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MACH FLOW ANGULARITY PROBE

CURVE FITTING/CALIBRATION ROUTINE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Michael Glenn Hatcher

August 1991

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ABSTRACT

A method of calibrating five-hole probes (mach flow angularity probes) that are used to measure local flow angles and Mach numbers in a flow field has been developed. Using a least squares curve fitting program, the misalignment angles of a mach flow angularity probe are determined using pressure data measured from all five orifices during a wind tunnel test. Calibration curves are then determined using a differential corrections technique that fits the data as a function of Mach number (pressure ratio) and total angle of attack which characterize the performance of a particular probe. Once a mach flow angularity probe has been calibrated, it can be used in the flow field of an aircraft to characterize the large variations in flow velocity and flow direction. Results are discussed from a calibration of supersonic data to illustrate the methodology used.

Other five hole probe calibration techniques are discussed to show a correlation of the method presented versus methods available. Disadvantages of using the other methods are discussed along with the advantages of using the mach flow angularity curve fitting/calibration routine.

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NOMENCLATURE

A, B, C	Probe Mach number calibration coefficients
ALPHAT	Total angle of attack, deg
ALPD	Misalignment in pitch of the probe with respect to the tunnel axis system, defined during the calibration (aerodynamically) positive for the probe tip rotated up, deg
ALPHA, α	Sector or probe support mechanism angle of attack, deg
CPHI	Local radial direction of the flow with respect to the probe, as defined by the probe pressure measurements, deg
A1, A2, A3	Probe total angle of attack coefficients
DP13	Differential pressure measurement of the probe in the pitch plane P1-P3, psid
DP24	Differential pressure measurement of the probe in the yaw plane P2-P4, psid
DPSQP	Normalized probe total angle-of-attack parameter based on the probe pressure measurements, $= SQRT[(DP13)^2 + (DP24)^2]/(2*P5)$
M, MACH	Free-stream Mach number
P	Free-stream static pressure, psia
P1 - P4	Probe static pressure at the probe orifices, corresponding to tube numbers 1 thru 4, psia
P5	Probe pitot pressure, psia
PAVGP5	Average of the four static pressures of the probe normalized by the probe pitot pressures, sometimes referred to as the probe Mach number parameter, $= (P1+P2+P3+P4)/(4*P5)$
PHII, ϕ_i	Indicated probe roll angle, deg

PHID	Misalignment in roll of the probe with respect to the tunnel axis, zero for orifice P1 on top and positive for P1 rotated clockwise looking upstream, (defined during the aerodynamic calibration), deg
PHIT, ϕ_T	Total roll angle, deg
PROBE	Probe identification number
PSID	Misalignment in yaw of the probe with respect to the tunnel axis, defined during the calibration (aerodynamically) positive for the probe rotated clockwise as viewed from above, deg
Pn	Cone or probe surface static pressure, psia
$P_o(M)$	Cone surface pressure parameter which is Mach number sensitive, psia
$p_1(M,\alpha)$	Rate-of-change of cone surface pressure with cone pitch angle, psia/deg
PT	Stilling chamber pressure measurement, psia
PT2, Pt2	Pitot pressure downstream of normal shock, psia
Q	Free-stream dynamic pressure, psia
RE, Re	Free-stream unit Reynolds number, ft^{-1}
RE_L	Local Reynolds number acting on the probe surface, based on the probe nominal diameter
RUN	Data set identification number
T	Free-stream static temperature, ^oR
TT	Tunnel stilling chamber temperature, ^oR
u, v, w	Local velocity components, ft/sec
V	Free-stream velocity, ft/sec

CHAPTER I

INTRODUCTION

Mach Flow Angularity (MFA) probes are probes that measure the local Mach number, total angle of attack and roll angle as a function of the probe pressure measurements. This probe concept is based on the idea that the local Mach number and velocity direction can be uniquely related to the circumferential variation in the surface pressure on a conical probe tip and the local pitot pressure. Like most measuring devices, MFA probes require calibration. This calibration procedure is done by performing wind tunnel tests to obtain pressure measurements from all five orifices of the probe which can then be correlated with known Mach numbers (or pressure ratios, P/PT2 for supersonic and P/PT for subsonic) and flow angles to obtain calibration constants. The range of Mach numbers must encompass the desired operation envelope of the probe.

The concept of using five hole probes as a flow angularity measuring device is not new as revealed by the fact that a number of technical references exist describing the design, calibration, and application of flow angularity probes. An article dating back to 1915 was written by C. E. Jones which indicates that five-hole probes were used to define the flow of water passing around ships or ship models. One unique feature of the present MFA probes is the significant reduction in probe size which permits better

resolution of local variations in flow angle in a subsonic/supersonic flow field.

The objective of the mach flow angularity curve fit/calibration program is to calibrate flow-field probes as a function of probe attitude and free-stream Mach number. For the current calibration, the test conditions were Mach numbers 2, 3, and 5.5 with unit Reynolds numbers of 1.3 X 10^6 to 4.1 X 10^6 per foot. The probe attitude was varied over an angle-of-attack from -11.5 to +11 deg and roll angles of -180 to 180 deg. The test procedures consisted of positioning a rake assembly (to which the five probes were attached) in known flow conditions and at known attitudes and then measuring the five pressures associated with each of the five probes. A discussion of the calibration procedures and results along with the formulation of the procedure for utilizing the calibration curves is presented. In addition, an assessment of the overall uncertainty of the calibration results is presented for the current data.

Marquart (ref. 1) discusses many of the problems associated with the calibration of MFA probes. He also presents the methodology that was used in formulating the curve fit/calibration routine. Probe sensitivity to Reynolds number is discussed for a MFA probe versus a five-hole cone probe. In addition, alternate calibration methods are presented with a discussion of the methodology used and possible limitations of each method.

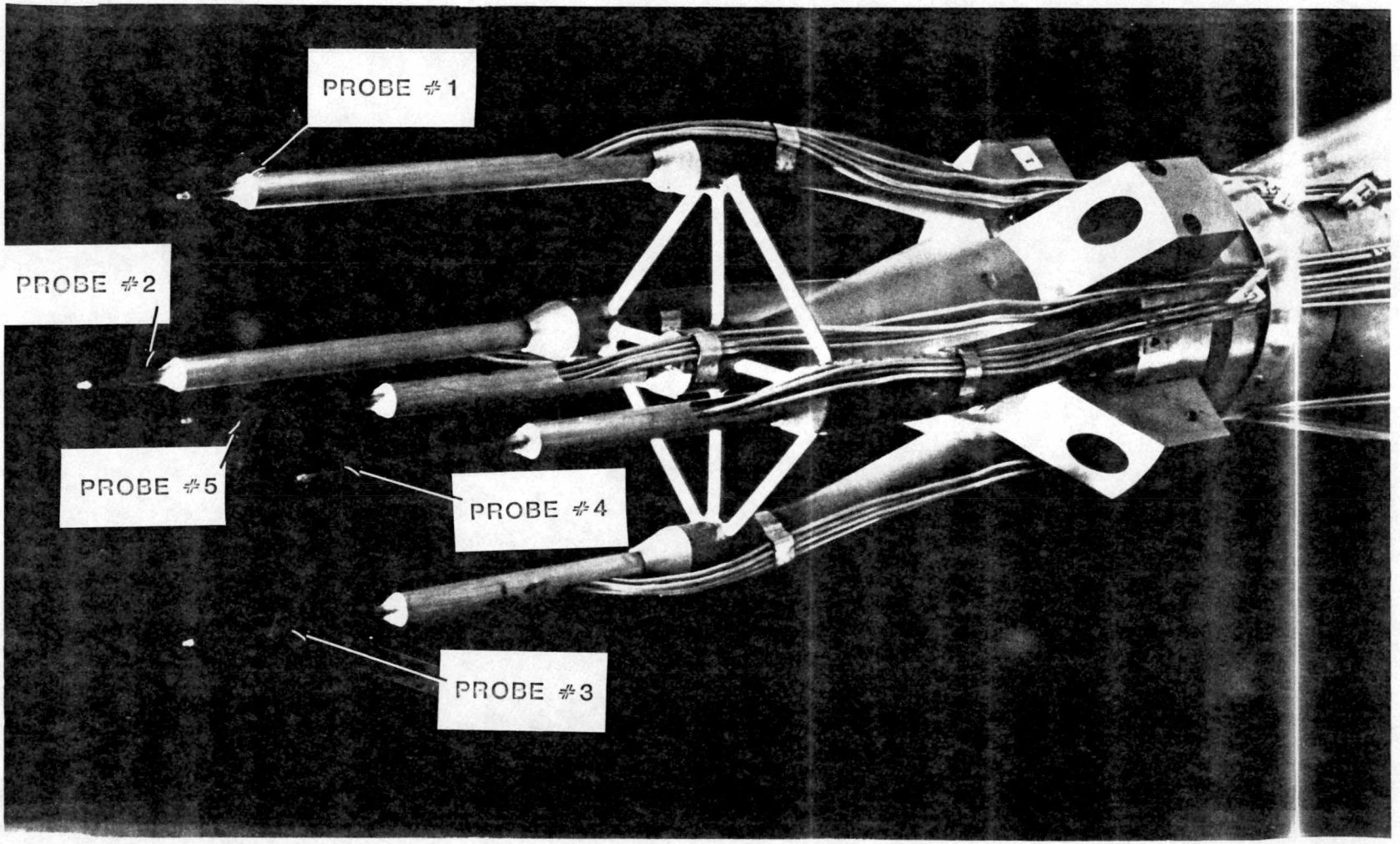
CHAPTER II

APPARATUS

1.0 Probes

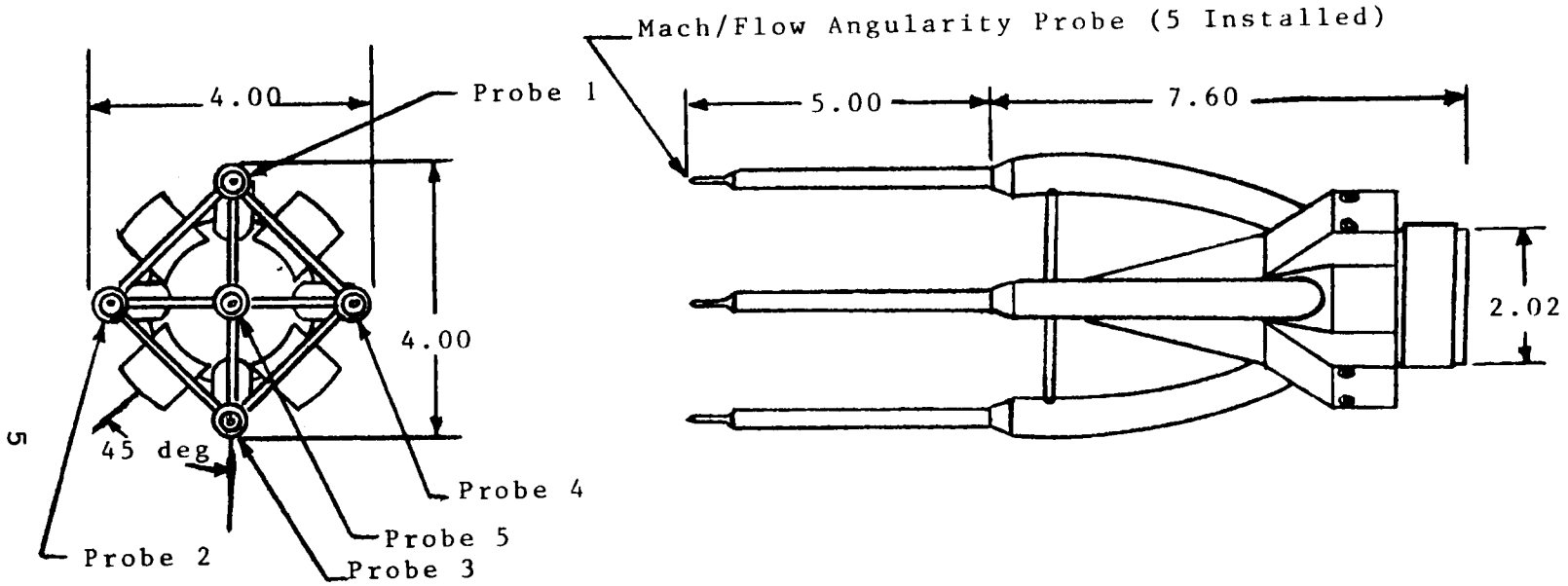
A five-tube flow-field probe (see Fig. 1) consists of five individual pressure orifices. The total pressure orifice (orifice 5) is centrally located with respect to four radially spaced static-pressure orifices (orifices 1-4). These four orifices are positioned on slices cut at angles nominally greater than 15 deg to the probe longitudinal axis. The calibration characteristics, or performance of the probe, are directly dependent on the symmetry and accuracy of these probe-tip cuts. The convention for numbering the five tubes of the probe is shown in Figure 2.

Previous techniques for fabricating MFA probes used five stainless-steel tubes silver-soldered together in a cruciform cross-sectional pattern. The method employed for the probes currently being calibrated consists of fabricating a probe from a single specimen of Inconel 600 (a single-phase wrought-nickel alloy). The procedure for fabricating the probe starts with the longitudinal drilling of five equally spaced holes through a test specimen approximately 1.5-in. in length and 0.4-in. in diameter (see Fig. 3). The section of the specimen to be elongated is 0.754-in. in length and 0.2-in. in diameter. The stretching process begins with the reduction in diameter of the



a. Probe Rake Installation

Figure 1. Probes Mounted In Probe Holder

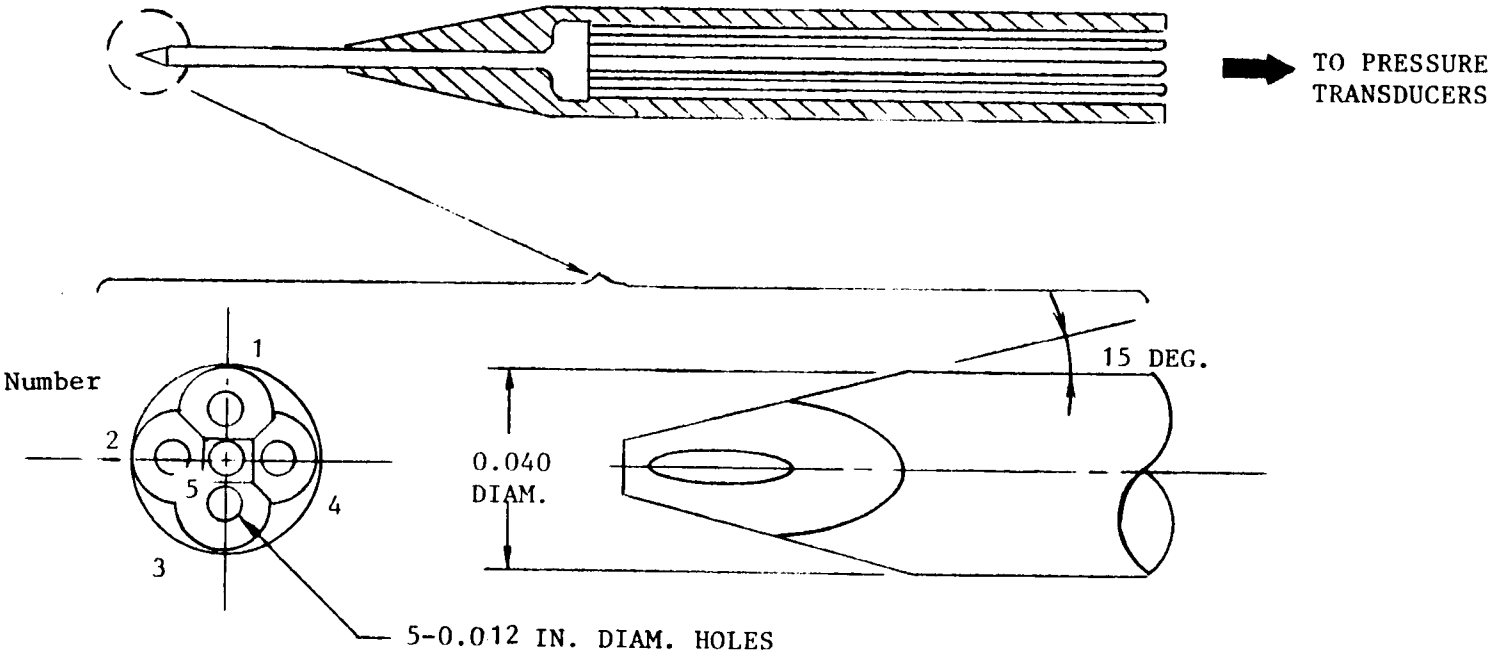


All dimensions in inches

Not drawn to scale

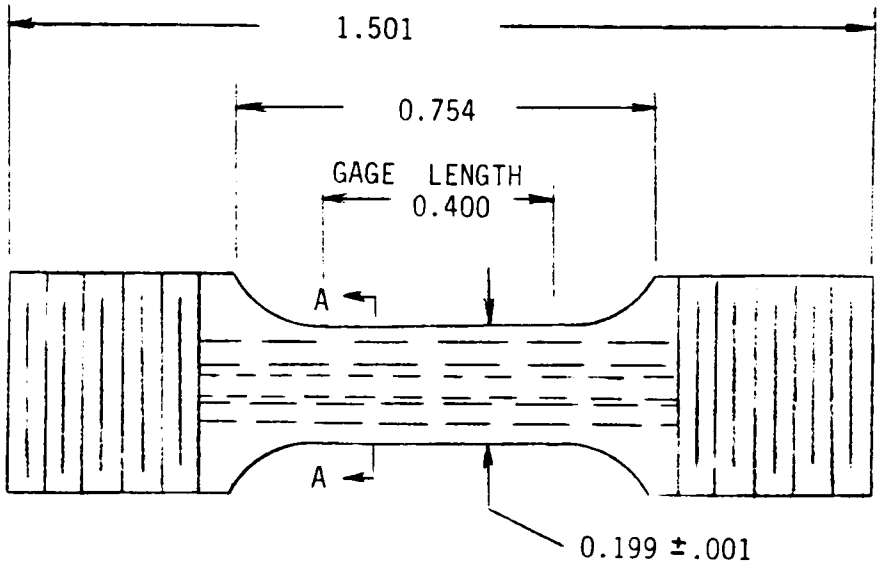
b. Probe Rake Details

Figure 1. (concluded)

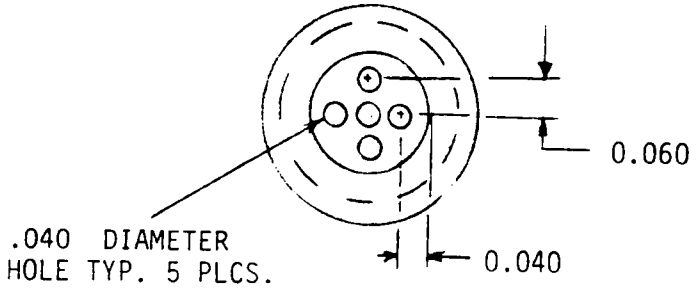


ALL DIMENSIONS IN INCHES

Figure 2. Typical Mach Flow Angularity Probe



A-A



ALL DIMENSIONS IN INCHES

Figure 3. MFA Probe Test Specimen

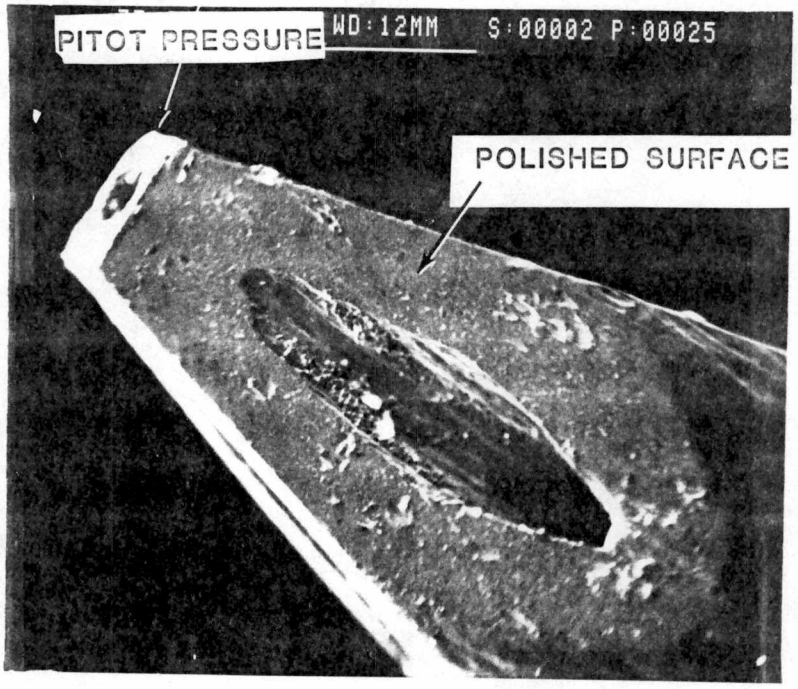
specimen through a series of cold-work elongations (10-percent increase in length) each followed by a full annealing process (elevating the specimen to 1800^{o}F for 15 min.). The elongation procedure continues until an outside probe tip diameter of 0.030-to 0.080-in. is reached or the specimen fractures, resulting in two potential probes. This one-piece probe fabrication method eliminates the difficult and failure-ridden process of brazing five individual stainless steel tubes together (ref. 2).

Following elongation, the specimen undergoes several operations required for tunnel installation. The first task involves using an electric-discharge machine (EDM) to burn 15-deg planes in which the outer holes are located and the 90-deg plane in which the central hole is located. At this point, the probe is leak checked to insure the integrity of the inner walls of each orifice has been maintained. A unique method, devised to perform this leak check, consists of a laser shadowgraph system which illuminates the probe tip as it sits in an alcohol bath and high-pressure air is injected into each hole from the base. Bubbles emanating from a hole other than the one in which the air is being injected indicates a leak. The final operation consists of soldering tubes into each hole at the aft end of the probe, and then leak checking each tube to verify good connections. After the tubes are attached and leak checked, the probe is

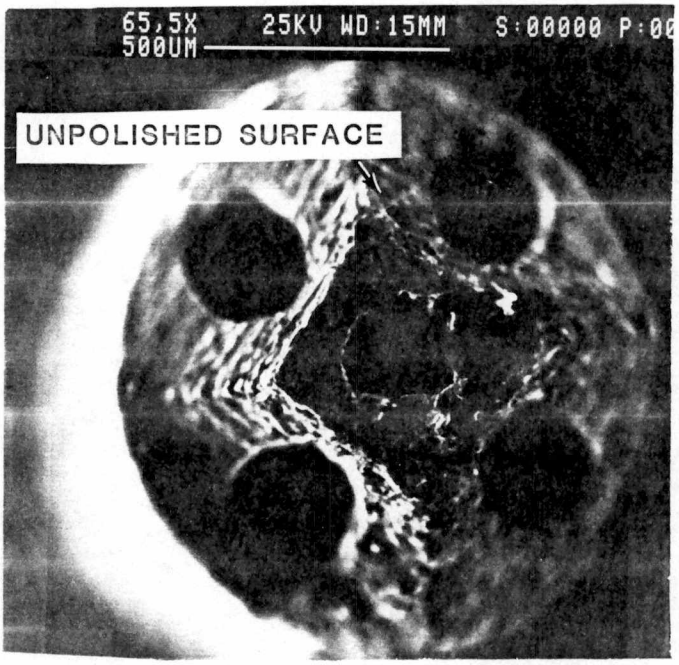
installed in a probe body compatible with wind tunnel probing mechanism hardware.

Probes 1 and 5 are comparable since both have their 15-deg side faces polished and their tips unpolished. Probes 2, 3, and 4 were left unpolished to compare the significance between polished and unpolished probes (see Fig. 4). All five probes had their tips ground flat to square the front face of each probe; however, it was deemed unnecessary to polish the tips since particles in the tunnel flow would deface the tips upon impact.

After examining the data for polished and unpolished probe effects, it was determined that polishing had no effect on the data trends. Squaring off the front face of the probe improves the "static" pressure measurement by making the angle between the plane of the total pressure measurement and the plane of the four "static" pressure measurements more uniform. Much care was exercised when drilling the location of the static pressure holes (P1 through P4) in order to keep the static pressure orifices a particular distance back on the 15 deg plane. MFA probes that have their four "static" pressure orifices cut too far forward on the 15 deg plane are influenced by the probe pitot pressure (P5). This distance on the 15-deg plane allows the measurement of a "static" pressure without "seeing" the effects of the pitot pressure for low angles of attack.



b. Probe #1



a. Probe #4

Figure 4. Mach Flow Angularity Probe Tip Photographs

CHAPTER III

INSTRUMENTATION

1.0 Test Instrumentation

A listing of the transducers and thermocouples, the recording devices and calibrating procedures used for measuring the stilling-chamber properties is itemized in Table 1. These basic measurements, in conjunction with previously established nozzle Mach number calibrations, are the basis for defining the test section properties.

2.0 Probe Pressures

Probe absolute-pressures P1 and P2 were measured using a 5-psi electronically scanned pressure (ESP) transducer. The differential pressure between DP13 and DP24 was measured directly with 1-psi differential transducers to minimize the measurement uncertainties since the differentials represent critical values in the probe calibration. Pressures 3 and 4 were computed by subtracting DP13 and DP24 from P1 and P2, respectively. The pitot pressure (P5) of the probe was measured using a 15-psi ESP since P5 encounters higher pressures in supersonic flow. Forty loops of data were obtained during the calibration in case a pressure prediction program had to be used to predict the pressure due to pressure lag. Only the last five loops of data were averaged to determine the measured pressures. Pressure lag-time estimates were calculated before the test using a 3-tube pressure prediction computer program. The probe

pressures were given this predetermined amount of time to stabilize before data measurements were obtained.

Table 1. Estimated Uncertainties

a. Measured Parameters

Steady State Estimated Measurement											
Parameter Designation	Precision Index (S)			Bias (B)		Uncertainty ± (B + t_{95}S)		Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement				
Stilling Chamber Pressure (PT & PTR), psia		0.002 0.002 0.007 0.017 0.08	>30 >30 >30 >30 >30		0.011 0.2 0.2 0.2 0.2		± 0.015 ± (0.2% + 0.004) ± (0.2% + 0.014) ± (0.2% + 0.034) ± (0.2% + 0.16)	<5.5 <15 <60 <150 <300	Bell & Howell force balance pressure transducer	Digital Data Acquisition system analog-to-digital converter	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the standards lab
Total Temperature (TT), °F		1	>30		2		± 4	0 - 300	Chromel-Alumel Thermocouples	Digital Thermometer and µProcessor Averaged (P_{R_i}) Digital Thermometer (Redundant)	Thermocouple verification of NBS conformity/voltage substitution calibration
Reference Pressure (PREF)		25 microns	>30	10		± (10% + 50µHg)		<1000 microns	Hastings vacuum gage	Digital data acquisition system/analog-to-digital converter	Comparison to facility reference gage
Pitch Angle (ALPI), deg Roll Angle (PHII), deg		0.025 0.15	>30 >30				± 0.05 ± 0.3	± 15 ± 180	Potentiometer		Heidenhain rotary encoder ROD700 Resolution: 0.0006° Overall accuracy: 0.001°
Dew Point (TDP), °F		0.5	>30		1		± 2	-100 to +167	EG&G moisture analyzer Model 300		In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the standards lab
P5, psia		± 0.0015	>30	0.15		± (0.003 + 15%)		0-15	Bell and Howell variable capacitance pressure transducer		
P1, P8, psia		0.004	30		0.005		± 0.013	0-5	± 5 psid multi-channel pressure transducer (ESP-32SL) w/vac ref.		
DP13, DP24, psia		0.0002	30		0.001		± 0.0014	0-1	Diffused Silicon strain gage transducer		

Table 1. (continued)

b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT								
	Precision Index (S)			Bias (B)		Uncertainty ± (B + t_{95}S)		M	Nominal Value
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement		
M		0.008			0		0.016	2.0	2.0
		0.008			0		0.016	2.99	2.99
		0.008			0		0.016	5.5	5.5
P		0.029			0.0047		0.063	2.0	2.34
		0.01			0.0016		0.0216	2.99	0.83
		0.001			0.0002		0.0017	5.5	0.14
T		1.29			1.11		3.69	2.0	327.6
		0.82			0.72		2.35	2.99	214.4
		0.28			0.28		0.84	5.5	95.4
Re, $ft^{-1} \times 10^{-6}$		0.018			0.021		0.057	2.0	4.15
		0.020			0.022		0.061	2.99	4.04
		0.011			0.012		0.033	5.5	4.21

Table 1. (concluded)

b. (concluded)

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT							M	Nominal Value
	Precision Index (S)			Bias (B)		Uncertainty ± (B + t_{95}S)			
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement		
Q		0.029			0.013		0.071	2.0	6.55
		0.035			0.010		0.079	2.99	5.19
		0.011			0.004		0.025	5.5	2.96
V		4.2			3.0		11.5	2.0	1774.6
		2.7			3.6		9.1	2.99	2146.1
		2.0			3.9		7.9	5.5	2633.7
PT2		0.069			0.026		0.163	2.0	13.19
		0.068			0.020		0.157	2.99	9.93
		0.020			0.007		0.046	5.5	5.5
PAVGP5		0.00042			0		0.00084	2.0	0.2818-0.3839
		0.00040			0		0.00080	2.99	0.1852-0.2312
		0.0010			0		0.0020	5.5	0.1216-0.1698
DPSQP		0.00012			0		0.00025	2.0	0.00533-0.1374
		0.00013			0		0.00026	2.99	0.00721-0.1331
		0.00020			0		0.00040	5.5	0.00720-0.1187

CHAPTER IV

CALIBRATION DESCRIPTION

1.0 Test Conditions

A test summary presenting the pitch and roll angles for each test condition is shown in Table 2. A summary of the nominal test conditions for each Mach number is listed below:

MACH	PT (psia)	TT (°R)	P (psia)	RE x 10^{-6} (ft-1)	T (°R)	V (ft/sec)
2.0	18.0	591	2.300	4.1	328.3	1776
3.0	17.0	584	0.492	2.5	209.5	2121
3.0	30.0	601	0.829	4.0	215.6	2152
5.5	40.0	679	0.043	1.3	96.3	2646
5.5	59.6	684	0.064	1.9	97.0	2656
5.5	80.0	687	0.086	2.5	97.4	2661

At some test conditions, particularly at sub-atmospheric stagnation pressures, the air humidity level affects the test section Mach number. For this test, this was not a problem since sub-atmospheric pressures were not tested.

2.0 Data Acquisition

Probe-attitude positioning and data recording were accomplished in the point-pause mode of operation. The probes were calibrated by setting the roll-angle position and then pitching the rake through an angle-of-attack range, stopping at specified points and waiting a prescribed time to record stabilized probe pressures. Forty loops of data at a constant time interval were obtained for each data point. This data sequence provided digital time histories for each pressure transducer to use a pressure prediction

Table 2. Test Run Summary

Run	Mach	RE X 10^{-6}/ft	ALPI (deg)	PHII (deg)
100	2.99	4.0	0	0
101-113	↓	↓	11.0 to -11.5	↓
114-126	↓	↓	↓	90.0
127-151	↓	↓	5.0	180 to -180
152-165	↓	↓	11.0 to -11.5	↓
179	↓	2.5	0	5.0
180-192	2.0	4.1	11.0 to -11.5	0
193-204	↓	↓	↓	90.0
205-229	↓	4.0	5.0	180 to -180
230	↓	0.7	5.0	-25
236-249	5.5	2.5	11.0 to -11.5	0
250-262	↓	↓	↓	90.0
263-287	↓	↓	↓	180 to -180
288	↓	1.9	5.0	0
289	↓	1.3	↓	↓

routine in the event that stabilized pressures were not obtained. The center of rotation for the probe holder was located at the tip of the center probe (probe 5). This center of rotation minimized the translation of the outer probes through the tunnel test-section flow field and, therefore reduced the influence of the variation in tunnel flow-field angularity on the probe calibration.

3.0 Data Uncertainty

In general, instrumentation calibrations and data uncertainty estimates were made using methods (ref. 3) recognized by the National Bureau of Standards (NBS). Measurement uncertainty is a combination of bias and precision errors defined as:

$$U = \pm(B + t_{95}S)$$

where B is the bias limit, S is the sample standard deviation, and t_{95} is the 95th percentile point for the two-tailed Students "t" distribution, which for degrees of freedom greater than 30 is taken to be equal to 2.

Estimates of the measurement uncertainties for this test are given in Table 1a. In general, measurement uncertainties are determined from in-place calibrations through the data-recording system and data reduction program. Uncertainty of the pressures are, therefore, dependent on transducer uncertainty. These uncertanties are combined in the total uncertainty listed in Table 1a. Uncertainties of the basic calculated parameters are listed

in Table 1b. Many of the sources of error for this type of calibration are discussed in ref. 4. The uncertainty is tabulated in terms of the percent of the reading or pressure, whichever was greater, for a given transducer pressure (or calibration) range. Uncertainties associated with the pressure measurements include the data-acquisition systems, linearity hysteresis and imprecision effects. In addition, tunnel flow nonuniformity effects, bias errors such as partially plugged pressure leads and pressure stabilization problems, dynamic low frequency flow fluctuation conditions particularly at Mach numbers less than 2 and finally the calibration curve fit of the data all contribute to sources of error in the calibration.

The maximum uncertainties in percent of the free-stream Mach number and in the local total angle of attack occurred at the lower Mach numbers. The overall uncertainty in the total angle-of-attack measurement is about equal to or greater than the overall nonuniformity or variation in the local test-section flow angle. The roll-angle uncertainty can be related directly to the uncertainty in the pressure differentials DP13 and DP24. Thus, the roll-angle uncertainty is tied to the nominal pitch angle of the probe; that is, small pitch angles will yield larger uncertainties in the roll angle.

CHAPTER V

CALIBRATION METHODOLOGY

Assumptions were made based on using small pertubation theory and slender body theory to characterize the flow field pressures measured by the probes. In order to make accurate, non-intrusive flow field measurements, a probe should consist of a slender body having a probe radius much less than the probe length. Slender body theory makes it possible to fully characterize the magnitude and direction of the flow velocity vector using the five pressure measurements. Since each probe has its own unique irregularities, each probe must be calibrated individually.

The calibration procedures involve fitting the equations used to calculate Mach number and total angle of attack to data acquired during the calibration wind tunnel test. Calibration constants are specified during the data-fit routine so as to minimize residuals between actual values and values calculated from the equations. The acceptability of the calibration constants is judged by quantitative and qualitative evidence. Calibration constants, defining the relationship of Mach number (pressure ratio) and total angle of attack (ALPHAT), are obtained from computer programs that fit the pressure data to functions of special forms. The functional forms of these equations are differentiated with respect to each calibration constant during the procedure used in solving for these calibration constants. Roll-angle

orientation (CPHI) of the flow velocity is calculated by a simple trigonometric function that does not contain calibration constants. The functions from which Mach number (pressure ratio) and total angle of attack are calculated and to which the calibration data are fit are composed of parameters corresponding to:

1. Tunnel free-stream properties.

2. Probe pitch and roll attitudes.

3. PAVGP5 which is the average of the four static pressures of the probe normalized by the probe pitot pressure, [PAVGP5 = (P1 + P2 + P3 + P4)/(4 * P5)].

4. DP13/P5 and DP24/P5, the probe static-pressure differential in the pitch and yaw planes of the probe, respectively, normalized by the probe pitot pressure, [DP13/P5 = (P1-P3)/P5; DP24/P5 = (P2-P4)/P5].

5. DPSQP, one-half the square root of the sum of the squares of DP13/P5 and DP24/P5, $DPSQP = SQRT[(DP13/P5)^2 + (DP24/P5)^2]/2$.

In general, the parameters PAVGP5 and DPSQP define the relationship between the local stream velocity and the measured probe pressures. Once the local-stream Mach number has been defined, the local total angle of attack of the probe can be defined as a function of DPSQP. The ratios of the terms DP13/P5 and DP24/P5 are used to define the roll orientation of the resultant local-stream velocity vector relative to the probe axis (ref. 5).

1.0 Probe Attitude

Prior to defining any relationships with respect to the local stream, the probe attitude must first be defined. The probe attitude relative to the calibration stream can be

defined in terms of the probe holder pitch (ALPHA) and roll (PHII) angles and the probe misalignment angles in pitch, yaw, and roll (i.e., ALPD, PSID, PHID, respectively). Angles ALPHA and PHII are shown in Fig. 5 and the misalignment angles are illustrated in Fig. 6. In this calibration, the sequence of angular rotations starting with the probe holder, was PHID, PSID, ALPD, PHII, and ALPHA. Therefore, the actual total angle of attack and roll angle of the probe was defined by standard angle transformations (ref. 6).

The total angle of attack, ALPHAT, is determined using the following relation:

$$ALPHAT = \cos^{-1}(U2 * \cos(PSID) + V2 * \sin(PSID))$$

where $U2 = \cos(ALPHA)*\cos(ALPD) - [\sin(ALPHA)*\sin(ALPD)]*\cos(PHII + PHID)$,

$V2 = \sin(ALPHA) * \sin(PHII + PHID)$,

$W2 = \cos(ALPHA)*\sin(ALPD) + [\sin(ALPHA)*\cos(ALPD)]*\cos(PHII + PHID)$

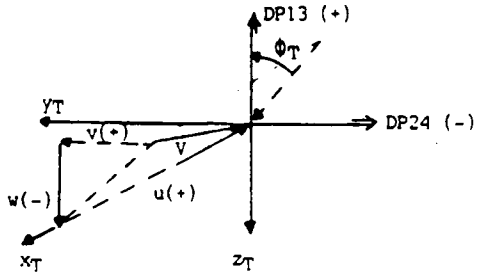
The corresponding roll angle, PHIT, is:

$$PHIT = \tan^{-1}((V2/W2)\cos(PSID) - (U2/W2)\sin(PSID)$$

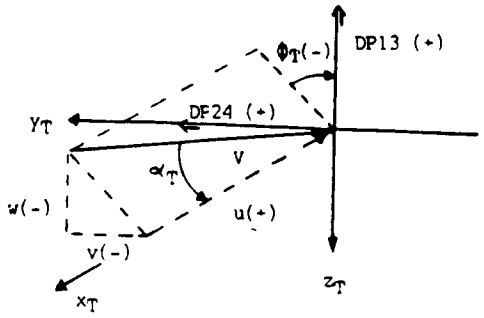
The pitch (ALPHA) and roll (PHII) positions of the probe holder are known, while the probe misalignment angles must be determined from the calibration data.

2.0 Probe Misalignment Angles

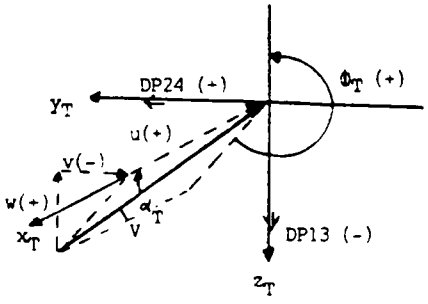
The first step in actual definition of the probe attitudes is to define the individual probe misalignment angles (ALPD, PSID, PHID as shown in Fig. 6). These angles



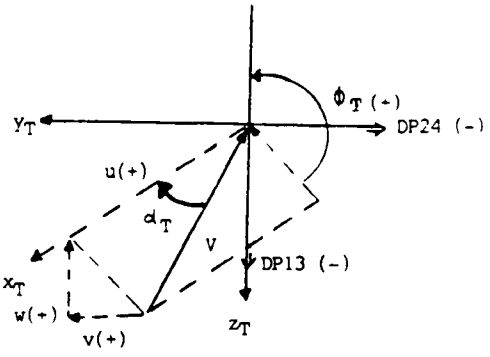
b. Quadrant I



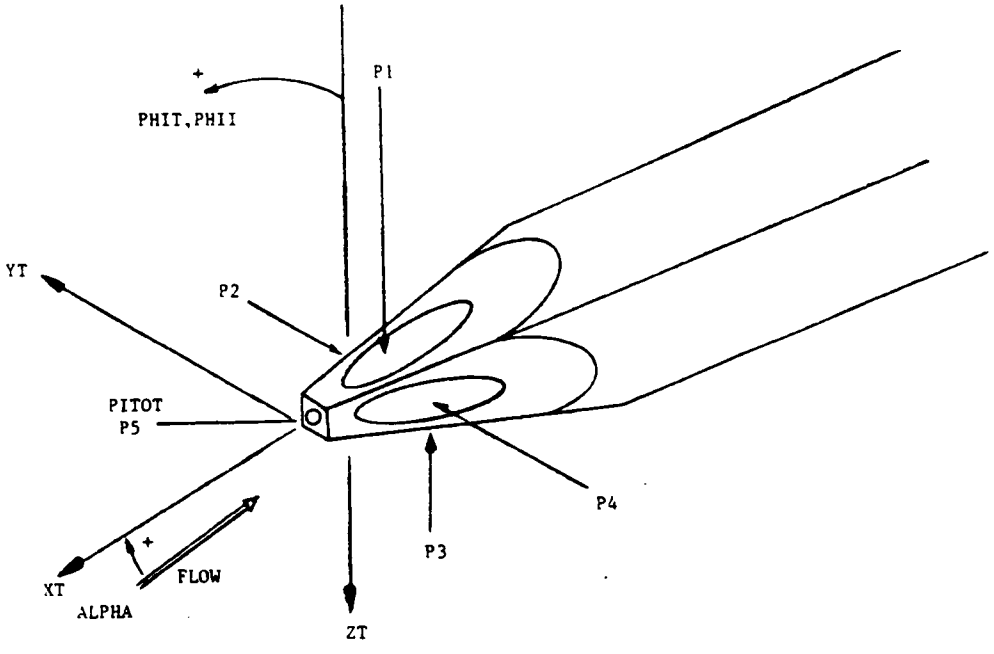
c. Quadrant II



d. Quadrant III



e. Quadrant IV



a. Probe Orientation and Coordinate System

Figure 5. MFA Probe Flow Field Coordinate System

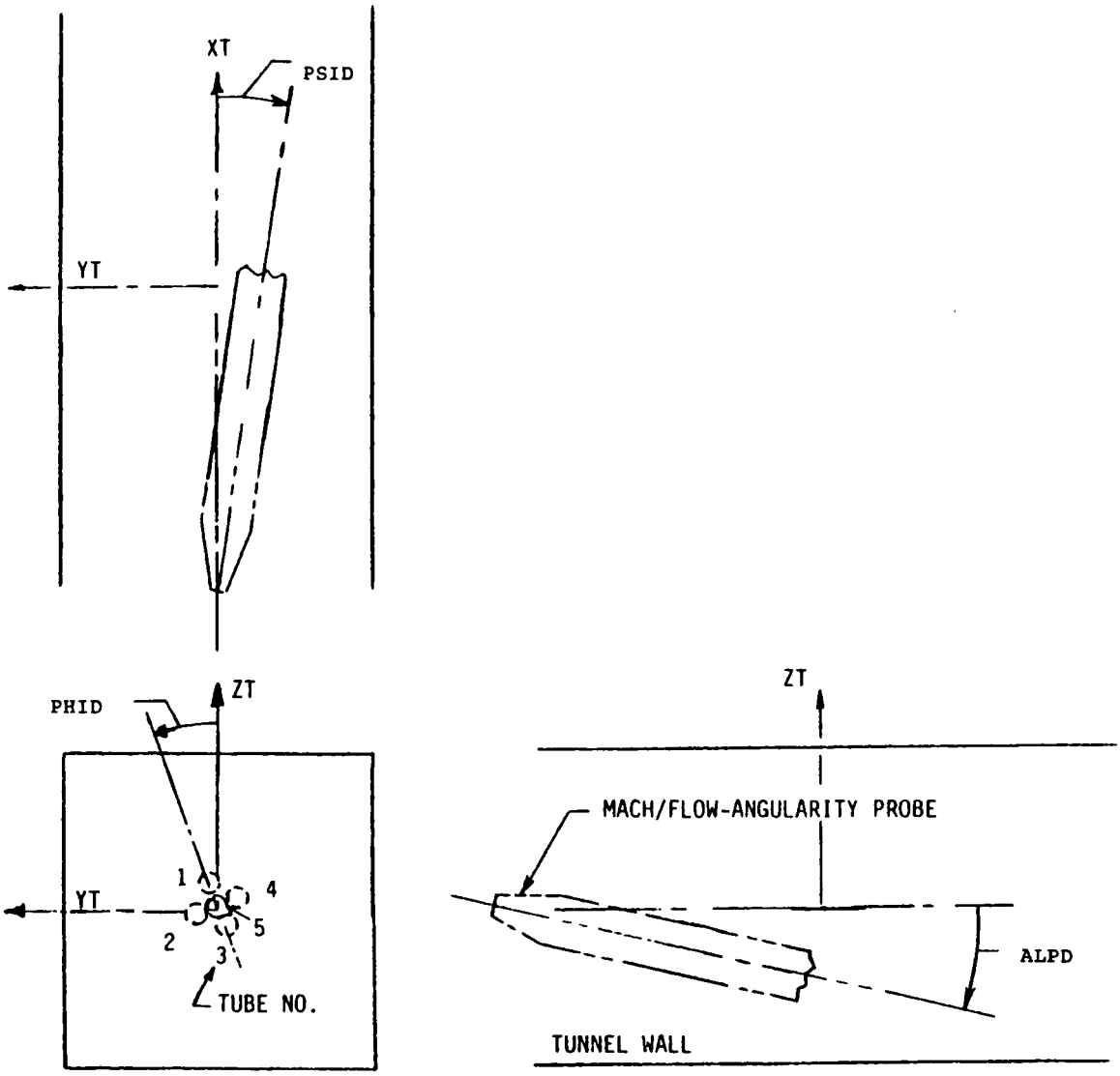


Figure 6. Velocity Vector Definition With Respect To Tunnel Axis

are the misalignments in pitch, yaw, and roll that exist when the probe holder is aligned with the freestream (at ALPHA = PHII = 0 deg). Probe misalignments were determined for each probe at every test condition (i.e., every Mach number and roll angle).

Probe misalignment angles are attributed to three general problems. First, the small size inhibits a completely symmetrical probe; that is, some slight variations in the four 15-deg cuts may exist. Second, the size also makes it difficult to align a probe in pitch and roll with respect to the tunnel axis system. Finally, the tunnel flow angularity varies throughout the test section and varies with changes in the test section Mach number. Although the misalignment effects cannot be easily assessed individually, the combined effect can be deduced and corrected.

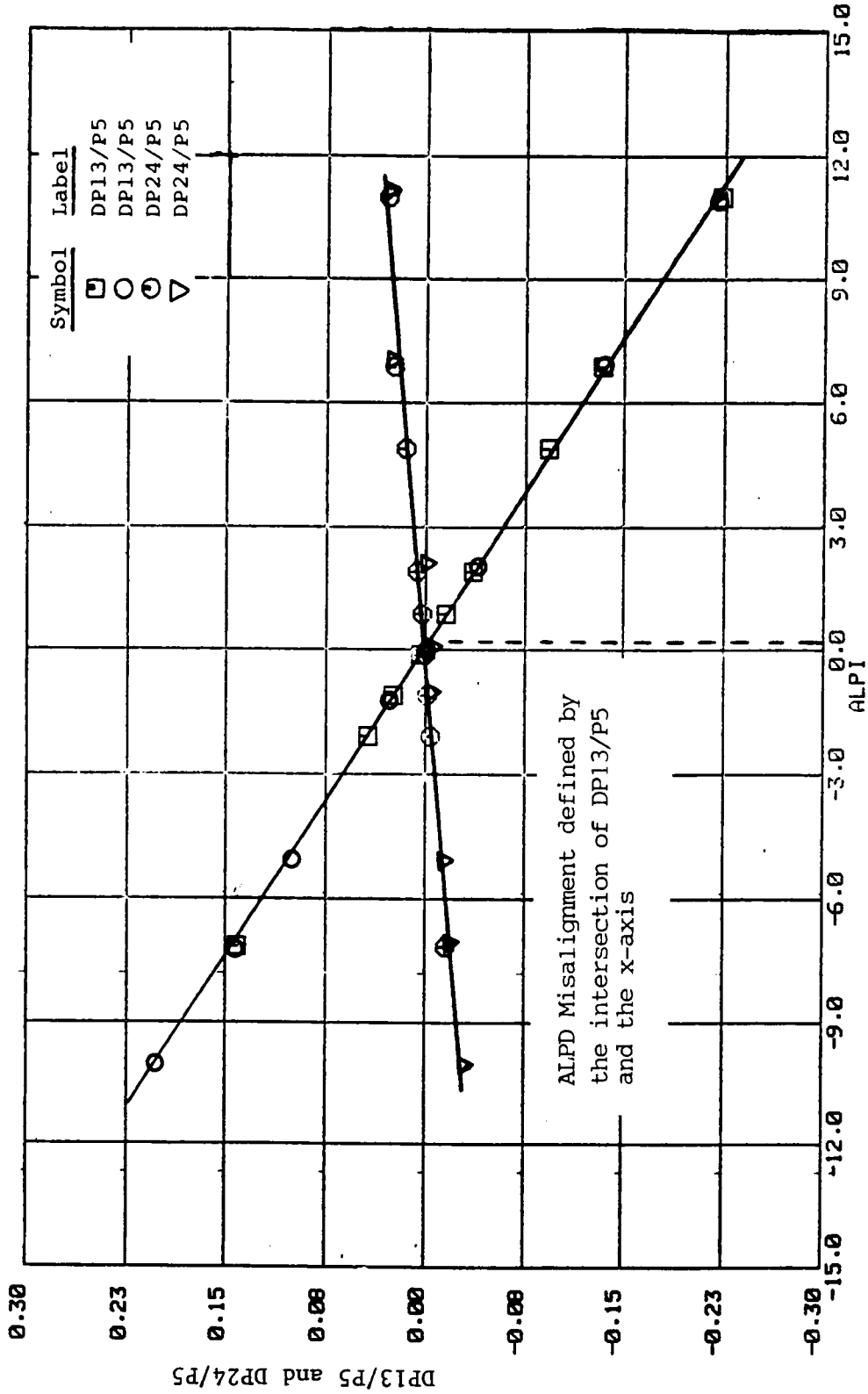
Probe misalignment angles are unique for each tunnel installation and, therefore, must be redefined each time a probe is used in a wind tunnel. Assuming the probes do not incur any physical damage, the calibration curves determined are unique calibrations for each probe and independent of the probe installation.

The pitch- and yaw- misalignment angles can be determined by finding the incidence angles at which the appropriate "static" pressure differential becomes null (P1 = P3 for pitch and P2 = P4 for yaw, see Fig. 2). The

roll-misalignment angle is determined by the roll angle at which P2 = P4 when the probe is at a nominal angle of attack (approximately 5 deg).

Upon determining the probe misalignment angles, the probe attitude can be related to the tunnel axis system, and hence, a velocity field sensed by a probe can also be related to the same system. The data must include these angles such that the associated pressure data may be related to the total angle of attack and total roll angle of the probe. These data and the probe attitude and test conditions form the basis from which calibration constants are obtained.

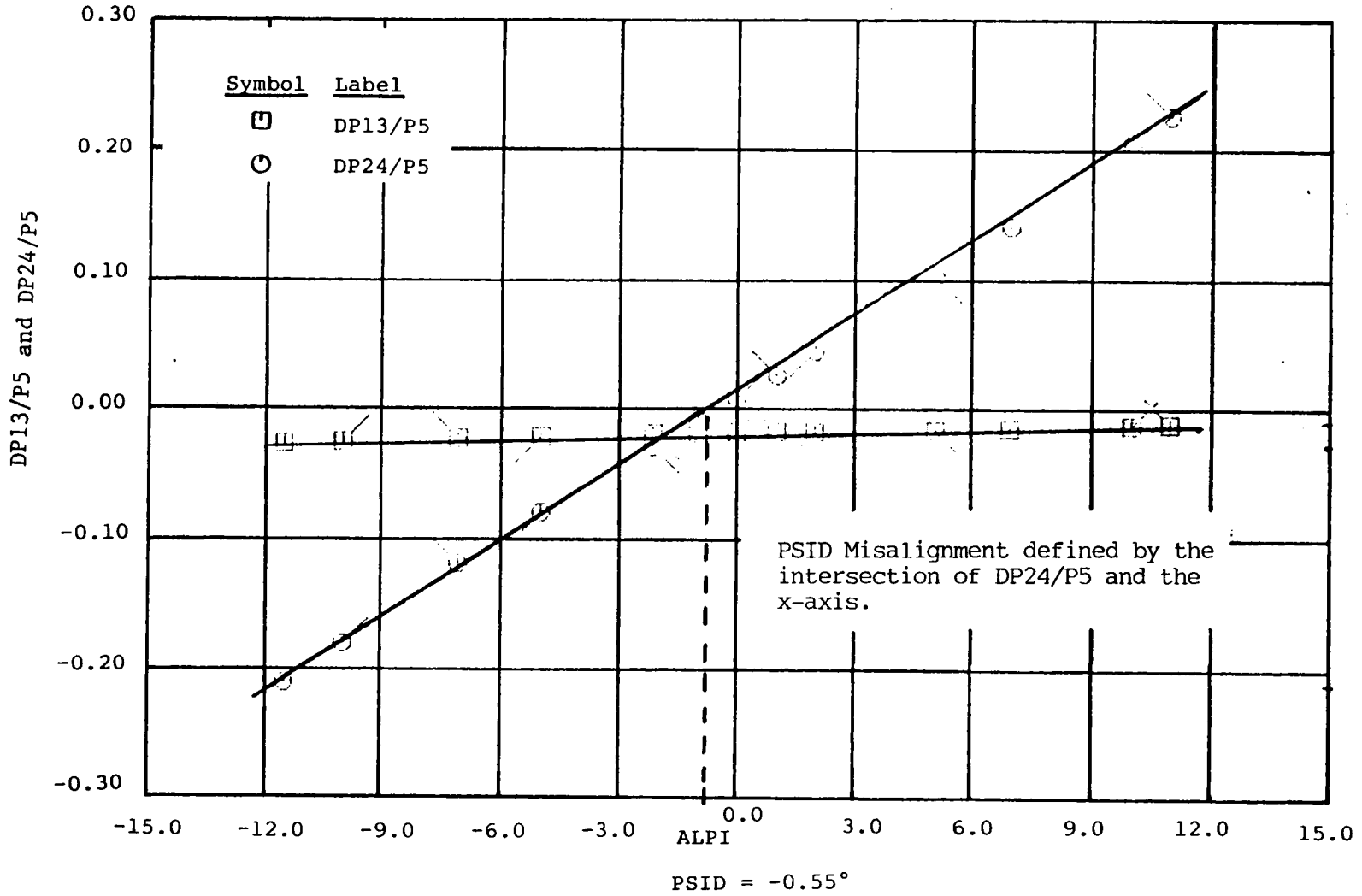
Misalignment angles can be estimated graphically from plots of the pressure differentials DP13/P5 and DP24/P5 versus the probe pitch attitude (ALPHA) as illustrated in Fig. 7. The pitch misalignment (ALPD) is the negative of the ALPHA value that best nulls the pressure differential DP13/P5, for PHII = 0 (see Fig. 7a). Similarly, the yaw misalignment (PSID) is determined from DP24/P5 vs ALPHA at PHII = 90 deg (Fig. 7b). Roll misalignment (PHID) is estimated from the slope of the calculated roll angle (CPHI) versus the total roll angle (PHIT) as shown in Fig. 7c. This slope should correspond to a 45-deg slope through the range of roll angles. The offset to the right or left of this 45-deg line is the misalignment in roll (PHID). The calculated misalignment angles can then be perturbed



ALPD = -0.15°

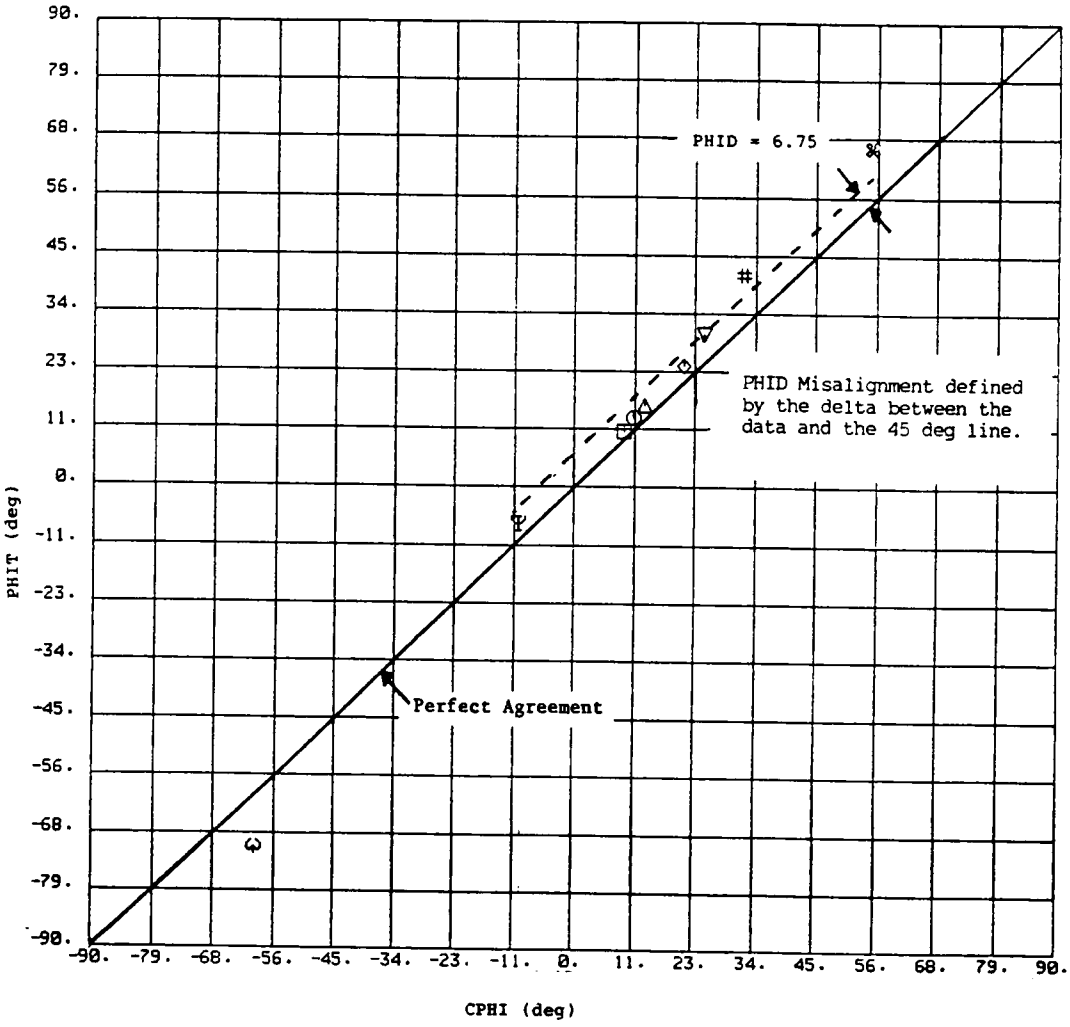
a. Pitch Determination, Probe 2

Figure 7. Graphical Evaluation of Probe Misalignment



b. Yaw Determination, Probe 5

Figure 7. (continued)



c. Roll Determination, Probe 5

Figure 7. (concluded)

slightly until the pressure parameter DPSQP as a function of ALPHAT collapses into a single value function. Otherwise, if the probe holder is pitched so that the probe pitch angle changes sign and the misalignment angles are incorrect, then the relationship between ALPHAT and DPSQP (both of which are positive for all possible values of ALPHAT and DPSQP) becomes doubled valued as ALPHAT approaches zero.

3.0 Methodology

The objective of the probe calibration is to formulate calibration parameters based solely on the probe pitot pressure and the four probe static pressures (that is pressures at the tubes which were cut at an angle of 15 deg). These calibration parameters will be selected to uniquely define a resultant local-stream Mach number and two flow angles, namely a total angle of attack with respect to the probe axis and a roll angle. The roll angle is defined by the planes formed by the resultant Mach number vector - probe axis and the probe axis - radial axis through static pressure tap number 1 of the probe (see Fig. 5). Aerodynamically, this five-tube probe functions somewhat like a more conventional cone probe in that the probe surface static pressure varies as a function of the cosine of the probe roll angle, that is

$$Pn = P_o(M) + p_1(M,\alpha)\ \alpha \cos \phi \qquad (1)$$

where $P_o(M)$ is the average of the four static-pressure measurements at zero angle of attack and $p_1(M,\alpha)$ is a

parameter describing the nonlinear change in static pressure as a function of the local-stream Mach number and the angle of attack.

At zero angle of attack, the probe pressure results can be normalized to produce the following parameters which will define a unique relationship between the probe pressures and the local-stream Mach number.

$$PAVGP5 = (0.25 \sum_{1}^{4} P_i)/P5 = P_o(M)/P5 \qquad (2)$$

A second parameter, DPSQP, can be formulated which is a function of the local stream Mach number and total angle of attack of the probe

$$DPSQP = SQRT[(DP13/P5)^2 + (DP24/P5)^2]/2 \qquad (3)$$

where $DP13 = P1 - P3$

$$P1 = P_o(M) + p_1(M,\alpha) \cos \phi$$

$$P3 = P_o(M) - p_1(M,\alpha) \cos \phi$$

and $DP24 = P2 - P4$

$$P2 = P_o(M) + p_1(M,\alpha) \sin \phi$$

$$P4 = P_o(M) - p_1(M,\alpha) \sin \phi$$

Therefore $DPSQP = p_1(M,\alpha)/(P5)$

These two parameters, PAVGP5 and DPSQP, were found to provide a unique relationship for defining the local-stream Mach number.

These results were curve fit using a least-squares type curve fit of Mach number as a function of two independent parameters (PAVGP5 and DPSQP). Based on previous

experience, the following function was found to provide the best calibration curve for the probe data

$$M = A + B*(DPSQP)^2 + C*(DPSQP)^4 \qquad (4)$$

where $$A = \sum_{1}^{6} C_k \ (\ln PAVGP5)^{k-1}$$

$$B = \sum_{7}^{11} C_k \ (\ln PAVGP5)^{k-7}$$

and $$C = \sum_{12}^{16} C_k \ (\ln PAVGP5)^{k-12}$$

Some of these coefficients were suppressed or zeroed to establish the curve fit. Once the local Mach number (M) has been determined, the local total angle of attack can be defined as a function of DPSQP by the equation

$$ALPHAT = [A_1 + A_2*(\ln M) + A_3*(\ln M)^2]*DPSQP \qquad (5)$$

These two equations contain constants that must be determined from calibration data (see Table 3). The data presented was curve fit using Eqs. 4 and 5. In an effort to obtain a better fit of the data, alternate parameters were investigated to use in the curve fit routine. After analyzing MFA data, it was determined that a better fit could be accomplished using the pressure ratio (based on supersonic or subsonic data) in place of the natural log of the Mach number. The Mach number was converted to a pressure ratio using equations 44 or 100 in NACA 1135 (ref. 7). Using the pressure ratio in place of Mach number provides for a more accurate fit due to the nature of the

Table 3. MFA Curve-Fit Coefficients

a. Mach Number

Coefficient	Probe No.				
	1	2	3	4	5
C_1	-0.397350E + 01	-0.136752E + 01	-0.144053E + 01	-0.797755E + 00	-0.332357E + 01
C_2	-0.128714E + 02	-0.588505E + 01	-0.369683E + 01	-0.389106E + 01	-0.120440E + 02
C_3	-0.137557E + 02	-0.679890E + 01	-0.216019E + 01	-0.420663E + 01	-0.138045E + 02
C_4	-0.650704E + 01	-0.346825E + 01	-0.408592E + 00	-0.197712E + 01	-0.687996E + 01
C_5	-0.107593E + 01	-0.587402E + 00	0.603155E-01	-0.260995E + 00	-0.118594E + 01
C_6	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00
C_7	0.705244E + 01	0.548418E + 01	0.151016E + 02	0.265821E + 01	0.239334E + 02
C_8	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00
C_9	-0.824731E + 01	-0.726847E + 01	-0.139777E + 02	-0.260718E + 01	-0.237781E + 02
C_{10}	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00
C_{11}	0.370614E + 01	0.303268E + 01	0.414930E + 01	0.223181E + 01	0.676310E + 01
C_{12}	-0.694695E + 02	-0.803374E + 02	-0.192219E + 03	-0.120794E + 03	-0.926509E + 03
C_{13}	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00
C_{14}	0.171107E + 03	0.155933E + 03	0.226573E + 03	0.269009E + 03	0.103309E + 04
C_{15}	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00	0.000000E + 00
C_{16}	-0.234812E + 02	0.337243E + 02	-0.183845E + 02	-0.438086E + 01	-0.179541E + 03

b. Flow Angle

Coefficient	Probe No.				
	1	2	3	4	5
A_1	0.755544E + 02	0.463554E + 02	0.373477E + 02	0.586940E + 02	0.497750E + 02
A_2	0.293125E + 02	0.679311E + 02	0.761305E + 02	0.478924E + 02	0.678576E + 02
A_3	-0.601021E + 01	-0.181341E + 02	-0.215814E + 02	-0.119522E + 02	-0.199620E + 02

curves. In addition, Mach number is usually a calibrated input based on nozzle setting whereas the measurement of total pressure and static pressure are usually made when operating a wind tunnel.

The data presented could not be refit using the pressure ratio due to the availability of the data. Equations 4 and 5 have been modified in the curve fit/calibration program as follows:

$$P/PT \text{ or } P/PT2 = A + B*(DPSQP)^2 + C*(DPSQP)^4$$

where $$A = \sum_{1}^{6} C_k \ (PAVGP5)^{k-1}$$

$$B = \sum_{7}^{11} C_k \ (PAVGP5)^{k-7}$$

and $$C = \sum_{12}^{16} C_k \ (PAVGP5)^{k-12}$$

$$ALPHAT = [A_1 + A_2*(P/PT2) + A_3*(P/PT2)^2]*DPSQP \quad \text{(supersonic)}$$

$$ALPHAT = [A_1 + A_2*(P/PT) + A_3*(P/PT)^2]*DPSQP \quad \text{(subsonic)}$$

The roll orientation of the flow velocity is calculated using the relation:

$$CPHI = \tan^{-1}[-(DP24/DP13)] + 90*[1-DP13/ABS(DP13)] \quad (6)$$

These three equations are used with probe-pressure measurements to determine properties of a flow field with respect to the wind-tunnel axis system.

CHAPTER VI

CURVE FITTING TECHNIQUE

The equations used to calculate Mach number and total angle of attack contain constants C_n and A_n, respectively. These constants are determined by computer programs that fit the equations to calibration data and are, therefore, referred to as calibration constants. Even though the equations used to determine Mach number and total angle of attack are different, the method of solution for the calibration constants is the same. This method is described below.

For any general function (f),

$$y = f(x_i, C_j)$$

to fit measured data points (Y_n) such that the RMS between y_n and Y_n be minimized, a closed form solution is not possible. However, an iterative technique that alters initial guesses until a solution is obtained may be employed. This technique is generally referred to as a differential corrections technique (ref. 1).

The theory upon which the differential corrections technique is based, begins with initial guesses of the calibration constants (designated C_{ej}). Now the final constants (C_j) are assumed to be of the form:

$$Cj = C_{ej} + \Delta C_j$$

where ΔC_j is a small alteration of C_{ej}.

Expanding y_n in a Taylor series involving only first order terms yields

$$Y_n = (Y_e)_n + \sum_j \Delta C_j \frac{\partial Y_n}{\partial C_j}$$

The sum over all data points of the square of the residuals is:

$$\sum_n (Y_n - Y_n)^2 = \sum_n [(Y_e)_n + \sum_j \Delta C_j \frac{\partial Y_n}{\partial C_j} - Y_n]^2$$

the conditions for which the previous sum becomes a minimum is:

$$\frac{\partial [\sum_n (Y_n - Y_n)]^2}{\partial C_j} = 0$$

Using these conditions with the above equation for the sum of the residuals squared, the normal set of equations may be constructed. The normal set of equations is:

$$\left[\sum_n \frac{\partial Y_n}{\partial C_i} \frac{\partial Y_n}{\partial C_j} \right] (\Delta C_i) = \left[\sum_n (Y_n - Y_n) \frac{\partial Y_n}{\partial C_i} \right]$$

or more commonly,

$$D_{ij} \Delta C_i = R_i$$

where D_{ij}, ΔC_i, and R_i are the matrix of parametric influence coefficients, vector of coefficient correction terms, and residual vector, respectively. The form of the equations used to relate probe pressure data to Mach number and total angle of attack is chosen to allow simplification in obtaining the matrix of parametric influence

coefficients. The normal equations are linear and, therefore, D_{ij} can be inverted to obtain the following relation:

$$\Delta C_i = D_{ij}^{-1} R_i$$

The actual relation used to obtain optimal alterations of initial guesses of the calibration constants is:

$$\Delta C_i = \delta_{ij} D_{ij}^{-1} R_i$$

where δ_{ij} is the Kronecher delta and represents the main diagonal identity matrix. The inclusion of the Kronecher delta amounts to the assumption of neglecting the cross effects among the constants.

Altered calibration constants are again used as initial guesses and the procedure is repeated until levels of the square root of the sum of the square of the residuals obtained from two successive iterations differ by some prescribed small amount. The above describes a specific method by which constants in a general function may be specified to minimize residuals between measured values and corresponding values calculated from the function. This specific method was used with Eqs. 4 and 5 (see Chapter 5.3) to obtain calibration constants for calculating Mach number (pressure ratio) and total angle of attack.

CHAPTER VII

CALIBRATION ANALYSIS

The probes were calibrated over a Mach number range from 2.0 to 5.5 and the results are shown in Fig. 8. As previously assumed, a unique relationship between the local Mach number and the pressure parameters PAVGP5 and DPSQP was found to exist which includes the effects of the probe pitch and roll position. When all five of the probes are plotted together as shown in Fig. 8, the characteristic behavior of the probes is essentially the same. However, probe 4 shows a variation in PAVGP5 at Mach 5.5; this variation is thought to be caused by one of the 15-deg side face holes intersecting the squared-off front face of the probe. The intersection of the front and side plane causes a higher static pressure reading than would normally be measured. This higher measurement (caused by the pressure measuring pitot and static together) is more noticeable at higher Mach numbers. Another source of error in the Mach uncertainty calculation is caused by the wide band of scatter at Mach 2.0 due to PAVGP5 sensitivity to Mach number. This scatter can be attributed in part to the local flow behavior at the lower Mach numbers. The roll data (shown in Fig. 8) is also a source of error in the uncertainty calculation due to the scatter measured at the lower Mach numbers. The roll scatter influence is discussed later in the text.

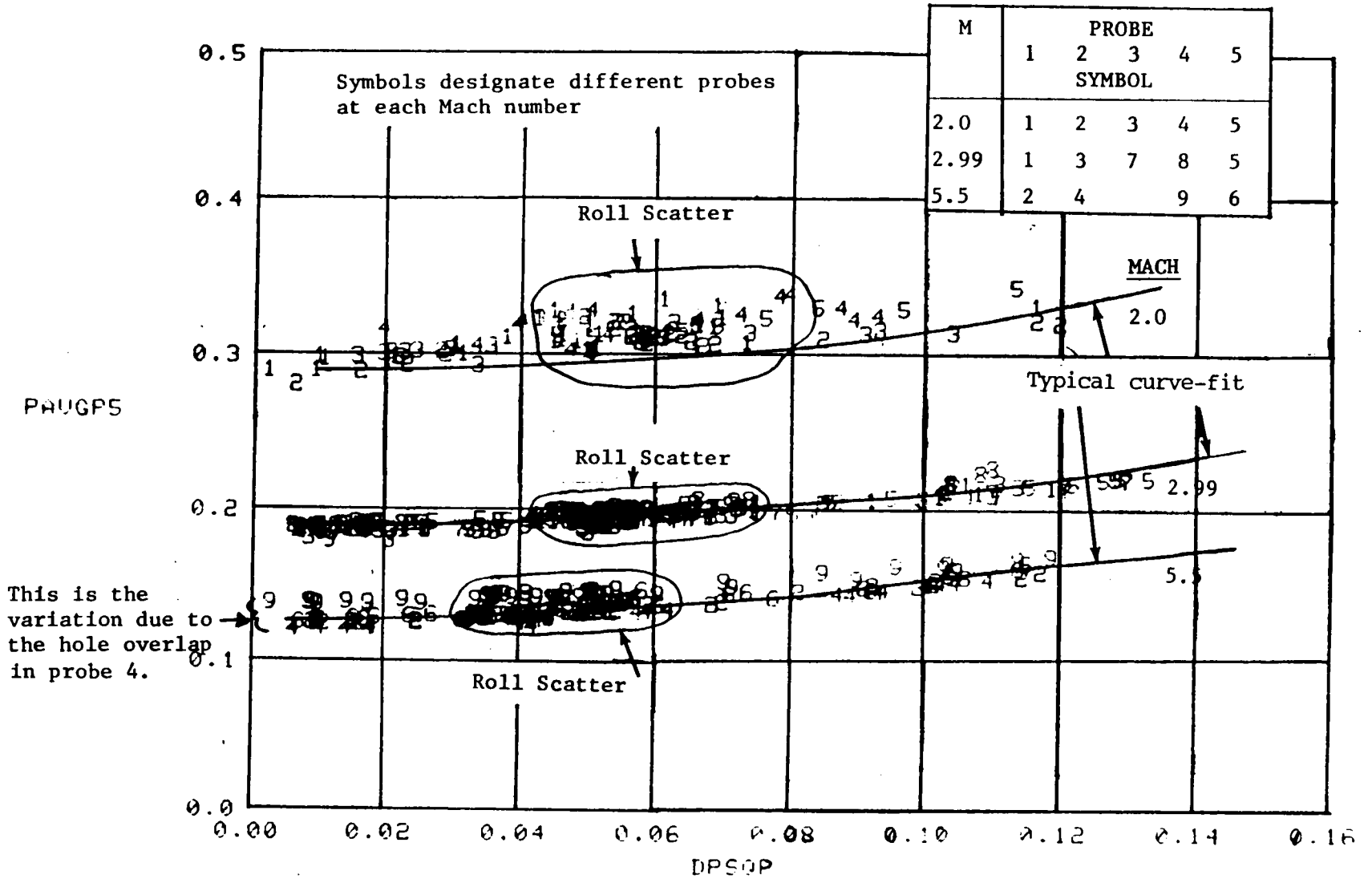
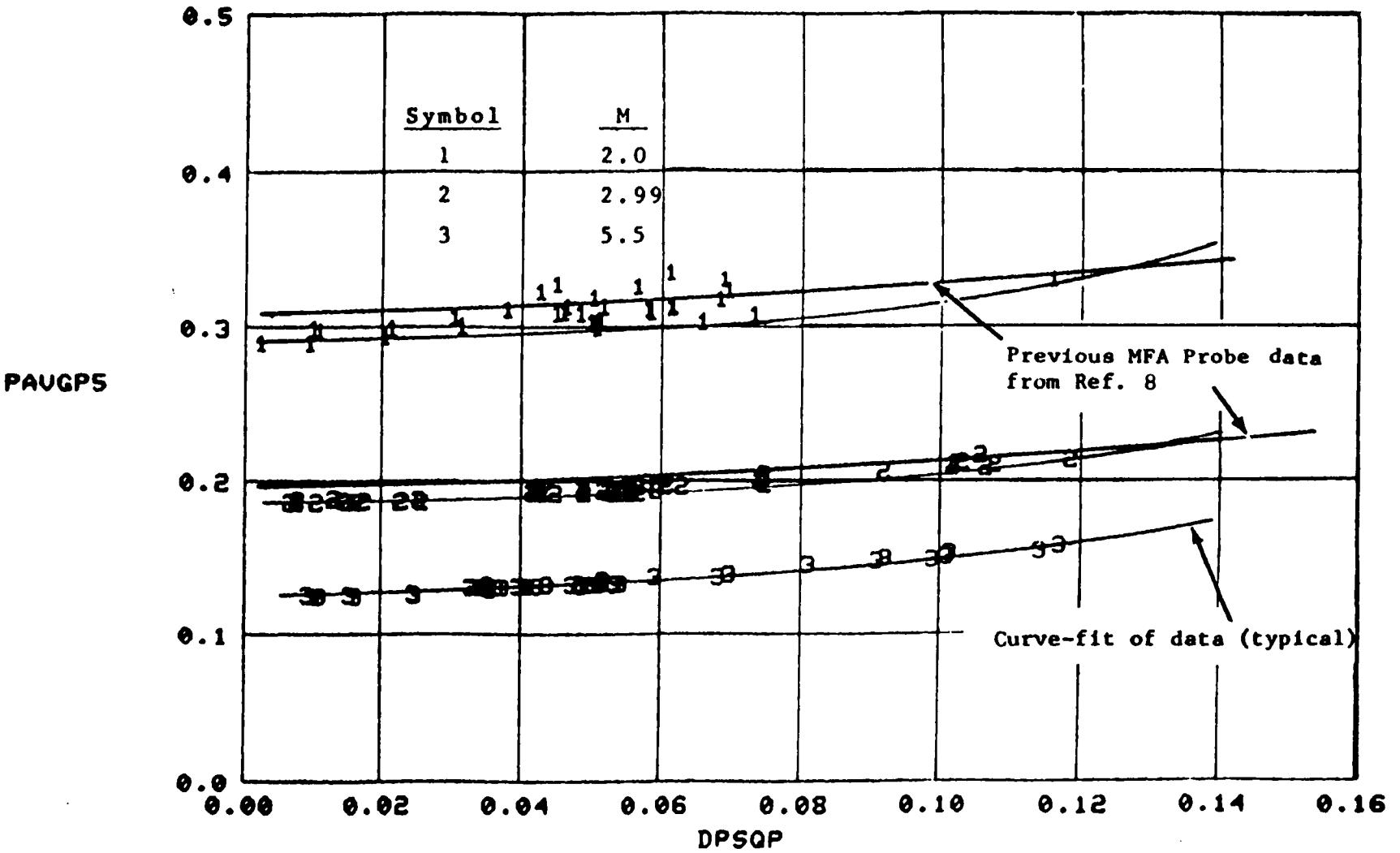


Figure 8. Mach Number Calibrations

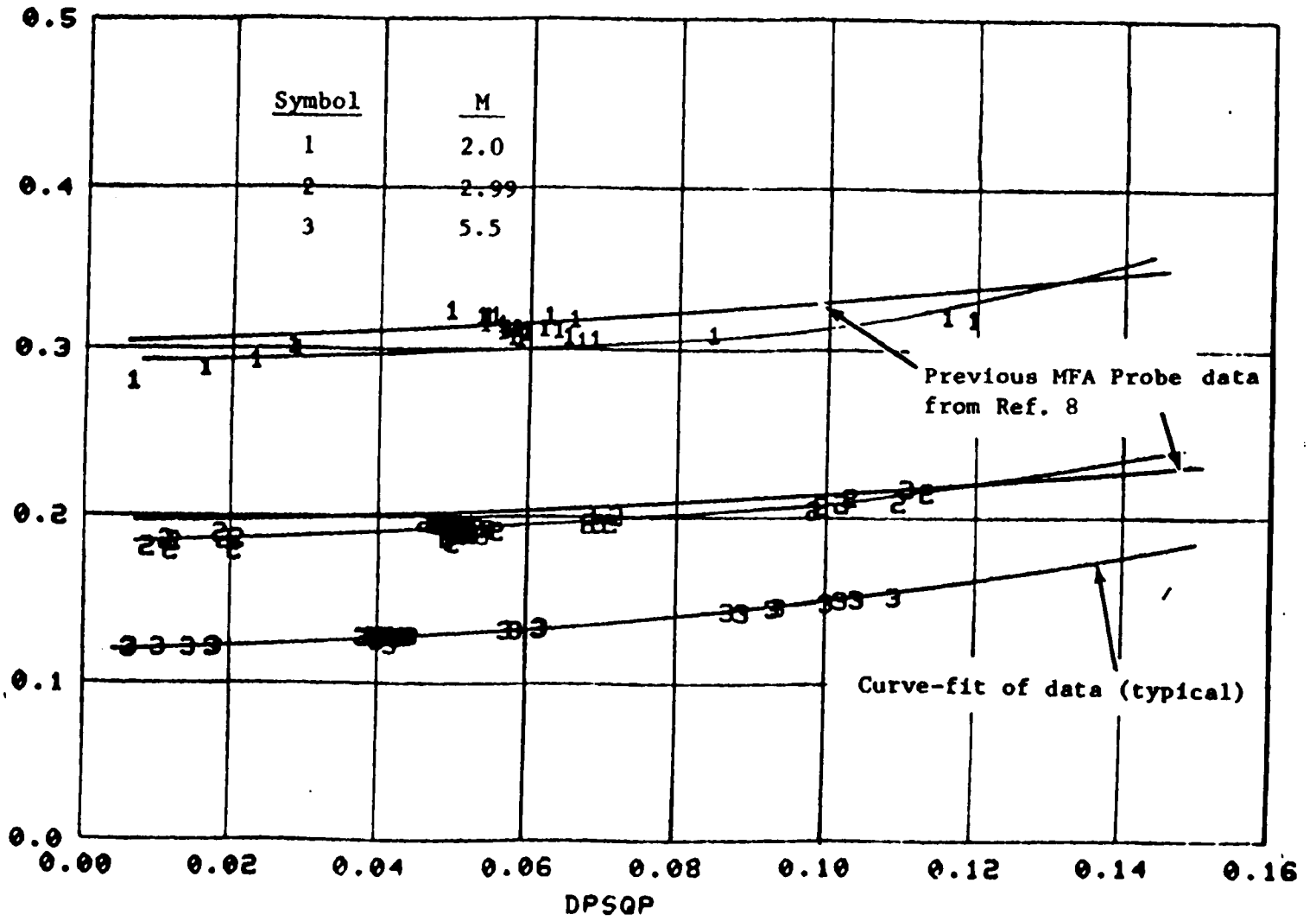
Figure 9 presents the calibration data in a manner that shows the local Mach number to be a function of the correlation parameters, DPSQP and PAVGP5. Comparison of the data with previous MFA data (ref. 8) shows good correlation in the curvature of the lines at Mach 2.0 and 2.99 for values of DPSQP less than 0.10 (see Fig. 9). However, as seen in Fig. 9, the previous MFA data shows higher values for PAVGP5 due to differences in design of the probes. Previous MFA probes had the four side-face holes drilled too close to the front face. This caused the pressures (P1, P2, P3, P4) to be higher than those of the presently calibrated probes. The quality of the sine waves produced during the roll was also improved by the new design pattern of the probes. This gave better probe roll uncertainty. The new hole pattern (that is, greater wall thickness) of these probes also added strength to the probes. Previous MFA probes were structurally less durable. Sometimes during testing, the walls of the tubes would crack when the probe touched the model causing the loss of the probe.

Figure 10 shows the local total angle of attack to be a function of the parameter, DPSQP, for a given Mach number. A comparison of the five probes shows good correlation except at Mach 2.0 where the data shows a wide band of scatter. Figures 11a-11e show DPSQP vs ALPHAT for each individual probe. As can be seen from the plots, the data is better fit by the curve-fit at the higher Mach numbers.



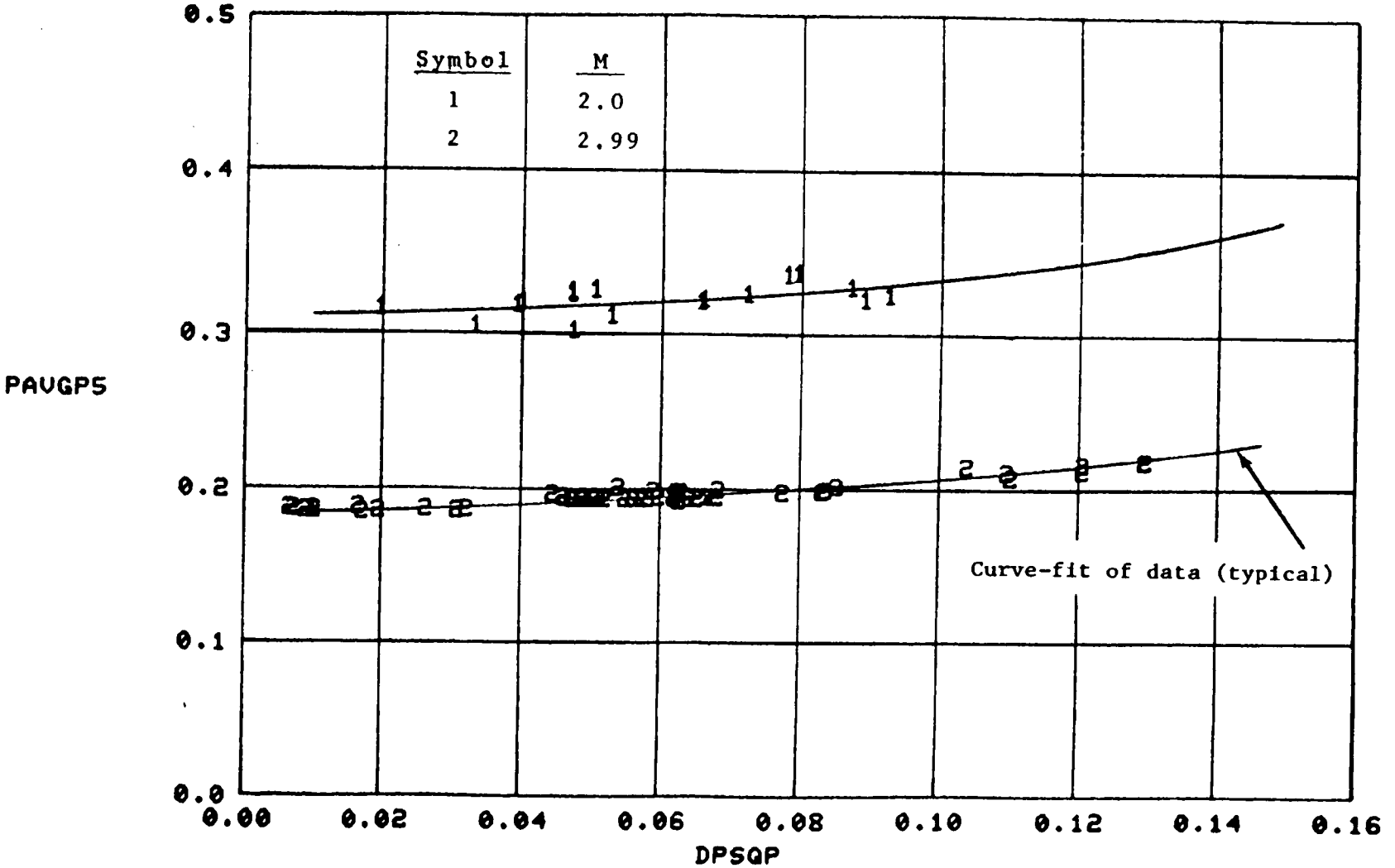
a. Probe Number 1

Figure 9. Individual Probe Mach Number Calibrations



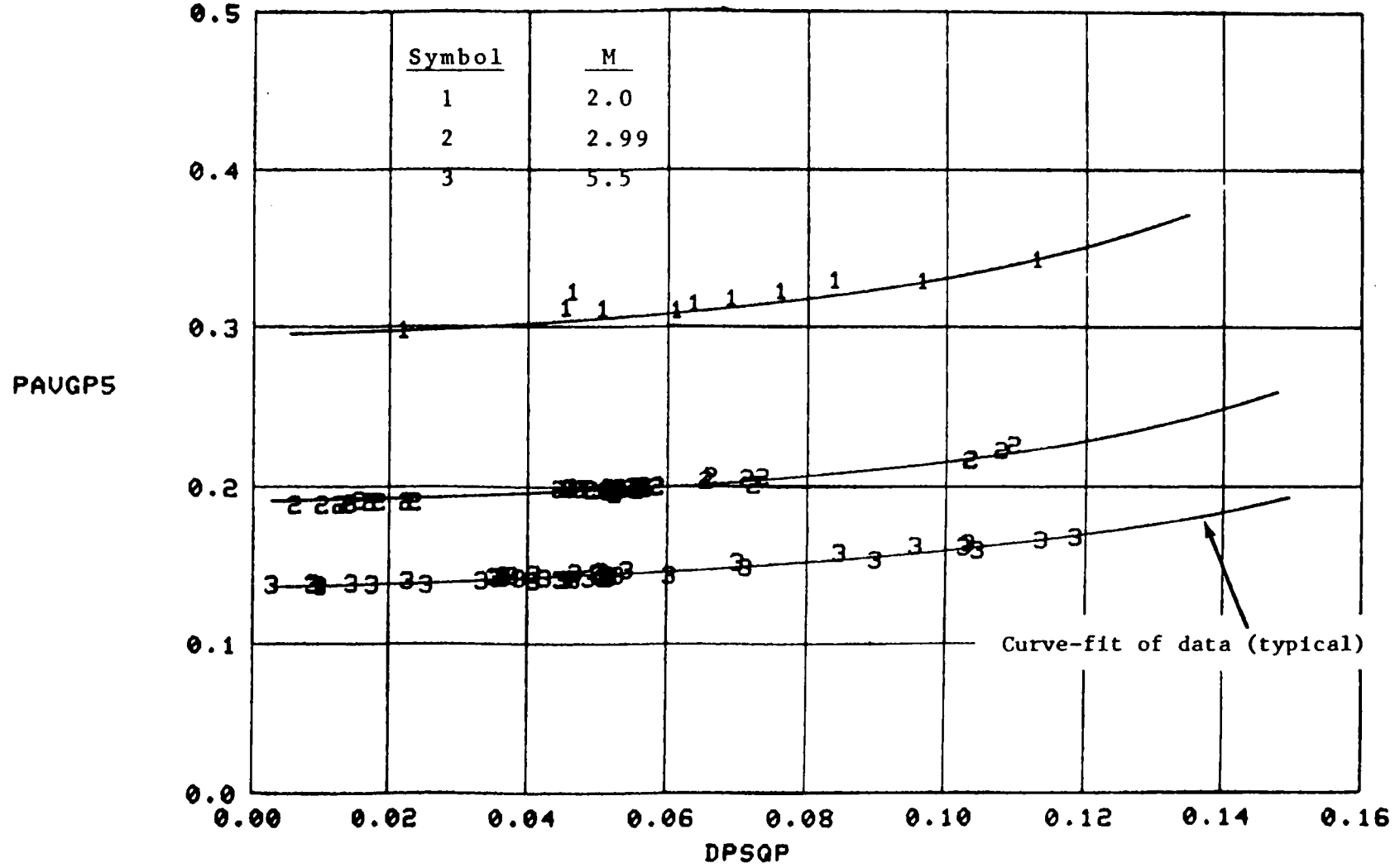
b. Probe Number 2

Figure 9. (continued)



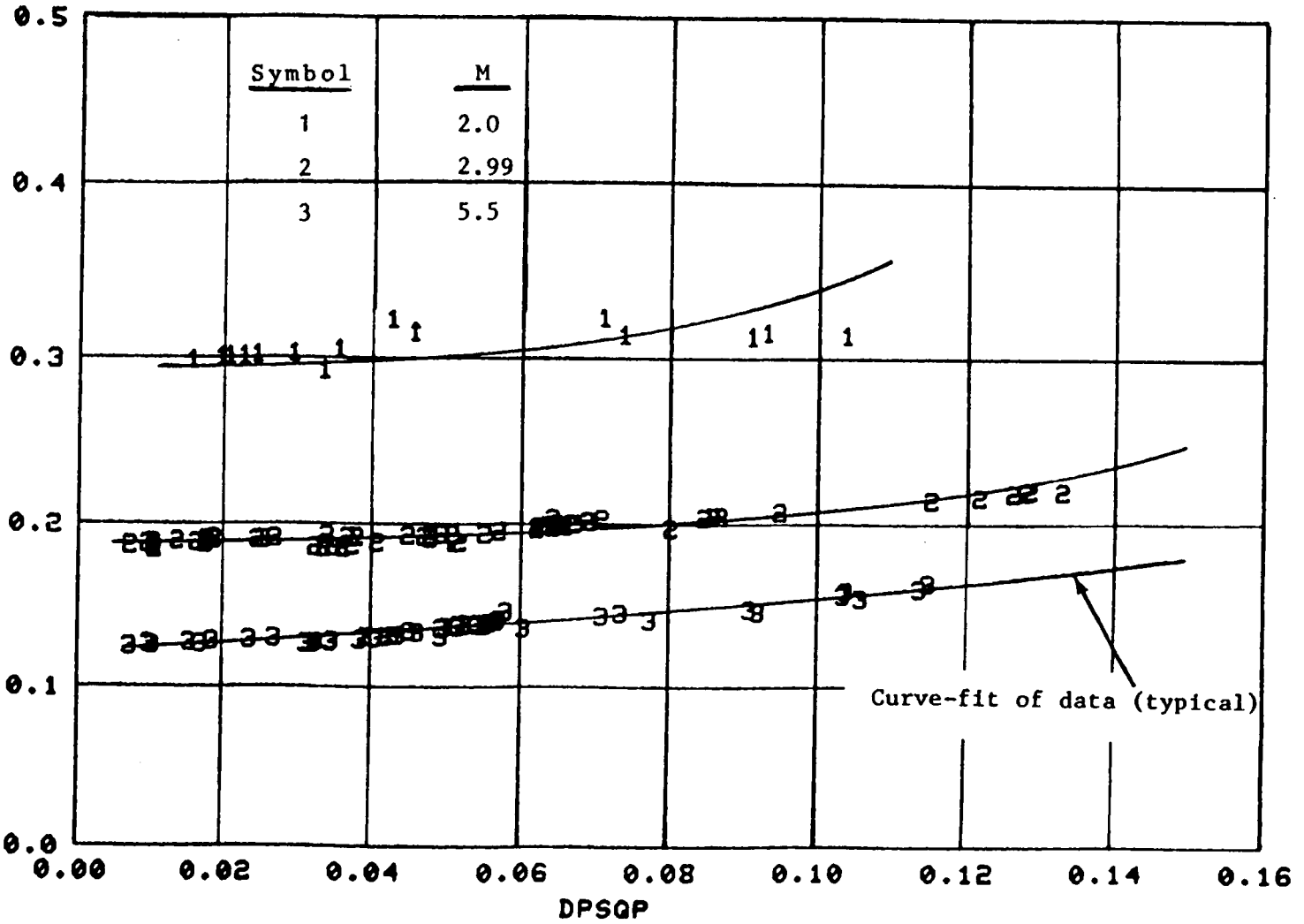
c. Probe Number 3

Figure 9. (continued)



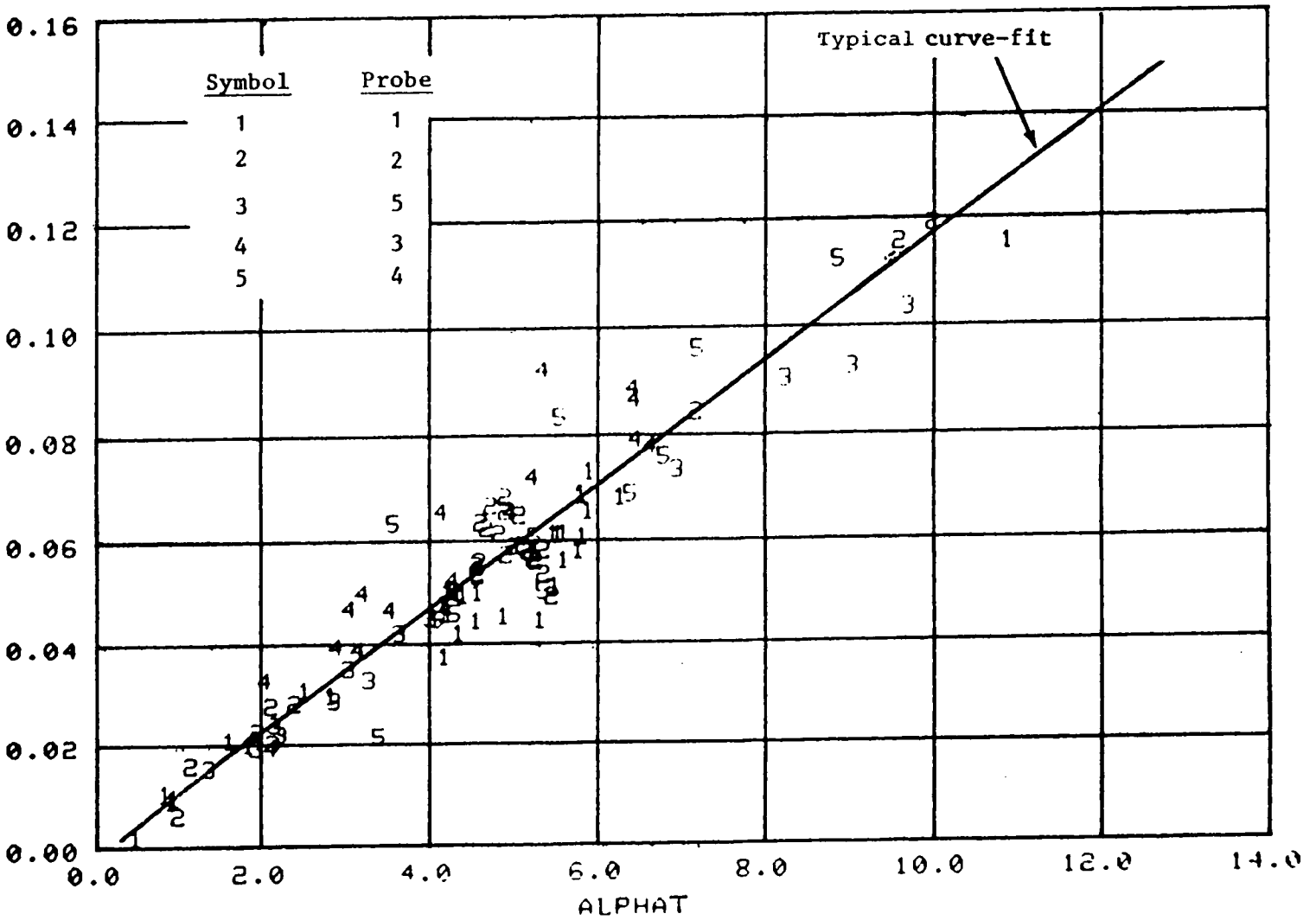
d. Probe Number 4

Figure 9. (continued)



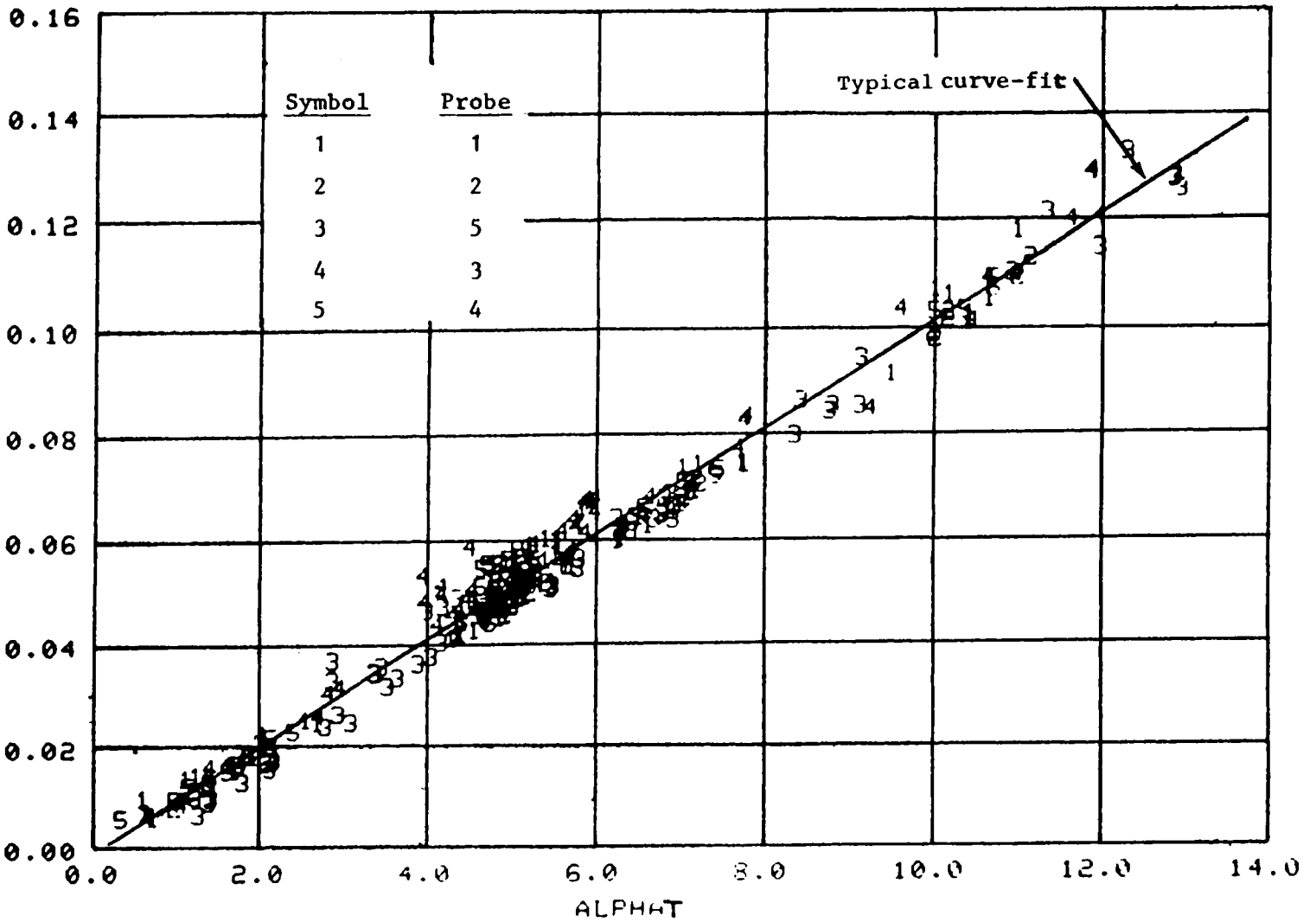
e. Probe Number 5

Figure 9. (concluded)



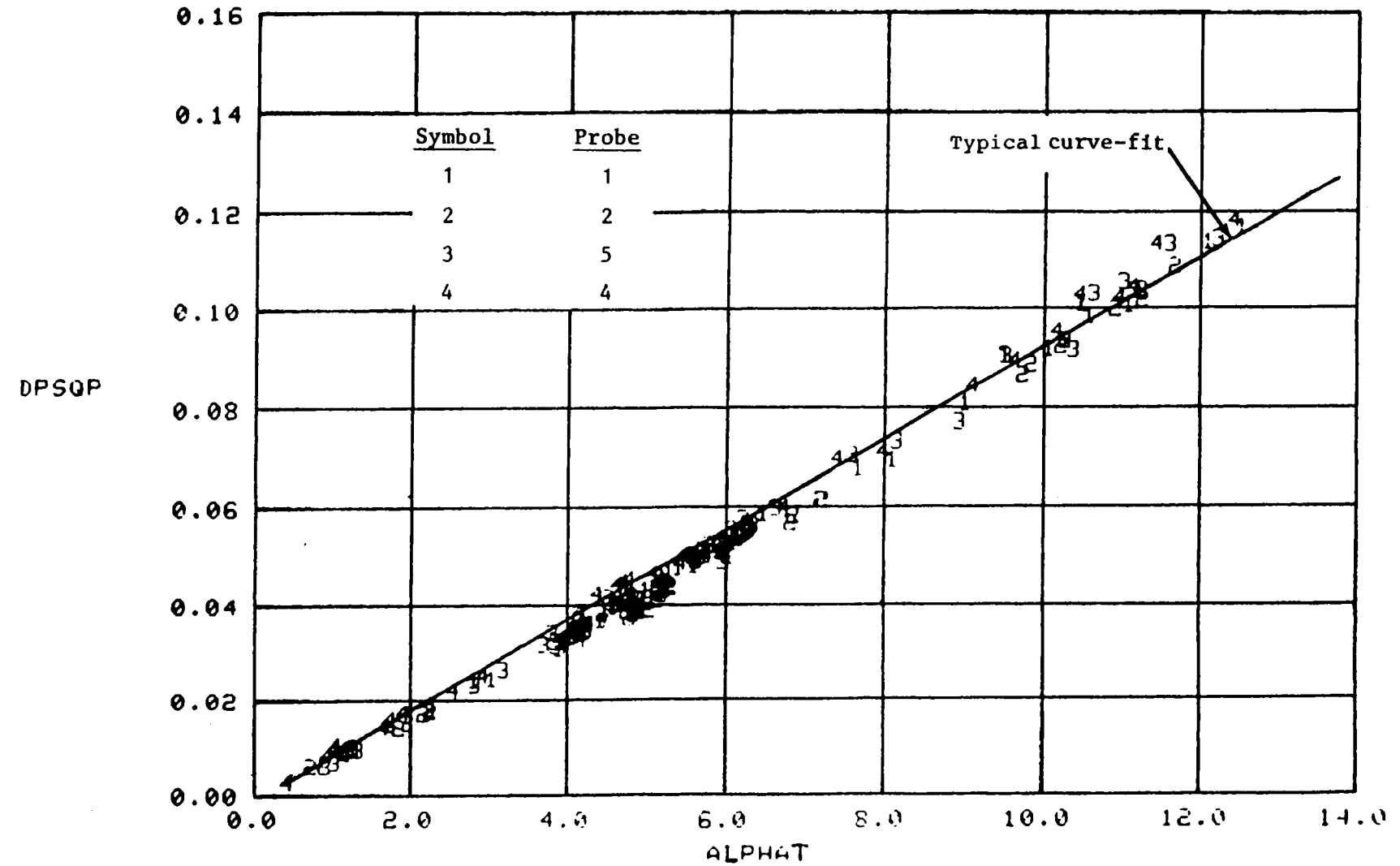
a. Mach 2.0

Figure 10. Flow Field Pitch Angle Calibrations



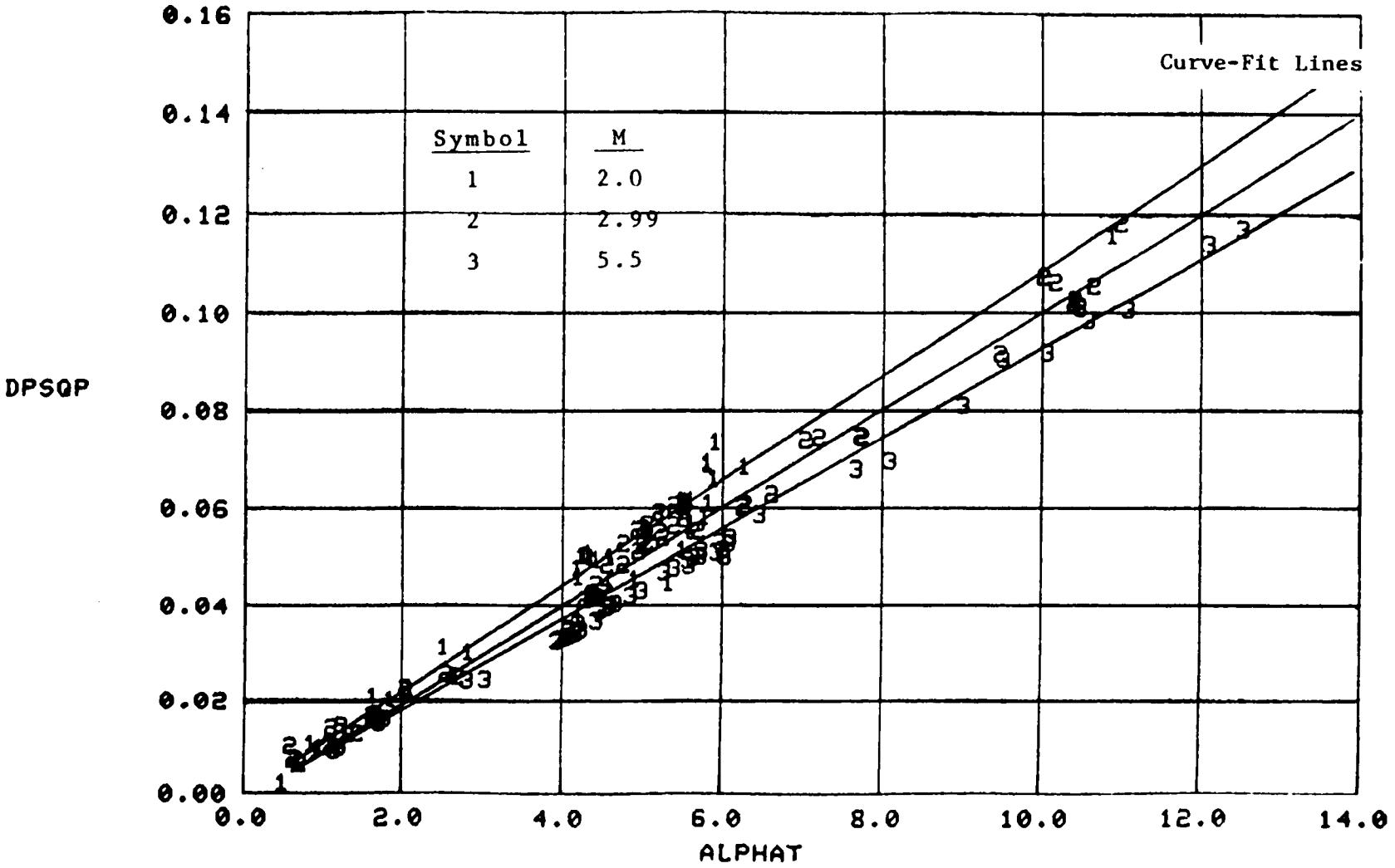
b. Mach 2.99

Figure 10. (continued)



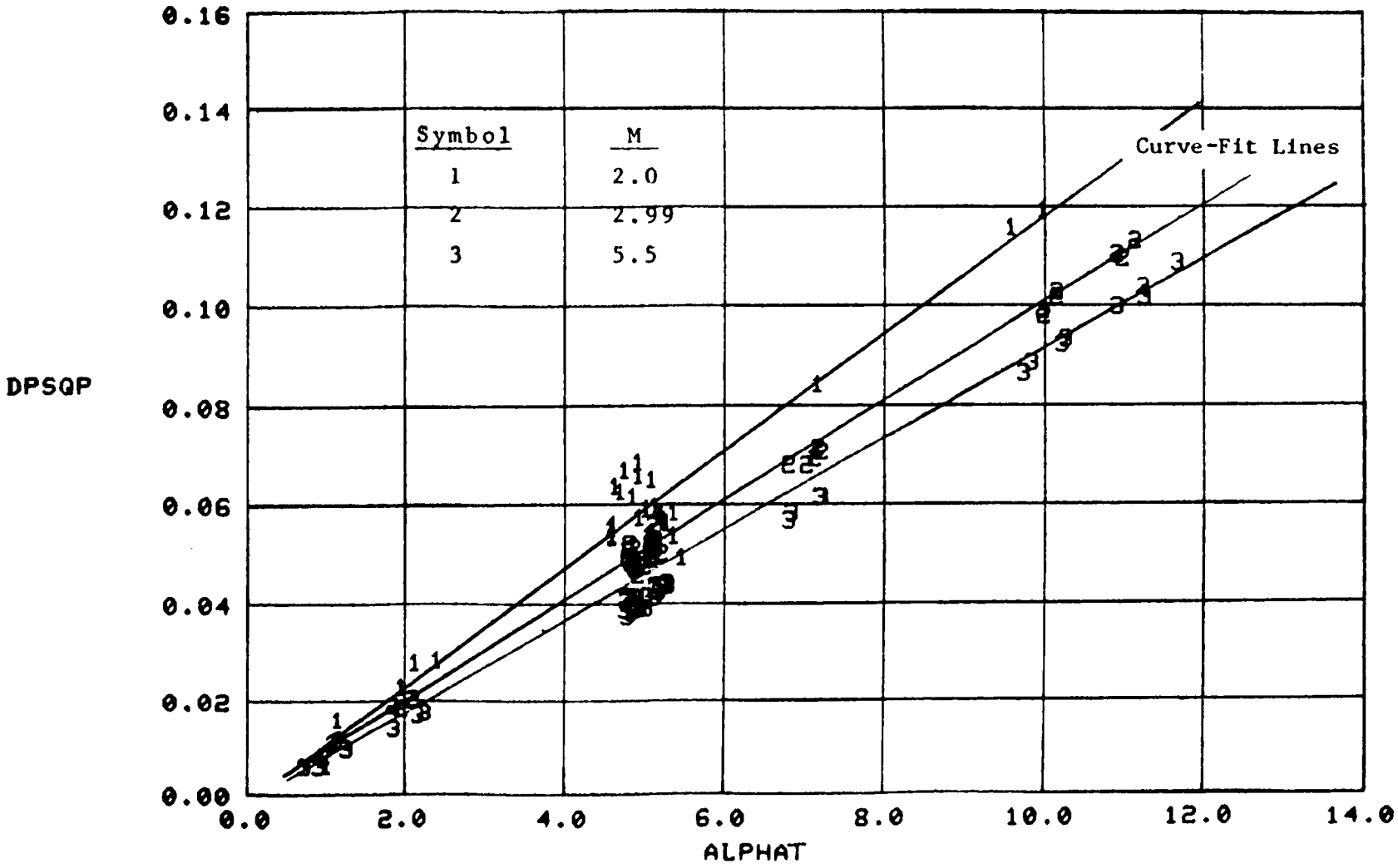
c. Mach 5.5

Figure 10. (concluded)



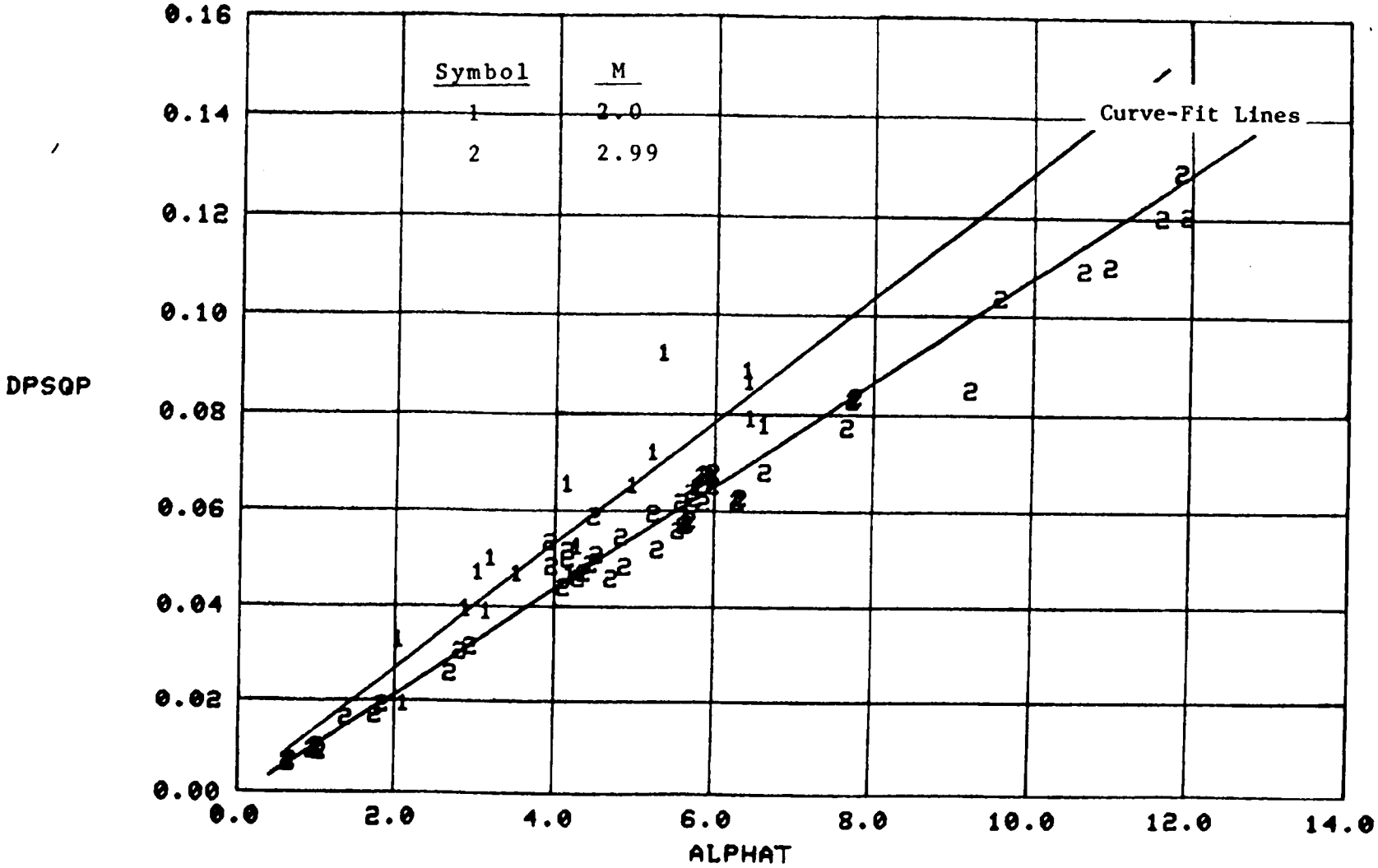
a. Probe Number 1

Figure 11. Individual Probe Flow Field Pitch Angle Calibrations



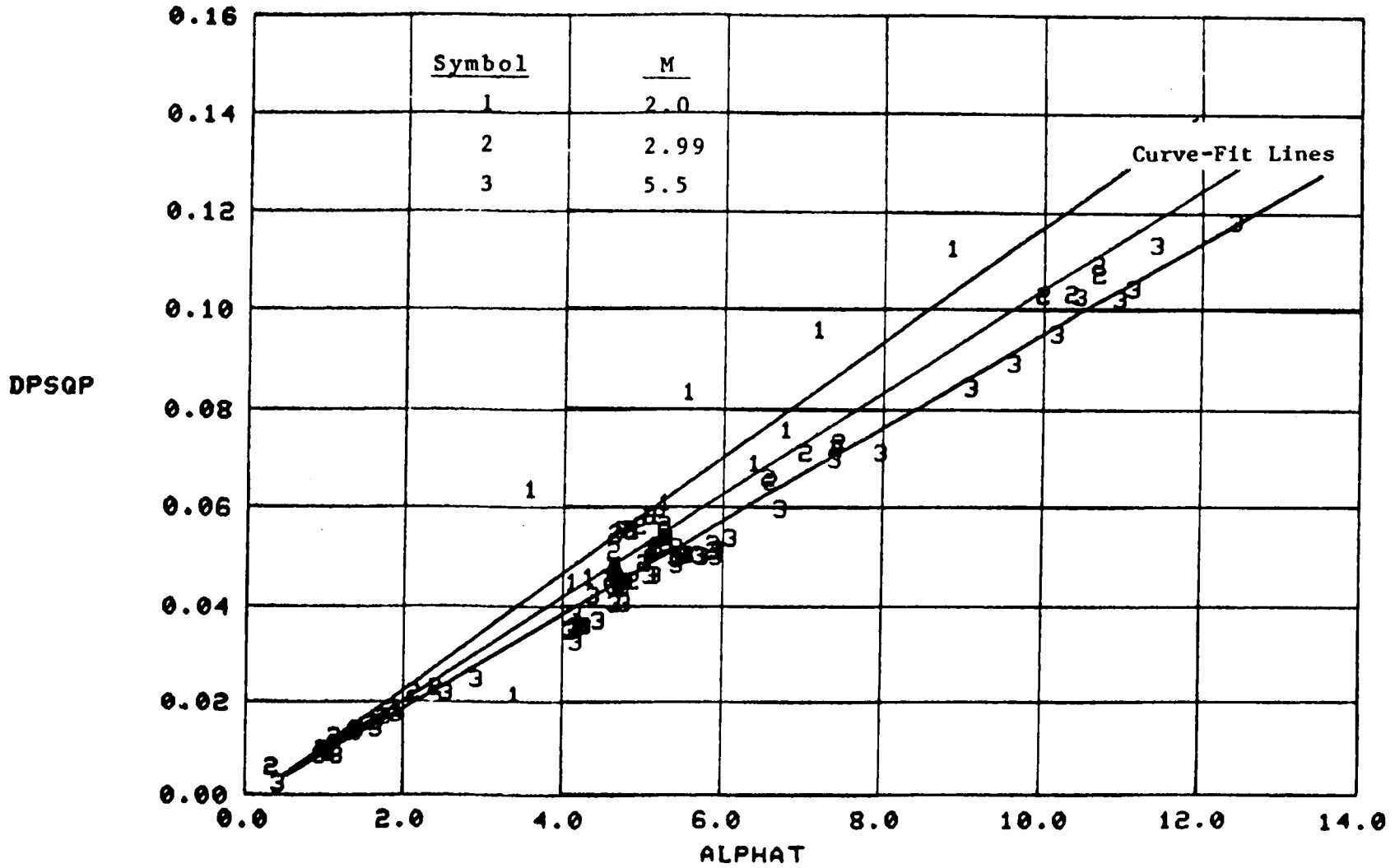
b. Probe Number 2

Figure 11. (continued)



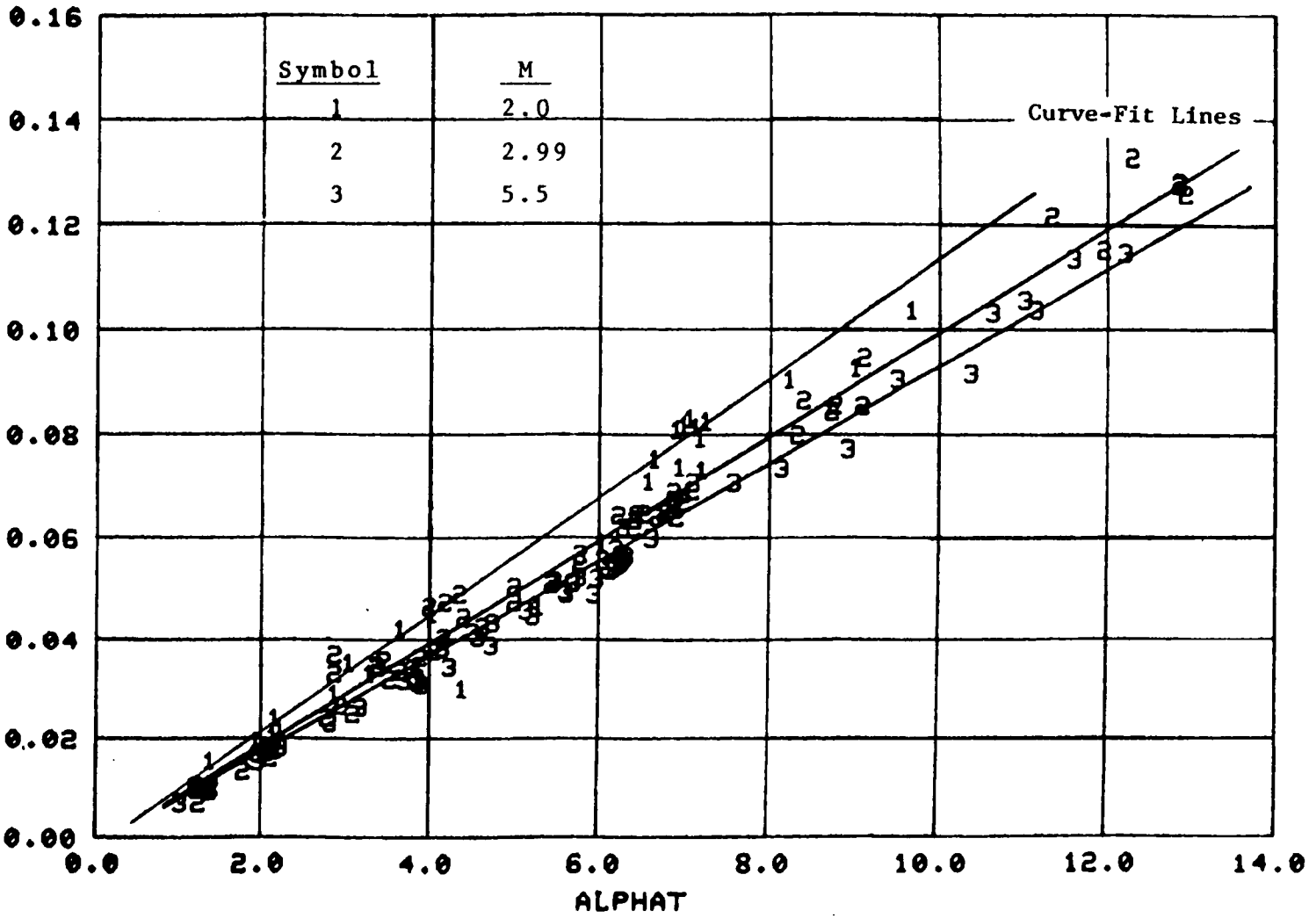
c. Probe Number 3

Figure 11. (continued)



d. Probe Number 4

Figure 11. (continued)



e. Probe Number 5

Figure 11. (concluded)

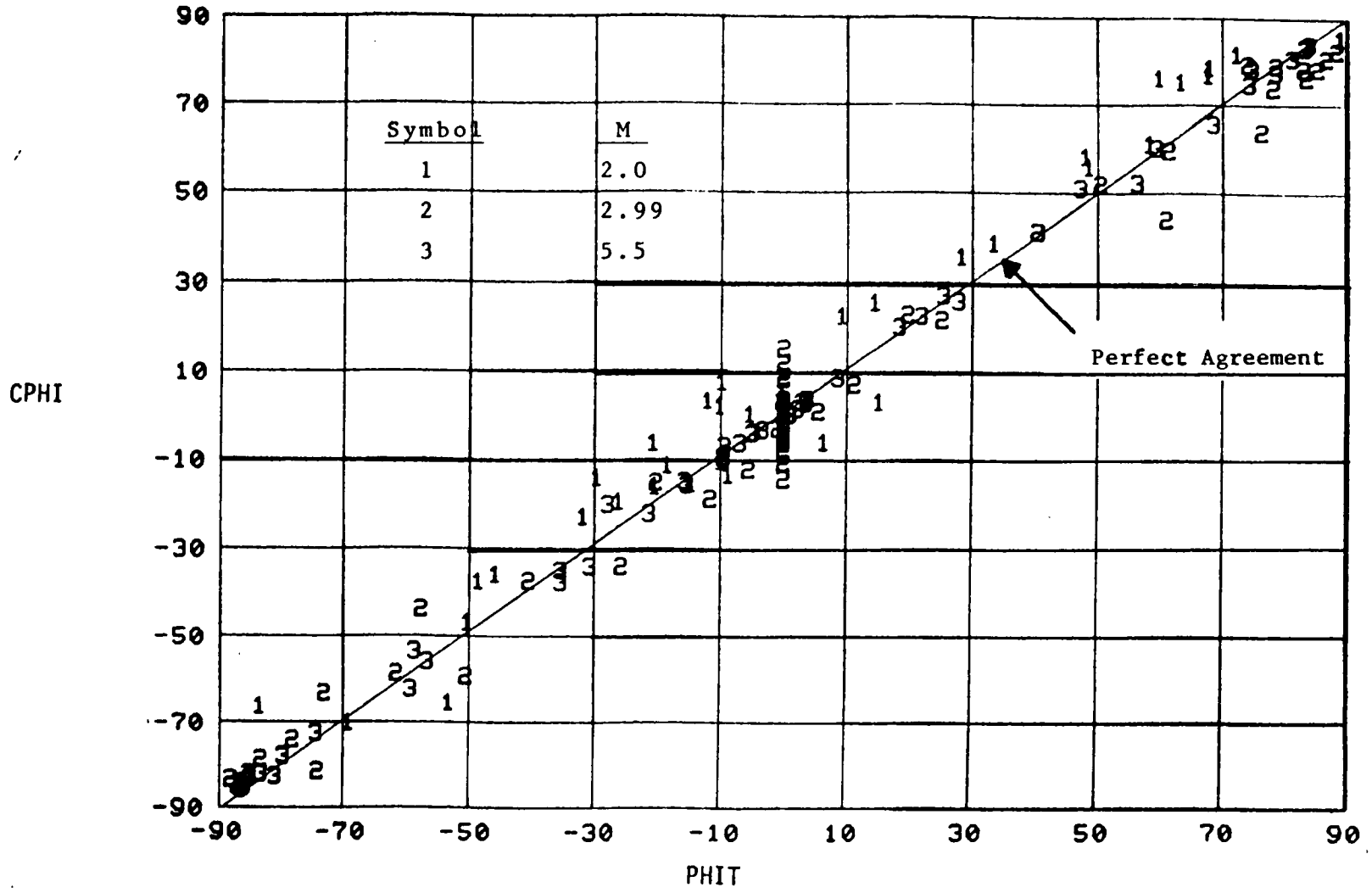
The scatter of the data around the curve-fit at the lower Mach numbers can be attributed to the local-flow behavior as discussed previously. The uncertainty in angle of attack for all five probes is less than 1.0 deg as shown in Table 4. This uncertainty could be improved to less than 0.5 deg if the roll data obtained at an angle of attack of 5-deg was not considered. However, more analysis must be done on the importance of the roll data before this data can be neglected.

Table 4. MFA Probe Uncertainties

PROBE	MACH (%)	ALPHAT (deg)	PHIT (deg)
1	5.1	0.7	13.5
2	5.9	0.7	11.3
3	5.2	1.0	18.1
4	5.6	0.9	13.8
5	6.1	0.7	11.0

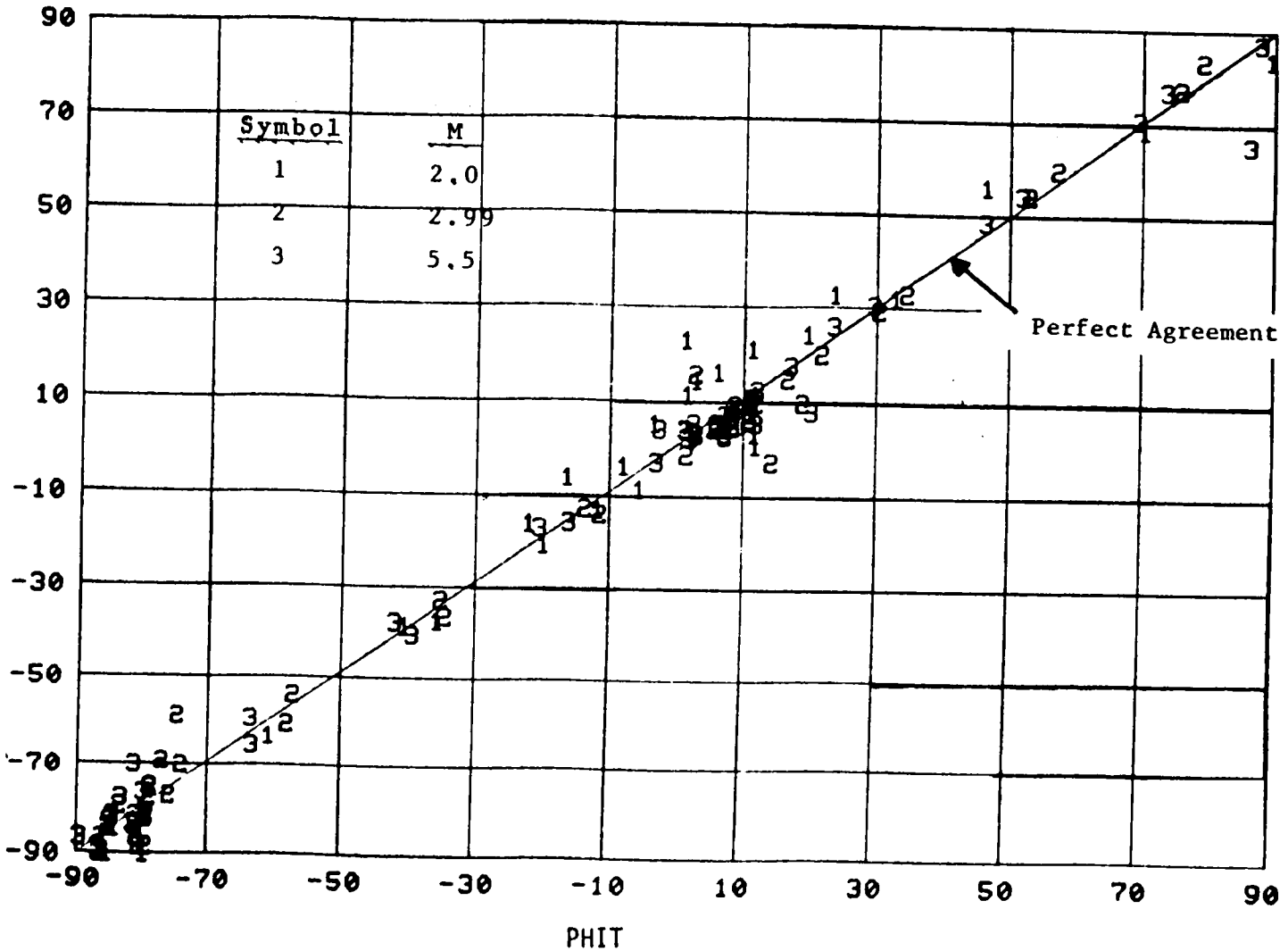
Note: Each probe individually examined and curve fit.

Comparisons of pressure-sensed roll angle (CPHI) with the actual probe roll angle (PHIT) are presented in Fig. 12. The data acquired during periods of sweeping through roll angles are not necessary to secure calibration constants associated with Mach number and total angle of attack. However, some of this type of data should be acquired to ensure that the pressure levels from the four static



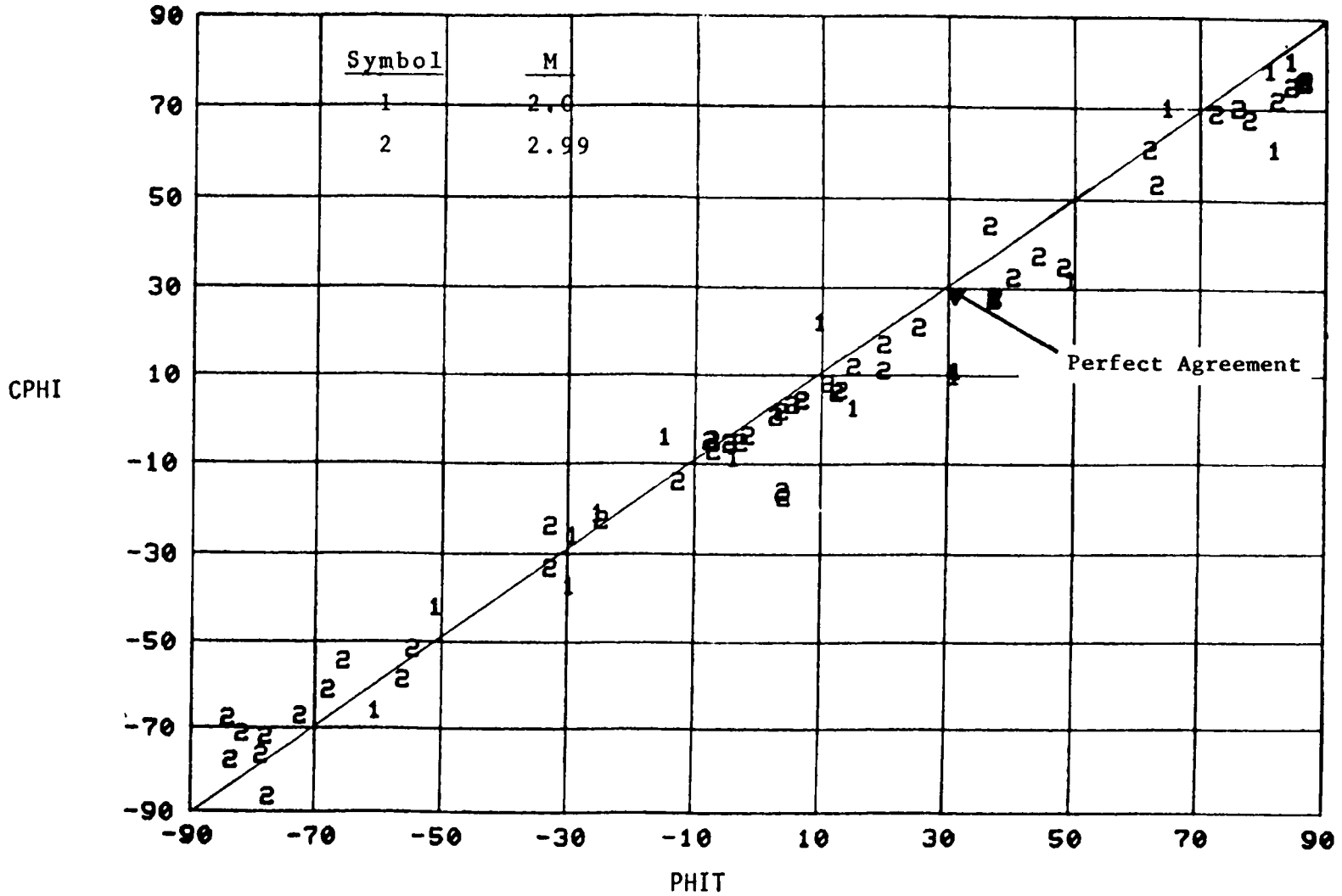
a. Probe Number 1

Figure 12. Comparison of Calculated Roll Angle Versus Actual Roll Angle



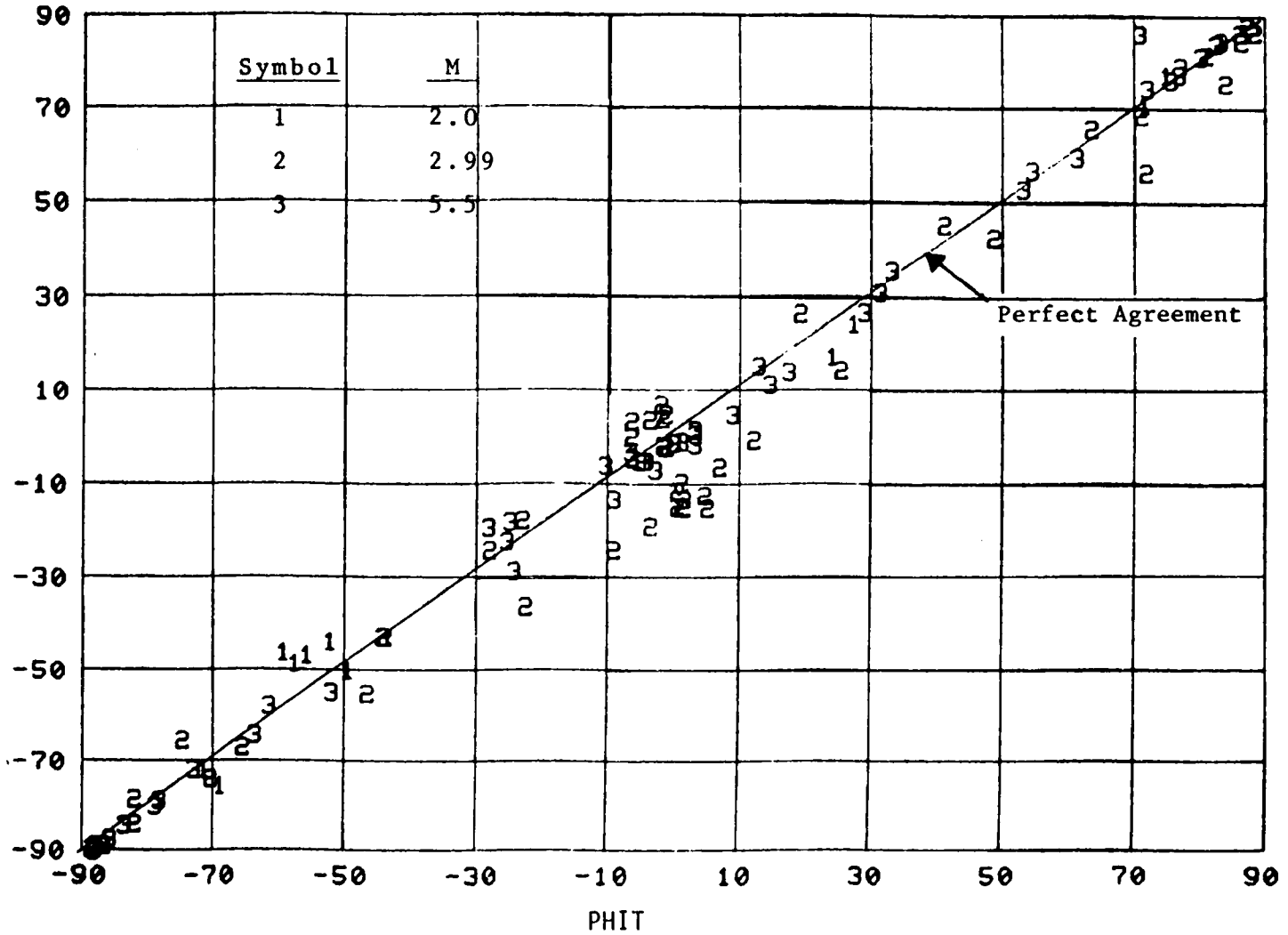
b. Probe Number 2

Figure 12. (continued)



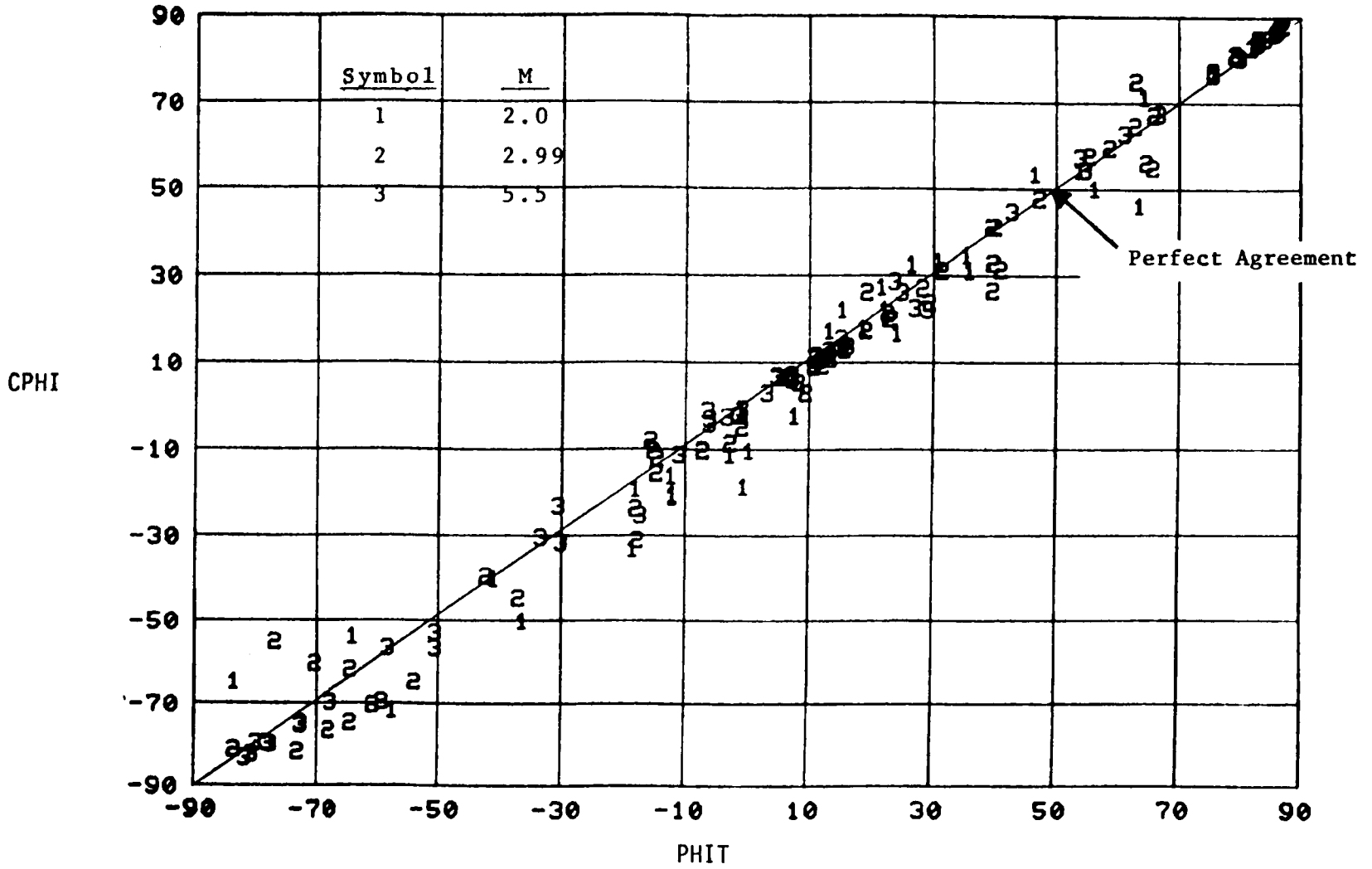
c. Probe Number 3

Figure 12. (continued)



d. Probe Number 4

Figure 12. (continued)



e. Probe Number 5

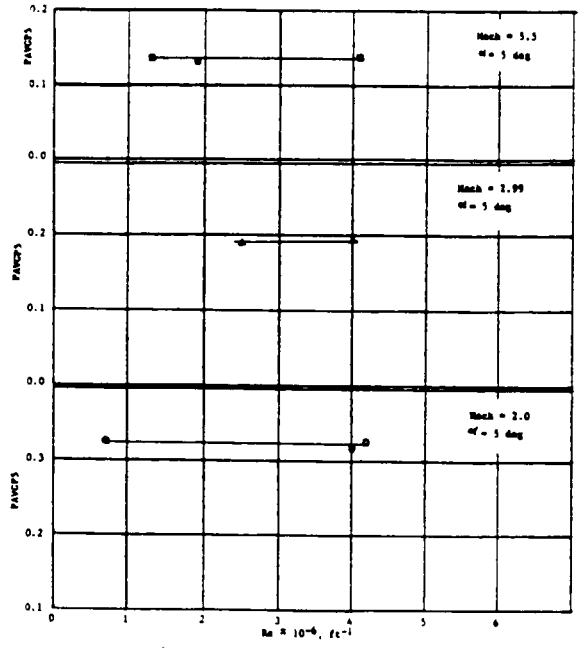
Figure 12. (concluded)

pressure orifices of a probe produce sine waves when plotted versus total roll angle. The quality of these sine waves relates to the ability of a probe to measure roll-angle orientation of the flow velocity. An exact correlation of CPHI vs PHIT would be a 45 deg line. Roll angle differences (PHIT-CPHI) are typically less than 10 deg. The uncertainty level in roll for all five probes is nominally less than 13.5 deg. A noticeable difference in the new probes versus previous MFA probes was observed in the roll data for PAVGP5 versus DPSQP. Previous MFA data (ref. 8) was uni-directional around the pitch data whereas the data this time was one-directional with respect to the pitch data. This one-directional roll data makes it harder to curve-fit the data and shows up in the uncertainty depending on whether the pitch data or roll data is fit. This is one area where engineering judgement must be used when curve fitting the data.

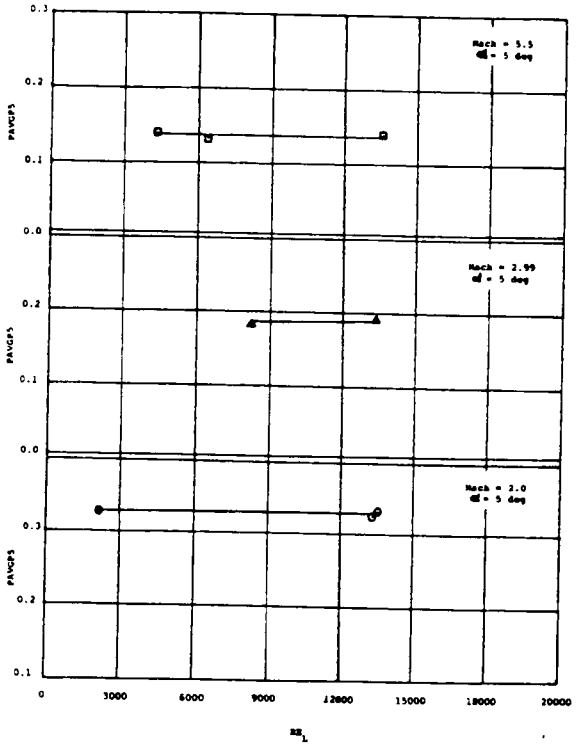
To allow more universal applications of these probes, the Reynolds number effect (or viscous effect) on the unique relations of DPSQP and PAVGP5 to local Mach number and total angle of attack must be established. Previous data (ref. 1) have shown DPSQP to be independent of Reynolds number whereas a distinct Reynolds number effect on PAVGP5 was observed. The previous data showed that for a given probe attitude (fixed DPSQP), the value of PAVGP5 consistently increased as Reynolds number was decreased. The presently

calibrated MFA probes showed no effect of Reynolds number on the pressure parameter PAVGP5 as shown in Figure 13. Based on previous, more extensive calibrations of other mach flow angularity probes (ref. 1), the Reynolds number effect was assumed to be independent of Mach number. For the present calibrations, the Reynolds number was varied from 1.3×10^6 to 4.1×10^6 per foot and showed negligible effects. Therefore, the correlations presented should be restricted to Mach number 2.0 to 5.5 and free-stream Reynolds number of 1.3- to 4.1- million per foot.

A comparison of cone probes versus wedge probes (MFA probes) with the same semivertex angle shows that cone probes are more apt to show a Reynolds number effect due to crossflow effects as the flow moves downstream. For small angles of attack, the pressure rise on a cone is much less than on a wedge. This lower pressure rise is due to the three-dimensional effect, which gives more room for adjustment of the flow over the cone. The flow quantities remain constant for a cone probe on all concentric conical surfaces lying between the shock wave and the body. For a wedge probe, which has four independent planes, the flow behind the shock consists of uniform streams parallel to each plane of the wedge. Pressure changes occur at the nose wave for a wedge, whereas for cone flow, the pressure rises continuously downstream of the Mach cone. As the angle of attack is increased, the static pressures on the



a. Freestream Unit Reynolds Number

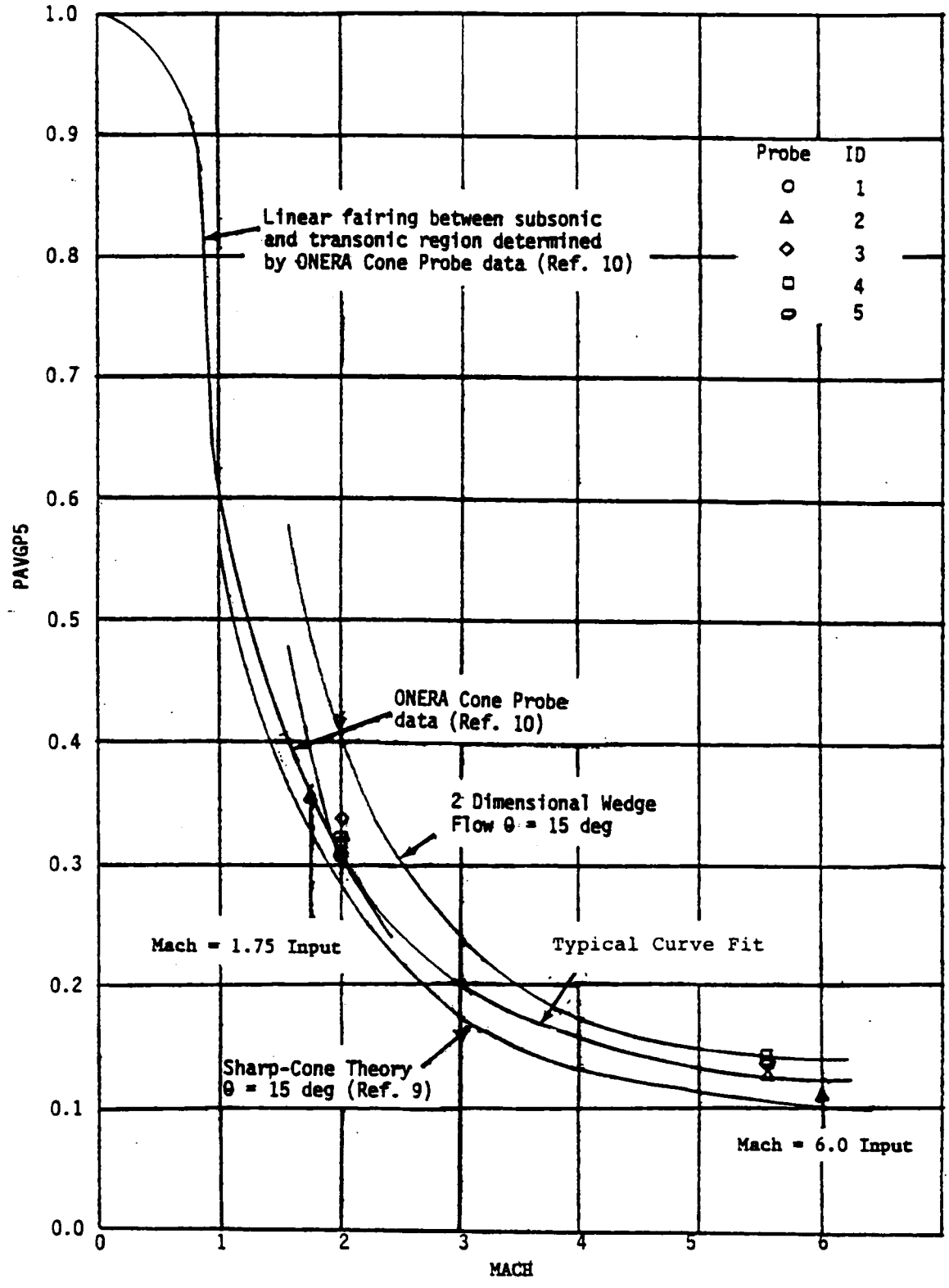


b. Local Reynolds Number

Figure 13. Reynolds Number Effect on the MFA Probe Calibration

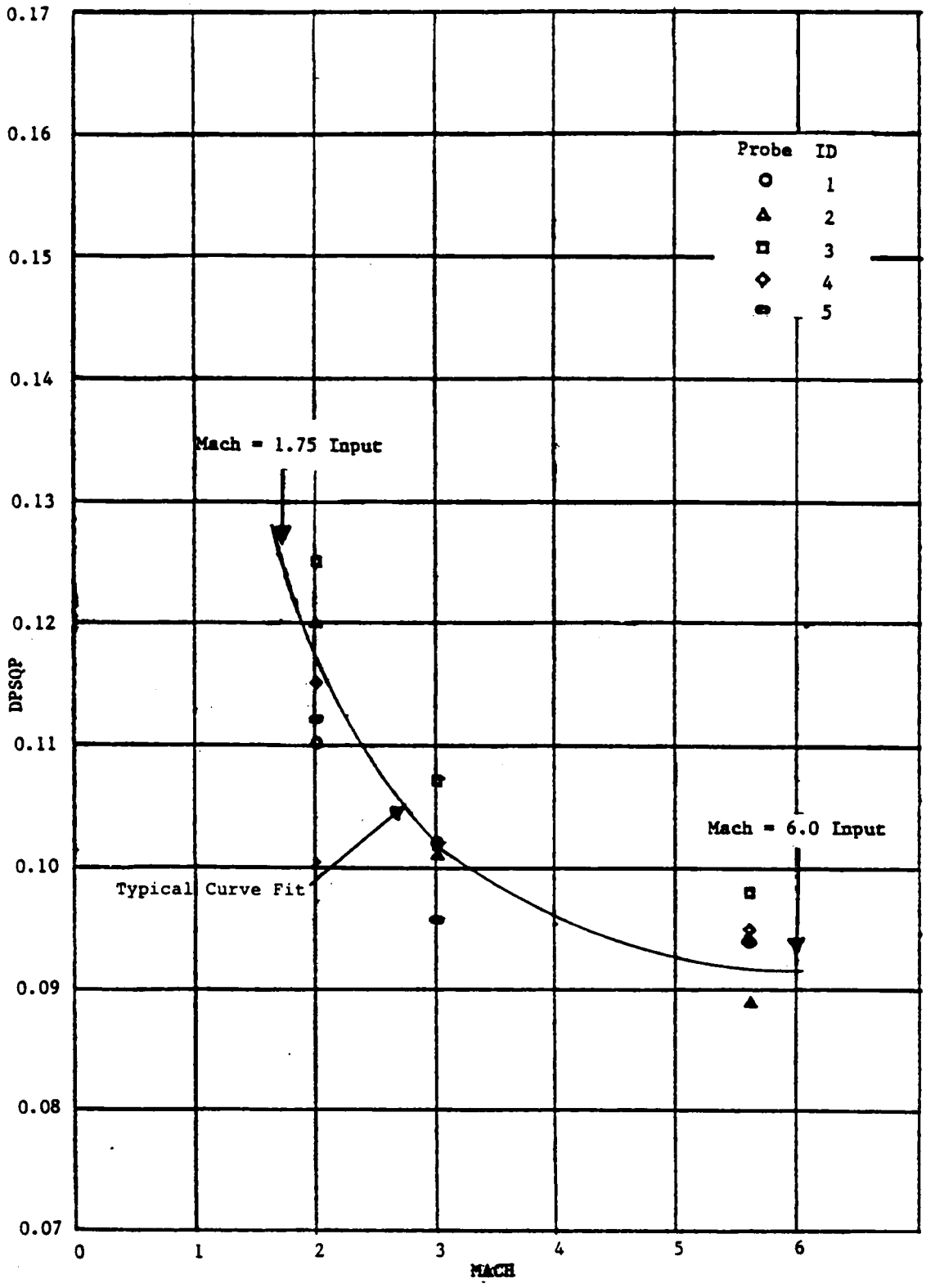
leeward side of the cone probe are influenced by the boundary layer buildup due to the crossflow characteristic of the flow as it translates downstream from the cone apex. This boundary layer buildup promotes transition from a laminar boundary layer to a turbulent boundary layer which increases the probe sensitivity to Reynolds number. This effect is not as noticeable for a wedge probe since the boundary layer separates at the juncture of the side planes. This explains why many of the references listed in the bibliography noted a Reynolds number effect on the five-hole cone probes they calibrated.

The sensitivity of these probes as measured by the parameter PAVGP5 increases as the Mach number decreases (see Fig. 14a). Since these probes are intended for flow-field probing around models, behind their bow shocks and into the boundary-layer region, this increased sensitivity is a very good characteristic. In general, the uncertainty or scatter in the calibration results increases as the free stream Mach number decreases, but the probe sensitivity to Mach number as defined by PAVGP5 increases (large changes in PAVGP5 produce small changes in the local Mach number). Also the Mach number sensitivity as influenced by the probe angle of attack as defined by DPSQP diminishes as the local stream Mach number increases (see Fig. 14b). These trends tend to compensate for the scatter in the calibration results at Mach number 2.0.



a. PAVGP5 vs MACH @ DPSQP = 0.06

Figure 14. Extension of Curve-Fit Calibration Lines



b. DPSQP vs MACH @ ALPHAT = 10 deg

Figure 14. (concluded)

The test data were plotted (PAVGP5 vs MACH and DPSQP vs MACH) to extend the range of the calibration (see Fig. 14). Theory lines were input at Mach 1.75 and 6.0 after being extrapolated from the plots and then fit with the test data to give the curve-fits shown in Table 3. By extending the range of the actual test data, the quoted MFA uncertainties in Table 4 are accurate to the limits of the Mach numbers. The calibration of the probes will be extended over the range of Mach numbers as calibration data is obtained from various tests. As shown in Fig. 14a, sharp-cone theory (ALPHA = 15 deg) and two-dimensional wedge-flow theory (ALPHA = 15 deg) agree fairly well with the test data (ref. 9). The sensitivity of PAVGP5 to variations in Mach number is clearly illustrated. This sensitivity comparison was made where the effective angle of attack of the probe was zero, that is DPSQP = 0.0. Data obtained by ONERA (ref. 10) on a similarly constructed MFA probe shows excellent agreement between the data measurements.

1.0 Calibration Summary

Based on the calculated uncertainties, no effect was observed between polished and unpolished probes. Probes 1 and 2 gave the best uncertainty level when calibrated based on the uncertainty in Mach number, total angle of attack and total roll angle. These two probes were shorter in length (approximately 1.2-in. shorter) than the other three probes and had larger pressure-orifice diameters. However, it is

believed that the shorter length and larger diameter holes were not the reason for the better uncertainty levels. Probes 3, 4 and 5 were bent during the calibration test due to improper handling and this caused the probes to have large misalignment angles. These large misalignment angles caused greater error in the curve-fitting process when calibrating these probes. Probe 4 would be an excellent measurement probe except for the one side face that overlaps the front face of the probe. Probe 3 is an excellent probe for measuring Mach number (uncertainty = 5.6%) and gives the total angle of attack within 0.9 deg; however, calibration data were not obtained at Mach 5.5 and this caused the total roll angle uncertainty to increase due to the Mach 2.0 roll scatter influence. Probe 5 measures the total angle of attack within 0.9 deg and Mach number can be measured within 6.6%.

CHAPTER VIII

CALIBRATION IMPROVEMENTS

The following lists suggestions to consider when calibrating mach flow angularity probes:

1. Use a differential pressure transducer that is calibrated at high enough pressure ranges to encompass the wide range of differential pressures measured between DP13 and DP24 while still giving the desired accuracy in the measurement.
2. Take roll data at more than one pitch angle to help in the determination of the calibration line. The roll data will alleviate the engineering judgement of the importance of the data with respect to the curve-fit.
3. Be sure to obtain calibration data over the range of Reynolds numbers at which the probes will be tested. Previous data (ref. 6) has shown Reynolds number to have a distinct effect on the parameter PAVGP5 and the effects on the calibration should always be examined.
4. Expand the curve-fit calibration program to examine the precision and bias uncertainty instead of assuming zero bias and only calculating the uncertainty in precision.

CHAPTER IX

MFA PROGRAM METHODOLOGY

A package of programs were developed for use on a personal computer (PC) to reduce supersonic and subsonic wind tunnel pressure data measured by a MFA probe. The programs calculate the misalignment angles and determine curve fit coefficients for Mach number (pressure ratio) and total angle of attack based on the range of data provided. The probe data reduction must account for the misalignment angles so that the associated pressure data may be related to the total angle of attack and total roll angle of the probe. These data and the probe attitude and test conditions form the basis from which calibration constants are obtained. The calibration procedure involves fitting equations to data acquired during the calibration wind tunnel test used to calculate Mach number and total angle of attack.

Calibration constants are determined during the data-fit routine to minimize residuals between actual values and values calculated from the equations. The calibration constants, defining the relationship of Mach number and total angle of attack, are obtained from PC programs that curve fit the pressure data to functions of special forms. The functional forms of these equations are differentiated with respect to each calibration constant during the procedure used in solving for these calibration constants.

Roll-angle orientation (CPHI) of the flow velocity is calculated by a simple trigonometric function that does not contain calibration constants.

In general, the parameters PAVGP5 and DPSQP are used to define the relationship between the local-stream velocity and the measured probe pressures. Once the local-stream Mach number has been defined, the local total angle of attack of the probe can be defined as a function of DPSQP. The ratio of DP13/P5 and DP24/P5 are used to define the roll orientation of the resultant local-stream velocity vector relative to the probe axis.

1.0 Program Description

The package is user-friendly and is essentially self-explanatory to proceed through the programs. To run the programs, the MFA pressure data which contains the range of data to curve fit should be stored in a data file using the following format:

RUN PROBE PT PHI ALPHA P1 P2 DP13 DP24 P5 0

The last loop of data should have a 999 in place of the 0 after column P5 to prompt the program that all data have been entered. The horizontal spacing of the data is not important as long as there is one blank space between parameters (do not use commas). Mach number can be used in place of PT if Mach number is known.

A batch file, MFAE.BAT (Appendix 1), has been set up to run the MFA curve fit/calibration program package.

To run the batch file:

TYPE: MFAE <RET>

The first program in the package is called MFAFIX. The program first prompts the user for the name of the pressure data file (unit file). Whatever name the MFA pressure data file was called, type (i.e. MFA.DAT) in using the keyboard. The program next asks the user if a printer is being used during the program execution. If a printer is not used, then data files, FILE1 through FILE5, will be created to store the output. The next prompt asks the user to enter Mach or PT based on how the data was entered in the MFA pressure data file. The last prompt asks if the data being curve fit is subsonic or supersonic. Fitting the supersonic data separately from subsonic data provides for a better fit due to the nature of the data characteristics. Flow discontinuities caused by shock waves in supersonic flow change the pressure measurements significantly from the freestream test conditions; whereas pressure variations in subsonic flow are mainly due to pitch or yaw angle variations. The program determines the Mach number parameter (PAVGP5) and the angle-of-attack parameter (DPSQP) along with the calculated roll angle orientation based on the pressure measurements. The data is then stored in a formatted output file (MFAFIT.DAT) to be read by the next program.

The misalignment angles are calculated using the program MFAFIXQR. This program determines the misalignment angles and creates an output data file, UMOD.DAT, with the misalignment angle corrections applied to the data. The total angle of attack (ALPHAT) and probe roll angle orientation (PHIT) are determined based on the misalignment angles.

The order of the program, MFAFIXQR, is to determine a first order least squares curve fit of the data (DP13/P5 vs ALPHA and DP24/P5 vs ALPHA). The program displays the first group of data that misalignment angles will be determined from. A group of data consists of the same Mach number and the same roll angle. A plot of the data versus the curve fit is shown for each DPxx/P5 to examine the goodness of the fit. Once the curve fit of DP13/P5 and DP24/P5 are defined and all bad data points have been deleted, the misalignment angles are determined. From this point, plots of the data can be looked at to determine if the misalignment angles need to be perturbed. A plot of DPSQP vs ALPHAT will show if the angles need to be perturbed. The pressure parameter, DPSQP as a function of ALPHAT, will collapse into a single value function when the misalignment angles have been properly determined. When perturbing the misalignment angles, begin with PHID and end with ALPD. It is recommended that only one angle be perturbed at a time in order to see the effect that the perturbation has on the

data. Once the proper misalignment angles have been determined for a specific group of data, the program will proceed with the next group of data following the same steps. The following plots can be examined to verify that the proper misalignment angles have been determined:

1. ALPHAT vs PAVGP5
2. ALPHAT vs DPSQP
3. DPSQP vs PAVGP5
4. ALPHA vs DP13/P5 and DP24/P5
5. PHIT vs CPHI (should collapse into a 45 deg line from the origin)

When all of the probe misalignment angles have been determined for all Mach numbers, the calibration data is ready to be curve fit to determine the calibration constants for Mach number (pressure ratio) and total angle of attack. The calibration constants are determined from the following programs which are included in the MFAE batch file:

1. MFAFIT

   This program creates two data files (MMODR.DAT and AMODR.DAT) that are used in determining the Mach number and total angle of attack calibration curve fits.

2. MACH

   This program determines the Mach number calibration constants which best curve fit the data. To determine the calibration constants, the Mach number is converted to a static pressure normalized by the pitot pressure (P/Pt2) for supersonic data and to the freestream pressure normalized by the total

pressure (P/PT) for subsonic data. This ratio is then curve fit versus PAVGP5 and DPSQP to determine the calibration constants using the methodology discussed in chapters V and VI.

3. ALPHA

   This program determines the total angle-of-attack calibration constants which best curve fit the data. The total angle of attack is curve fit versus DPSQP and the pressure ratio to determine the calibration constants.

4. GRAPH

   Using the calibration constants determined for Mach number and total angle of attack, this program generates curve fit lines for each Mach number. In addition, the uncertainty of the calibration constants versus the actual Mach number or total angle of attack is computed. The data is then stored in data files and sent to a graphics program which prints out the results.

The program GRAPH will print out the final curve fits for Mach number (pressure ratio) and total angle of attack. In addition, a printout of the calculated versus computed parameters is presented showing the goodness of the fit. The program will prompt the user for the number of Mach line solutions desired. This option provides the user with a method for determining solutions for Mach numbers that are

not available. The program generates Mach (pressure ratio) lines for the solutions requested using a Newton-Raphson iteration technique. Up to 50 data points can be generated for each Mach number based on tolerance criteria for angle of attack and pressure ratio. The generated Mach lines should be verified to check the accuracy of the curve fit and verify that the data agrees with the trends of the wind tunnel data. If the fit of the data is not acceptable to the user, then the data file UMOD.DAT should be edited to remove the bad data points that cannot be fit and the programs MFAFIT, MACH, ALPHA, and GRAPH should be rerun. The data files MMODR.DAT, AMODR.DAT, MCOEF.DAT, ACOEF.DAT, MSOL.DAT, CURVES.DAT, and FILE3.DAT through FILE5.DAT should be deleted before rerunning the programs to prevent the programs from giving an error message.

A graphics package is included in the curve fit/calibration routine to plot the results. The program prompts the user for what type of printer or plotter is available. If a printer or plotter is not available, then the user can crash the program by typing <CTRL> C at the same time. Otherwise the program will crash on its own after determining a printer/plotter is not available.

Appendices 1 through 7 provide a listing of the computer programs used in the mach flow angularity curve fit/calibration routine. The programs MACH.FOR, ALPHA.FOR, and GRAPH.FOR, were not originated by the author but were

modified for use in the curve fit/calibration routine. Appendix 8 provides a sample printout of the inputted subsonic data and the results produced by the final program (GRAPH.EXE). The data presented in Appendix 8 is subsonic data provided to the author by the University of Tennessee Space Institute. The subsonic data can be stored in a data file in the event the reader would like to run a test case to learn the operation of the program package.

CHAPTER X

FIVE HOLE PROBE CALIBRATION TECHNIQUES

Other calibration schemes used to calibrate five hole probes that measure velocity and flow angles are discussed in references 10 through 15. Gaillard (ref. 10) investigated the influence of the cone angle on probe sensitivity by calibrating a series of four probes with 30, 40, 60, and 80 degree cone angles. His method determines calibration coefficients, similar to PAVGP5, DPSQP, and PHIT, and a pressure ratio based on supersonic or subsonic flow. The calibration coefficients are stored in the computer in four calibration arrays. Each calibration domain is divided into a pressure ratio, pitch angle, and roll angle subdomain. The subdomain which contains the solution for Mach number, pitch angle, and roll angle is found by iteration; then the solution is computed by a trilinear interpolation. The complete data reduction of one measurement point requires approximately 0.6 sec computing time. Gaillard observed from the results that the sensitivity of the probe with respect to the flow Mach number decreases when the cone angle increases and that for a given cone angle, the sensitivity is minimum around M = 1. The data seem to indicate that flow separation occured at about pitch angles equal to 30 degrees for the 40 degree cone. This phenomenon was not observed for the 60 degree

cone. Gaillard deduced that the sensitivity of the probe with respect to the pitch angle increases with the cone angle.

Landhaeusser (ref. 11) and Lee (ref. 12) use similar approaches for calibrating five hole probes. Pressure coefficients are determined in the pitch and yaw planes that define the flow field in each plane. A total pressure coefficient is also calculated during the calibration as a means of determining the flow velocity. The pressure coefficients are normalized by a parameter determined from the probes pitot pressure minus the average of the probe's four static pressures. This normalization parameter is used with the pressure coefficient as a means of reducing the scatter in the data. Typically, the freestream dynamic pressure is used as the reference pressure to normalize pressures. However, Lee states that the dynamic pressure, which is a constant in the flow field, is independent of the probe condition and therefore fluctuations in the measured pressure coefficients can not be smoothed by this constant. By using the pitot pressure minus the probe average static pressure as the normalization parameter, this provides a local pressure acting on the surface of the probe which changes as the probe incidence angle is varied. Lee uses a two-dimensional spline curve fit to fit the pressure coefficients (pitch, yaw, total, and static) as a function of the pitch and yaw angles. Landhaeusser uses a surface

spline interpolation scheme to fit the pitch and yaw pressure coefficients, dynamic pressure reading error, and total pressure reading error as a function of the pitch and yaw angles. The spline coefficients are then stored and used during a probing test to determine the velocity and flow angles (alpha and beta) based on the probe pressure measurements.

Hodges (ref. 13) developed a numerical search algorithm technique to calibrate five hole probes. His Type III method defines a pitch and yaw pressure coefficient (similar to the method used in refs. 11 and 12) that relates the probe attitude to a particular pressure measurement. The velocity, pitch angle, roll angle, pitch and yaw pressure coefficients, and average static pressure normalized by the probe pitot pressure are then stored in a table which define the characteristics of a particular probe. Once the table is complete for the calibration range desired, the probe is ready for use. Hodges derived a computer code that accepts the five pressure probe inputs and calculates the parameters which correspond to the parameters stored in the lookup table. A numerical search is then performed to correlate the calculated parameters with the corresponding stored values in the table. The velocity, pitch angle, and roll angle are then extracted from the table and used to describe the flow vector in the X-Z and X-Y planes.

In reference 14, Bhat discusses the calibration of a five-port-cone probe to determine the local flow conditions, i.e., Mach number, static pressure and the flow angularity in pitch and yaw. Bhat mentions two methods of calibrating a probe denoted as a null mode and a fixed mode calibration. The null mode calibration consists of determining the flow angularity by orienting the probe until the pressure measurements on opposite sets of orifices are balanced. The cone probe must be repositioned for every measurement to null all differential pressures on opposing cone probe ports. This method requires 3-D orientation adjustment of the probe and therefore is not desirable in situations where rapid measurements are needed.

In the fixed mode of calibration, differential pressures from symmetrically opposing ports and static and total pressure on cone ports are measured. The pressures are normalized by the pitot pressure minus the average static pressure and converted to a pitch, yaw, and total pressure coefficient. The calibration data are then represented by third order algebraic polynomials which are fitted through the total pressure, static pressure, pitch and yaw angles using a least square curve fit. Each polynomial has 20 coefficients which are used to back out the total pressure, static pressure, and pitch and yaw angles based on the measured pressures. Bhat uses a computer program that was written to determine the coefficient vector (using the 20

coefficients) for each alpha, beta, total pressure, and static pressure based on the calibration data.

Guyton (ref. 15) uses a similar approach as Bhat to calibrate five hole probes. Like Bhat, he calculates a pitch and yaw pressure coefficient, total pressure coefficient, and a static pressure coefficient. He also determines a mach number coefficient as a means for determining the flow velocity. Guyton incorporates a statistical stepwise linear regression solution to increase the capability of the third order algebraic polynomial fit. The linear regression routine is capable of computing the polynomial coefficients for an equation with up to 80 independent variables and can handle a data set containing up to 10,000 points. The method is capable of solving supersonic and subsonic data as long as the data sets are kept separate, thus providing two sets of probe equations. Guyton states that this presents a problem when the probe is put into a flow field that has the potential to be either subsonic or supersonic. The mach number coefficient is presently used as a means to distinguish between the subsonic and supersonic regimes. Further refinement in the detection of the supersonic condition versus the subsonic condition is being investigated.

One disadvantage of using the above calibration schemes is that a probe can only be used for the precise calibration range that data were obtained. In addition, the

interpolation schemes can not be extrapolated for Mach numbers outside the range of calibration thus limiting the calibration. For pitch and yaw angles larger than approximately 15 degrees, the pressure response is non-linear, and stronger coupling between pitch and yaw can be observed which decreases the accuracy of the spline fits. Gaillard noted that when the pitch angle exceeds a value of about 10 deg, the influence of the Mach number and pitch angle must be taken into account to deduce the total pressure from the pressure measurement of the center port (P5). The calibration scheme presented by Lee can only be used for subsonic data since the total pressure coefficient used to determine the flow velocity subtracts the total pressure from the probe pitot pressure which would give a negative value for supersonic data. Hodges method requires a large amount of computer memory storage to encompass a broad range of Mach numbers. In addition, calibration data beyond the desired calibration range must be obtained to ensure that the match always falls within the search range. All six methods will yield reasonable accuracy for measuring flow angularity and velocity and can be used when known test conditions can be expected.

CHAPTER X

CONCLUDING REMARKS

The calibration of these probes demonstrates that reliable flow field Mach number and flow angularity results can be obtained with miniature five-tube probes when a proper fit of the data is obtained. Use of the MFA curve fit/calibration routine will determine calibration curves as a function of Mach number (pressure ratio) and total angle of attack for a particular probe. The probe can then be used in the flow field of an aircraft boundary layer or jet wake to characterize the flow field. Reynolds number effects were determined negligible for the probes calibrated based on the data examined. However, previous documented references (ref. 16) have shown Reynolds number to have a distinct effect on PAVGP5 (Mach number parameter) and this should be examined during each calibration. The present calibration is valid for the Mach numbers from 2.0 to 5.5 and angles of attack between -11.5 to +11 deg.

The estimated overall uncertainty in the Mach number derived from these probe calibrations is nominally 5.5%. The corresponding flow-angle evaluations based on the probe-pressure measurements are reliable to within 0.85 degrees for the total angle of attack (ALPHAT) and 13 degrees for the total roll angle (CPHI). The calibrations can be extended as calibration data is obtained on the

probes at Mach numbers not presently in the calibrated Mach number envelope.

Use of the MFA curve fit/calibration routine prevents much of the engineering quantitative judgement from being used when determining the probe misalignment angles. This in turn allows for a more repeatable method for determining the misalignment angles and provides a quick and accurate method for calibrating a probe. Data can be generated for Mach numbers that wind tunnel data were not obtained thus increasing the capability of the probe. The curve fits can also be used to extrapolate the data to determine a probe's characteristics outside the range of calibration.

BIBLIOGRAPHY

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APPENDICES

```
DEL MFAFIT.DAT
DEL ANS.DAT
DEL MACH.DAT
DEL FILE1.DAT
DEL FILE2.DAT
DEL FILE3.DAT
DEL FILE4.DAT
DEL FILE5.DAT
DEL UMOD.DAT
MFAFIX
CLS
MFAFIXQR
CLS
DEL AMODR.DAT
DEL MMODR.DAT
DEL ACOEF.DAT
DEL MCOEF.DAT
DEL MSOL.DAT
DEL CURVES.DAT
CLS
MFAFIT
CLS
MACH
CLS
ALPHA
CLS
GRAPH
CLS
ASSIGN B A
COPY UMOD.DAT A:\GRAPH
COPY CURVES.DAT A:\GRAPH
DEL UMOD.DAT
DEL CURVES.DAT
ASSIGN B B
REM
REM     This batch file plots the pressure data to verify the fit
REM
CD A:\GRAPH
INSTALL
KEY A:\GRAPH\GRAPH /ML /OW+ /OP500
A:\GRAPH\GRAPHER
KEY /K
REM
REM
DEL *.OPT
DEL *.PLT
CD \
```

Appendix 1. MFAE.BAT

```
C
C********************** MFAFIX.FOR ***************************
C
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 MINF

      DIMENSION IRUN(500),IPRB(500),MINF(500),
     *     ALPI(500),PHI(500),DP24(500),DP13(500),
     *     P1(500),P2(500),P5(500),PT(500),
     *     PAVGP5(500),DPSQP(500),CPHI(500)

C

      WRITE (*,*) ' '
      WRITE (*,*) ' '
      WRITE (*,*) 'INPUT THE DATA FILE NAME'
      WRITE (*,*) ' '
     OPEN (UNIT=41,FILE=' ',STATUS='OLD')
     OPEN (UNIT=42,FILE='MFAFIT.DAT',STATUS='NEW')
      WRITE (*,*) ' '
      WRITE (*,*) 'ARE YOU USING A PRINTER FOR OUTPUT?'
      WRITE (*,*) ' '
      WRITE (*,*) 'INPUT:  1. YES'
      WRITE (*,*) '        2. NO'
      WRITE (*,*) ' '
      READ (*,*) IPRINT
      IF (IPRINT .EQ. 2) GOTO 22
     OPEN (UNIT=7,FILE='PRN',STATUS='NEW')
        GOTO 23
22    OPEN (UNIT=7,FILE='FILE1.DAT',STATUS='NEW')
23    OPEN (UNIT=12,FILE='ANS.DAT',STATUS='NEW')
     OPEN (UNIT=14,FILE='MACH.DAT',STATUS='NEW')
      WRITE (12,*) IPRINT

      I=0
      JJ=0
      INC1=0
      INC=0
      WRITE (*,*) ' '
      WRITE (*,*) ' '
      WRITE (*,*) 'IS MACH NUMBER OR PT BEING USED IN THE DATA FILE?'
      WRITE (*,*) ' '
      WRITE (*,*) 'INPUT:  1. MACH'
      WRITE (*,*) '        2. PT'
      WRITE (*,*) ' '
      READ (*,*) IANS
      WRITE (*,*) ' '
      WRITE (*,*) 'IS THE DATA SUPERSONIC OR SUBSONIC?'
```

Appendix 2. MFAFIX.FOR

```
      WRITE (*,*) ' '
      WRITE (*,*) 'INPUT:  1. SUPERSONIC (M > 1)'
      WRITE (*,*) '        2. SUBSONIC (M < 1)'
      WRITE (*,*) ' '
      READ (*,*) ISPEED
      WRITE (14,*) ISPEED
308   I=I+1
      IF(IANS .EQ. 1) GOTO 55
      READ(41,*) IRUN(I),IPRB(I),PT(I),PHI(I),ALPI(I),P1(I),P2(I),
     1 DP13(I),DP24(I),P5(I),JJ
      GOTO 56
55    READ(41,*) IRUN(I),IPRB(I),MINF(I),PHI(I),ALPI(I),P1(I),P2(I),
     1 DP13(I),DP24(I),P5(I),JJ
56    IF(IPRB(I).NE.0) GOTO 350
      IRUN(I)=IRUN(I-1)
      IPRB(I)=IPRB(I-1)
      MINF(I)=MINF(I-1)
      PT(I)=PT(I-1)
      PHI(I)=PHI(I-1)
      ALPI(I)=ALPI(I-1)
      P1(I)=P1(I-1)
      P2(I)=P2(I-1)
      DP13(I)=DP13(I-1)
      DP24(I)=DP24(I-1)
      P5(I)=P5(I-1)
350   IF(JJ.NE.999) GOTO 308
      CONTINUE
      IF(IANS .EQ. 1) GOTO 76

C******* RAYLEIGH PITOT FORMULA TO CALCULATE MACH NUMBER USING *****
C******* THE BISECTION METHOD TO DETERMINE EQ. 99 IN NACA 1135 *****

51    INC1=INC+1
      INC=I
      OTAU=P5(INC1)/PT(INC1)
      DO 47 N=INC1,INC
      IF(N .EQ. INC1) GOTO 49
      OTAU=P5(N-1)/PT(N-1)
49    IF(ABS((P5(N)/PT(N))-OTAU)/OTAU .GE. 0.005) GOTO 48
47    CONTINUE
48    INC=N-1
      IF(N .EQ. I) INC=I
      TEMP= ALPI(INC1)
      DO 44 N=INC1,INC
      IF(ABS(ALPI(N)) .GT. ABS(TEMP)) GOTO 44
       LOOP = N
       TEMP = ALPI(N)
44    CONTINUE
      IF(ISPEED .EQ. 2) THEN
```

Appendix 2. (continued)

```
      PT2PT1 = ((P1(LOOP)+P2(LOOP))/2)/PT(LOOP)
      ELSE
      PT2PT1 = P5(LOOP)/PT(LOOP)
      ENDIF
          HI = 20.0
          HO = 0.01
      DO 13 J=1,35
          AM = (HI+HO)/2
          IF(ISPEED .EQ. 2) THEN
          Y = (1+(AM**2)/5)**(-3.5)
          ELSE
          Y = ((6*AM**2/(AM**2+5))**3.5)*((6/(7*AM**2-1))**2.5)
          ENDIF
          IF(Y .GT. PT2PT1) HO = AM
          IF(Y .LT. PT2PT1) HI = AM
13    CONTINUE
      DO 46 J=INC1,INC
          MINF(J) = AM
46    CONTINUE
      IF(INC .NE. I) GOTO 51
76    IF(IANS .EQ. 1) WRITE(7,112)
      IF(IANS .EQ. 2) WRITE(7,113)
      DO 330 N=1,I
      IF(IANS .EQ. 1) WRITE(7,111) MINF(N),PHI(N),ALPI(N),
     1 P1(N),P2(N),DP13(N),DP24(N),P5(N),IRUN(N),IPRB(N)
      IF(IANS .EQ. 2) WRITE(7,114) MINF(N),PHI(N),ALPI(N),
     1 PT(N),P1(N),P2(N),DP13(N),DP24(N),P5(N),IRUN(N),IPRB(N)
330   CONTINUE
112   FORMAT(1H1,35X,'MACH FLOW ANGULARITY CALIBRATION DATA',//,4X,
     1 'M',9X,'PHI',5X,'ALPHA',7X,'P1',8X,'P2',7X,'DP13',6X,
     2 'DP24',7X,'P5',4X,'RUN',2X,'PROBE',/)
113   FORMAT(1H1,35X,'MACH FLOW ANGULARITY CALIBRATION DATA',//,4X,
     1 'M',9X,'PHI',5X,'ALPHA',7X,'PT',9X,'P1',8X,'P2',7X,'DP13',6X,
     2 'DP24',7X,'P5',4X,'RUN',2X,'PROBE',/)
111   FORMAT(1X,3(F6.2,4X),5(F7.3,3X),I3,2X,I3)
114   FORMAT(1X,3(F6.2,4X),6(F7.3,3X),I3,2X,I3)

C******** CALCULATION OF PAVGP5, DPSQP AND CPHI *************

      DO 10 N=1,I
      PAVGP5(N)=DSQRT((DP13(N))**2+(DP24(N))**2)/(2*P5(N))
      DPSQP(N)=(2*(P1(N)+P2(N))-(DP13(N)+DP24(N)))/(4*P5(N))
      CPHI(N)=((DATAN(-DP24(N)/DP13(N)))*57.2957)
      CPHI(N)=CPHI(N)+90*(1-DP13(N)/DABS(DP13(N)))
10    IF(CPHI(N) .LT. 0.) CPHI(N) = CPHI(N) + 360.0

C*********** WRITING THE DATA TO MFAFIT.DAT ******************

      WRITE(7,118)
```

Appendix 2. (continued)

```
      DO 33 N=1,I
      WRITE(7,119) IRUN(N),IPRB(N),MINF(N),PHI(N),ALPI(N),P1(N),
     1 P2(N),DP13(N),DP24(N),P5(N),PAVGP5(N),DPSQP(N),CPHI(N)
      WRITE(42,120) IRUN(N),IPRB(N),MINF(N),PHI(N),ALPI(N),P1(N),
     1 P2(N),DP13(N),DP24(N),P5(N),PAVGP5(N),DPSQP(N),CPHI(N)
33    CONTINUE
118   FORMAT(1H1,35X,'MACH FLOW ANGULARITY DATA CALCULATED ',
     1 'PARAMETERS',//,2X,'RUN',1X,'PROBE',3X,'M',7X,'PHI',6X,
     2 'ALPHA',8X,'P1',8X,'P2',9X,'DP13',6X,'DP24',7X,
     3 'P5',9X,'DPSQP',6X,'PAVGP5',4X,'CPHI',/)
119   FORMAT(1X,2(I3,2X),3(F6.2,3X),1X,7(F8.4,3X),1X,F6.2)
120   FORMAT(2(I3,1X),11(F8.4,1X))
115   FORMAT(1H1)
999   CONTINUE
      WRITE(7,115)
      STOP
      END
```

Appendix 2. (concluded)

```
REM----------MFAFIXQR.BAS------------
REM
REM----THIS PROGRAM CURVE FITS DATA FROM A MACH FLOW ANGULARITY--------
REM---PROBE AND USES THE FITS TO DETERMINE THE MISALIGNMENT ANGLES-----
REM
25 CLS
   LOCATE 5, 8: PRINT "ENTER THE NUMBER CORRESPONDING TO"
   LOCATE 6, 8: PRINT "THE TYPE OF MONITOR YOU ARE USING"
   LOCATE 8, 8: PRINT "1. COLOR MONITOR"
   LOCATE 9, 8: INPUT "2. MONOCHROME "; MT
   IF MT <> 1 AND MT <> 2 THEN GOTO 25
   IF MT = 1 THEN COLOR 14, 1
CLS
   LOCATE 5, 8: PRINT "ENTER THE NUMBER CORRESPONDING TO"
   LOCATE 6, 8: PRINT "THE TYPE OF ADAPTER CARD YOU ARE USING"
   LOCATE 8, 8: PRINT "1.  Hercules Graphics Adapter (HGA)"
   LOCATE 9, 8: PRINT "2.  Color Graphics Adapter (CGA)"
   LOCATE 10, 8: PRINT "3.  Enhanced Graphics Adapter (EGA)"
   LOCATE 11, 8: INPUT "4.  Video Graphics Adapter (VGA) "; ADAP
'
REM------ MX DEFINES THE SIZE OF THE ARRAYS FOR DATA STORAGE --------"
REM------ BASIC LIMITS THE SIZE OF THE ARRAYS DUE TO DATA STORAGE ---
MX = 500
EF = 999
MD = 2
PI = 3.1415926654#
CNT1 = 0
CNT2 = 0
INC = 0
INC1 = 0
DIM X(2 * MX), Y(2 * MX), DP13(MX), DP24(MX), DP13N(MX), DP24N(MX), DPSQP(MX)
DIM IRUN(MX), ALPP(MX), PHIP(MX), P1(MX), P2(MX), P5(MX), CPHI(MX), PAVGP5(MX)
DIM IPRB(MX), ALPHAT(MX), PHIT(MX), UPRIME(MX), VPRIME(MX), WPRIME(MX)
DIM UP(MX), VP(MX), WP(MX), ALPHAD(MX)
DIM UF(MX), VF(MX), WF(MX), ALF(MX), YAWF(MX), TAU(MX)
Q = MD + 1: DIM A(Q, Q), R(Q), V(Q), FIT(Q, 2)
Q = MD * 2: DIM P(Q)
CLS
LOCATE 5, 18: PRINT "MACH FLOW ANGULARITY CURVE FIT ROUTINE"
LOCATE 8, 8: PRINT "The program is currently set to accept a maximum of"; MX; " data pairs."
LOCATE 10, 8: PRINT "The current fit is a 1st order."
LOCATE 12, 8: PRINT "Make sure that data at different roll angles (ie. 0 vs 90 deg)"
LOCATE 13, 8: PRINT "for the same Mach number are separated in the data input file."
LOCATE 16, 8: PRINT "        STRIKE ANY KEY TO CONTINUE "
PRINT
 JUNK$ = INPUT$(1)
J = 0
FILE$ = "MFAFIT.DAT"
OPEN FILE$ FOR INPUT AS #1
```

Appendix 3. MFAFIXQR.BAS

Appendix 3. (continued)

```
FILE1$ = "UMOD.DAT"
FILE2$ = "FILE2.DAT"
FILE3$ = "ANS.DAT"
FILE4$ = "MACH.DAT"
OPEN FILE1$ FOR OUTPUT AS #2
OPEN FILE3$ FOR INPUT AS #4
OPEN FILE4$ FOR INPUT AS #5
INPUT #4, IPRINT
INPUT #5, ISPEED
CL$
IF IPRINT = 1 THEN GOTO 379
OPEN FILE2$ FOR OUTPUT AS #3
GOTO 380
379 OPEN "LPT1" FOR OUTPUT AS #3
380 NP = 0
PRINT #3,
PRINT #3, "        MACH FLOW ANGULARITY DATA INPUTS TO CALCULATE MISALIGNMENT ANGLES"
PRINT #3,
PRINT #3, "RUN PROBE  MACH    PHI   ALPHA    P1     P2   DP13   DP24     P5   DPSQP   PAVGP5"
430 NP = NP + 1
INPUT #1, IRUN(NP), IPRB(NP), TAU(NP), PHIP(NP), ALPP(NP), P1(NP), P2(NP), DP13(NP), DP24(NP), P5(NP), DPSQP(NP), PAVGP5(NP), CPHI(NP)
PRINT #3, USING "### ###   ##.## ####.## ###.## ##.### ##.### ##.### ##.### ###.### ##.### ##.###"; IRUN(NP); IPRB(NP); TAU(NP); PHIP(NP); ALPP(NP); P1(NP); P2(NP); DP13(NP);
  DP13N(NP) = DP13(NP) / P5(NP)
  DP24N(NP) = DP24(NP) / P5(NP)
  PAST = EOF(1)
IF PAST = 0 THEN GOTO 430
JJ = 999
CLOSE #1
NP1 = NP
IF NP = 0 THEN GOTO 560
540 GOSUB 4890
GOTO 590
560 NP = J: PRINT
IF NP = 0 THEN PRINT "**FATAL ERROR**"
IF NP = 0 THEN PRINT "-- NO DATA ENTERED": STOP
590 GOSUB 910
PRINT
INPUT " ARE ALL INPUTS CORRECT (Y/N) "; ANS$
IF ANS$ = "Y" OR ANS$ = "y" THEN GOTO 1170
760 CLS
LOCATE 5, 8: PRINT "OPTIONS:"
LOCATE 7, 8: PRINT "C - CHANGE INPUT "
LOCATE 8, 8: PRINT "D - DELETE POINTS "
LOCATE 9, 8: PRINT "F - FIT INPUTS "
LOCATE 10, 8: PRINT "S - SEE INPUTS (QUIT SECTION)"
LOCATE 12, 8: INPUT "INPUT OPTION: "; ANS$
IF ANS$ = "C" OR ANS$ = "c" THEN GOTO 1300
IF ANS$ = "D" OR ANS$ = "d" THEN GOTO 980
IF ANS$ = "F" OR ANS$ = "f" THEN GOTO 1170
```

```
  LOCATE 17, 8: INPUT "ENTER THE NUMBER OF THE PARAMETER YOU WISH TO CHANGE "; NUM
  IF NUM = 1 GOTO 1510
  IF NUM = 2 GOTO 1530
  IF NUM = 3 GOTO 1550
  IF NUM = 4 GOTO 1570
  IF NUM = 5 GOTO 1590
  IF NUM = 6 GOTO 1610
  IF NUM > 6 GOTO 1620
1510 LOCATE 20, 8: INPUT "DP13 = "; DP13(POSITION)
GOTO 1620
1530 LOCATE 20, 8: INPUT "DP24 = "; DP24(POSITION)
GOTO 1620
1550 LOCATE 20, 8: INPUT "P1 = "; P1(POSITION)
GOTO 1620
1570 LOCATE 20, 8: INPUT "P2 = "; P2(POSITION)
GOTO 1620
1590 LOCATE 20, 8: INPUT "P5 = "; P5(POSITION)
GOTO 1620
1610 LOCATE 20, 8: INPUT "INPUT ALPHA, DP13, DP24, P1, P2, P5 "; ALPP(POSITION), DP13(POSITION), DP24(POSITION), P1(POSITION), P2(POSITION), P5(POSITION)
1620   DP13N(POSITION) = DP13(POSITION) / P5(POSITION)
       DP24N(POSITION) = DP24(POSITION) / P5(POSITION)
DPSQP(POSITION) = SQR((DP13(POSITION)) ^ 2 + (DP24(POSITION)) ^ 2) / (2 * P5(POSITION))
PAVGP5(POSITION) = (2 * (P1(POSITION) + P2(POSITION)) - (DP13(POSITION) + DP24(POSITION))) / (4 * P5(POSITION))
CPHI(POSITION) = (ATN(-DP24(POSITION) / DP13(POSITION)) * 57.2957) + 90 * (1 - DP13(POSITION) / ABS(DP13(POSITION)))
IF CPHI(POSITION) < 0 THEN CPHI(POSITION) = CPHI(POSITION) + 360!
GOTO 760
1680 CLS
REM------ THIS IS WHERE THE 1st ORDER CURVE FIT IS PERFORMED ------
REM------ A HIGHER ORDER CURVE FIT CAN BE USED WITH MODIFICATIONS ---
REM------ MADE TO THE PROGRAM ----------------------
LOCATE 4, 26: PRINT SAYS; "/P5 CURVE FIT"
LOCATE 6, 8: PRINT POINTS; "DATA PAIRS ENTERED"
LOCATE 8, 8: PRINT "DEGREE OF POLYNOMINAL FITTED IS A 1st ORDER LEAST SQUARES FIT"
D = 1
D = INT(D): IF D < POINTS THEN GOTO 1780
LOCATE 10, 8: PRINT "** ERROR! ** -- NOT ENOUGH DATA": IFLAG = 1
LOCATE 20, 15: PRINT "STRIKE ANY KEY TO CONTINUE"
JUNK$ = INPUT$(1): CNT1 = 1: CNT2 = 1: POSITION = INC1: GOTO 44
1780 D2 = 2 * D
IF D > MD THEN LOCATE 10, 8: PRINT "**ERROR! --DEGREE TOO HIGH": LOCATE 20, 15: PRINT "STRIKE ANY KEY TO CONTINUE": JUNK$ = INPUT$(1): GOTO 2110
N = D + 1
LDD = N
FOR J = 1 TO D2: P(J) = 0: FOR K = INC1 TO INC
P(J) = P(J) + X(K) ^ J: NEXT: NEXT: P(0) = POINTS
R(1) = 0: FOR J = INC1 TO INC: R(1) = R(1) + Y(J)
NEXT: IF N = 1 THEN GOTO 1870
FOR J = 2 TO N: R(J) = 0: FOR K = INC1 TO INC
R(J) = R(J) + Y(K) * X(K) ^ (J - 1): NEXT: NEXT
1870 FOR J = 1 TO N: FOR K = 1 TO N: A(J, K) = P(J + K - 2)
NEXT: NEXT
```

Appendix 3. (continued)

```
IF ANS$ = "S" OR ANS$ = "s" THEN GOTO 590
GOTO 760
980 GOSUB 910
REM----- THIS IS WHERE THE PROGRAM DELETES BAD POINTS ----------
PRINT
PRINT
   INPUT "INPUT POSITION (I) OF POINT TO DELETE "; POSITION
44 FOR II = INC1 TO NP
      IF II < POSITION THEN GOTO 1100
       DP13N(II) = DP13N(II + 1): DP24N(II) = DP24N(II + 1): P5(II) = P5(II + 1)
       IPRB(II) = IPRB(II + 1): IRUN(II) = IRUN(II + 1): TAU(II) = TAU(II + 1)
       ALPP(II) = ALPP(II + 1): PNIP(II) = PNIP(II + 1): P1(II) = P1(II + 1)
       P2(II) = P2(II + 1): DP13(II) = DP13(II + 1): DP24(II) = DP24(II + 1)
       DPSQP(II) = DPSQP(II + 1): PAVGP5(II) = PAVGP5(II + 1): CPNI(II) = CPNI(II + 1)
1100   NEXT II
   NP = NP - 1
   INC = INC - 1
   POINTS = POINTS - 1
   IF IFLAG = 1 THEN GOTO 2110
GOTO 760
REM----- THIS IS WHERE DP13/P5 OR DP24/P5 ARE ASSIGNED --------
REM----- TO BE CURVE FIT VERSUS ALPP -----------
1170 CLS
     LOCATE 5, 8: PRINT "OPTIONS:"
     LOCATE 7, 8: PRINT "1.  FIT DP13/P5 VS ALPHA"
     LOCATE 8, 8: PRINT "2.  FIT DP24/P5 VS ALPHA"
     LOCATE 10, 8: INPUT "INPUT OPTION NUMBER: "; SAY
     IF SAY = 1 THEN SAY$ = "DP13"
     IF SAY = 2 THEN SAY$ = "DP24"
FOR LP = INC1 TO INC
X(LP) = ALPP(LP)
IF SAY = 1 THEN Y(LP) = DP13N(LP)
IF SAY = 2 THEN Y(LP) = DP24N(LP)
NEXT LP
GOTO 1680
1300 GOSUB 910
REM----- THIS IS WHERE INCORRECT VALUES CAN BE EDITED -------
PRINT
  INPUT "INPUT POSITION (I) OF INCORRECT VALUE: "; POSITION
  CLS
  LOCATE 5, 8: PRINT "  ALPHA   DP13      DP24      P1        P2        P5"
  LOCATE 6, 8: PRINT USING "###.##  ##.#####  ##.#####  ##.####  ##.####  ###.####"; ALPP(POSITION); DP13(POSITION); DP24(POSITION); P1(POSITION); P2(POSITION); P5(POSITION)
  LOCATE 9, 8: PRINT "1.  CHANGE DP13"
  LOCATE 10, 8: PRINT "2.  CHANGE DP24"
  LOCATE 11, 8: PRINT "3.  CHANGE P1"
  LOCATE 12, 8: PRINT "4.  CHANGE P2"
  LOCATE 13, 8: PRINT "5.  CHANGE P5"
  LOCATE 14, 8: PRINT "6.  CHANGE ALPHA, DP13, DP24, P1, P2, P5"
  LOCATE 15, 8: PRINT "7.  LEAVE INPUTS ALONE"
```

Appendix 3. (continued)

Appendix 3. (continued)

```
GOSUB 2470
REM LOCATE 10, 6: PRINT "X POWER       COEFFICIENT"
REM LOCATE 11, 6: PRINT "--------      -------------"
REM FOR J = 1 TO N: PRINT "       "; J - 1, "    "; V(J): NEXT
IF SAY = 1 THEN LOCATE 12, 8: PRINT "DP13/P5 = "; V(2); "α + "; V(1)
IF SAY = 2 THEN LOCATE 12, 8: PRINT "DP24/P5 = "; V(2); "α + "; V(1)
IF SAY = 1 THEN FOR J = 1 TO N: FIT(J, 1) = V(J): CNT1 = N: NEXT
IF SAY = 2 THEN FOR J = 1 TO N: FIT(J, 2) = V(J): CNT2 = N: NEXT
IF CNT1 < CNT2 THEN CNT = CNT2 ELSE CNT = CNT1
Q = 0: FOR J = INC1 TO INC: Q = Q + Y(J): NEXT
M = Q / INC: T = 0: G = 0: FOR J = INC1 TO INC
Q = 0: FOR K = 1 TO N: Q = Q + V(K) * X(J) ^ (K - 1): NEXT
T = T + (Y(J) - Q) ^ 2
2010 G = G + (Y(J) - M) ^ 2: NEXT: IF G = 0 THEN T = 1: GOTO 2010
T = 1 - T / G
IF SAY = 1 THEN FIT(3, 1) = T
IF SAY = 2 THEN FIT(3, 2) = T
LOCATE 16, 8: PRINT "GOODNESS OF FIT ="; T
LOCATE 20, 15: PRINT "STRIKE ANY KEY TO VIEW PLOT"
JUNK$ = INPUT$(1)
GOSUB 2950
GOTO 2110
IF CNT1 > 0 AND CNT2 > 0 THEN PRINT #3, : PRINT #3, "MACH "; TAU(INC); " CURVE FIT"
IF CNT1 > 0 AND CNT2 > 0 THEN PRINT #3, : PRINT #3, "DP13/P5 FIT   DP24/P5 FIT"
IF CNT1 > 0 AND CNT2 > 0 THEN PRINT #3, : FOR I = 1 TO CNT: PRINT #3, USING "##.#####      ##.#####"; FIT(I, 1); FIT(I, 2): NEXT: PRINT #3, : PRINT #3, "GOODNESS OF FIT": PRINT
                                          PRINT #3,
IF CNT1 > 0 AND CNT2 > 0 THEN GOSUB 3410
2110 CLS
2130 LOCATE 5, 8: PRINT "--CONTINUATION OPTIONS--"
LOCATE 7, 8: PRINT "1 - DETERMINE A Y-VALUE FOR A SPECIFIC X-VALUE"
LOCATE 8, 8: PRINT "2 - CHANGE THE CURRENT INPUTS"
LOCATE 9, 8: PRINT "3 - CURVE FIT DP13/P5 VS. ALPHA OR DP24/P5 VS. ALPHA FOR MACH "; TAU(INC)
LOCATE 10, 8: PRINT "4 - CALCULATE MISALIGNMENT ANGLES (DO ONLY AFTER DP13/P5 AND DP24/P5"
LOCATE 11, 8: PRINT "    HAVE BEEN CURVE FIT)"
LOCATE 12, 8: PRINT "5 - CURVE FIT THE NEXT GROUP OF DATA IN SEQUENTIAL ORDER"
LOCATE 13, 8: PRINT "6 - CURVE FIT A PARTICULAR GROUP OF DATA"
LOCATE 14, 8: PRINT "7 - QUIT PROGRAM"
NUM = 0
LOCATE 18, 8: INPUT "INPUT OPTION "; Q: Q = INT(Q)
IF Q = 7 THEN GOSUB 4810: CLOSE #2: CLS : END
2270 CLS
IF Q = 2 THEN GOTO 590
IF Q = 3 THEN GOTO 1170
IF Q = 6 THEN GOTO 5580
IF Q = 4 AND CNT1 = 0 THEN LOCATE 16, 14: PRINT "DP13/P5 HASN'T BEEN CURVE FIT FOR MACH"; TAU(INC): GOTO 2130
IF Q = 4 AND CNT2 = 0 THEN LOCATE 16, 14: PRINT "DP24/P5 HASN'T BEEN CURVE FIT FOR MACH"; TAU(INC): GOTO 2130
IF Q = 4 THEN GOTO 3410
IF Q = 5 AND INC = NP THEN LOCATE 16, 14: PRINT "ALL DATA HAS BEEN CURVE FIT": PRINT : GOTO 2130
IF Q = 5 AND CNT1 = 0 THEN LOCATE 16, 14: PRINT "DP13/P5 HASN'T BEEN CURVE FIT FOR MACH"; TAU(INC): GOTO 2130
```

```
IF Q = 5 AND CNT2 = 0 THEN LOCATE 16, 14: PRINT "DP24/P5 HASN'T BEEN CURVE FIT FOR MACH"; TAU(INC): GOTO 2130
IF Q = 5 THEN CNT1 = 0: CNT2 = 0: GOTO 540
IF Q <> 1 THEN 2110
CLS
LOCATE 5, 8: PRINT "ENTER"; EF; " TO LEAVE THIS MODE"
2430 LOCATE 7, 8: INPUT "X= "; XV: IF XV = EF THEN GOTO 2110
YV = 0: FOR K = 1 TO N
YV = YV + V(K) * XV ^ (K - 1): NEXT: LOCATE 8, 8: PRINT "Y= "; YV
GOTO 2430
2470 IF N = 1 THEN V(1) = R(1) / A(1, 1): RETURN
FOR K = 1 TO N - 1
I = K + 1
L = K
2510 IF ABS(A(I, K)) > ABS(A(L, K)) THEN L = I
IF I < N THEN I = I + 1: GOTO 2510
IF L = K THEN 2570
FOR J = K TO N: Q = A(K, J): A(K, J) = A(L, J)
A(L, J) = Q: NEXT
Q = R(K): R(K) = R(L): R(L) = Q
2570 I = K + 1
2580 Q = A(I, K) / A(K, K): A(I, K) = 0
FOR J = K + 1 TO N: A(I, J) = A(I, J) - Q * A(K, J): NEXT
R(I) = R(I) - Q * R(K): IF I < N THEN I = I + 1: GOTO 2580
NEXT
V(N) = R(N) / A(N, N): FOR I = N - 1 TO 1 STEP -1
Q = 0: FOR J = I + 1 TO N: Q = Q + A(I, J) * V(J)
V(I) = (R(I) - Q) / A(I, I): NEXT: NEXT
RETURN
REM ---------- GRAPH THE RESULTS ----------
2950 CLS
     IF ADAP = 1 THEN SCREEN 10
     IF ADAP = 2 THEN SCREEN 8
     IF ADAP = 3 THEN SCREEN 12
     IF ADAP = 4 THEN SCREEN 12
XMAX = X(INC1)
MAXX = X(INC1)
XMIN = X(INC1)
YMAX = Y(INC1)
MAXY = Y(INC1)
YMIN = Y(INC1)
IF NUM = 4 THEN INC = NPP
FOR I = INC1 TO INC
    IF ABS(X(I)) > ABS(XMAX) THEN XMAX = X(I)
    IF X(I) > MAXX THEN MAXX = X(I)
    IF X(I) < XMIN THEN XMIN = X(I)
    IF ABS(Y(I)) > ABS(YMAX) THEN YMAX = Y(I)
    IF Y(I) > MAXY THEN MAXY = Y(I)
    IF Y(I) < YMIN THEN YMIN = Y(I)
NEXT I
```

Appendix 3. (continued)

```
XINC = XMAX * .5
YINC = YMAX * .5
IF ABS(XMAX) > ABS(YMAX) THEN
   SCALE = XMAX
  ELSE
   SCALE = YMAX
END IF
IF NUM = 0 OR NUM = 4 THEN
   WINDOW (-1.1 * XMAX, -1.1 * YMAX)-(1.1 * XMAX, 1.1 * YMAX)
  ELSEIF NUM = 5 THEN
   WINDOW (-1.1 * SCALE, -1.1 * SCALE)-(1.1 * SCALE, 1.1 * SCALE)
  ELSE
   WINDOW (-XINC, -YINC)-(1.3 * XMAX, 1.3 * YMAX)
END IF
IF NUM = 5 THEN
   LINE (-SCALE, 0)-(SCALE, 0): LINE (0, -SCALE)-(0, SCALE)
  ELSE
   LINE (-XMAX, 0)-(1.2 * XMAX, 0): LINE (0, -YMAX)-(0, 1.2 * YMAX)
END IF
FOR I = INC1 TO INC
PSET (X(I), Y(I))
NEXT I
IF NUM > 0 THEN GOTO 3280
DU = ABS(XMAX) / 300
XX = XMIN
3210 YY = 0
FOR I = 1 TO N
YY = YY + V(I) * XX ^ (I - 1)
NEXT I
PSET (XX, YY)
XX = XX + DU
IF XX < XMAX GOTO 3210
3280 LOCATE 1, 2: PRINT "STRIKE ANY KEY TO CONTINUE"
LOCATE 2, 56: PRINT "   MINIMUM MAXIMUM"
LOCATE 3, 56: PRINT USING "X (###.###,###.###)"; XMIN; MAXX
LOCATE 4, 56: PRINT USING "Y (###.###,###.###)"; YMIN; MAXY
IF NUM = 0 AND SAY = 1 THEN LOCATE 1, 40: PRINT "ALPP VS DP13/P5"
IF NUM = 0 AND SAY = 2 THEN LOCATE 1, 40: PRINT "ALPP VS DP24/P5"
IF NUM = 1 THEN LOCATE 1, 40: PRINT "ALPHAT VS PAVGP5"
IF NUM = 2 THEN LOCATE 1, 40: PRINT "ALPHAT VS DPSQP"
IF NUM = 3 THEN LOCATE 1, 40: PRINT "DPSQP VS PAVGP5"
IF NUM = 4 THEN LOCATE 1, 40: PRINT "ALPP VS DP13/P5 AND DP24/P5"
IF NUM = 5 THEN LOCATE 1, 40: PRINT "PHIT VS CPHI"
JUNK$ = INPUT$(1)
SCREEN 0
IF NUM = 4 THEN INC = NPP / 2
IF MT = 1 THEN COLOR 14, 1
RETURN
3410 NUM = 0
```

Appendix 3. (continued)

```
REM---- THIS IS WHERE THE MISALIGNMENT ANGLES ARE DETERMINED ------
IF (ABS(PHIP(INC1)) > 45) AND (ABS(PHIP(INC1)) < 135) THEN GOTO 3500
IF (ABS(PHIP(INC1)) > 225) AND (ABS(PHIP(INC1)) < 315) THEN GOTO 3500
ALPD = FIT(1, 1) / FIT(2, 1)
EPS = FIT(2, 2) * (-FIT(1, 1) / FIT(2, 1)) + FIT(1, 2)
3480 PSID = EPS / FIT(2, 1)
PHID = -ATN(FIT(2, 2) / FIT(2, 1))
GOTO 3530
3500 PSID = -FIT(1, 2) / FIT(2, 2)
EPS = FIT(2, 1) * (-FIT(1, 2) / FIT(2, 2)) + FIT(1, 1)
ALPD = -EPS / FIT(2, 2)
PHID = -ATN(FIT(2, 1) / FIT(2, 2))
3530 ALPD = ALPD * (PI / 180)
PSID = PSID * (PI / 180)
3560 FOR I = INC1 TO INC
ALPP(I) = ALPP(I) * (PI / 180)
PHIP(I) = PHIP(I) * (PI / 180)
ALPHAD(I) = ALPD + ALPP(I)
NEXT
REM----------PROBE MISALIGNMENT ANGLES-------------------------
FOR I = INC1 TO INC
UPRIME(I) = COS(ALPP(I)) * COS(ALPD) - SIN(ALPP(I)) * SIN(ALPD) * COS(PHID + PHIP(I))
VPRIME(I) = SIN(ALPP(I)) * SIN(PHID + PHIP(I))
WPRIME(I) = COS(ALPP(I)) * SIN(ALPD) + SIN(ALPP(I)) * COS(ALPD) * COS(PHID + PHIP(I))
REM---------CORRECTED TOTAL ANGLE OF ATTACK----------------------
TEMPU = UPRIME(I) * COS(PSID) + VPRIME(I) * SIN(PSID)
ALPHAT(I) = ATN(SQR(1 - TEMPU ^ 2) / TEMPU)
PHIT(I) = ATN(((VPRIME(I) / WPRIME(I)) * COS(PSID)) - ((UPRIME(I) / WPRIME(I)) * SIN(PSID)))
PHIT(I) = PHIT(I) + (90 * PI / 180) * (1 - (WPRIME(I) / ABS(WPRIME(I))))
IF PHIT(I) < 0 THEN PHIT(I) = PHIT(I) + 2 * PI
NEXT
REM--------RESULTANT PROBE AXIS NORMALIZED VELOCITIES-----------
FOR I = INC1 TO INC
UP(I) = COS(ALPHAT(I))
VP(I) = SIN(ALPHAT(I)) * SIN(PHIT(I))
WP(I) = SIN(ALPHAT(I)) * COS(PHIT(I))
NEXT
AN = SIN(PSID) * SIN(PHID) + SIN(-ALPD) * COS(PSID) * COS(PHID)
AO = -COS(PSID) * SIN(-PHID) + SIN(ALPD) * SIN(PSID) * COS(PHID)
FOR I = INC1 TO INC
REM UF(I)=UP(I)*(COS(ALPD)*COS(PSID))+VP(I)*(COS(ALPD)*SIN(PSID))-WP(I)*(SIN(ALPD))
UF(I) = UP(I) * (COS(ALPP(I)) * COS(ALPD) * COS(PSID) - SIN(-ALPP(I)) * AN) + VP(I) * (COS(ALPP(I)) * COS(ALPD) * SIN(-PSID) - SIN(-ALPP(I)) * AO) + WP(I) * (-COS(ALPP(I))
REM VF(I)=-UP(I)*SIN(PSID)+VP(I)*COS(PSID)
VF(I) = UP(I) * (-SIN(-PSID) * COS(PHID) + SIN(ALPD) * COS(PSID) * SIN(PHID)) + VP(I) * (COS(PSID) * COS(PHID) + SIN(-ALPD) * SIN(PSID) * SIN(PHID)) + WP(I) * (COS(ALPD) *
REM WF(I)=UP(I)*(SIN(ALPD)*COS(PSID))+VP(I)*(SIN(ALPD)*SIN(PSID))+WP(I)*COS(ALPD)
WF(I) = UP(I) * (SIN(-ALPP(I)) * COS(ALPD) * COS(PSID) + COS(ALPP(I)) * AN) + VP(I) * (SIN(ALPP(I)) * COS(ALPD) * SIN(PSID) + COS(ALPP(I)) * AO) + WP(I) * (-SIN(ALPP(I)) *
ALF(I) = ATN(WF(I) / UF(I))
YAWF(I) = ATN(VF(I) / UF(I))
REM--------CONVERT THE ANGLES FROM RADIANS TO DEGREES--------------
```

```
ALPP(I) = ALPP(I) * (180 / PI)
PHIP(I) = PHIP(I) * (180 / PI)
ALPHAD(I) = ALPHAD(I) * (180 / PI)
ALPHAT(I) = ALPHAT(I) * (180 / PI)
PHIT(I) = PHIT(I) * (180 / PI)
ALF(I) = ALF(I) * (180 / PI)
YAWF(I) = YAWF(I) * (180 / PI)
NEXT
ALPD = ALPD * (180 / PI)
PSID = PSID * (180 / PI)
PHID = PHID * (180 / PI)
IF NUM = 6 THEN GOSUB 4550: NUM = 2: CLS : GOSUB 2950: GOSUB 5250
IF NUM = 6 THEN GOTO 4100
GOSUB 4150
4100 GOSUB 5050
4110 PRINT
4120 LOCATE 24, 5: INPUT "WOULD YOU LIKE TO VARY THE MISALIGNMENT ANGLES "; ANG$
CLS
IF ANG$ = "Y" OR ANG$ = "y" THEN GOSUB 5255
GOTO 2110
4150 CLS
LOCATE 5, 8: PRINT "         X AXIS VS Y AXIS"
LOCATE 7, 8: PRINT "1 - PLOT ALPHAT VS PAVGP5"
LOCATE 8, 8: PRINT "2 - PLOT ALPHAT VS DPSQP"
LOCATE 9, 8: PRINT "3 - PLOT DPSQP VS PAVGP5"
LOCATE 10, 8: PRINT "4 - PLOT ALPP VS DP13/P5 AND DP24/P5"
LOCATE 11, 8: PRINT "5 - PLOT PHIT VS CPHI"
IF NUM = 0 THEN GOTO 4250
IF NUM < 6 THEN GOTO 4280
4250 LOCATE 13, 8: INPUT "WOULD YOU LIKE TO PLOT THE RESULTS "; ANG$
IF ANG$ = "N" OR ANG$ = "n" THEN GOTO 4490
4280 FOR I = 1 TO 2 * NP
X(I) = 0
Y(I) = 0
NUM = 0
NEXT
LOCATE 15, 8: INPUT "ENTER THE NUMBER OF THE PLOT YOU WISH TO VIEW "; NUM
IF NUM = 1 THEN GOSUB 4500
IF NUM = 2 THEN GOSUB 4550
IF NUM = 3 THEN GOSUB 4600
IF NUM = 4 THEN GOSUB 4650
IF NUM = 5 THEN GOSUB 4730
CLS
GOSUB 2950
LOCATE 10, 5: INPUT "WOULD YOU LIKE TO VIEW ANOTHER PLOT "; ANS$
CLS
IF ANS$ = "Y" OR ANS$ = "y" THEN GOSUB 4150
FOR I = INC1 TO INC
X(I) = ALPP(I)
```

Appendix 3. (continued)

```
IF SAY = 1 THEN Y(I) = DP13N(I)
IF SAY = 2 THEN Y(I) = DP24N(I)
NEXT
4490 RETURN
4500 FOR I = INC1 TO INC
X(I) = ALPHAT(I)
Y(I) = PAVGP5(I)
NEXT
RETURN
4550 FOR I = INC1 TO INC
X(I) = ALPHAT(I)
Y(I) = DPSQP(I)
NEXT
RETURN
4600 FOR I = INC1 TO INC
X(I) = DPSQP(I)
Y(I) = PAVGP5(I)
NEXT
RETURN
4650 FOR I = INC1 TO INC
X(I) = ALPP(I)
X(I + POINTS) = ALPP(I)
Y(I) = DP13N(I)
Y(I + POINTS) = DP24N(I)
NEXT
NPP = (INC1 + 2 * POINTS) - 1
RETURN
4730 FOR I = INC1 TO INC
X(I) = PHIT(I)
Y(I) = CPHI(I)
NEXT
RETURN
REM ---------SUBROUTINE TO PRINT THE DATA TO UMOD.DAT -----------
4810 FOR I = 1 TO NP
IF I = NP THEN GOTO 4850
PRINT #2, USING "### ##     ##.##   ##.#####  ##.#####   ###.##    ####.#   ##.####   ##.####    "; IRUN(I); IPRB(I); TAU(I); PAVGP5(I); DPSQP(I); ALPHAT(I); PHIT(I); DP24(I);
GOTO 4860
4850 PRINT #2, USING "### ##     ##.##   ##.#####  ##.#####   ###.##    ####.#   ##.####   ##.#### ###"; IRUN(I); IPRB(I); TAU(I); PAVGP5(I); DPSQP(I); ALPHAT(I); PHIT(I); DP24
4860 NEXT
RETURN
REM ----SUBROUTINE TO GROUP THE NEXT DATA SET TO BE CURVE FIT -------
4890 INC1 = INC + 1
INC = NP
OTAU = TAU(INC1)
FOR I = INC1 TO INC
IF I = INC1 GOTO 4950
REM OTAU = TAU(I - 1)
4950 IF ISPEED = 2 THEN
IF (ABS(TAU(I) - OTAU) / OTAU) > .1 THEN GOTO 4970
```

```
ELSE
IF (ABS(TAU(I) - OTAU) / OTAU) > .025 THEN GOTO 4970
END IF
NEXT
4970 INC = I - 1
IF I = NP THEN INC = I
POINTS = (INC - INC1) + 1
CNT1 = 0
CNT2 = 0
RETURN
REM ----SUBROUTINE TO PRINT THE MISALIGNMENT ANGLES ------------
REM ----- AND THEIR CALCULATED EFFECTS ON THE DATA  --------------
5050 CLS
PRINT #3,
HEAD1$ = "POSITION  ALPHAT    PHIT     CPHI   ALPHAD     PSID      PHID      ALF     YAWF"
PRINT #3, USING "&"; HEAD1$
PRINT #3,
FOR I = INC1 TO INC
PRINT #3, USING "###     ###.##   ####.##   ####.##  ###.##   ###.##   ####.##   ###.##   ###.##"; I; ALPHAT(I); PHIT(I); CPHI(I); ALPHAD(I); PSID; PHID; ALF(I); YAWF(I)
NEXT
PRINT #3,
PRINT #3, USING "ALPD = ####.##   PSID = ####.##   PHID = ####.##"; ALPD; PSID; PHID
PRINT #3,
PRINT USING "&"; HEAD1$
PRINT
FOR I = INC1 TO INC
PRINT USING "###     ###.##   ####.##   ####.##  ###.##   ###.##   ####.##   ###.##   ###.##"; I; ALPHAT(I); PHIT(I); CPHI(I); ALPHAD(I); PSID; PHID; ALF(I); YAWF(I)
NEXT
PRINT
PRINT USING "      ALPD = ####.##   PSID = ####.##   PHID = ####.##"; ALPD; PSID; PHID
PRINT
RETURN
REM -------SUBROUTINE TO VARY THE MISALIGNMENT ANGLES ------------
5250 CLS
LOCATE 5, 8: INPUT "WOULD YOU LIKE TO CHANGE A VALUE OF ALPD, PSID, OR PHID (Y OR N)"; Z$
CLS
IF Z$ = "Y" OR Z$ = "y" THEN GOTO 5255
GOTO 5550
5255 CLS
     LOCATE 7, 8: PRINT USING "ALPD = ####.##   PSID = ####.##   PHID = ####.##"; ALPD; PSID; PHID
5320 LOCATE 10, 8: PRINT "1.  CHANGE ALPD"
     LOCATE 11, 8: PRINT "2.  CHANGE PSID"
     LOCATE 12, 8: PRINT "3.  CHANGE PHID"
     LOCATE 13, 8: PRINT "4.  CHANGE ALPD, PSID, PHID"
     LOCATE 14, 8: PRINT "5.  DO NOT CHANGE ANY ANGLES"
     LOCATE 16, 8: INPUT "ENTER THE NUMBER OF THE PARAMETER YOU WISH TO CHANGE "; NUM
  IF NUM = 1 GOTO 5420
  IF NUM = 2 GOTO 5440
  IF NUM = 3 GOTO 5460
```

```
  IF NUM = 4 GOTO 5480
  IF NUM = 5 GOTO 2110
5420   LOCATE 18, 8: INPUT "ALPD = "; ALPD
GOTO 5500
5440   LOCATE 18, 8: INPUT "PSID = "; PSID
GOTO 5500
5460   LOCATE 18, 8: INPUT "PHID = "; PHID
GOTO 5500
5480   LOCATE 18, 8: INPUT "ALPD, PSID, PHID (SEPARATED BY A COMMA) "; ALPD, PSID, PHID
5500 ALPD = ALPD * (PI / 180)
PHID = PHID * (PI / 180)
PSID = PSID * (PI / 180)
NUM = 6
GOTO 3560
5550 NUM = 7
RETURN
REM----SUBROUTINE TO CURVE FIT A PARTICULAR RANGE OF THE DATA-----------
5580 CLS
LOCATE 5, 8: PRINT "WHEN USING THIS OPTION, THE PROGRAM NO LONGER STEPS"
LOCATE 6, 8: PRINT "THROUGH THE DATA FILE SEQUENTIALLY.  IF THIS OPTION IS"
LOCATE 7, 8: PRINT "USED, MAKE SURE THAT ALL DATA IN THE DATA FILE HAS BEEN CURVE FIT"
LOCATE 8, 8: PRINT "BEFORE QUITTING THE PROGRAM.  OTHERWISE THE OUTPUTTED DATA"
LOCATE 9, 8: PRINT "FILE WILL NOT HAVE THE PROPER CORRECTIONS APPLIED TO THE DATA."
LOCATE 10, 8: PRINT "ONE SUGGESTION IS TO ALWAYS RETURN TO THE POSITION WHERE YOU LEFT"
LOCATE 11, 8: PRINT "OFF AFTER YOU FINISH CURVE FITTING A PARTICULAR RANGE OF DATA."
LOCATE 14, 8: PRINT "        STRIKE ANY KEY TO CONTINUE "
PRINT
 JUNK$ = INPUT$(1)
 COUNT = 0
 PRINT
 PRINT USING "&"; HEAD$
 PRINT
FOR II = 1 TO NP1
PRINT USING "####   ##.##  ####.##  ###.##  ##.#####  ##.#####  ##.####  ##.####  ###.####"; II; TAU(II); PHIP(II); ALPP(II); DP13(II); DP24(II); P1(II); P2(II); P5(II)
  COUNT = COUNT + 1
  IF COUNT < 18 THEN GOTO 5820
  COUNT = 0
PRINT
PRINT "        STRIKE ANY KEY TO CONTINUE "
PRINT
JUNK$ = INPUT$(1)
5820 NEXT II
PRINT
PRINT "ENTER THE POSITION NUMBERS OF THE RANGE"
INPUT "TO CURVE FIT (SEPARATED BY A COMMA) "; INC1, INC
PRINT
POINTS = (INC - INC1) + 1
CNT1 = 0
CNT2 = 0
```

```
GOTO 1170
910 COUNT = 0
CLS
HEAD$ = " POINT  MACH    PHI    ALPHA    DP13    DP24    P1    P2    P5"
PRINT USING "&"; HEAD$
PRINT
FOR II = INC1 TO INC
PRINT USING "#####  ##.##  #####.##  ####.##  ##.######  ##.######  ##.#####  ##.#####  ####.#####"; II; TAU(II); PHIP(II); ALPP(II); DP13(II); DP24(II); P1(II); P2(II); P5(II)
   COUNT = COUNT + 1
   IF COUNT < 18 THEN GOTO 720
   COUNT = 0
   PRINT
   PRINT "       STRIKE ANY KEY TO CONTINUE "
   PRINT
   JUNK$ = INPUT$(1)
720 NEXT II
RETURN
```

Appendix 3. (concluded)

```
C**************** MFAFIT ******************************
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 MINF
      DIMENSION IRUN(500),IPRB(500),
     1 PHI(500),DP24(500),DP13(500)
      COMMON/MEAS/MINF(500),DPSQP(500),PAVGP5(500),Q(500)
C
      OPEN (UNIT=9,FILE='AMODR.DAT',STATUS='NEW')
      OPEN (UNIT=10,FILE='MMODR.DAT',STATUS='NEW')

      WRITE (*,*) 'THIS PROGRAM IS USED TO CALIBRATE MFA PROBES'
      WRITE (*,*) 'TO MEASURE MACH NUMBER AND ANGLE OF ATTACK'
      WRITE (*,*) 'AN UNMODIFIED DATA SET NAME HAS BEEN CREATED'
      WRITE (*,*) 'FROM THE MFAFIXQB PROGRAM WITH THE FOLLOWING'
      WRITE (*,*) 'FORMAT(2I3,7F10.4,I4) RUN PROBE M PAVGP5 DPSQP'
      WRITE (*,*) 'ALPHAT PHIT DP24 DP13'
      WRITE (*,*) 'NOTE, LAST DATA LOOP MUST HAVE 999 IN COLUMNS'
      WRITE (*,*) '78 79 80. AFTER THIS PROGRAM HAS FINISHED, PLOTS'
      WRITE (*,*) 'WILL BE PLOTTED FROM GRAPHER'
      WRITE (*,*)
      WRITE (*,*)
      OPEN (UNIT=2,FILE='UMOD.DAT',STATUS='OLD')
       I=0
       JJ=0
333    I=I+1
      READ (2,300) IRUN(I),IPRB(I),MINF(I),PAVGP5(I),DPSQP(I),Q(I),
     1 PHI(I),DP24(I),DP13(I),JJ
      WRITE (9,300) IRUN(I),IPRB(I),MINF(I),PAVGP5(I),DPSQP(I),Q(I),
     1 PHI(I),DP24(I),DP13(I),JJ
      WRITE (10,300) IRUN(I),IPRB(I),MINF(I),PAVGP5(I),DPSQP(I),Q(I),
     1 PHI(I),DP24(I),DP13(I),JJ
       IF(JJ.NE.999) GO TO 333
300   FORMAT(2I3,7F10.4,I4)
C
      STOP
      END
```

Appendix 4. MFAFIT.FOR

```
C
****************** MACH ****************************
C
C ***************************************************************
C                  NOMENCLATURE
C
C    NITER       NUMBER OF ITERATIONS
C    BOUND       CONVERGENCE CRITERIA
C    IRUN        RUN NUMBER
C    IPRB        PROBE NUMBER
C    MINF        MEASURED FREESTREAM MACH NUMBER
C    PAVGP5      PROBE MACH NUMBER PARAMETER
C    DPSQP       NORMALIZED PROBE TOTAL ANGLE OF ATTACK
C    ALPI        TOTAL ANGLE OF ATTACK
C    PHI         ROLL ANGLE
C    TAUL        Pinf/PT2 BASED ON Minf
C    AACON       INITIAL ESTIMATES OF COEFFICIENTS
C    NCON        DEFINES NUMBER OF ZERO COEFFICIENTS (1 OR 0)
C    NC          MAXIMUM NUMBER OF COEFFICIENTS
C    NSUM        ACTUAL NUMBER OF COEFFICIENTS
C    N, XN       NUMBER OF VALUES TO BE CURVE FITTED
C    NR          ITERATION LOOP NUMBER
C    C, WXX      ITERATED COEFFICIENT VALUE
C    EC          CONVERGENCE IN PERCENT OF BOUND
C
C ***************************************************************
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 M(500),MINF

      DIMENSION C(30,60),CON(30),CCON(30),NCON(30),
     *     WXX(30),ACON(30),WX(30),CT(30,31),
     *     CC(30,60),AACON(30),IRUN(500),IPRB(500),
     *     PHI(500),DP24(500),DP13(500)

      COMMON/MEAS/MINF(500),DPSQP(500),DIA(500),TW(500),
     * PAVGP5(500),CF(500),ALPI(500),M,TAUL(500)
      COMMON/CALC/TAUC(500),PT(1),RT(500),CFC(500),TAUCL(500)

      EQUIVALENCE (C(1,1),CC(1,1))
C     THESE VALUES MAY BE CHANGED IF NECESSARY FOR BETTER FIT
C
C  ***************** INITIAL GUESSES OF CURVEFITS **************
C
C     DATA AACON/5*1.,0.,10*1.,14*0./
      DATA NCON/5*1,0,10*1,14*0/
      DATA AACON/-11.164,58.4913,-109.91,92.3711,-28.7941,0.,
     * -8031.42,43518.2,-87887.4,78374.9,-26009.8,-492067.,
     * 2952040.,-6621550.,6582950.,-2448440.,14*0./
```

Appendix 5. MACH.FOR

```
      NITER=20
      BOUND=1.0E-16
C
      OPEN (UNIT=12,FILE='ANS.DAT',STATUS='OLD')
      READ (12,*) IPRINT
      OPEN (UNIT=14,FILE='MACH.DAT',STATUS='OLD')
      READ (14,*) ISPEED
      IF (IPRINT .EQ. 2) GOTO 828
      OPEN (UNIT=7,FILE='PRN',STATUS='NEW')
      GOTO 829
828   OPEN (UNIT=7,FILE='FILE3.DAT',STATUS='NEW')
829   OPEN (UNIT=10,FILE='MMODR.DAT',STATUS='OLD')
      OPEN (UNIT=20,FILE='MCOEF.DAT',STATUS='NEW')

      I=0
      JJ=0
308   I=I+1
      READ(10,300)IRUN(I),IPRB(I),MINF(I),PAVGP5(I),DPSQP(I),
     1 ALPI(I),PHI(I),DP24(I),DP13(I),JJ
      IF(MINF(I).NE.0.) THEN
      IF(ISPEED .EQ. 2) THEN
      TAUL(I)=(1+(MINF(I)**2)/5)**(-3.5)
      ELSE
      TAUL(I)=1.0/(((6*MINF(I)**2)/5)**3.5*(6/
     1 ((7*MINF(I)**2)-1))**2.5)
      ENDIF
      ENDIF
      IF(MINF(I).NE.0.) GO TO 350
      MINF(I)=MINF(I-1)
      PAVGP5(I)=PAVGP5(I-1)
      DPSQP(I)=DPSQP(I-1)
      ALPI(I)=ALPI(I-1)
      TAUL(I)=TAUL(I-1)
350   CONTINUE
      IF(JJ.NE.999) GO TO 308
300   FORMAT(2I3,7F10.4,I4)
      N=I
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,222)
      ELSE
      WRITE(7,113)
      ENDIF
      DO 330 I=1,N
330   WRITE(7,114) MINF(I),TAUL(I),PAVGP5(I),DPSQP(I),ALPI(I),
     * IRUN(I),IPRB(I),I
113   FORMAT(1H1,35X,'MACH INPUT VARIABLES',//,4X,'M',11X,'P/Pt2',9X,
     1 'PAVGP5',8X,'DPSQP',9X,'ALPHA',6X,'RUN',1X,'PROBE',/)
114   FORMAT(1X,F6.2,4X,3(F10.4,4X)F10.2,6X,I3,1X,I3,2X,I3)
222   FORMAT(1H1,35X,'MACH INPUT VARIABLES',//,4X,'M',12X,'P/Pt',9X,
```

Appendix 5. (continued)

```
     1 'PAVGP5',8X,'DPSQP',9X,'ALPHA',6X,'RUN',1X,'PROBE',/)
       WRITE(7,115)
       NC=30
       NSUM=0
C
C      DEFINES INITIAL ESTIMATES OF CONSTANTS
C
       DO 12 I=1,NC
       ACON(I)=AACON(I)
12     CCON(I)=0.D+0
C
C      DETERMINES WHICH CONSTANTS WILL BE COMPUTED
C
       DO 11 I=1,NC
       IF(NCON(I).EQ.1) CCON(I)=1.D+0
11     IF(NCON(I).EQ.1) NSUM=NSUM+1
C
C      DEFINES NUMBER OF CONSTANTS
C
       SUM=NSUM
       XN=N
       DO 605 I=1,NC
605    CON(I)=ACON(I)
       CHECK=XN-SUM
       IF(CHECK.LE.0.D+0) GO TO 999
       NT=NC+1
       E=0.D+0
       NR=0
20     CONTINUE
       CALL INTGRL(RESSUM,N,C,CON,CCON,NC)
C
C      CHECK FOR CONVERGENCE
C
       IF(NSUM.GT.0) GO TO 601
       DO 600 I=1,NC
       WXX(I)=0.D+0
600    ACON(I)=CON(I)
       GO TO 603
601    CONTINUE
       NR=NR+1
       RESSUM=DSQRT(RESSUM)
       E1=RESSUM/DSQRT(XN-SUM)
       EC=DABS((E1-E)/BOUND)*100
       WRITE(7,110)RESSUM,E1,EC
       IF(DABS(E1-E)-BOUND) 36,36,21
21     IF(NR-NITER) 22,22,36
22     NTRIG=0
38     CONTINUE
       E=E1
```

Appendix 5. (continued)

```
      IF(NSUM.EQ.1) GO TO 33
C
C     CONTRACT C MATRIX - REMOVE ZERO ROWS AND COLUMNS
C
      DO 23 I=1,NC
      DO 23 J=1,NT
23    CT(I,J)=C(I,J)
      LL=0
      DO 90 I=1,NC
92    IF((I+LL).GT.NC) GO TO 90
      IF(NCON(I+LL)) 91,91,93
91    LL=LL+1
      GO TO 92
93    L=LL+I
      DO 94 K=1,NT
94    C(I,K)=CT(L,K)
90    CONTINUE
      LL=0
      LM=NSUM
      DO 80 I=1,NC
82    IF((I+LL).GT.NC) GO TO 80
      IF(NCON(I+LL)) 81,81,83
81    LL=LL+1
      GO TO 82
83    L=LL+I
      DO 84 K=1,LM
84    CT(K,I)=C(K,L)
80    CONTINUE
      DO 85 I=1,LM
85    CT(I,LM+1)=C(I,NT)
      L=NSUM
      LL=NSUM+1
      DO 71 I=1,L
      DO 71 J=1,L
71    C(I,J)=CT(I,J)
C
C     MATRIX INVERSION OF C
C
      IF(NTRIG) 40,27,40
27    CALL INV(CT,L,LL,WX,CC)
      GO TO 41
40    CALL INV(CT,L,L,WX,CC)
41    DO 32 I=1,NC
      C(I,LL)=0.D+0
      WX(I)=CT(I,I)
32    WXX(I)=0.D+0
      LM=0
C
C     EXPAND C INVERSE TO INCLUDE ZERO ROWS AND COLUMNS
```

Appendix 5. (continued)

```
C
      DO 31 I=1,NC
      IF(NCON(I)) 28,28,30
28    LM=LM-1
      GO TO 31
30    IT=LM+I
      C(I,LL)=CT(IT,LL)
      WXX(I)=WX(IT)
31    CONTINUE
      GO TO 34
C
C     SOLVE FOR CORRECTION TO COEFFICIENTS
C
33    DO 35 I=1,NC
      IF(NCON(I)-1) 39,49,49
49    C(I,NT)=C(I,NT)/C(I,I)
      WXX(I)=1.D+0/C(I,I)
      GO TO 35
39    C(I,NT)=0.D+0
      WXX(I)=0.D+0
35    CONTINUE
      LL=NT
34    IF(NTRIG.EQ.1) GO TO 42
      WRITE(7,104) NR
      DO 60 I=1,NC
60    WXX(I)=C(I,LL)
      DO 50 I=1,NC
      ACON(I)=CON(I)
50    WRITE(7,103) ACON(I),WXX(I)
      DO 43 I=1,NC
43    CON(I)=CON(I)+C(I,LL)
      GO TO 20
36    CONTINUE
      NTRIG=1
37    GO TO 38
42    CONTINUE
C
C     COMPUTE PROBABLE ERROR IN COEFFICIENTS
C
      DO 44 I=1,NC
44    WXX(I)=E1*DSQRT(DABS(WXX(I)))
603   WRITE(7,105)
604   CONTINUE
      IF(NR.GT.NITER) WRITE(7,109)NR
      DO 45 I=1,NC
      WRITE(20,106) I,ACON(I),WXX(I)
45    WRITE(7,106) I,ACON(I),WXX(I)
      WRITE(20,110)RESSUM,E1,E
      JJ=1
```

Appendix 5. (continued)

```
      II=1
47    IF(ISPEED .EQ. 2) THEN
      WRITE(7,223)
      ELSE
      WRITE(7,107)
      ENDIF
      SUMERR=0.
      DO 210 I=1,N
      ERROR=TAUL(I)-TAUCL(I)
      ERROR=ERROR/TAUL(I)
      ERROR=ERROR*100.D+0
      SUMERR=SUMERR+ERROR**2
      NTEMP=II*50
      IF(NTEMP.EQ.I) THEN
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,223)
      ELSE
      WRITE(7,107)
      ENDIF
      ENDIF
      IF(NTEMP.EQ.I) II=II+1
210   WRITE(7,116) DPSQP(I),ALPI(I),PAVGP5(I),MINF(I),TAUL(I),
     1 TAUCL(I),ERROR,IRUN(I),IPRB(I),I
      SUMERR=DSQRT(SUMERR/(XN-SUM))
      WRITE(7,*)
      WRITE(7,142) SUMERR
      DO 606 I=1,NC
606   AACON(I)=ACON(I)
999   CONTINUE
105   FORMAT(///,6X,'MACH FINAL CONSTANTS AND PROBABLE ERROR',10X,/)
106   FORMAT(5X,'C(',I3,') =',E13.6,5X,'(',E13.6,')',2X)
109   FORMAT(1X,'**** CONVERGENCE CRITERIA NOT SATISFIED AFTER',I4,
     1 1X,'ITERATIONS ****')
110   FORMAT(1H1,1X,'SUM OF RESIDUALS',E13.6,5X,
     1 'NEW RMS DEVIATION  =',E13.6,5X,'PERCENT OF CONVERGENCE ',
     2 'CRITERIA =',E13.6)
104   FORMAT(/,1X,'ITERATION NO ',I3,/,4X,'CON',13X,'DELTA CON')
103   FORMAT(1X,2(E13.6,5X))
107   FORMAT(1H1,5X,'DATA FIT COMPARISON',//,2X,
     1 'DPSQP/MEAS',4X,'ALPHA/MEAS',6X,'PAVGP5/MEAS',3X,'M/MEAS',5X,
     2 '(P/Pt2)/MEAS',2X,'(P/Pt2)/CALC',2X,'ERROR (%)',5X,
     3 'RUN',1X,'PROBE',/)
223   FORMAT(1H1,5X,'DATA FIT COMPARISON',//,2X,
     1 'DPSQP/MEAS',4X,'ALPHA/MEAS',6X,'PAVGP5/MEAS',3X,'M/MEAS',5X,
     2 '(P/Pt)/MEAS',3X,'(P/Pt)/CALC',3X,'ERROR (%)',5X,
     3 'RUN',1X,'PROBE',/)
142   FORMAT(6X,'STANDARD DEVIATION OF THE ERRORS (%) =',E12.4)
115   FORMAT(1H1)
116   FORMAT(1X,3(F10.4,4X),F8.2,4X,2(F10.4,4X),
```

Appendix 5. (continued)

```
     1 E11.4,5X,I3,1X,I3,2X,I3)
       STOP
       END
C
       SUBROUTINE INTGRL(RESSUM,N,C,CON,CCON,NC)
C
       IMPLICIT REAL*8(A-H,O-Z)
       REAL*8 MW(500),M
       DIMENSION C(30,60),CON(30),CCON(30),P(100)
       COMMON/MEAS/TAUO(500),DPSQP(500),DIA(500),T(500),
     1 PAVGP5(500),CF(500),ALPI(500),MW,TAUOL(500)
       COMMON/CALC/TAUCO(500),PT(1),RT(500),CFC(500),TAUCOL(500)
       DO 300 I=1,N
       S1=0.D+0
       S2=0.D+0
       S3=0.D+0
C      S4=0.D+0
C      S5=0.D+0
       DO 400 J=1,5
       S1=S1+CON(J+1)*(PAVGP5(I))**J
       S2=S2+CON(6+J)*(DPSQP(I)**2)*(PAVGP5(I))**(J-1)
       S3=S3+CON(11+J)*(DPSQP(I)**4)*(PAVGP5(I))**(J-1)
C      S4=S4+CON(16+J)*(DPSQP(I)**6)*(PAVGP5(I))**(J-1)
C      S5=S5+CON(21+J)*(DPSQP(I)**8)*(PAVGP5(I))**(J-1)
400    CONTINUE
300    TAUCOL(I)=(CON(1)+S1+S2+S3)
C      TAUCO(I)=TAUCOL(I)
       NL=NC+1
C
C      RESET THE MATRIX COEFFICIENTS TO ZERO
C
       DO 301 I=1,NC
       DO 301 J=1,NL
301    C(I,J)=0.D+0
       RESSUM=0.D+0
       DO 302 K=1,N
       DO 303 I=1,NC
       S1=0.D+0
       S2=0.D+0
       S3=0.D+0
C      S4=0.D+0
C      S5=0.D+0
       DO 401 J=1,5
       D2=(PAVGP5(K))**J
       D1=(PAVGP5(K))**(J-1)
       S1=S1+DUM(J+1,I)*D2
       S2=S2+DUM(J+6,I)*(DPSQP(K)**2)*D1
       S3=S3+DUM(J+11,I)*(DPSQP(K)**4)*D1
C      S4=S4+DUM(J+16,I)*(DPSQP(K)**6)*D1
```

Appendix 5. (continued)

```
C       S5=S5+DUM(J+21,I)*(DPSQP(K)**8)*D1
401     CONTINUE
        P(I)=TAUCOL(K)*(DUM(1,I)+S1+S2+S3)
303     P(I)=P(I)/TAUOL(K)
        DO 304 I=1,NC
        DO 304 J=1,NC
        C(I,J)=C(I,J)+P(I)*P(J)
        C(I,J)=C(I,J)*CCON(I)*CCON(J)
304     CONTINUE
        DO 305 J=1,NC
        C(J,NL)=C(J,NL)+(TAUOL(K)-TAUCOL(K))*P(J)
305     C(J,NL)=C(J,NL)*CCON(J)
302     RESSUM=RESSUM+((TAUOL(K)-TAUCOL(K))/TAUOL(K))**2
        RETURN
        END
C
        SUBROUTINE INV(C,NC,NCS1,WXX,CC)
C
        IMPLICIT REAL*8(A-H,O-Z)
        DIMENSION WXX(30),PIVOT(2),C(30,31),CC(30,60)
3000    FORMAT(/10X,'DET IS EQUAL TO ZERO')
        NCT=NC*2
        NCP1=NC+1
        DO 10 I=1,NC
        DO 10 J=1,NC
10      CC(I,J)=C(I,J)
        DO 20 I=1,NC
        DO 20 J=NCP1,NCT
20      CC(I,J)=0.D+0
        DO 30 I=1,NC
30      CC(I,NC+I)=1.D+0
        DO 205 I=1,NC
        PIVOT(1)=CC(I,I)
        DO 200 K=1,NC
        PIVOT(2)=CC(K,I)
126     IF(K-I) 135,130,140
130     DO 150 J=1,NCT
        IF(PIVOT(1)) 134,210,134
134     CC(K,J)=CC(I,J)/PIVOT(1)
150     CONTINUE
        GO TO 200
135     DO 160 J=1,NCT
        IF(PIVOT(1)) 136,160,136
136     CC(K,J)=CC(K,J)-CC(I,J)*PIVOT(2)/PIVOT(1)
160     CONTINUE
        GO TO 200
140     DO 170 J=1,NCT
        IF(PIVOT(2)) 145,170,145
145     CC(K,J)=CC(K,J)/PIVOT(2)-CC(I,J)
```

Appendix 5. (continued)

```
170     CONTINUE
200     CONTINUE
205     CONTINUE
        GO TO 250
210     WRITE(7,3000)
250     DO 300 I=1,NC
        DO 300 J=1,NC
300     C(I,J)=CC(I,J+NC)
        NCS=NCS1
350     IF(NCS-NC) 500,500,400
400     DO 420 I=1,NC
        WXX(I)=C(I,NCS)
420     C(I,NCS)=0.D+0
        DO 450 I=1,NC
        DO 450 J=1,NC
450     C(I,NCS)=C(I,NCS)+C(I,J)*WXX(J)
        NCS=NCS-1
        GO TO 350
500     CONTINUE
        RETURN
        END
        FUNCTION DUM(I,J)
        IMPLICIT REAL*8(A-H,O-Z)
        DUM=0.D+0
        IF(I.EQ.J) DUM=1.D+0
        RETURN
        END
```

Appendix 5. (concluded)

```
C
C********************** ALPHA *********************************
C
C*****************************************************************
C            NOMENCLATURE
C
C   NITER        NUMBER OF ITERATIONS
C   BOUND        CONVERGENCE CRITERIA
C   IRUN         RUN NUMBER
C   IPRB         PROBE NUMBER
C   MINF         MEASURED FREESTREAM MACH NUMBER
C   PAVGP5       PROBE MACH NUMBER PARAMETER
C   DPSQP        NORMALIZED PROBE ANGLE OF ATTACK
C   ALPI         TOTAL ANGLE OF ATTACK
C   PHI          ROLL ANGLE
C   TAUL         PINF/PT2 BASED ON Minf
C   AACON        INITIAL ESTIMATES OF COEFFICIENTS
C   NCON         DEFINES NUMBER OF COEFFICIENTS (1 OR 0)
C   NC           MAXIMUM NUMBER OF COEFFICIENTS
C   NSUM         ACTUAL NUMBER OF COEFFICIENTS
C   N, XN        NUMBER OF VALUES TO BE CURVE FITTED
C   NR           ITERATION LOOP NUMBER
C   C, WXX       ITERATED COEFFICIENT VALUE
C   EC           CONVERGENCE IN PERCENT OF BOUND
C
C*****************************************************************
C
      IMPLICIT REAL*8 (A-H,O-Z)

      REAL*8 MINF

      DIMENSION C(30,60),CON(30),CCON(30),NCON(30),
     *     WXX(30),ACON(30),WX(30),CT(30,31),
     *     CC(30,60),AACON(30),IRUN(500),IPRB(500),
     *     PHI(500),DP24(500),DP13(500)

      COMMON/MEAS/MINF(500),DPSQP(500),DIA(500),TW(500),PAVGP5(500),
     *     CF(500),ALPI(500),TAUL(500)

      EQUIVALENCE (C(1,1),CC(1,1))
C
C***** INITIAL GUESSES OF CURVEFITS ***************
C
      DATA AACON/-62197.6,253388.,-341533.,152799.,-1926.14,
     *  2553.6,24*0./
      DATA NCON/6*1,24*0/

      NITER=20
      BOUND=1.0E-20
```

Appendix 6. ALPHA.FOR

```
      OPEN (UNIT=12,FILE='ANS.DAT',STATUS='OLD')
      READ (12,*) IPRINT
      OPEN (UNIT=14,FILE='MACH.DAT',STATUS='OLD')
      READ (14,*) ISPEED
      IF (IPRINT .EQ. 2) GOTO 828
      OPEN (UNIT=7,FILE='PRN',STATUS='NEW')
      GOTO 829
828   OPEN (UNIT=7,FILE='FILE4.DAT',STATUS='NEW')
829   OPEN (UNIT=21,FILE='ACOEF.DAT',STATUS='NEW')
      OPEN (UNIT=31,FILE='AMODR.DAT',STATUS='OLD')

       I=0
       JJ=0
308    I=I+1
       READ(31,300) IRUN(I),IPRB(I),MINF(I),PAVGP5(I),DPSQP(I),
     1 ALPI(I),PHI(I),DP24(I),DP13(I),JJ
       IF(MINF(I).NE.0.) THEN
       IF(ISPEED .EQ. 2) THEN
       TAUL(I)=(1+(MINF(I)**2)/5)**(-3.5)
       ELSE
       TAUL(I)=1.0/(((6*MINF(I)**2)/5)**3.5*(6/
     1 ((7*MINF(I)**2)-1))**2.5)
       ENDIF
       ENDIF
       IF(MINF(I).NE.0.) GO TO 350
       MINF(I)=MINF(I-1)
       PAVGP5(I)=PAVGP5(I-1)
       DPSQP(I)=DPSQP(I-1)
       ALPI(I)=ALPI(I-1)
       TAUL(I)=TAUL(I-1)
350    CONTINUE
       IF(JJ.NE.999) GO TO 308
300    FORMAT(213,7F10.4,I4)
       N=I
       IF(ISPEED .EQ. 2) THEN
       WRITE(7,222)
       ELSE
       WRITE(7,113)
       ENDIF
       DO 330 I=1,N
330    WRITE(7,114) MINF(I),TAUL(I),PAVGP5(I),DPSQP(I),ALPI(I),
     * IRUN(I),IPRB(I),I
113    FORMAT(1H1,35X,'ALPHA INPUT VARIABLES',//,6X,'M',11X,'P/Pt2',
     1 9X,'PAVGP5',8X,'DPSQP',7X,'ALPHA',6X,'RUN',1X,'PROBE',/)
114    FORMAT(1X,F8.2,4X,3(F10.4,4X),F8.2,6X,I3,1X,I3,2X,I3)
222    FORMAT(1H1,35X,'ALPHA INPUT VARIABLES',//,6X,'M',11X,'P/Pt',
     1 10X,'PAVGP5',8X,'DPSQP',7X,'ALPHA',6X,'RUN',1X,'PROBE',/)
       WRITE(7,115)
```

Appendix 6. (continued)

```
      NC=30
      NSUM=0
C
C     DEFINES INITIAL ESTIMATE OF CONSTANTS
C
      DO 12 I=1,NC
      ACON(I)=AACON(I)
12    CCON(I)=0.D+0
C
C     DETERMINES WHICH CONSTANTS WILL BE COMPUTED
C
      DO 11 I=1,NC
      IF(NCON(I).EQ.1) CCON(I)=1.D+0
11    IF(NCON(I).EQ.1) NSUM=NSUM+1
C
C     DEFINES NUMBER OF CONSTANTS
C
      SUM=NSUM
      XN=N
      DO 605 I=1,NC
605   CON(I)=ACON(I)
      CHECK=XN-SUM
      IF(CHECK.LE.0.D+0) GO TO 999
      NT=NC+1
      E=0.D+0
      NR=0
20    CONTINUE
      CALL INTGRL(RESSUM,N,C,CON,CCON,NC)
C
C     CHECK FOR CONVERGENCE
C
      IF(NSUM.GT.0) GO TO 601
      DO 600 I=1,NC
      WXX(I)=0.D+0
600   ACON(I)=CON(I)
      GO TO 603
601   CONTINUE
      NR=NR+1
      RESSUM=DSQRT(RESSUM)
      E1=RESSUM/DSQRT(XN-SUM)
      EC=DABS((E1-E)/BOUND)*100
      WRITE(7,110)RESSUM,E1,EC
      IF(DABS(E1-E)-BOUND) 36,36,21
21    IF(NR-NITER) 22,22,36
22    NTRIG=0
38    CONTINUE
      E=E1
      IF(NSUM.EQ.1) GO TO 33
C
```

Appendix 6. (continued)

```
C       CONTRACT C MATRIX - REMOVE ZERO ROWS AND COLUMNS
C
        DO 23 I=1,NC
        DO 23 J=1,NT
23      CT(I,J)=C(I,J)
        LL=0
        DO 90 I=1,NC
92      IF((I+LL).GT.NC) GO TO 90
        IF(NCON(I+LL)) 91,91,93
91      LL=LL+1
        GO TO 92
93      L=LL+I
        DO 94 K=1,NT
94      C(I,K)=CT(L,K)
90      CONTINUE
        LL=0
        LM=NSUM
        DO 80 I=1,NC
82      IF((I+LL).GT.NC) GO TO 80
        IF(NCON(I+LL)) 81,81,83
81      LL=LL+1
        GO TO 82
83      L=LL+I
        DO 84 K=1,LM
84      CT(K,I)=C(K,L)
80      CONTINUE
        DO 85 I=1,LM
85      CT(I,LM+1)=C(I,NT)
        L=NSUM
        LL=NSUM+1
        DO 71 I=1,L
        DO 71 J=1,L
71      C(I,J)=CT(I,J)
C
C       MATRIX INVERSION OF C
C
        IF(NTRIG) 40,27,40
27      CALL INV(CT,L,LL,WX,CC)
        GO TO 41
40      CALL INV(CT,L,L,WX,CC)
41      DO 32 I=1,NC
        C(I,LL)=0.D+0
        WX(I)=CT(I,I)
32      WXX(I)=0.D+0
        LM=0
C
C       EXPAND C INVERSE TO INCLUDE ZERO ROWS AND COLUMNS
C
        DO 31 I=1,NC
```

Appendix 6. (continued)

```
      IF(NCON(I)) 28,28,30
28    LM=LM-1
      GO TO 31
30    IT=LM+I
      C(I,LL)=CT(IT,LL)
      WXX(I)=WX(IT)
31    CONTINUE
      GO TO 34
C
C     SOLVE FOR CORRECTION TO COEFFICIENTS
C
33    DO 35 I=1,NC
      IF(NCON(I)-1) 39,49,49
49    C(I,NT)=C(I,NT)/C(I,I)
      WXX(I)=1.D+0/C(I,I)
      GO TO 35
39    C(I,NT)=0.D+0
      WXX(I)=0.D+0
35    CONTINUE
      LL=NT
34    IF(NTRIG.EQ.1) GO TO 42
      WRITE(7,104) NR
      DO 60 I=1,NC
60    WXX(I)=C(I,LL)
      DO 50 I=1,NC
      ACON(I)=CON(I)
50    WRITE(7,103) ACON(I),WXX(I)
      DO 43 I=1,NC
43    CON(I)=CON(I)+C(I,LL)
      GO TO 20
36    CONTINUE
      NTRIG=1
37    GO TO 38
42    CONTINUE
C
C     COMPUTE PROBABLE ERROR IN COEFFICIENTS
C
      DO 44 I=1,NC
44    WXX(I)=E1*DSQRT(DABS(WXX(I)))
603   WRITE(7,105)
      IF(NR.GT.NITER) WRITE(7,109) NR
      DO 45 I=1,NC
      WRITE(21,106)I,ACON(I),WXX(I)
45    WRITE(7,106) I,ACON(I),WXX(I)
      WRITE(21,110)RESSUM,E1,EC
      JJ=1
      II=1
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,223)
```

Appendix 6. (continued)

```
      ELSE
      WRITE(7,107)
      ENDIF
      DO 210 I=1,N
      ERROR=ALPI(I)-DIA(I)
      SUMERR=SUMERR+ERROR**2
      NTEMP=II*50
      IF(NTEMP.EQ.I) THEN
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,223)
      ELSE
      WRITE(7,107)
      ENDIF
      ENDIF
      IF(NTEMP.EQ.I) II=II+1
210   WRITE(7,116) DPSQP(I),MINF(I),TAUL(I),PAVGP5(I),ALPI(I),DIA(I),
     1 ERROR,IRUN(I),IPRB(I),I
      SUMERR=DSQRT(SUMERR/(XN-SUM))
      WRITE(7,*)
      WRITE(7,142) SUMERR
      DO 606 I=1,NC
606   AACON(I)=ACON(I)
999   CONTINUE
105   FORMAT(///,6X,'ALPHA FINAL CONSTANTS AND PROBABLE ERROR',10X,/)
106   FORMAT(5X,'C(',I3,') =',E13.6,5X,'(',E13.6,')',2X)
109   FORMAT(1X,'**** CONVERGENCE CRITERIA NOT SATISFIED AFTER',I4,
     1 1X,'ITERATIONS ****')
110   FORMAT(1H1,1X,'SUM OF RESIDUALS',E13.6,5X,
     1 'NEW RMS DEVIATION  =',E13.6,5X,'PERCENT OF CONVERGENCE ',
     2 'CRITERIA =',E13.6)
104   FORMAT(/,1X,'ITERATION NO ',I3,/,4X,'CON',13X,'DELTA CON')
103   FORMAT(1X,2(E13.6,5X))
107   FORMAT(1H1,5X,'DATA FIT COMPARISON',//,2X,
     1 'DPSQP/MEAS',6X,'M/MEAS',5X,'(P/Pt2)/MEAS',2X,'PAVGP5/MEAS',3X,
     2 'ALPHA/MEAS',5X,'ALPHA/CALC',5X,
     3 'ERROR',7X,'RUN',1X,'PROBE',/)
223   FORMAT(1H1,5X,'DATA FIT COMPARISON',//,2X,
     1 'DPSQP/MEAS',6X,'M/MEAS',5X,'(P/Pt)/MEAS',3X,'PAVGP5/MEAS',3X,
     2 'ALPHA/MEAS',5X,'ALPHA/CALC',5X,
     3 'ERROR',7X,'RUN',1X,'PROBE',/)
142   FORMAT(6X,'STANDARD DEVIATION OF THE ERRORS (DEG) =',E12.4)
115   FORMAT(1H1)
116   FORMAT(1X,F10.4,4X,F8.2,4X,2(F10.4,4X),2(F10.2,4X),
     1 E11.4,5X,I3,1X,I3,2X,I3)
      STOP
      END
C
C-----------------------------------------------------------------
      SUBROUTINE INTGRL(RESSUM,N,C,CON,CCON,NC)
```

Appendix 6. (continued)

```
C
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 RM
      DIMENSION C(30,60),CON(30),CCON(30),P(100)
      COMMON/MEAS/TAUO(500),DPSQP(500),DIA(500),T(500),PAVGP5(500),
     *     CF(500),ALPI(500),TAUOL(500)
      DO 500 I=1,N
      RM=TAUOL(I)
      S1=CON(1)+CON(2)*RM+CON(3)*RM**2+CON(4)*RM**3
      S2=CON(5)+CON(6)*RM
500   DIA(I)=S1*DPSQP(I)+(S2*DPSQP(I)**1.5)
      NL=NC+1
      DO 301 I=1,NC
      DO 301 J=1,NL
301   C(I,J)=0.D+0
      RESSUM=0.D+0
      DO 302 K=1,N
      RM=TAUOL(K)
      P(1)=DPSQP(K)
      P(2)=P(1)*RM
      P(3)=P(2)*RM
      P(4)=P(3)*RM
      P(5)=DPSQP(K)**1.5
      P(6)=RM*P(5)
      DO 304 I=1,NC
      DO 304 J=1,NC
      C(I,J)=C(I,J)+P(I)*P(J)
      C(I,J)=C(I,J)*CCON(I)*CCON(J)
304   CONTINUE
      DO 305 J=1,NC
      C(J,NL)=C(J,NL)+(ALPI(K)-DIA(K))*P(J)
305   C(J,NL)=C(J,NL)*CCON(J)
302   RESSUM=RESSUM+(ALPI(K)-DIA(K))**2
      RETURN
      END
C
C-----------------------------------------------------------------
      SUBROUTINE INV(C,NC,NCS1,WXX,CC)
C
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION WXX(30),PIVOT(2),C(30,31),CC(30,60)
3000  FORMAT(/10X,'DET IS EQUAL TO ZERO')
      NCT=NC*2
      NCP1=NC+1
      DO 10 I=1,NC
      DO 10 J=1,NC
10    CC(I,J)=C(I,J)
      DO 20 I=1,NC
      DO 20 J=NCP1,NCT
```

Appendix 6. (continued)

```
20      CC(I,J)=0.D+0
        DO 30 I=1,NC
30      CC(I,NC+I)=1.D+0
        DO 205 I=1,NC
        PIVOT(1)=CC(I,I)
        DO 200 K=1,NC
        PIVOT(2)=CC(K,I)
126     IF(K-I) 135,130,140
130     DO 150 J=1,NCT
        IF(PIVOT(1)) 134,210,134
134     CC(K,J)=CC(I,J)/PIVOT(1)
150     CONTINUE
        GO TO 200
135     DO 160 J=1,NCT
        IF(PIVOT(1)) 136,160,136
136     CC(K,J)=CC(K,J)-CC(I,J)*PIVOT(2)/PIVOT(1)
160     CONTINUE
        GO TO 200
140     DO 170 J=1,NCT
        IF(PIVOT(2)) 145,170,145
145     CC(K,J)=CC(K,J)/PIVOT(2)-CC(I,J)
170     CONTINUE
200     CONTINUE
205     CONTINUE
        GO TO 250
210     WRITE(7,3000)
250     DO 300 I=1,NC
        DO 300 J=1,NC
300     C(I,J)=CC(I,J+NC)
        NCS=NCS1
350     IF(NCS-NC) 500,500,400
400     DO 420 I=1,NC
        WXX(I)=C(I,NCS)
420     C(I,NCS)=0.D+0
        DO 450 I=1,NC
        DO 450 J=1,NC
450     C(I,NCS)=C(I,NCS)+C(I,J)*WXX(J)
        NCS=NCS-1
        GO TO 350
500     CONTINUE
        RETURN
        END
        FUNCTION DUM(I,J)
        IMPLICIT REAL*8(A-H,O-Z)
        DUM=0.D+0
        IF(I.EQ.J) DUM=1.D+0
        RETURN
        END
```

Appendix 6. (concluded)

```
***************************** GRAPH ******************************
C
C ***************************************************************
C                        NOMENCLATURE
C
C     IRUN        RUN NUMBER
C     IPRB        PROBE NUMBER
C     MINF        MEASURED FREESTREAM MACH NUMBER
C     PAVGP5      PROBE MACH NUMBER PARAMETER
C     DPSQP       NORMALIZED PROBE TOTAL ANGLE OF ATTACK
C     ALPI        TOTAL ANGLE OF ATTACK
C     PHI         ROLL ANGLE
C     TAUL        Pinf/PT2 BASED ON Minf
C     C(I)        PRESSURE RATIO CURVE FIT COEFFICIENTS
C     A(I)        ALPHAT CURVE FIT COEFFICIENTS
C     N           NUMBER OF MACH LINES TO BE CURVE FITTED
C
C ***************************************************************
C
      IMPLICIT REAL*8 (A-H,O-Z)
      REAL*8 M(12),MINF
      DIMENSION PHI(500),CPHI(500),EPHI(500),AMACH(15),
     * PMIN(50),C(30),TAUCL(500),AMERR(500),TAUEL(500),TAUL(500),
     * MINF(500),A(30),AATCA(500),AAERR(500),DP13(500),DP24(500)
      COMMON/NAME/IRUN(500),IPRB(500),DPSQP(500),PAVGP5(500),ALPI(500)
       OPEN (UNIT=8,FILE='MSOL.DAT',STATUS='NEW')
       WRITE(*,305)
305    FORMAT(1X,'HOW MANY MACH LINES WOULD YOU LIKE SOLUTIONS FOR?,I2')
       READ (*,301) N
       WRITE(8,301) N
301    FORMAT(I2)
       DO 304 I=1,N
       WRITE(*,302) I
       READ (*,303) AMACH(I)
304    WRITE(8,303) AMACH(I)
302    FORMAT(1X,'WHAT IS THE MACH NUMBER OF LINE ',I2,1X,',F10.3?')
303    FORMAT(F10.3)
       CLOSE (UNIT=8)
       OPEN (UNIT=12,FILE='ANS.DAT',STATUS='OLD')
       OPEN (UNIT=14,FILE='MACH.DAT',STATUS='OLD')
       READ (12,*) IPRINT
       READ (14,*) ISPEED
       IF (IPRINT .EQ. 2) GOTO 828
       OPEN (UNIT=7,FILE='PRN',STATUS='NEW')
       GOTO 829
828    OPEN (UNIT=7,FILE='FILE5.DAT',STATUS='NEW')
829    OPEN (UNIT=8,FILE='MSOL.DAT',STATUS='OLD')
       OPEN (UNIT=9,FILE='UMOD.DAT',STATUS='OLD')
       OPEN (UNIT=12,FILE='CURVES.DAT',STATUS='NEW')
```

Appendix 7. GRAPH.FOR

```
      OPEN (UNIT=20,FILE='MCOEF.DAT',STATUS='OLD')
      OPEN (UNIT=21,FILE='ACOEF.DAT',STATUS='OLD')
      K=0
      SAVE=0.0
      I=0
308   I=I+1
      READ(9,300)IRUN(I),IPRB(I),MINF(I),PAVGP5(I),DPSQP(I),
     *ALPI(I),PHI(I),DP24(I),DP13(I),JJ
300   FORMAT(2I3,7F10.4,I4)
      IF(MINF(I).NE.0.) THEN
      IF(ISPEED .EQ. 2) THEN
      TAUL(I)=(1+(MINF(I)**2)/5)**(-3.5)
      ELSE
      TAUL(I)=1.0/(((6*MINF(I)**2)/5)**3.5*(6/
     *((7*MINF(I)**2)-1))**2.5)
      ENDIF
      ENDIF
      IF(MINF(I).NE.0.) GO TO 350
      MINF(I)=MINF(I-1)
      PAVGP5(I)=PAVGP5(I-1)
      DPSQP(I)=DPSQP(I-1)
      ALPI(I)=ALPI(I-1)
      TAUL(I)=TAUL(I-1)
      PHI(I)=PHI(I-1)
      DP24(I)=DP24(I-1)
      DP13(I)=DP13(I-1)
350   CONTINUE
      IF(JJ.NE.999) GO TO 308
      N=I
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,222)
      ELSE
      WRITE(7,113)
      ENDIF
113   FORMAT(1H1,35X,'INPUT VARIABLES',//,7X,'M',8X,'P/Pt2',5X,
     * 'PAVGP5',6X,'DPSQP',5X,'ALPHAT',5X,'PHIT',8X,'DP24',7X,'DP13',
     * 2X,'RUN',2X,'PROBE',/)
222   FORMAT(1H1,35X,'INPUT VARIABLES',//,7X,'M',8X,'P/Pt',6X,
     * 'PAVGP5',6X,'DPSQP',5X,'ALPHAT',5X,'PHIT',8X,'DP24',7X,'DP13',
     * 2X,'RUN',2X,'PROBE',/)
      DO 330 I=1,N
      WRITE(7,114) MINF(I),TAUL(I),PAVGP5(I),DPSQP(I),ALPI(I),
     * PHI(I),DP24(I),DP13(I),IRUN(I),IPRB(I),I
114   FORMAT(F10.2,1X,3(F10.4,1X),2(F10.2,1X),2(F10.4,1X),3(I3,1X))
330   CONTINUE
      IRA=0
      IRC=0
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,223)
```

Appendix 7. (continued)

```
      ELSE
      WRITE(7,462)
      ENDIF
462   FORMAT(1H1,'CONSTANTS',8X,'P/Pt2',20X,'ALPHA',/)
223   FORMAT(1H1,'CONSTANTS',8X,'P/Pt',21X,'ALPHA',/)
      DO 50 I=1,30
      READ(20,120) C(I)
      IF(C(I) .NE. 0.0) IRC=IRC+1
      READ(21,120) A(I)
      IF(A(I) .NE. 0.0) IRA=IRA+1
50    WRITE(7,121) I,C(I),A(I)
120   FORMAT(13X,E13.6)
121   FORMAT(1X,I3,10X,E13.6,10X,E13.6)
123   FORMAT(//,1X,I3,5X,E13.6)
      READ(8,47) NL
47    FORMAT(I2)
      WRITE(7,124)
124   FORMAT(1H1,5X,'GENERATED LINES',//)
      WRITE(7,88)
      WRITE(7,89)
      WRITE(7,90)
      WRITE(7,91)
      WRITE(7,92)
      WRITE(7,93)
88    FORMAT(4X,'CAREFULLY CHECK THE GENERATED MACH LINES TO')
89    FORMAT(4X,'VERIFY THAT THEY DO INDEED MATCH THE CALCULATED')
90    FORMAT(4X,'DATA.  TRYING TO GENERATE MACH LINES CAN')
91    FORMAT(4X,'SOMETIMES GIVE ERRONEOUS NUMBERS.  THE CURVE')
92    FORMAT(4X,'FITS PROVIDE AN ACCURATE SOLUTION WHEN PRESSURE')
93    FORMAT(4X,'MEASUREMENTS ARE USED TO DETERMINE SOLUTIONS',//)
      DO 10 I=1,NL
      READ(8,48) M(I)
      IF(ISPEED .EQ. 2) THEN
      RM=(1+(M(I)**2)/5)**(-3.5)
      ELSE
      RM=1.0/(((6*M(I)**2)/5)**3.5*(6/
     *((7*M(I)**2)-1))**2.5)
      ENDIF
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,226) RM,M(I)
      ELSE
      WRITE(7,20) RM,M(I)
      ENDIF
      DO 15 IJ=1,50
15    PMIN(IJ) = 0.
      DO 14 IK=1,50
      IF(ISPEED .EQ. 2) THEN
        IF(RM .GE. 0.95) THEN
          PMIN(IK) = 0.0004*IK
```

Appendix 7. (continued)

```
        ELSEIF(RM .GE. 0.75) THEN
          PMIN(IK) = 0.0010*IK
        ELSE
          PMIN(IK) = 0.0024*IK
        ENDIF
      ELSE
        IF(RM .GE. 0.25) THEN
          PMIN(IK) =  0.0012*IK
        ELSE
          PMIN(IK) =  0.0024*IK
        ENDIF
      ENDIF
14    CONTINUE
48    FORMAT(F10.3)
      P = RM
      AV1 = 0.D+0
      DO 11 J=1,50
      ITER=0
1000  S1=0.D+0
      S2=0.D+0
      S3=0.D+0
      TS1=0.D+0
      TS2=0.D+0
      TS3=0.D+0
      DO 12 IP=1,5
      S1=S1+C(1+IP)*(P**IP)
      S2=S2+C(6+IP)*(PMIN(J)**2)*(P**(IP-1))
      S3=S3+C(11+IP)*(PMIN(J)**4)*(P**(IP-1))
      TS1 = TS1+IP*C(1+IP)*(P**(IP-1))
      TS2 = TS2+(IP-1)*C(6+IP)*(PMIN(J)**2)*(P**(IP-2))
      TS3 = TS3+(IP-1)*C(11+IP)*(PMIN(J)**4)*(P**(IP-2))
12    CONTINUE
C
C******* NEWTON-RAPHSON METHOD TO ***************
C*******     DETERMINE PAVGP5     ***************
C
      RNUM = -RM + C(1) + S1 + S2 + S3
      DEN = TS1 + TS2 + TS3
      RIP1 = P-RNUM/DEN
      RIP2 = DABS(-RNUM/DEN)
      ITER=ITER+1
      IF(ITER .GE. 10) GOTO 10
      IF(RIP2 .LT. 1.E-12) GOTO 2000
      P = RIP1
      GO TO 1000
2000  P = RIP1
      IF(P .LT. 0.) GOTO 11
      AV=(A(1)+A(2)*P+A(3)*P**2+A(4)*P**3)*PMIN(J)
     1+(A(5)+A(6)*P)*PMIN(J)**1.5
```

Appendix 7. (continued)

```
      IF(AV .LT. 0. .OR. AV .GE. 16.0) GOTO 11
      IF(AV .LT. AV1) GOTO 11
      AV1 = AV
      WRITE(7,21) P,PMIN(J),AV
21    FORMAT(1X,3E11.4)
11    CONTINUE
10    CONTINUE
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,224)
      ELSE
      WRITE(7,107)
      ENDIF
107   FORMAT(1H1,5X,'DATA FIT COMPARISON',//,2X,
     1'DPSQP/M',2X,'PAVGP5/M',2X,'MACH/M',3X,
     2'P/Pt2/M',4X,'P/Pt2/C',3X,'P/Pt2/E',5X,
     3'ALPHA/M',3X,'ALPHA/C',4X,'ALPHA/E',3X,
     4'PHI/M',5X,'PHI/C',5X,'PHI/E',3X,'RUN',1X,'PROBE',1X)
224   FORMAT(1H1,5X,'DATA FIT COMPARISON',//,2X,
     1'DPSQP/M',2X,'PAVGP5/M',2X,'MACH/M',3X,
     2'P/Pt/M',5X,'P/Pt/C',4X,'P/Pt/E',6X,
     3'ALPHA/M',3X,'ALPHA/C',4X,'ALPHA/E',3X,
     4'PHI/M',5X,'PHI/C',5X,'PHI/E',3X,'RUN',1X,'PROBE',1X)
      PRESUM=0.
      ARESUM=0.
      DO 500 I=1,N
      CPHI(I)=((DATAN(-DP24(I)/DP13(I)))*57.2957)
      CPHI(I)=CPHI(I)+90*(1-DP13(I)/DABS(DP13(I)))
      IF(CPHI(I) .LT. 0.) CPHI(I) = CPHI(I) + 360.0
      EPHI(I)=PHI(I)-CPHI(I)
      IF(ABS(EPHI(I)) .GT. 180.) THEN
      IF(CPHI(I).GT.270. .AND. PHI(I).LT.90.) EPHI(I) =
     *(360.-CPHI(I))+(PHI(I)-0.)
      IF(CPHI(I).LT.90. .AND. PHI(I).GT.270.) EPHI(I) =
     *(360.-PHI(I))+(CPHI(I)-0.)
      ENDIF
      FSUM=FSUM+EPHI(I)**2
      S1=0.D+0
      S2=0.D+0
      S3=0.D+0
      DO 400 J=1,5
      S1=S1+C(J+1)*(PAVGP5(I)**J)
      S2=S2+C(6+J)*(DPSQP(I)**2)*(PAVGP5(I)**(J-1))
      S3=S3+C(11+J)*(DPSQP(I)**4)*(PAVGP5(I)**(J-1))
400   CONTINUE
      TAUCL(I)=(C(1)+S1+S2+S3)
      TAUEL(I)=TAUL(I)-TAUCL(I)
      DM=TAUCL(I)
      AMERR(I)=((TAUL(I)-TAUCL(I))*100.)/TAUL(I)
      AATCA(I)=(A(1)+A(2)*DM+A(3)*DM**2+A(4)*DM**3)*DPSQP(I)
```

Appendix 7. (continued)

```
     *+(A(5)+A(6)*DM)*DPSQP(I)**1.5
      AAERR(I)=ALPI(I)-AATCA(I)
      ARESUM=ARESUM+AAERR(I)**2
      PRESUM=PRESUM+AMERR(I)**2
      IPART=MINF(I)*100+0.05
      IF(DABS(IPART-SAVE) .LT. .1) GO TO 200
      GO TO 210
200   K=K+1
210   K=1
220   CONTINUE
      SAVE=IPART
      WRITE(7,116) DPSQP(I),PAVGP5(I),MINF(I),TAUL(I),TAUCL(I),
     *TAUEL(I),ALPI(I),AATCA(I),AAERR(I),PHI(I),CPHI(I),EPHI(I),
     *IRUN(I),IPRB(I),I
      WRITE(12,116) DPSQP(I),PAVGP5(I),MINF(I),TAUL(I),TAUCL(I),
     *TAUEL(I),ALPI(I),AATCA(I),AAERR(I),PHI(I),CPHI(I),EPHI(I),
     *IRUN(I),IPRB(I),I
500   CONTINUE
      FSUM=(DSQRT(FSUM/(N-1)))*2
      ARESUM=(DSQRT(ARESUM/(N-IRA)))*2
      PRESUM=(DSQRT(PRESUM/(N-IRC)))*2
      IF(ISPEED .EQ. 2) THEN
      WRITE(7,225)PRESUM,ARESUM,FSUM
      ELSE
      WRITE(7,25)PRESUM,ARESUM,FSUM
      ENDIF
25    FORMAT(/,1X,'P/Pt2 UNCERTAINTY (%) =',E11.4,3X,
     *'ALPHAT UNCERTAINTY (DEG) =',E11.5,3X,'PHIT UNCERTAINTY '
     *'(DEG) =',E11.4)
225   FORMAT(/,1X,'P/Pt UNCERTAINTY (%) =',E11.4,4X,
     *'ALPHAT UNCERTAINTY (DEG) =',E11.5,3X,'PHIT UNCERTAINTY '
     *'(DEG) =',E11.4)
20    FORMAT(/,1X,'**** P/Pt2 =',F8.4,3X,'M =',F6.2,//,6X,'PAVGP5',
     * 6X,'DPSQP',6X,'AATCA',/)
226   FORMAT(/,1X,'**** P/Pt =',F8.4,4X,'M =',F6.2,//,6X,'PAVGP5',
     * 6X,'DPSQP',6X,'AATCA',/)
116   FORMAT(1X,2(F8.4),2X,F8.2,2X,3(F8.4,2X),2X,6(F8.2,2X),1X,I3,
     * 1X,I3,1X,I3)
      STOP
      END
```

Appendix 7. (concluded)

RUN	PROBE	PT	PHI	ALPHA	P1	P2	DP13	DP24	P5
22	1	14.694	0.0	3.0	14.356	14.340	0.050	-0.005	14.750 0
22	1	14.727	0.0	14.0	14.426	14.259	0.223	0.001	14.740 0
22	1	14.710	0.0	-1.0	14.320	14.328	-0.015	-0.005	14.711 0
22	1	14.727	0.0	23.0	14.531	14.193	0.350	0.003	14.654 0
22	1	14.743	0.0	9.0	14.409	14.279	0.145	-0.001	14.740 0
22	1	14.702	0.0	1.0	14.310	14.345	0.014	-0.003	14.721 0
22	1	14.735	0.0	-3.0	14.304	14.328	-0.042	-0.003	14.654 0
22	1	14.669	0.0	20.0	14.511	14.210	0.308	-0.001	14.692 0
22	1	14.702	0.0	26.0	14.528	14.172	0.340	0.008	14.605 0
22	1	14.718	0.0	0.0	14.327	14.331	-0.002	-0.001	14.731 0
22	1	14.669	0.0	17.0	14.475	14.239	0.250	0.001	14.683 0
22	1	14.735	0.0	11.0	14.429	14.317	0.174	-0.003	14.750 0
22	1	14.702	0.0	-5.0	14.287	14.314	-0.072	-0.004	14.692 0
22	1	14.751	0.0	5.0	14.350	14.328	0.083	-0.006	14.760 0
22	1	14.743	0.0	7.0	14.386	14.317	0.116	-0.003	14.692 0
32	1	15.234	0.0	0.0	14.400	14.377	0.004	-0.009	15.277 0
32	1	15.275	0.0	17.0	14.703	14.216	0.559	-0.002	15.219 0
32	1	15.217	0.0	14.0	14.650	14.285	0.470	-0.002	15.258 0
32	1	15.201	0.0	11.0	14.608	14.331	0.364	-0.004	15.248 0
32	1	15.250	0.0	7.0	14.499	14.377	0.235	-0.007	15.258 0
32	1	15.267	0.0	20.0	14.792	14.149	0.660	0.001	15.190 0
32	1	15.275	0.0	1.0	14.430	14.366	0.031	-0.007	15.248 0
32	1	15.225	0.0	-3.0	14.354	14.360	-0.097	-0.013	15.219 0
32	1	15.275	0.0	23.0	14.825	14.092	0.743	0.002	15.152 0
32	1	15.258	0.0	9.0	14.552	14.328	0.292	-0.007	15.210 0
32	1	15.225	0.0	-5.0	14.328	14.383	-0.161	-0.013	15.248 0
32	1	15.250	0.0	-1.0	14.384	14.371	-0.035	-0.012	15.268 0
32	1	15.275	0.0	5.0	14.473	14.389	0.170	-0.010	15.277 0
32	1	15.258	0.0	3.0	14.440	14.386	0.105	-0.010	15.268 0
32	1	15.267	0.0	26.0	14.000	13.988	0.829	0.004	15.113 0
40	1	15.947	0.0	-5.0	14.364	14.374	-0.274	-0.014	15.915 0
40	1	15.889	0.0	-3.0	14.413	14.383	-0.142	-0.026	15.915 0
40	1	15.980	0.0	7.0	14.722	14.334	0.400	-0.021	16.002 0
40	1	15.972	0.0	3.0	14.587	14.397	0.176	-0.020	15.934 0
40	1	15.955	0.0	9.0	14.775	14.311	0.501	-0.018	15.983 0
40	1	15.955	0.0	20.0	15.117	13.976	1.085	-0.012	15.809 0
40	1	15.939	0.0	-1.0	14.459	14.397	-0.042	-0.022	15.944 0
40	1	15.898	0.0	23.0	15.232	13.861	1.232	-0.004	15.751 0
40	1	15.972	0.0	5.0	14.660	14.389	0.292	-0.021	15.992 0
40	1	15.930	0.0	26.0	15.314	13.716	1.362	-0.002	15.655 0
40	1	15.930	0.0	0.0	14.492	14.386	0.011	-0.026	15.992 0
40	1	15.972	0.0	1.0	14.541	14.412	0.070	-0.024	15.944 0
40	1	15.906	0.0	11.0	14.837	14.270	0.615	-0.018	15.896 0
40	1	15.881	0.0	14.0	14.929	14.169	0.763	-0.018	15.877 0
40	1	15.930	0.0	17.0	15.021	14.086	0.926	-0.013	15.867 0
52	1	16.987	0.0	5.0	14.884	14.613	0.448	-0.025	17.021 0
52	1	16.996	0.0	14.0	15.348	14.304	1.229	-0.014	16.915 0

Appendix 8. Sample Subsonic Data

52	1	16.987	0.0	1.0	14.703	14.627	0.100	-0.024	16.954 0
52	1	16.954	0.0	3.0	14.782	14.601	0.277	-0.021	16.982 0
52	1	16.963	0.0	11.0	15.177	14.448	0.978	-0.021	16.925 0
52	1	16.922	0.0	23.0	15.785	13.747	1.902	-0.005	16.626 0
52	1	17.102	0.0	-5.0	14.447	14.624	-0.464	-0.028	17.089 0
52	1	16.987	0.0	9.0	15.065	14.480	0.794	-0.018	16.963 0
52	1	16.938	0.0	26.0	15.930	13.520	2.143	0.007	16.520 0
52	1	16.946	0.0	7.0	14.983	14.549	0.620	-0.017	16.934 0
52	1	16.938	0.0	20.0	15.647	13.967	1.704	-0.014	16.751 0
52	1	16.963	0.0	-1.0	14.598	14.630	-0.084	-0.033	16.963 0
52	1	16.864	0.0	0.0	14.644	14.627	0.010	-0.026	16.915 0
52	1	16.963	0.0	17.0	15.499	14.166	1.469	-0.021	16.790 0
52	1	17.012	0.0	-3.0	14.526	14.627	-0.258	-0.025	17.011 0
60	1	18.245	0.0	0.0	14.849	14.848	0.001	-0.042	18.209 0
60	1	18.229	0.0	20.0	16.306	13.838	2.581	-0.026	17.987 0
60	1	18.270	0.0	9.0	15.497	14.661	1.202	-0.026	18.200 0
60	1	18.254	0.0	11.0	15.651	14.536	1.479	-0.034	18.190 0
60	1	18.254	0.0	17.0	16.089	14.147	2.218	-0.023	18.065 0
60	1	18.254	0.0	14.0	15.865	14.349	1.831	-0.037	18.151 0
60	1	18.295	0.0	26.0	16.756	13.215	3.242	-0.009	17.631 0
60	1	18.212	0.0	-5.0	14.533	14.782	-0.647	-0.039	18.161 0
60	1	18.369	0.0	-1.0	14.786	14.883	-0.152	-0.039	18.344 0
60	1	18.254	0.0	3.0	15.069	14.828	0.407	-0.031	18.228 0
60	1	18.344	0.0	-3.0	14.664	14.822	-0.408	-0.050	18.306 0
60	1	18.295	0.0	1.0	14.937	14.828	0.143	-0.026	18.248 0
60	1	18.155	0.0	23.0	16.490	13.561	2.877	-0.034	17.698 0
60	1	18.212	0.0	5.0	15.171	14.776	0.643	-0.045	18.161 0
60	1	18.237	0.0	7.0	15.322	14.727	0.944	-0.031	18.180 0
70	1	20.003	0.0	9.0	16.058	14.861	1.693	-0.056	19.924 0
70	1	19.822	0.0	7.0	15.782	14.933	1.285	-0.053	19.750 0
70	1	19.814	0.0	14.0	16.512	14.443	2.518	-0.067	19.664 0
70	1	19.871	0.0	-5.0	14.720	15.026	-0.919	-0.050	19.808 0
70	1	19.880	0.0	23.0	17.446	13.309	4.040	-0.039	19.288 0
70	1	19.740	0.0	-3.0	14.848	15.063	-0.524	-0.056	19.702 0
70	1	19.781	0.0	26.0	17.690	12.865	4.392	0.007	18.902 0
70	1	19.723	0.0	17.0	16.789	14.111	3.021	-0.048	19.509 0
70	1	19.847	0.0	0.0	15.147	15.109	0.0001	-0.064	19.789 0
70	1	19.740	0.0	3.0	15.404	15.052	0.562	-0.059	19.741 0
70	1	19.822	0.0	5.0	15.605	15.006	0.930	-0.056	19.779 0
70	1	19.863	0.0	1.0	15.243	15.109	0.199	-0.048	19.779 0
70	1	19.912	0.0	20.0	17.180	13.731	3.618	-0.042	19.538 0
70	1	19.797	0.0	11.0	16.203	14.688	2.016	-0.056	19.721 0
70	1	19.962	0.0	-1.0	15.088	15.141	-0.194	-0.048	19.905 0
80	1	21.848	0.0	1.0	15.744	15.609	0.199	-0.195	21.632 0
80	1	21.963	0.0	-5.0	15.096	15.528	-1.209	-0.182	21.777 0
80	1	21.807	0.0	20.0	18.293	13.702	4.742	-0.178	21.121 0
80	1	21.790	0.0	7.0	16.481	15.375	1.638	-0.178	21.545 0
80	1	21.831	0.0	26.0	19.119	12.479	6.085	-0.079	20.619 0
80	1	21.683	0.0	17.0	17.810	14.221	4.013	-0.115	21.188 0

Appendix 8. (continued)

80	1	21.823	0.0	11.0	17.024	15.026	2.642	-0.187	21.478	0
80	1	21.807	0.0	-3.0	15.291	15.540	-0.718	-0.160	21.555	0
80	1	21.708	0.0	14.0	17.409	14.671	3.321	-0.151	21.362	0
80	1	21.667	0.0	-1.0	15.432	15.566	-0.264	-0.146	21.487	0
80	1	21.733	0.0	23.0	18.625	13.125	5.347	-0.084	20.812	0
80	1	21.757	0.0	5.0	16.211	15.485	1.157	-0.173	21.526	0
80	1	21.996	0.0	3.0	16.027	15.574	0.680	-0.191	21.777	0
80	1	21.601	0.0	9.0	16.698	15.194	2.101	-0.169	21.429	0
80	1	21.593	0.0	0.0	15.554	15.508	-0.053	-0.133	21.362	0
92	1	24.045	0.0	26.0	20.552	12.577	7.586	0.046	22.801	0
92	1	24.111	0.0	23.0	20.082	13.333	6.788	0.001	23.273	0
92	1	24.399	0.0	7.0	17.599	16.163	2.126	-0.097	24.296	0
92	1	24.111	0.0	-5.0	15.701	16.149	-1.423	-0.142	24.026	0
92	1	24.119	0.0	17.0	19.085	14.669	5.032	-0.016	23.727	0
92	1	24.119	0.0	3.0	16.836	16.241	0.856	-0.115	24.006	0
92	1	23.897	0.0	9.0	17.664	15.791	2.607	-0.093	23.784	0
92	1	24.119	0.0	20.0	19.615	14.020	5.977	-0.016	23.582	0
92	1	23.955	0.0	5.0	17.059	16.100	1.461	-0.106	23.881	0
92	1	24.144	0.0	14.0	18.598	15.263	4.120	-0.075	23.948	0
92	1	24.004	0.0	-3.0	15.915	16.206	-0.795	-0.160	23.891	0
92	1	24.169	0.0	1.0	16.540	16.339	0.301	-0.128	24.045	0
92	1	24.086	0.0	0.0	16.388	16.293	-0.020	-0.101	24.016	0
92	1	23.971	0.0	-1.0	16.174	16.250	-0.322	-0.097	23.842	0
92	1	24.103	0.0	11.0	18.089	15.626	3.221	-0.093	23.968	0
951	1	25.591	0.0	-1.0	16.938	17.060	-0.319	-0.121	25.523	0
951	1	25.616	0.0	7.0	18.280	16.737	2.312	-0.103	25.513	0
951	1	25.369	0.0	3.0	17.458	16.867	0.946	-0.125	25.205	0
951	1	25.591	0.0	11.0	18.987	16.266	3.628	-0.072	25.426	0
951	1	25.657	0.0	-5.0	16.346	16.817	-1.539	-0.192	25.436	0
951	1	25.459	0.0	17.0	19.947	15.141	5.526	-0.058	25.031	0
951	1	25.632	0.0	9.0	18.645	16.535	2.903	-0.098	25.523	0
951	1	25.221	0.0	23.0	20.862	13.656	7.277	-0.031	24.385	0
951	1	25.443	0.0	0.0	17.007	16.959	0.006	-0.157	25.311	0
951	1	25.681	0.0	1.0	17.287	17.071	0.281	-0.143	25.571	0
951	1	25.616	0.0	14.0	19.490	15.796	4.540	-0.058	25.359	0
951	1	25.575	0.0	5.0	17.895	16.855	1.601	-0.130	25.397	0
951	1	25.575	0.0	-3.0	16.622	16.942	-0.934	-0.161	25.465	0
951	1	25.550	0.0	20.0	20.552	14.440	6.521	-0.040	24.925	999

Appendix 8. (continued)

INPUT VARIABLES

M	P/Pt	PAVGP5	DPSQP	ALPHAT	PHIT	DP24	DP13	RUN	PROBE	
.20	.9725	.9720	.0017	3.41	3.70	-.0050	.0500	22	1	1
.20	.9725	.9692	.0076	14.40	360.00	.0010	.2230	22	1	2
.20	.9725	.9740	.0005	.67	153.10	-.0050	-.0150	22	1	3
.19	.9751	.9741	.0119	23.40	359.50	.0030	.3500	22	1	4
.19	.9751	.9707	.0049	9.40	.60	-.0010	.1450	22	1	5
.19	.9751	.9731	.0005	1.42	10.60	-.0030	.0140	22	1	6
.20	.9725	.9777	.0014	2.62	172.40	-.0030	-.0420	22	1	7
.17	.9800	.9722	.0105	20.40	359.60	-.0010	.3080	22	1	8
.19	.9751	.9766	.0116	26.40	359.40	.0080	.3400	22	1	9
.20	.9725	.9728	.0001	.49	35.30	-.0010	-.0020	22	1	10
.20	.9725	.9735	.0085	17.40	359.80	.0010	.2500	22	1	11
.20	.9725	.9715	.0059	11.40	.30	-.0030	.1740	22	1	12
.20	.9725	.9746	.0025	4.61	175.20	-.0040	-.0720	22	1	13
.20	.9725	.9702	.0028	5.40	1.90	-.0060	.0830	22	1	14
.20	.9725	.9749	.0039	7.40	1.10	-.0030	.1160	22	1	15
.29	.9433	.9419	.0003	.33	76.40	-.0090	.0040	32	1	16
.28	.9470	.9409	.0184	17.08	.10	-.0020	.5590	32	1	17
.28	.9470	.9405	.0154	14.08	.30	-.0020	.4700	32	1	18
.28	.9470	.9430	.0119	11.08	.70	-.0040	.3640	32	1	19
.28	.9470	.9425	.0077	7.08	1.70	-.0070	.2350	32	1	20
.29	.9433	.9418	.0217	20.08	359.90	.0010	.6600	32	1	21
.29	.9433	.9439	.0010	1.12	15.90	-.0070	.0310	32	1	22
.29	.9433	.9452	.0032	2.94	172.70	-.0130	-.0970	32	1	23
.29	.9433	.9419	.0245	23.08	359.80	.0020	.7430	32	1	24
.29	.9433	.9447	.0096	9.08	1.10	-.0070	.2920	32	1	25
.29	.9433	.9443	.0053	4.94	175.30	-.0130	-.1610	32	1	26
.29	.9433	.9424	.0012	.98	159.70	-.0120	-.0350	32	1	27
.29	.9433	.9420	.0056	5.08	2.70	-.0100	.1700	32	1	28
.29	.9433	.9424	.0035	3.09	5.10	-.0100	.1050	32	1	29
.38	.9052	.9074	.0086	4.75	174.30	-.0140	-.2740	40	1	30
.38	.9052	.9073	.0045	2.76	170.50	-.0260	-.1420	40	1	31
.38	.9052	.9020	.0125	7.28	2.70	-.0210	.4000	40	1	32
.38	.9052	.9071	.0056	3.30	6.70	-.0200	.1760	40	1	33
.38	.9052	.9023	.0157	9.28	1.90	-.0180	.5010	40	1	34
.37	.9098	.9032	.0343	20.27	.50	-.0120	1.0850	40	1	35
.38	.9052	.9059	.0015	.85	149.30	-.0220	-.0420	40	1	36
.36	.9143	.9040	.0391	23.27	.30	-.0040	1.2320	40	1	37
.37	.9098	.9040	.0092	5.29	3.90	-.0210	.2920	40	1	38
.37	.9098	.9055	.0435	26.27	.20	-.0020	1.3620	40	1	39
.38	.9052	.9031	.0009	.50	57.00	-.0260	.0110	40	1	40
.38	.9052	.9072	.0023	1.34	17.80	-.0240	.0700	40	1	41
.38	.9052	.9062	.0194	11.28	1.50	-.0180	.6150	40	1	42
.38	.9052	.9046	.0240	14.27	1.00	-.0180	.7630	40	1	43
.38	.9052	.9028	.0292	17.27	.70	-.0130	.9260	40	1	44
.45	.8703	.8603	.0132	5.14	2.90	-.0250	.4480	52	1	45

Appendix 8. (continued)

.46	.8650	.8585	.0363	14.14	.70	-.0140	1.2290	52	1	46
.46	.8650	.8639	.0030	1.18	15.10	-.0240	.1000	52	1	47
.46	.8650	.8614	.0082	3.15	5.20	-.0210	.2770	52	1	48
.46	.8650	.8610	.0289	11.14	1.00	-.0210	.9780	52	1	49
.45	.8703	.8596	.0572	23.14	.10	-.0050	1.9020	52	1	50
.49	.8486	.8578	.0136	4.88	175.60	-.0280	-.4640	52	1	51
.49	.8486	.8594	.0234	9.14	1.40	-.0180	.7940	52	1	52
.45	.8703	.8588	.0649	26.14	.00	.0070	2.1430	52	1	53
.45	.8703	.8631	.0183	7.14	1.90	-.0170	.6200	52	1	54
.44	.8755	.8587	.0509	20.14	.30	-.0140	1.7040	52	1	55
.45	.8703	.8632	.0027	.92	159.10	-.0330	-.0840	52	1	56
.45	.8703	.8655	.0008	.35	66.60	-.0260	.0100	52	1	57
.44	.8755	.8619	.0438	17.14	.40	-.0210	1.4690	52	1	58
.55	.8142	.8610	.0076	2.85	174.10	-.0250	-.2580	52	1	59
.55	.8142	.8160	.0012	.33	59.70	-.0420	.0010	60	1	60
.53	.8259	.8024	.0717	20.16	.50	-.0260	2.5810	60	1	61
.53	.8259	.8124	.0330	9.17	1.50	-.0260	1.2020	60	1	62
.53	.8259	.8099	.0407	11.17	1.20	-.0340	1.4790	60	1	63
.53	.8259	.8065	.0614	17.17	.70	-.0230	2.2180	60	1	64
.53	.8259	.8076	.0504	14.17	.90	-.0370	1.8310	60	1	65
.54	.8201	.8041	.0919	26.16	.30	-.0090	3.2420	60	1	66
.55	.8142	.8165	.0178	4.85	176.40	-.0390	-.6470	60	1	67
.55	.8142	.8113	.0043	.88	161.20	-.0390	-.1520	60	1	68
.55	.8142	.8149	.0112	3.18	4.80	-.0310	.4070	60	1	69
.55	.8142	.8116	.0112	2.85	174.10	-.0500	-.4080	60	1	70
.55	.8142	.8140	.0040	1.20	13.40	-.0260	.1430	60	1	71
.53	.8259	.8088	.0813	23.16	.40	-.0340	2.8770	60	1	72
.66	.7465	.8163	.0177	4.60	3.50	-.0450	.6430	60	1	73
.66	.7465	.8139	.0260	6.60	2.50	-.0310	.9440	60	1	74
.66	.7465	.7554	.0425	8.59	2.00	-.0560	1.6930	70	1	75
.66	.7465	.7620	.0326	6.60	2.50	-.0530	1.2850	70	1	76
.66	.7465	.7559	.0640	13.59	1.30	-.0670	2.5180	70	1	77
.66	.7465	.7631	.0232	5.42	177.50	-.0500	-.9190	70	1	78
.62	.7716	.7454	.1047	23.10	.40	-.0390	4.0400	70	1	79
.64	.7591	.7664	.0134	2.92	173.20	-.0560	-.5240	70	1	80
.62	.7716	.7501	.1162	26.10	.30	.0070	4.3920	70	1	81
.60	.7840	.7538	.0774	17.10	.70	-.0480	3.0210	70	1	82
.64	.7591	.7653	.0016	.34	72.90	-.0640	.0001	70	1	83
.64	.7591	.7650	.0143	3.12	5.60	-.0590	.5620	70	1	84
.64	.7591	.7628	.0236	5.11	3.30	-.0560	.9300	70	1	85
.64	.7591	.7654	.0052	1.15	16.20	-.0480	.1990	70	1	86
.61	.7778	.7453	.0926	20.10	.50	-.0420	3.6180	70	1	87
.64	.7591	.7584	.0511	11.10	1.30	-.0560	2.0160	70	1	88
.64	.7591	.7624	.0050	.96	159.70	-.0480	-.1940	70	1	89
.71	.7145	.7246	.0064	1.11	39.30	-.1950	.1990	80	1	90
.71	.7145	.7191	.0281	5.19	171.60	-.1820	-1.2090	80	1	91
.68	.7338	.7034	.1123	19.87	1.50	-.1780	4.7420	80	1	92
.68	.7338	.7223	.0382	6.89	5.40	-.1780	1.6380	80	1	93
.70	.7209	.6934	.1476	25.86	1.00	-.0790	6.0850	80	1	94

Appendix 8. (continued)

.67	.7401	.7099	.0947	16.87	1.80	-.1150	4.0130	80	1	95
.72	.7080	.7175	.0617	10.88	3.20	-.1870	2.6420	80	1	96
.72	.7080	.7254	.0171	3.23	166.70	-.1600	-.7180	80	1	97
.72	.7080	.7138	.0778	13.87	2.40	-.1510	3.3210	80	1	98
.71	.7145	.7261	.0070	1.35	147.60	-.1460	-.2640	80	1	99
.69	.7274	.6996	.1285	22.86	1.20	-.0840	5.3470	80	1	100
.70	.7209	.7248	.0272	4.91	7.80	-.1730	1.1570	80	1	101
.70	.7209	.7199	.0162	2.94	13.50	-.1910	.6800	80	1	102
.70	.7209	.7216	.0492	8.88	4.10	-.1690	2.1010	80	1	103
.70	.7209	.7292	.0034	.73	101.00	-.1330	-.0530	80	1	104
.75	.6886	.6428	.1664	24.29	359.30	.0460	7.5860	92	1	105
.74	.6951	.6450	.1458	21.30	359.70	.0010	6.7880	92	1	106
.79	.6625	.6739	.0438	7.16	2.60	-.0970	2.1260	92	1	107
.79	.6625	.6791	.0298	4.87	174.30	-.1420	-1.4230	92	1	108
.73	.7016	.6584	.1060	16.99	.50	-.0160	5.0320	92	1	109
.75	.6886	.6812	.0180	3.01	7.10	-.1150	.8560	92	1	110
.75	.6886	.6769	.0548	8.99	1.80	-.0930	2.6070	92	1	111
.74	.6951	.6500	.1267	19.99	.30	-.0160	5.9770	92	1	112
.74	.6951	.6801	.0307	5.00	3.90	-.1060	1.4610	92	1	113
.77	.6756	.6647	.0860	13.99	.80	-.0750	4.1200	92	1	114
.77	.6756	.6822	.0170	3.05	171.20	-.1600	-.7950	92	1	115
.77	.6756	.6819	.0068	1.07	22.20	-.1280	.3010	92	1	116
.77	.6756	.6817	.0021	.42	91.60	-.1010	-.0200	92	1	117
.77	.6756	.6844	.0071	1.10	156.70	-.0970	-.3220	92	1	118
.77	.6756	.6707	.0672	10.99	1.30	-.0930	3.2210	92	1	119
.77	.6756	.6703	.0067	1.10	156.70	-.1210	-.3190	951	1	120
.77	.6756	.6646	.0454	6.99	2.50	-.1030	2.3120	951	1	121
.77	.6756	.6728	.0189	3.01	7.10	-.1250	.9460	951	1	122
.77	.6756	.6583	.0714	10.99	1.30	-.0720	3.6280	951	1	123
.77	.6756	.6689	.0305	5.04	174.30	-.1920	-1.5390	951	1	124
.75	.6886	.6463	.1104	16.99	.50	-.0580	5.5260	951	1	125
.75	.6886	.6617	.0569	8.99	1.80	-.0980	2.9030	951	1	126
.76	.6821	.6335	.1492	22.99	.10	-.0310	7.2770	951	1	127
.78	.6691	.6725	.0031	.46	92.80	-.1570	.0060	951	1	128
.78	.6691	.6705	.0062	1.07	24.10	-.1430	.2810	951	1	129
.80	.6560	.6515	.0895	13.98	.80	-.0580	4.5400	951	1	130
.80	.6560	.6697	.0316	4.99	4.20	-.1300	1.6010	951	1	131
.80	.6560	.6698	.0186	3.06	170.50	-.1610	-.9340	951	1	132
.80	.6560	.6369	.1308	19.97	.30	-.0400	6.5210	951	1	133

Appendix 8. (continued)

CONSTANTS	P/Pt	ALPHA
1	-.740072E+01	-.359737E+05
2	.399041E+02	.147494E+06
3	-.757417E+02	-.200195E+06
4	.646653E+02	.904979E+05
5	-.204321E+02	-.788401E+03
6	.000000E+00	.942011E+03
7	-.667665E+04	.000000E+00
8	.361457E+05	.000000E+00
9	-.729502E+05	.000000E+00
10	.650238E+05	.000000E+00
11	-.215690E+05	.000000E+00
12	-.497254E+06	.000000E+00
13	.295475E+07	.000000E+00
14	-.656968E+07	.000000E+00
15	.647943E+07	.000000E+00
16	-.239271E+07	.000000E+00
17	.000000E+00	.000000E+00
18	.000000E+00	.000000E+00
19	.000000E+00	.000000E+00
20	.000000E+00	.000000E+00
21	.000000E+00	.000000E+00
22	.000000E+00	.000000E+00
23	.000000E+00	.000000E+00
24	.000000E+00	.000000E+00
25	.000000E+00	.000000E+00
26	.000000E+00	.000000E+00
27	.000000E+00	.000000E+00
28	.000000E+00	.000000E+00
29	.000000E+00	.000000E+00
30	.000000E+00	.000000E+00

Appendix 8. (continued)

GENERATED LINES

CAREFULLY CHECK THE GENERATED MACH LINES TO VERIFY THAT THEY DO INDEED MATCH THE CALCULATED DATA. TRYING TO GENERATE MACH LINES CAN SOMETIMES GIVE ERRONEOUS NUMBERS. THE CURVE FITS PROVIDE AN ACCURATE SOLUTION WHEN PRESSURE MEASUREMENTS ARE USED TO DETERMINE SOLUTIONS

**** P/Pt = .9725 M = .20

PAVGP5	DPSQP	AATCA
.9719E+00	.4000E-03	.5431E+00
.9719E+00	.8000E-03	.1087E+01
.9719E+00	.1200E-02	.1632E+01
.9719E+00	.1600E-02	.2177E+01
.9719E+00	.2000E-02	.2722E+01
.9719E+00	.2400E-02	.3268E+01
.9720E+00	.2800E-02	.3815E+01
.9720E+00	.3200E-02	.4362E+01
.9720E+00	.3600E-02	.4910E+01
.9720E+00	.4000E-02	.5458E+01
.9720E+00	.4400E-02	.6007E+01
.9721E+00	.4800E-02	.6557E+01
.9721E+00	.5200E-02	.7107E+01
.9721E+00	.5600E-02	.7658E+01
.9721E+00	.6000E-02	.8210E+01
.9722E+00	.6400E-02	.8762E+01
.9722E+00	.6800E-02	.9316E+01
.9723E+00	.7200E-02	.9871E+01
.9723E+00	.7600E-02	.1043E+02
.9724E+00	.8000E-02	.1098E+02
.9724E+00	.8400E-02	.1154E+02
.9725E+00	.8800E-02	.1210E+02
.9725E+00	.9200E-02	.1267E+02
.9726E+00	.9600E-02	.1323E+02
.9727E+00	.1000E-01	.1380E+02
.9728E+00	.1040E-01	.1436E+02
.9729E+00	.1080E-01	.1493E+02
.9730E+00	.1120E-01	.1551E+02

**** P/Pt = .8956 M = .40

PAVGP5	DPSQP	AATCA

Appendix 8. (continued)

.8981E+00	.1000E-02	.5748E+00
.8981E+00	.2000E-02	.1150E+01
.8980E+00	.3000E-02	.1726E+01
.8979E+00	.4000E-02	.2301E+01
.8978E+00	.5000E-02	.2873E+01
.8977E+00	.6000E-02	.3444E+01
.8975E+00	.7000E-02	.4012E+01
.8973E+00	.8000E-02	.4577E+01
.8970E+00	.9000E-02	.5137E+01
.8968E+00	.1000E-01	.5694E+01
.8965E+00	.1100E-01	.6245E+01
.8962E+00	.1200E-01	.6792E+01
.8959E+00	.1300E-01	.7333E+01
.8956E+00	.1400E-01	.7869E+01
.8952E+00	.1500E-01	.8398E+01
.8948E+00	.1600E-01	.8921E+01
.8944E+00	.1700E-01	.9438E+01
.8940E+00	.1800E-01	.9949E+01
.8936E+00	.1900E-01	.1045E+02
.8932E+00	.2000E-01	.1095E+02
.8928E+00	.2100E-01	.1144E+02
.8923E+00	.2200E-01	.1193E+02
.8919E+00	.2300E-01	.1241E+02
.8914E+00	.2400E-01	.1288E+02
.8910E+00	.2500E-01	.1335E+02
.8905E+00	.2600E-01	.1381E+02
.8901E+00	.2700E-01	.1426E+02
.8896E+00	.2800E-01	.1472E+02
.8892E+00	.2900E-01	.1516E+02
.8887E+00	.3000E-01	.1561E+02

**** P/Pt = .7840 M = .60

PAVGP5	DPSQP	AATCA
.7966E+00	.1000E-02	.2274E+00
.7965E+00	.2000E-02	.4538E+00
.7965E+00	.3000E-02	.6794E+00
.7964E+00	.4000E-02	.9043E+00
.7964E+00	.5000E-02	.1129E+01
.7963E+00	.6000E-02	.1352E+01
.7962E+00	.7000E-02	.1575E+01
.7960E+00	.8000E-02	.1798E+01
.7959E+00	.9000E-02	.2019E+01
.7957E+00	.1000E-01	.2240E+01
.7955E+00	.1100E-01	.2460E+01
.7953E+00	.1200E-01	.2680E+01
.7951E+00	.1300E-01	.2898E+01
.7949E+00	.1400E-01	.3116E+01

Appendix 8. (continued)

.7947E+00	.1500E-01	.3333E+01
.7944E+00	.1600E-01	.3549E+01
.7941E+00	.1700E-01	.3765E+01
.7939E+00	.1800E-01	.3979E+01
.7936E+00	.1900E-01	.4192E+01
.7933E+00	.2000E-01	.4405E+01
.7929E+00	.2100E-01	.4616E+01
.7926E+00	.2200E-01	.4827E+01
.7923E+00	.2300E-01	.5036E+01
.7919E+00	.2400E-01	.5245E+01
.7916E+00	.2500E-01	.5453E+01
.7912E+00	.2600E-01	.5659E+01
.7908E+00	.2700E-01	.5865E+01
.7904E+00	.2800E-01	.6070E+01
.7900E+00	.2900E-01	.6273E+01
.7896E+00	.3000E-01	.6476E+01
.7892E+00	.3100E-01	.6678E+01
.7887E+00	.3200E-01	.6879E+01
.7883E+00	.3300E-01	.7079E+01
.7879E+00	.3400E-01	.7278E+01
.7874E+00	.3500E-01	.7477E+01
.7870E+00	.3600E-01	.7674E+01
.7865E+00	.3700E-01	.7871E+01
.7861E+00	.3800E-01	.8066E+01
.7856E+00	.3900E-01	.8261E+01
.7851E+00	.4000E-01	.8455E+01
.7847E+00	.4100E-01	.8648E+01
.7842E+00	.4200E-01	.8841E+01
.7837E+00	.4300E-01	.9033E+01
.7832E+00	.4400E-01	.9224E+01
.7827E+00	.4500E-01	.9414E+01
.7822E+00	.4600E-01	.9604E+01
.7818E+00	.4700E-01	.9793E+01
.7813E+00	.4800E-01	.9981E+01
.7808E+00	.4900E-01	.1017E+02
.7803E+00	.5000E-01	.1036E+02

**** P/Pt = .6560 M = .80

PAVGP5	DPSQP	AATCA
.6590E+00	.2400E-02	.4209E+00
.6589E+00	.4800E-02	.8249E+00
.6588E+00	.7200E-02	.1217E+01
.6586E+00	.9600E-02	.1599E+01
.6584E+00	.1200E-01	.1972E+01
.6581E+00	.1440E-01	.2334E+01
.6578E+00	.1680E-01	.2688E+01
.6575E+00	.1920E-01	.3031E+01

Appendix 8. (continued)

.6571E+00	.2160E-01	.3365E+01
.6567E+00	.2400E-01	.3689E+01
.6562E+00	.2640E-01	.4001E+01
.6557E+00	.2880E-01	.4303E+01
.6552E+00	.3120E-01	.4594E+01
.6546E+00	.3360E-01	.4873E+01
.6540E+00	.3600E-01	.5139E+01
.6534E+00	.3840E-01	.5393E+01
.6527E+00	.4080E-01	.5633E+01
.6520E+00	.4320E-01	.5860E+01
.6513E+00	.4560E-01	.6073E+01
.6506E+00	.4800E-01	.6272E+01
.6498E+00	.5040E-01	.6457E+01
.6491E+00	.5280E-01	.6626E+01
.6483E+00	.5520E-01	.6780E+01
.6475E+00	.5760E-01	.6919E+01
.6467E+00	.6000E-01	.7043E+01
.6459E+00	.6240E-01	.7151E+01
.6451E+00	.6480E-01	.7244E+01
.6443E+00	.6720E-01	.7322E+01
.6434E+00	.6960E-01	.7384E+01
.6426E+00	.7200E-01	.7431E+01
.6418E+00	.7440E-01	.7464E+01
.6410E+00	.7680E-01	.7482E+01
.6402E+00	.7920E-01	.7486E+01

Appendix 8. (continued)

DATA FIT COMPARISON

DPSQP/M	PAVGPS/M	MACH/M	P/Pt/M	P/Pt/C	P/Pt/E	ALPHA/M	ALPHA/C	ALPHA/E	PHI/M	PHI/C	PHI/E	RUN	PROBE	
.0017	.9720	.20	.9725	.9726	-.0001	3.41	2.33	1.08	3.70	5.71	-2.01	22	1	1
.0076	.9692	.20	.9725	.9698	.0027	14.40	10.15	4.25	360.00	359.74	.26	22	1	2
.0005	.9740	.20	.9725	.9743	-.0018	.67	.70	-.03	153.10	161.57	-8.47	22	1	3
.0119	.9741	.19	.9751	.9732	.0019	23.40	16.52	6.88	359.50	359.51	-.01	22	1	4
.0049	.9707	.19	.9751	.9713	.0038	9.40	6.64	2.76	.60	.40	.20	22	1	5
.0005	.9731	.19	.9751	.9735	.0016	1.42	.69	.73	10.60	12.09	-1.49	22	1	6
.0014	.9777	.20	.9725	.9775	-.0050	2.62	2.02	.60	172.40	175.91	-3.51	22	1	7
.0105	.9722	.17	.9800	.9720	.0080	20.40	14.38	6.02	359.60	.19	.59	22	1	8
.0116	.9766	.19	.9751	.9752	-.0001	26.40	16.46	9.94	359.40	358.65	.75	22	1	9
.0001	.9728	.20	.9725	.9733	-.0008	.49	.14	.35	35.30	153.43	-118.13	22	1	10
.0085	.9735	.20	.9725	.9734	-.0009	17.40	11.81	5.59	359.80	359.77	.03	22	1	11
.0059	.9715	.20	.9725	.9719	.0005	11.40	8.06	3.34	.30	.99	-.69	22	1	12
.0025	.9746	.20	.9725	.9748	-.0023	4.61	3.51	1.10	175.20	176.82	-1.62	22	1	13
.0028	.9702	.20	.9725	.9709	.0016	5.40	3.77	1.63	1.90	4.13	-2.23	22	1	14
.0039	.9749	.20	.9725	.9750	-.0025	7.40	5.50	1.90	1.10	1.48	-.38	22	1	15
.0003	.9419	.29	.9433	.9434	-.0001	.33	.30	.03	76.40	66.04	10.36	32	1	16
.0184	.9409	.28	.9470	.9441	.0029	17.08	18.47	-1.39	.10	.20	-.10	32	1	17
.0154	.9405	.28	.9470	.9434	.0036	14.08	15.33	-1.25	.30	.24	.06	32	1	18
.0119	.9430	.28	.9470	.9454	.0016	11.08	12.11	-1.03	.70	.63	.07	32	1	19
.0077	.9425	.28	.9470	.9444	.0026	7.08	7.73	-.65	1.70	1.71	-.01	32	1	20
.0217	.9418	.29	.9433	.9448	-.0015	20.08	22.00	-1.92	359.90	359.91	-.01	32	1	21
.0010	.9439	.29	.9433	.9454	-.0021	1.12	1.01	.11	15.90	12.72	3.18	32	1	22
.0032	.9452	.29	.9433	.9468	-.0035	2.94	3.29	-.35	172.70	172.37	.33	32	1	23
.0245	.9419	.29	.9433	.9444	-.0012	23.08	24.75	-1.67	359.80	359.85	-.05	32	1	24
.0096	.9447	.29	.9433	.9469	-.0036	9.08	9.92	-.84	1.10	1.37	-.27	32	1	25
.0053	.9443	.29	.9433	.9461	-.0028	4.94	5.41	-.47	175.30	175.38	-.08	32	1	26
.0012	.9424	.29	.9433	.9439	-.0006	.98	1.19	-.21	159.70	161.08	-1.38	32	1	27
.0056	.9420	.29	.9433	.9437	-.0004	5.08	5.57	-.49	2.70	3.37	-.67	32	1	28
.0035	.9424	.29	.9433	.9440	-.0007	3.09	3.48	-.39	5.10	5.44	-.34	32	1	29
.0086	.9074	.38	.9052	.9071	-.0019	4.75	5.54	-.79	174.30	177.08	-2.78	40	1	30
.0045	.9073	.38	.9052	.9062	-.0010	2.76	2.86	-.10	170.50	169.62	.88	40	1	31
.0125	.9020	.38	.9052	.9022	.0029	7.28	7.61	-.33	2.70	3.01	-.31	40	1	32
.0056	.9071	.38	.9052	.9061	-.0010	3.30	3.56	-.26	6.70	6.48	.22	40	1	33
.0157	.9023	.38	.9052	.9038	.0014	9.28	9.75	-.47	1.90	2.06	-.16	40	1	34
.0343	.9032	.37	.9098	.9111	-.0014	20.27	23.43	-3.16	.50	.63	-.13	40	1	35
.0015	.9059	.38	.9052	.9044	.0008	.85	.93	-.08	149.30	152.35	-3.05	40	1	36
.0391	.9040	.36	.9143	.9114	.0029	23.27	26.83	-3.56	.30	.19	.11	40	1	37
.0092	.9040	.37	.9098	.9035	.0063	5.29	5.68	-.39	3.90	4.11	-.21	40	1	38
.0435	.9055	.37	.9098	.9102	-.0004	26.27	29.46	-3.19	.20	.08	.12	40	1	39
.0009	.9031	.38	.9052	.9012	.0040	.50	.54	-.04	57.00	67.07	-10.07	40	1	40
.0023	.9072	.38	.9052	.9059	-.0007	1.34	1.45	-.11	17.80	18.92	-1.12	40	1	41
.0194	.9062	.38	.9052	.9095	-.0044	11.28	12.93	-1.65	1.50	1.68	-.18	40	1	42
.0240	.9046	.38	.9052	.9097	-.0045	14.27	16.06	-1.79	1.00	1.35	-.35	40	1	43
.0292	.9028	.38	.9052	.9097	-.0046	17.27	19.58	-2.31	.70	.80	-.10	40	1	44
.0132	.8603	.45	.8703	.8554	.0149	5.14	4.66	.48	2.90	3.19	-.29	52	1	45
.0363	.8585	.46	.8650	.8660	-.0010	14.14	14.48	-.34	.70	.65	.05	52	1	46

Appendix 8. (continued)

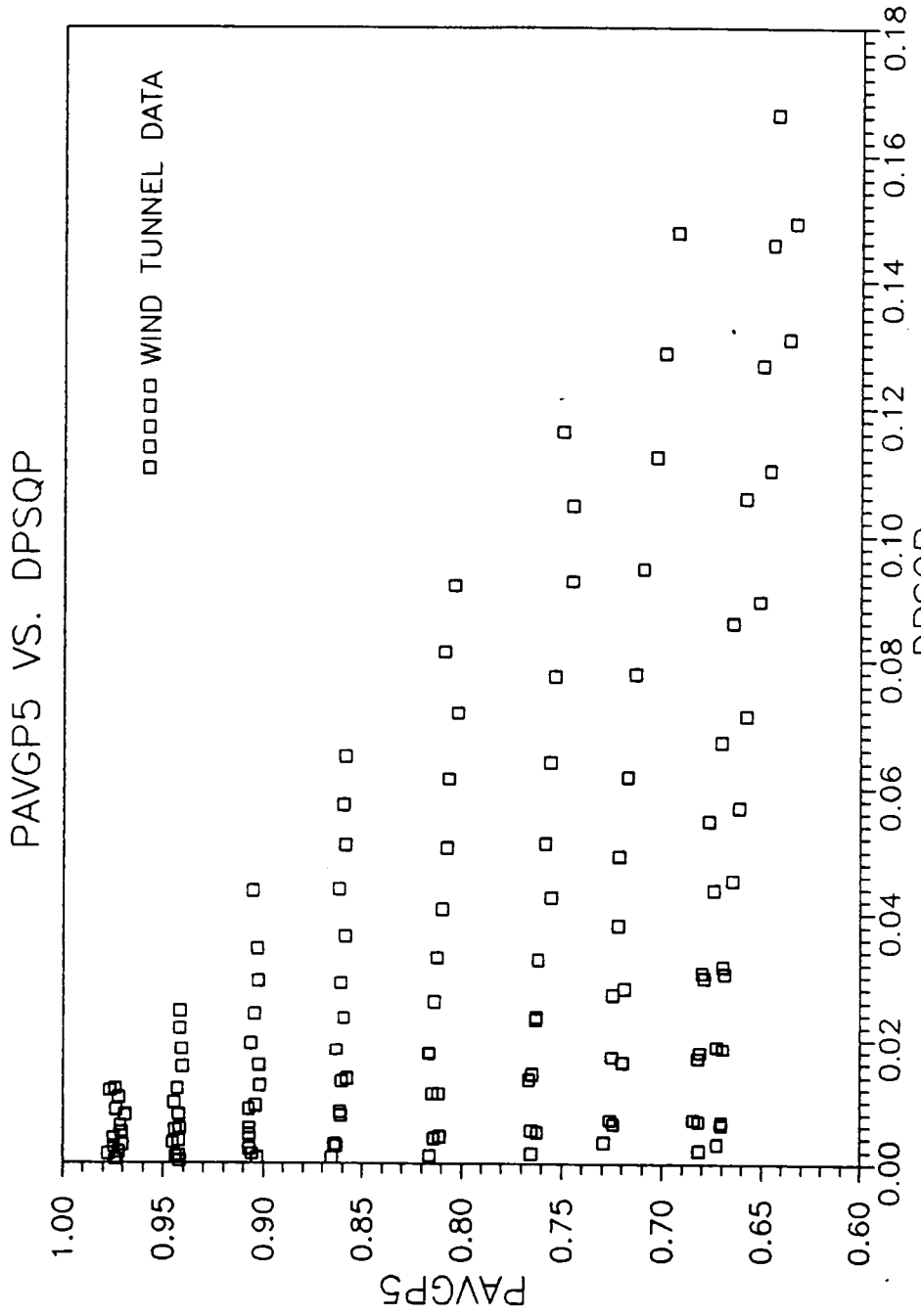
.0030	.8639	.46	.8650	.8570	.0080	1.18	1.07	.11	15.10	13.50	1.60	52	1	47
.0082	.8614	.46	.8650	.8551	.0099	3.15	2.88	.27	5.20	4.34	.86	52	1	48
.0289	.8610	.46	.8650	.8643	.0006	11.14	11.29	-.15	1.00	1.23	-.23	52	1	49
.0572	.8596	.45	.8703	.8730	-.0027	23.14	24.81	-1.67	.10	.15	-.05	52	1	50
.0136	.8578	.49	.8486	.8527	-.0041	4.88	4.67	.21	175.60	176.55	-.95	52	1	51
.0234	.8594	.49	.8486	.8592	-.0106	9.14	8.63	.51	1.40	1.30	.10	52	1	52
.0649	.8588	.45	.8703	.8682	.0021	26.14	26.66	-.52	.00	359.81	.19	52	1	53
.0183	.8631	.45	.8703	.8607	.0095	7.14	6.86	.28	1.90	1.57	.33	52	1	54
.0509	.8587	.44	.8755	.8724	.0031	20.14	21.91	-1.77	.30	.47	-.17	52	1	55
.0027	.8632	.45	.8703	.8562	.0141	.92	.96	-.04	159.10	158.55	.55	52	1	56
.0008	.8655	.45	.8703	.8587	.0116	.35	.29	.06	66.60	68.96	-2.36	52	1	57
.0438	.8619	.44	.8755	.8735	.0020	17.14	19.09	-1.95	.40	.82	-.42	52	1	58
.0076	.8610	.55	.8142	.8545	-.0403	2.85	2.65	.20	174.10	174.47	-.37	52	1	59
.0012	.8160	.55	.8142	.8043	.0099	.33	.28	.05	59.70	88.64	-28.94	60	1	60
.0717	.8024	.53	.8259	.8212	.0047	20.16	18.36	1.80	.50	.58	-.08	60	1	61
.0330	.8124	.53	.8259	.8109	.0150	9.17	7.90	1.27	1.50	1.24	.26	60	1	62
.0407	.8099	.53	.8259	.8126	.0133	11.17	9.84	1.33	1.20	1.32	-.12	60	1	63
.0614	.8065	.53	.8259	.8211	.0048	17.17	15.73	1.44	.70	.59	.11	60	1	64
.0504	.8076	.53	.8259	.8160	.0099	14.17	12.44	1.73	.90	1.16	-.26	60	1	65
.0919	.8041	.54	.8201	.8234	-.0033	26.16	23.91	2.25	.30	.16	.14	60	1	66
.0178	.8165	.55	.8142	.8082	.0060	4.85	4.22	.63	176.40	176.55	-.15	60	1	67
.0043	.8113	.55	.8142	.7995	.0147	.88	.98	-.10	161.20	165.61	-4.41	60	1	68
.0112	.8149	.55	.8142	.8044	.0097	3.18	2.61	.57	4.80	4.36	.44	60	1	69
.0112	.8116	.55	.8142	.8009	.0133	2.85	2.56	.29	174.10	173.01	1.09	60	1	70
.0040	.8140	.55	.8142	.8023	.0119	1.20	.93	.27	13.40	10.30	3.10	60	1	71
.0813	.8088	.53	.8259	.8291	-.0033	23.16	22.24	.92	.40	.68	-.28	60	1	72
.0177	.8163	.66	.7465	.8079	-.0614	4.60	4.19	.41	3.50	4.00	-.50	60	1	73
.0260	.8139	.66	.7465	.8088	-.0623	6.60	6.16	.44	2.50	1.88	.62	60	1	74
.0425	.7554	.66	.7465	.7533	-.0068	8.59	8.48	.11	2.00	1.89	.11	70	1	75
.0326	.7620	.66	.7465	.7561	-.0096	6.60	6.58	.02	2.50	2.36	.14	70	1	76
.0640	.7559	.66	.7465	.7641	-.0176	13.59	12.69	.90	1.30	1.52	-.22	70	1	77
.0232	.7631	.66	.7465	.7542	-.0077	5.42	4.73	.69	177.50	176.89	.61	70	1	78
.1047	.7454	.62	.7716	.7702	.0015	23.10	20.52	2.58	.40	.55	-.15	70	1	79
.0134	.7664	.64	.7591	.7552	.0039	2.92	2.77	.15	173.20	173.90	-.70	70	1	80
.1162	.7501	.62	.7716	.7770	-.0054	26.10	23.09	3.01	.30	359.91	.39	70	1	81
.0774	.7538	.60	.7840	.7686	.0154	17.10	15.34	1.76	.70	.91	-.21	70	1	82
.0016	.7653	.64	.7591	.7530	.0061	.34	.34	.00	72.90	89.91	-17.01	70	1	83
.0143	.7650	.64	.7591	.7540	.0051	3.12	2.95	.17	5.60	5.99	-.39	70	1	84
.0236	.7628	.64	.7591	.7540	.0052	5.11	4.81	.30	3.30	3.45	-.15	70	1	85
.0052	.7654	.64	.7591	.7533	.0059	1.15	1.09	.06	16.20	13.56	2.64	70	1	86
.0926	.7453	.61	.7778	.7659	.0119	20.10	18.10	2.00	.50	.67	-.17	70	1	87
.0511	.7584	.64	.7591	.7604	-.0012	11.10	10.18	.92	1.30	1.59	-.29	70	1	88
.0050	.7624	.64	.7591	.7504	.0088	.96	1.05	-.09	159.70	166.10	-6.40	70	1	89
.0064	.7246	.71	.7145	.7154	-.0009	1.11	1.34	-.23	39.30	44.42	-5.12	80	1	90
.0281	.7191	.71	.7145	.7136	.0008	5.19	5.61	-.42	171.60	171.44	.16	80	1	91
.1123	.7034	.68	.7338	.7303	.0035	19.87	20.72	-.85	1.50	2.15	-.65	80	1	92
.0382	.7223	.68	.7338	.7194	.0144	6.89	7.54	-.65	5.40	6.20	-.80	80	1	93
.1476	.6934	.70	.7209	.7246	-.0036	25.86	26.29	-.43	1.00	.74	.26	80	1	94
.0947	.7099	.67	.7401	.7303	.0098	16.87	17.74	-.87	1.80	1.64	.16	80	1	95

Appendix 8. (continued)

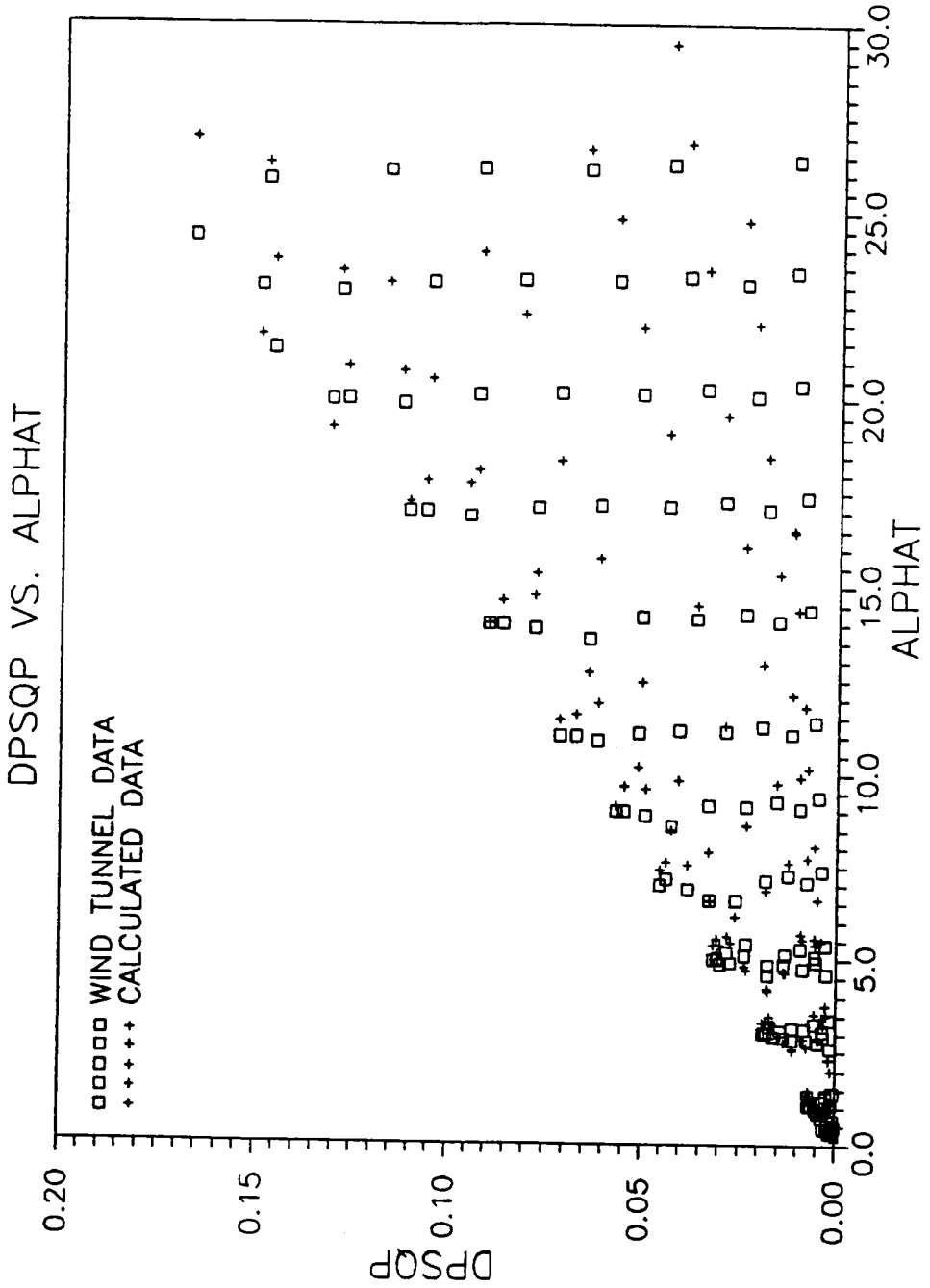
.0617	.7175	.72	.7080	.7236	-.0156	10.88	11.87	-.99	3.20	4.05	-.85	80	1	96
.0171	.7254	.72	.7080	.7172	-.0092	3.23	3.50	-.27	166.70	167.44	-.74	80	1	97
.0778	.7138	.72	.7080	.7270	-.0190	13.87	14.76	-.89	2.40	2.60	-.20	80	1	98
.0070	.7261	.71	.7145	.7168	-.0023	1.35	1.47	-.12	147.60	151.06	-3.46	80	1	99
.1285	.6996	.69	.7274	.7300	-.0027	22.86	23.40	-.54	1.20	.90	.30	80	1	100
.0272	.7248	.70	.7209	.7187	.0023	4.91	5.46	-.55	7.80	8.50	-.70	80	1	101
.0162	.7199	.70	.7209	.7121	.0088	2.94	3.31	-.37	13.50	15.69	-2.19	80	1	102
.0492	.7216	.70	.7209	.7225	-.0016	8.88	9.59	-.71	4.10	4.60	-.50	80	1	103
.0034	.7292	.70	.7209	.7194	.0015	.73	.72	.01	101.00	111.73	-10.73	80	1	104
.1664	.6428	.75	.6886	.6959	-.0074	24.29	26.95	-2.66	359.30	359.65	-.35	92	1	105
.1458	.6450	.74	.6951	.6921	.0030	21.30	23.70	-2.40	359.70	359.99	-.29	92	1	106
.0438	.6739	.79	.6625	.6771	-.0146	7.16	7.61	-.45	2.60	2.61	-.01	92	1	107
.0298	.6791	.79	.6625	.6780	-.0155	4.87	5.37	-.50	174.30	174.30	.00	92	1	108
.1060	.6584	.73	.7016	.6893	.0122	16.99	17.82	-.83	.50	.18	.32	92	1	109
.0180	.6812	.75	.6886	.6777	.0109	3.01	3.34	-.33	7.10	7.65	-.55	92	1	110
.0548	.6769	.75	.6886	.6838	.0048	8.99	9.67	-.68	1.80	2.04	-.24	92	1	111
.1267	.6500	.74	.6951	.6900	.0050	19.99	20.84	-.85	.30	.15	.15	92	1	112
.0307	.6801	.74	.6951	.6791	.0159	5.00	5.55	-.55	3.90	4.15	-.25	92	1	113
.0860	.6647	.77	.6756	.6860	-.0104	13.99	14.61	-.62	.80	1.04	-.24	92	1	114
.0170	.6822	.77	.6756	.6784	-.0029	3.05	3.18	-.13	171.20	168.62	2.58	92	1	115
.0068	.6819	.77	.6756	.6772	-.0016	1.07	1.31	-.24	22.20	23.04	-.84	92	1	116
.0021	.6817	.77	.6756	.6768	-.0013	.42	.42	.00	91.60	101.20	-9.60	92	1	117
.0071	.6844	.77	.6756	.6794	-.0039	1.10	1.38	-.28	156.70	163.24	-6.54	92	1	118
.0672	.6707	.77	.6756	.6831	-.0075	10.99	11.57	-.58	1.30	1.65	-.35	92	1	119
.0067	.6703	.77	.6756	.6667	.0089	1.10	1.21	-.11	156.70	159.23	-2.53	951	1	120
.0454	.6646	.77	.6756	.6690	.0066	6.99	7.41	-.42	2.50	2.55	-.05	951	1	121
.0189	.6728	.77	.6756	.6702	.0054	3.01	3.34	-.33	7.10	7.53	-.43	951	1	122
.0714	.6583	.77	.6756	.6729	.0027	10.99	11.42	-.43	1.30	1.14	.16	951	1	123
.0305	.6689	.77	.6756	.6688	.0067	5.04	5.16	-.12	174.30	172.89	1.41	951	1	124
.1104	.6463	.75	.6886	.6780	.0105	16.99	17.24	-.25	.50	.60	-.10	951	1	125
.0569	.6617	.75	.6886	.6703	.0183	8.99	9.16	-.17	1.80	1.93	-.13	951	1	126
.1492	.6335	.76	.6821	.6757	.0064	22.99	21.67	1.32	.10	.24	-.14	951	1	127
.0031	.6725	.78	.6691	.6685	.0005	.46	.58	-.12	92.80	87.81	4.99	951	1	128
.0062	.6705	.78	.6691	.6668	.0022	1.07	1.13	-.06	24.10	26.97	-2.87	951	1	129
.0895	.6515	.80	.6560	.6741	-.0180	13.98	14.00	-.02	.80	.73	.07	951	1	130
.0316	.6697	.80	.6560	.6698	-.0138	4.99	5.37	-.38	4.20	4.64	-.44	951	1	131
.0186	.6698	.80	.6560	.6674	-.0114	3.06	3.22	-.16	170.50	170.22	.28	951	1	132
.1308	.6369	.80	.6560	.6742	-.0181	19.97	19.23	.74	.30	.35	-.05	951	1	133

P/Pt UNCERTAINTY (%) = .3216E+01 ALPHAT UNCERTAINTY (DEG) = .35409E+01 PHIT UNCERTAINTY (DEG) = .2184E+02

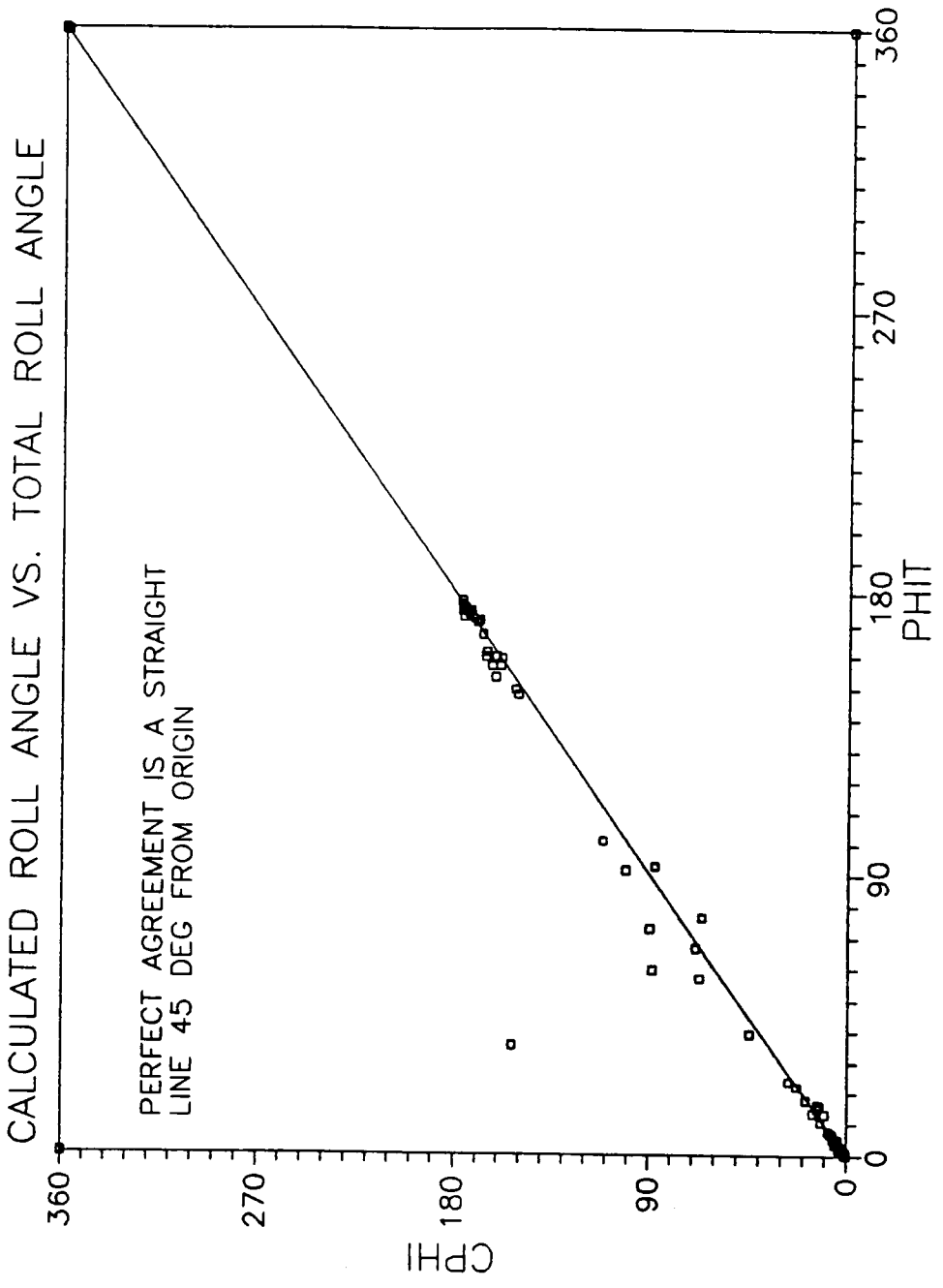
Appendix 8. (continued)



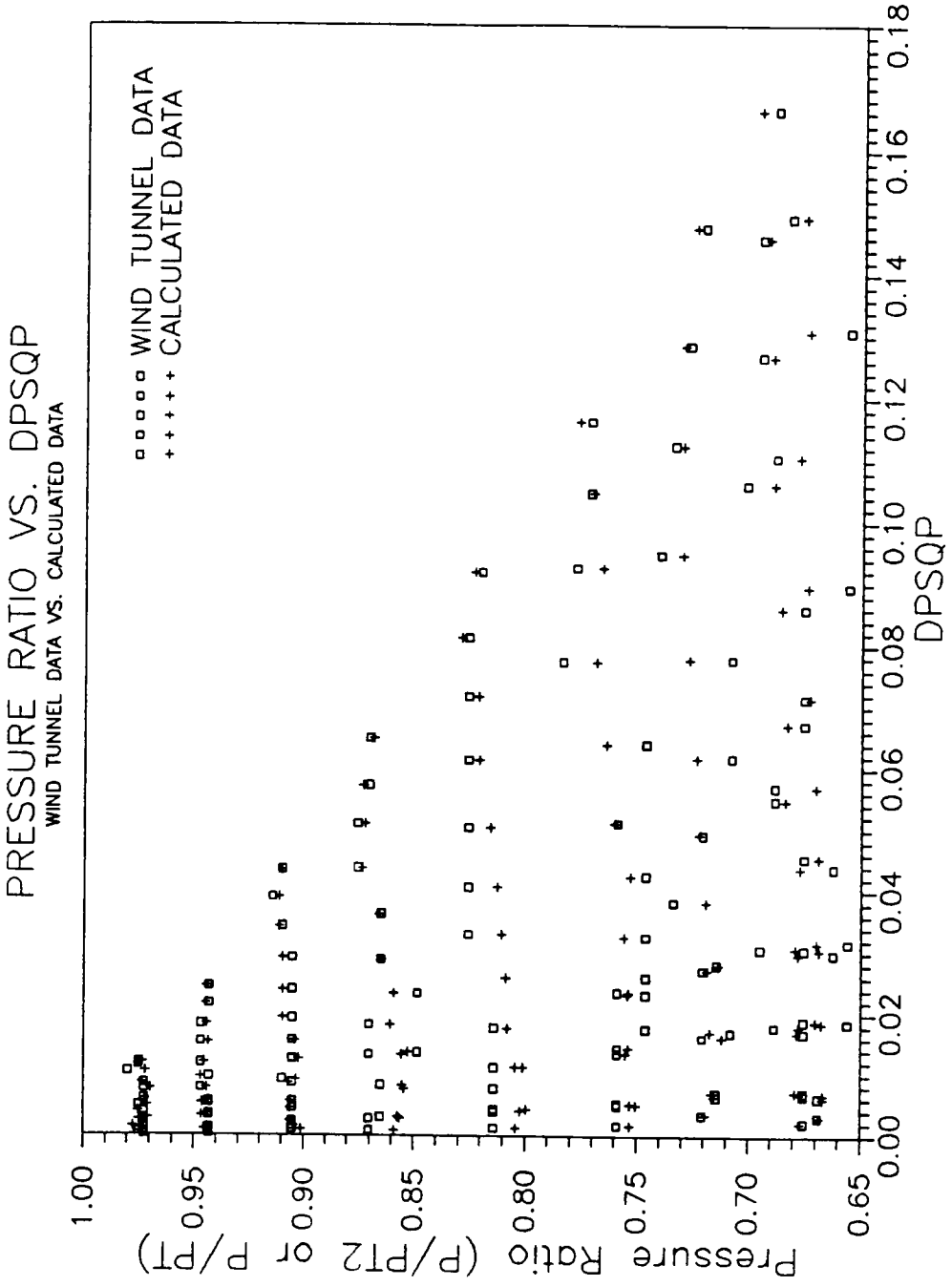
Appendix 8. (continued)



Appendix 8. (continued)



Appendix 8. (continued)



Appendix 8. (concluded)

VITA

Michael Glenn Hatcher was born in Bourne, Massachusetts on November 25, 1961. Being the son of an Air Force navigator made for many moves throughout his young life. The majority of his life was spent in Florida where he attended elementary school through high school. He graduated in May 1979 from Choctawhatchee High School in Fort Walton Beach, Florida. The following August, he entered Okaloosa Walton Junior College in Niceville, Florida, and in July 1981, he received a Associate of Arts degree in Pre Engineering. From there he attended the University of Florida in Gainesville, Florida where he received a Bachelor of Science degree in Aerospace Engineering in May 1985.

After graduation, he accepted the position of Engineer/Scientist with Calspan Corporation/AEDC Operations in Tullahoma, Tennessee. He worked there from June 1985 until May 1990 at which time he began employment with his present employer, Sverdrup Technology, Inc in Niceville, Florida. Concurrently, he studied at the University of Tennessee Space Institute in Tullahoma, Tennessee, and received a Master of Science degree in Aerospace Engineering in August 1991.