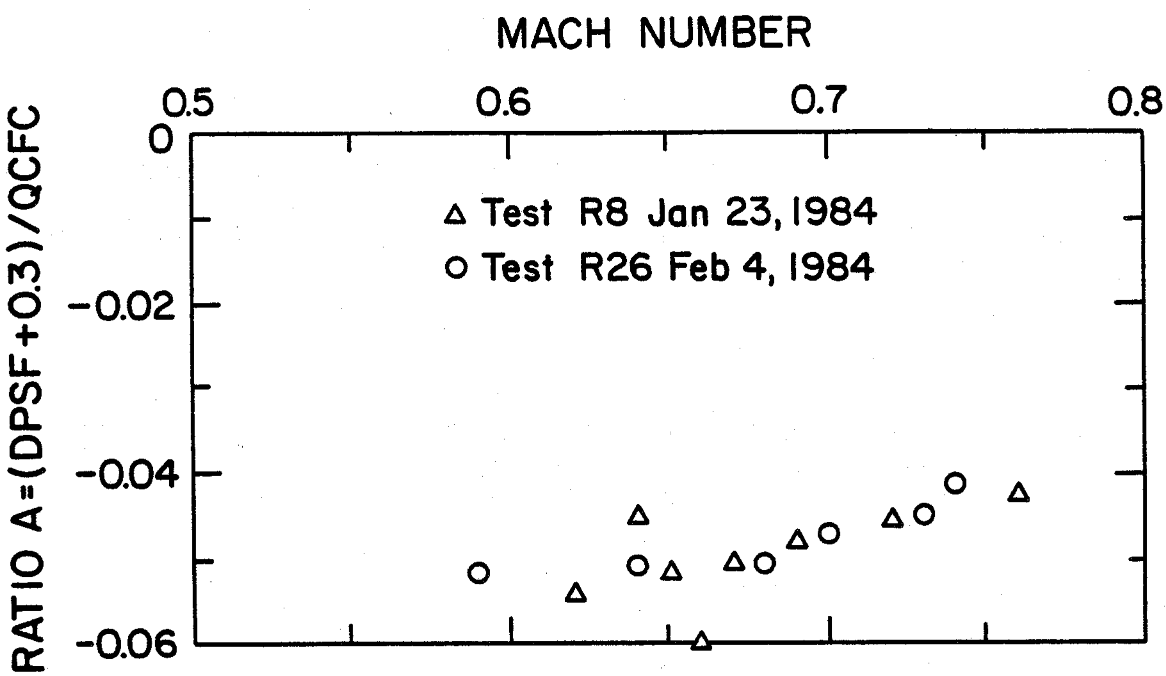

Figure 4 RATIO A or (DPSF + 0.3)/QCFC vs Mach number. This represents the static pressure error of the NCAR Sabreliner.

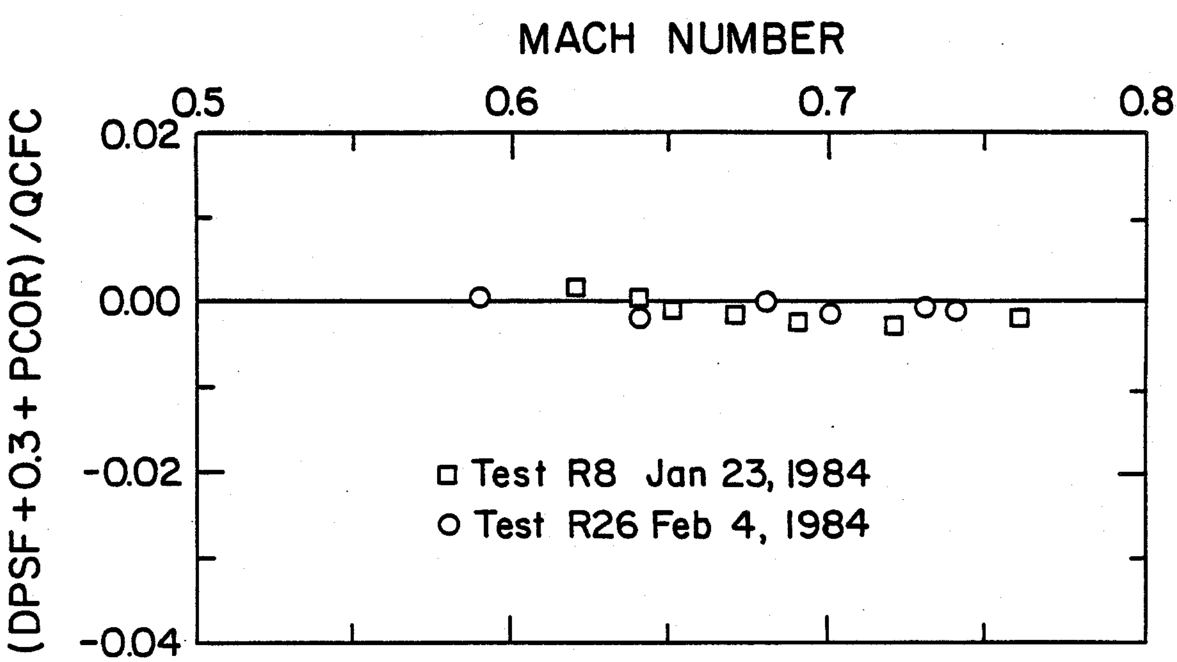

Figure 5 RATIO C vs Mach number

REFERENCES

1. Flight Test Procedure for Static Pressure Systems Installed in Subsonic Transport Aircraft. S.A.E. Aerospace Recommended Practice - 921. Issued July 15, 1971.

2. Trailing Cone Systems Applications, Douglas Aircraft Company Flight Development. TM-GEN-4158, 1967.