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**MACH NUMBER, FLOW ANGLE, AND LOSS MEASUREMENTS
DOWNSTREAM OF A TRANSONIC FAN-BLADE CASCADE**

By

Jeffrey G. Austin

March 1994

Thesis Advisor:

Raymond P. Shreeve

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**Mach Number, Flow Angle, and Loss Measurements Downstream of a Transonic
Fan-Blade Cascade**

by

**Jeffrey G. Austin
Lieutenant, United States Navy
B.S., University of Puget Sound, 1985**

**Submitted in partial fulfillment of the requirements for
the degree of**

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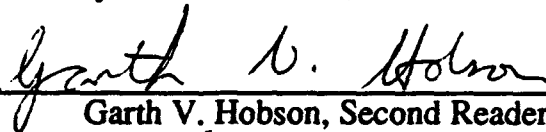
Author:


Jeffrey G. Austin

Approved by:



Raymond P. Shreeve, Thesis Advisor



Garth V. Hobson, Second Reader



Daniel J. Collins, Chairman,
Department of Aeronautics and Astronautics

ABSTRACT

Two dimensional flow measurements of Mach number and flow angle were conducted downstream of a transonic fan-blade cascade at a Mach number of 1.4 to provide baseline data for assessing the effect of vortex generating devices on the suction surface shock-boundary layer interaction. The experimental program consisted of the design and calibration of a traversing three-port pneumatic probe to measure Mach number and flow angle and initial cascade measurements to provide baseline data for the fully-mixed-out total pressure loss coefficient and flow turning angle. Similar tests are planned with the vortex generating devices installed. Comparisons with and without the vortex generating devices are needed to quantify the overall effect on the shock-boundary interaction in a transonic fan-blade passage, and to assess the potential for using vortex generating devices in military engine fans.

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LIST OF SYMBOLS

a_0 - a_6	Coefficients of Eq. (5)
b_0 - b_3	Coefficients of Eq. (6)
C_p	Specific heat at constant pressure
d_s	Distance of one blade space
d_1	Staggered passage width
M	Mach number
P	Pressure
P_T	Stagnation (total) pressure
P_1	Probe pressure (center tube)
P_2	Probe pressure (side hole-facing down)
P_3	Probe pressure (side hole-facing up)
P_{23}	Average of P_2 and P_3
T_T	Stagnation temperature
V	Velocity
V_T	Limiting velocity
X	Dimensionless velocity
B	Defined by Eq. (3)
β_i	Flow angle
γ	Ratio of Specific Heats
Γ	Defined by Eq. (4)
θ	Flow angle to the probe axis (and to inlet flow direction)
ϕ	Pitch angle
Φ	Pitch angle at X_i =constant

$\bar{\omega}$	Mass-averaged loss coefficient
ω_{mixed}	Mixed-out loss coefficient defined in Appendix E, Eq. (13)

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I. INTRODUCTION

The requirement to achieve higher compressor ratios in the fan stages of military and civilian engines has led to increasing supersonic relative inlet Mach numbers. The higher Mach numbers lead to stronger shock waves forming in the rotor passages near the blade leading edge. These strong shocks interact with the turbulent boundary layer on the suction side of each blade to produce the flow field depicted in Figure 1.

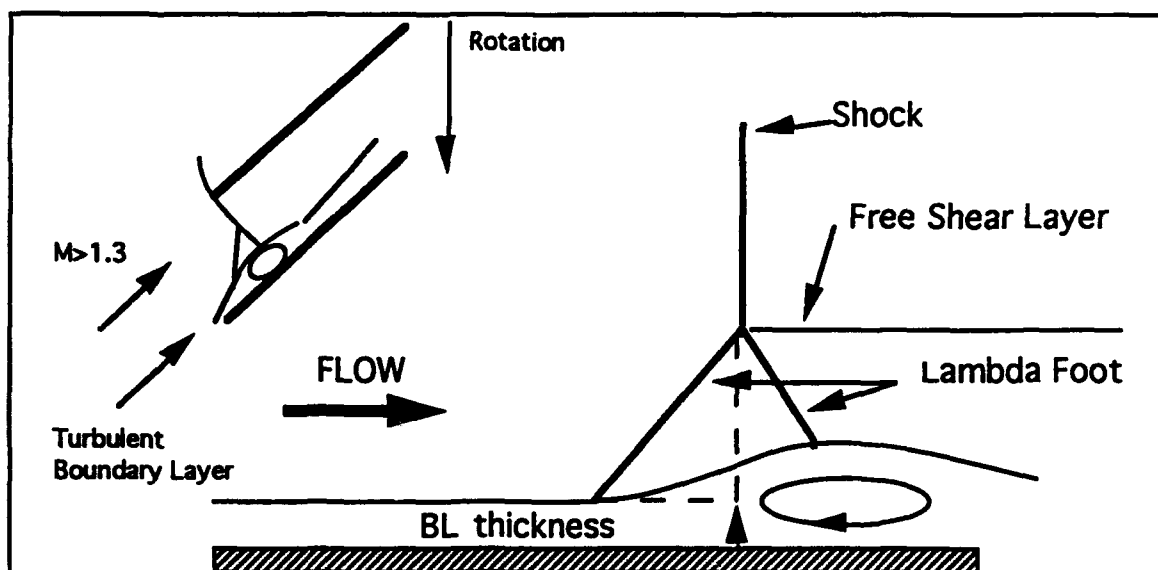


Figure 1. Shock-Boundary Layer Interaction

The shock-boundary layer interaction is characterized by the lambda foot and a local region of reversed flow. The strong shock-boundary layer interaction adversely effects the total pressure ratio and flow turning angle of the compressor blade row. A concept for alleviating the shock-induced boundary layer separation is the use of low-profile vortex generators affixed to the suction surface of the rotor blading, some distance ahead of where the shock impinges.

Vortex generator devices alleviate the shock interaction by energizing the low momentum region of the boundary layer with relative near-freestream flow via streamwise vortices. The vortex generators reduce the relative total pressure loss in the rotor by reducing the size of the local separation and also improve the flow turning angle toward that required by the design. In the present study, 6-5-1 "Triangular Plow Vortex Generators", depicted in Figure 2 and described by McCormick [Ref. 1] and United Technologies Research Center [Ref. 2], were to be used in a model transonic Fan-Blade cascade to quantify their effect on the total pressure losses and flow turning angle and thereby assess the potential benefits of this technique.

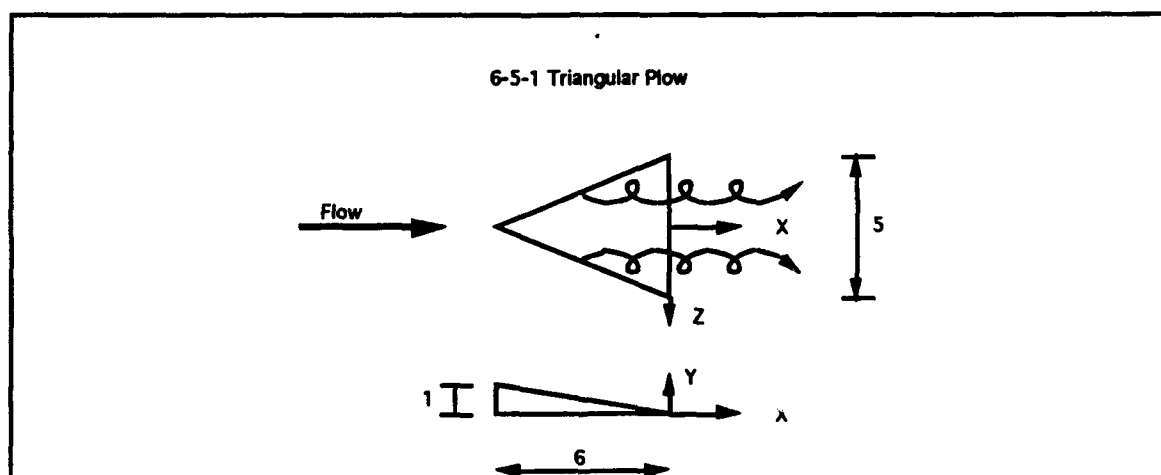


Figure 2. Low-Profile Vortex Generator

The model cascade apparatus was first assembled and operated by Collins [Ref. 3]. First successful static pressure measurements were made by Golden [Ref. 4] and impact probe traverse measurements by Myre [Ref. 5]. Tapp [Ref. 6] showed that repeatable periodic conditions could be achieved at the design flow angle using wall bleed. In the present study, a three-port traversing pneumatic probe was designed, calibrated, and used to measure dimensionless velocity and

flow angle over the outlet of a blade passage. These values were used to calculate a fully-mixed-out condition, and hence the total pressure loss and flow turning angle. A follow-on study will apply the techniques reported here to assess the effects of vortex generators. In the present document, Chapter II describes the design and calibration of the three-port probe and the transonic fan-blade cascade model. Chapter III describes the experimental program and test results. Chapter IV includes the conclusions and recommendations for further work.

II. EXPERIMENTAL DEVELOPMENTS

A. PROBE DESIGN

To measure Mach number and flow angle behind the model fan-blade passage required a probe that was sensitive to only Mach number and pitch angle, since the yaw angle was zero at mid-span. It was desirable (though not necessary) that the arrangement of sensors would result in two pressure coefficients such that one was insensitive to changes in pitch angle at constant Mach number and the other insensitive to changes in Mach number at constant pitch angle. AGARD-AG-207 [Ref. 7] reported probe designs that had such characteristics, which guided the present design shown in Figure 3.

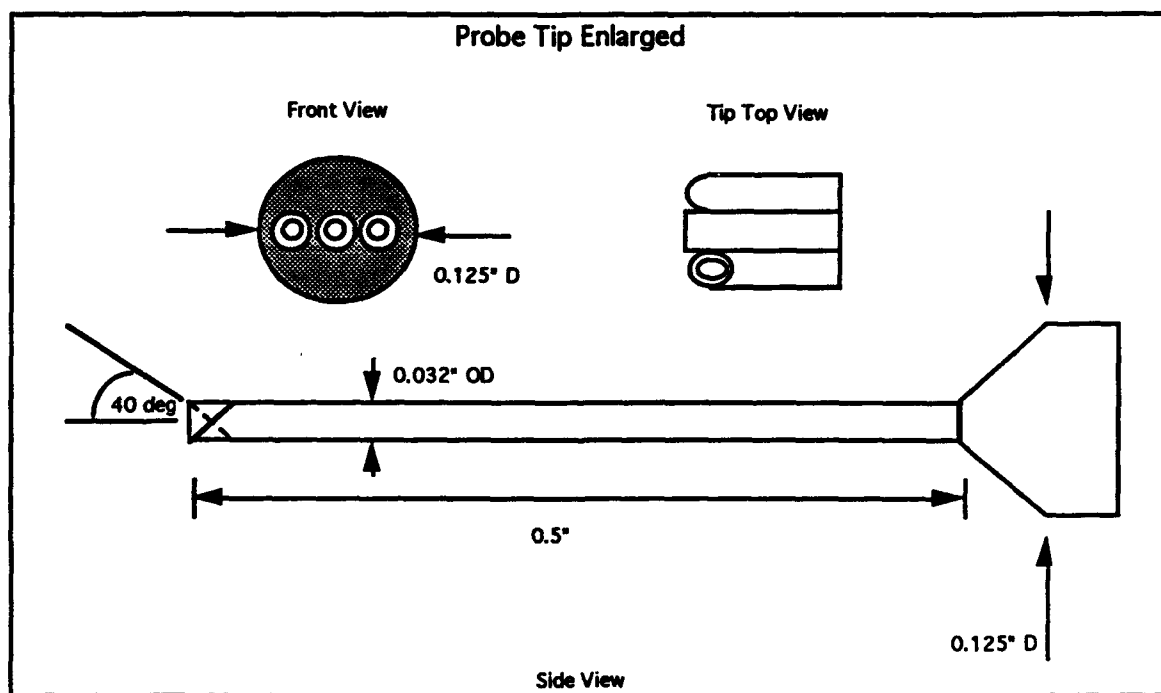


Figure 3. Probe Tip Enlarged

Additionally, the probe was required to measure velocities in a shear layer as it traversed through the fan-blade wake, which required that the ports all lie in the same plane. Myre [Ref. 5] developed a traversing impact probe system for use in the present experiment with the ability to accommodate different probe tips. The present probe was designed to fit the existing probe holder and traverse system for use with the current data acquisition system hardware and software reported by Myre [Ref. 5]. A three-port pneumatic probe was chosen using 0.032" O.D. stainless steel tubing. The center port was cut normal to the tunnel axis with the outer two ports shaved to an angle of approximately forty degrees in opposite directions.

B. PROBE CALIBRATION

The probe calibration was carried out in the Turbopropulsion Laboratory's free-jet calibration apparatus which is shown in Figure 4. The probe holder assembly is described by Myre [Ref. 5] and depicted in Figure 5. The nozzle of the free-jet was 4.25 inches in diameter and was fed by an Allis-Chalmers compressor delivering air at a pressure of up to three atmospheres. The Mach number range of the free-jet, which exhausted to atmosphere, was from 0 to 0.9. The probe holder was attached to an apparatus mounted to the free-jet nozzle which allowed the operator to accurately set and vary the pitch angle of the probe, as required for the calibration. A Prandtl probe was installed 0.5 inches from the jet centerline to provide redundancy in the measurement of Mach number.

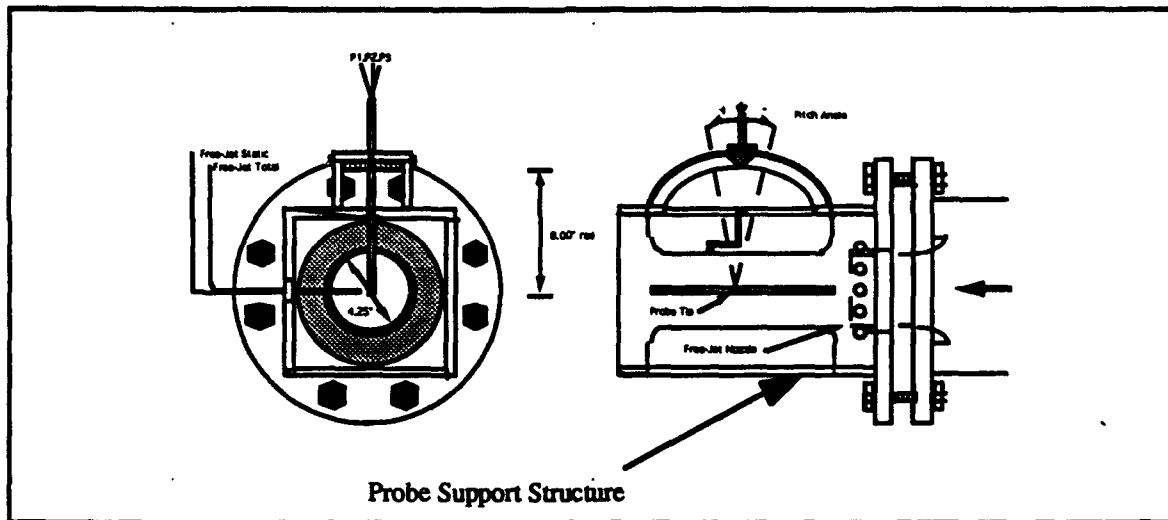


Figure 4. Free-Jet Calibration Apparatus

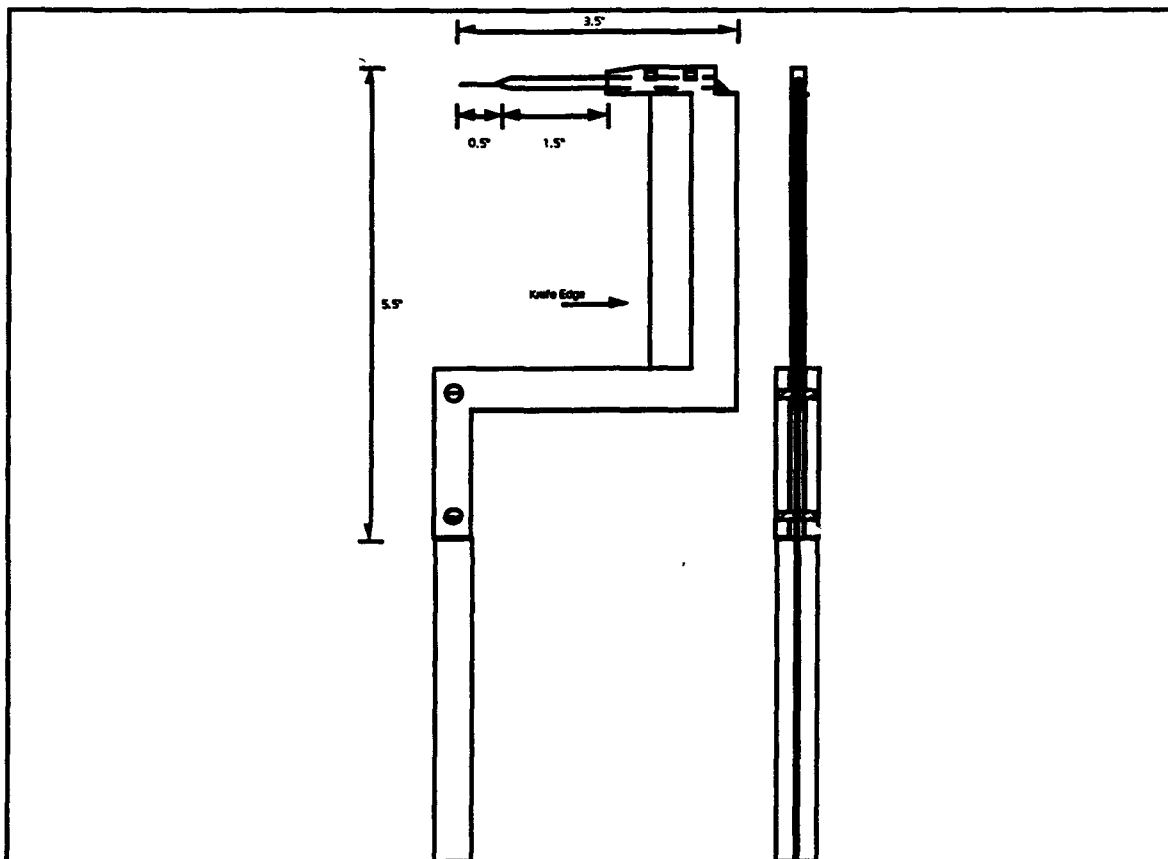


Figure 5. Probe Holder Assembly

1. Data Acquisition System

The pressure measurements of the probe (3), free-jet static pressure (atmospheric), and free-jet total pressure were acquired using a +/- 50 psid Scanivalve transducer controlled by a Hewlett-Packard 9000-300 series computer. The HP 9000 computer sent commands via a HG-78K Scanivalve controller developed by Geopfarth [Ref. 8] to the Scanivalve. It in turn sent the measured voltage of the transducer to a HP 3456A digital voltmeter, which was read by the computer. The voltages were recorded and converted to psia in an HP BASIC data acquisition program, "CAL_ACQ", listed in Appendix A. Golden [Ref. 4] describes in detail the use of the data acquisition system.

2. Program of Measurements

The impact probe and probe assembly were removed from the transonic cascade and the new three-port probe design was installed. The new probe and probe holder assembly were mounted in the free-jet calibration apparatus. The probe was leveled in its mount, then securely fastened in place. The probe tip was located at the center of the free-jet, which has been shown to have a uniform velocity profile by Neuhoﬀ [Ref. 9]. The free-jet static and total pressures were used to calculate the jet Mach number and limiting velocity using isentropic gas relations with the ratio of specific heats equal to 1.4. The relation between total (stagnation) pressure, static pressure, and dimensionless velocity is

$$\frac{P}{P_T} = (1 - X^2)^{\frac{\gamma}{\gamma-1}} \quad (1)$$

where

$$X = \frac{V}{\sqrt{2C_p T_T}}$$

The Mach number was held stable while 12 pitch angles were set in turn and pressure data were recorded. The Mach number was varied in steps of 0.1 from $M = 0.2$ to 0.9 , giving a total of 96 calibration data points. In the calculation of dimensionless velocity the center port pressure measurement was taken to be total pressure since it was always in the center of the flow and always read slightly higher than the Prandtl probe total pressure. The static pressure was taken to be atmospheric, which was consistent with the Prandtl probe measurements. The raw data from the calibration are listed in Table B1 and Table B2 of Appendix B.

3. Probe Characteristics

The derivation of the probe pressure coefficients followed the work of Neuhoﬀ [Ref. 9]. If P_1 is the pressure at the center port and P_2 and P_3 are the pressures of the two side ports, we define the average of P_2 and P_3 as P_{23} , where

$$P_{23} = \frac{P_2 + P_3}{2} \quad (2)$$

and the two pressure coefficients used to represent the calibration of the probe in terms of Mach number and pitch angle are

$$\text{Beta} = B = \frac{P_1 - P_{23}}{P_1} \quad (3)$$

and

$$\text{Gamma} = \Gamma = \frac{P_2 - P_3}{P_1 - P_{23}} \quad (4)$$

The measured characteristics of the probe in terms of Beta and Gamma are shown in Figures 6 and 7 respectively. The Mach-sensitive coefficient Beta

was found to be relatively insensitive to changes in pitch angle over the entire Mach range. The pitch sensitive coefficient Gamma was found to be relatively insensitive to changes in Mach number over the range of pitch angles.

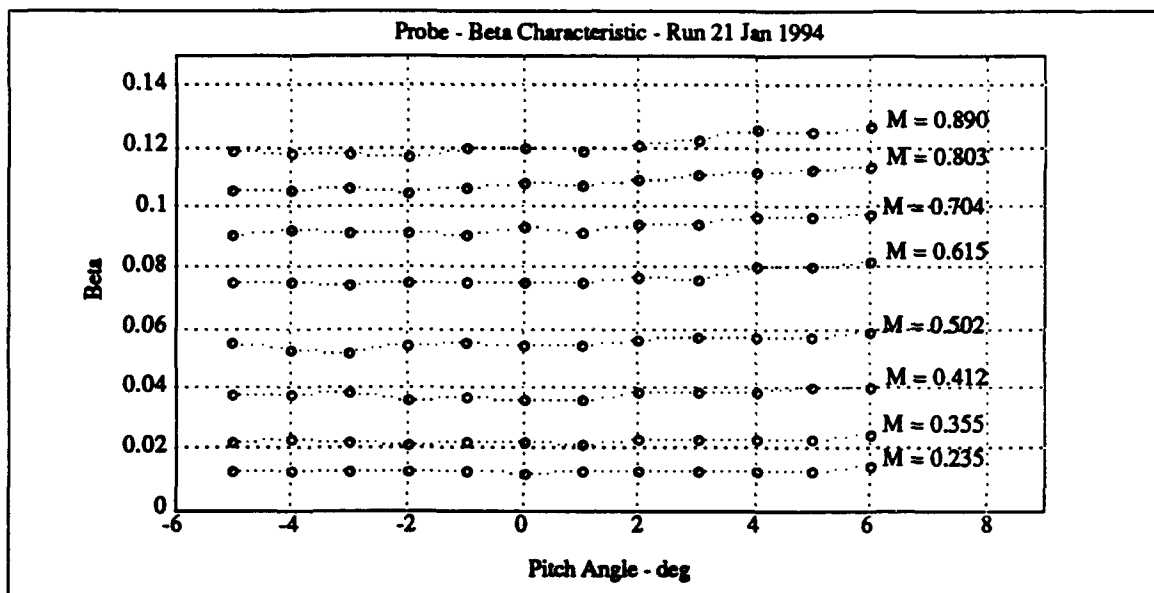


Figure 6. Beta Characteristic

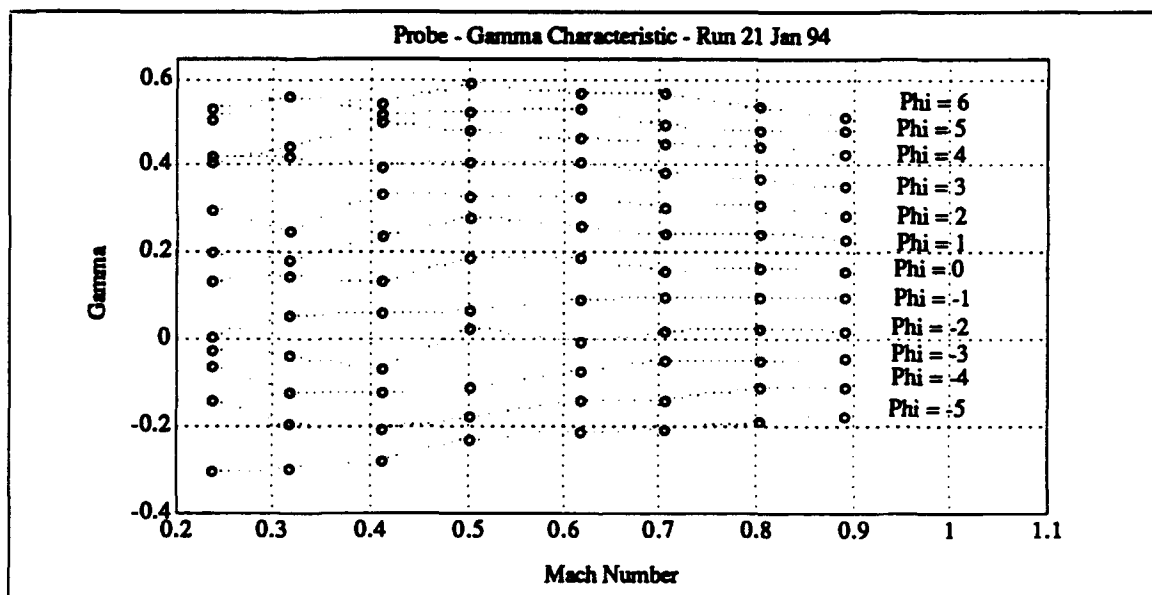


Figure 7. Gamma Characteristic

The insensitivity of Beta to pitch angle allowed the Mach number and dimensionless velocity, X, to be approximated by a polynomial in terms of Beta only. The polynomial for X as a function of Beta was derived utilizing the least-squares method, using an average value of Beta over the range of pitch angle. The program MATLAB was used to determine this polynomial and a choice of a sixth-order polynomial was found to give the least error in X over the calibration range. The polynomial is shown as Equation 5, with the values of the coefficients listed below. The sixth-order polynomial is shown and plotted vs. the actual data points in Appendix C.

$$\begin{aligned}
 X &= a_6 B^6 + a_5 B^5 + a_4 B^4 + a_3 B^3 + a_2 B^2 + a_1 B + a_0 \\
 a_6 &= -1733913.202 \\
 a_5 &= +679216.632 \\
 a_4 &= -104416.881 \\
 a_3 &= +8119.488 \\
 a_2 &= -344.912 \\
 a_1 &= +10.120 \\
 a_0 &= +0.018
 \end{aligned}
 \tag{5}$$

A third-order polynomial for pitch angle was derived in terms of Gamma at each average dimensionless velocity using the least-squares method and the MATLAB software. The polynomial has the form of Equation 6 with the coefficients summarized in Table 1. The third-order polynomials of pitch angle in terms of Gamma are plotted vs. the actual data points in Appendix C.

$$\Phi_i = b_3 \Gamma^3 + b_2 \Gamma^2 + b_1 \Gamma + b_0 \tag{6}$$

where

$$X_i = \text{constant}$$

TABLE 1. PROBE CALIBRATION COEFFICIENTS

	X_i	b_3	b_2	b_1	b_0
Φ_1	0.1047	-0.815	3.584	12.251	-1.841
Φ_2	0.1397	0.156	0.412	12.112	-1.548
Φ_3	0.1812	19.817	-5.526	9.996	-1.461
Φ_4	0.2192	13.149	-3.288	11.104	-1.973
Φ_5	0.2650	15.897	-5.546	12.155	-2.072
Φ_6	0.3002	3.438	0.520	13.270	-2.268
Φ_7	0.3378	11.242	-2.607	13.736	-2.349
Φ_8	0.3698	11.968	-3.634	14.607	-2.347

4. Application of the Calibration

The method of application of the calibration was first to take the measured probe pressures and determine the coefficients Beta and Gamma. From the Beta coefficient, the dimensionless velocity could be determined immediately using the sixth-order polynomial. With the dimensionless velocity known, the third-order polynomials of pitch angle in terms of Gamma could be calculated for the curves associated with the values of the dimensionless velocity above and below the calculated dimensionless velocity. An interpolation scheme given by Nakamura [Ref. 10] was then used to interpolate for the pitch angle at that known velocity and value of Gamma. The results of applying the calibration method to the actual data is given in Appendix C. Over the entire range of the calibration the uncertainty in dimensionless velocity was found to be +/- two percent with a confidence of 70 percent. The pitch angle uncertainty was found

to be ± 0.2 degrees with a confidence of 76 percent. Above a dimensionless velocity value of 0.18, the confidence level increased due to the improved resolution of the data acquisition system at the higher velocities. Above this velocity, where most of the cascade measurements were to be taken, the confidence in determining dimensionless velocity and pitch angle accurately rose to 73 percent and 96 percent respectively. A Kline and McClintock uncertainty analysis [Ref. 11] was performed and at the lower velocities, $X < 0.18$, the uncertainty in Beta and Gamma was much higher than at the higher velocities. This explains why the calibration scheme is more accurate at the higher velocities and why the Gamma characteristic behaves poorly at lower velocities. The calibration application program, written in Hewlett-Packard Basic is listed in the data reduction program "NEW_READ_ZOC1", in Appendix D.

C. TRANSONIC CASCADE MODEL AND DATA ACQUISITION

1. Transonic Cascade Model

The transonic cascade model attempts to simulate the relative flow at $M=1.4$ on a stream surface through a Navy developmental transonic fan. The current model has been shown by Golden [Ref. 4] to be closely two dimensional with the placement of the shock structure set manually using an in-line shadowgraph while adjusting back pressure and bleed valves. The vertically-traversing probe assembly designed by Myre [Ref. 5] was used with the new probe design. Myre also describes the use of the traversing system [Ref. 5]. The wind tunnel facility is shown schematically in Figure 8. The transonic cascade model test section is shown in Figure 9. The model simulation is of the flow through two passages of the transonic blading geometry which is shown in Figure 10. In the cascade simulation, the design pressure ratio and shock

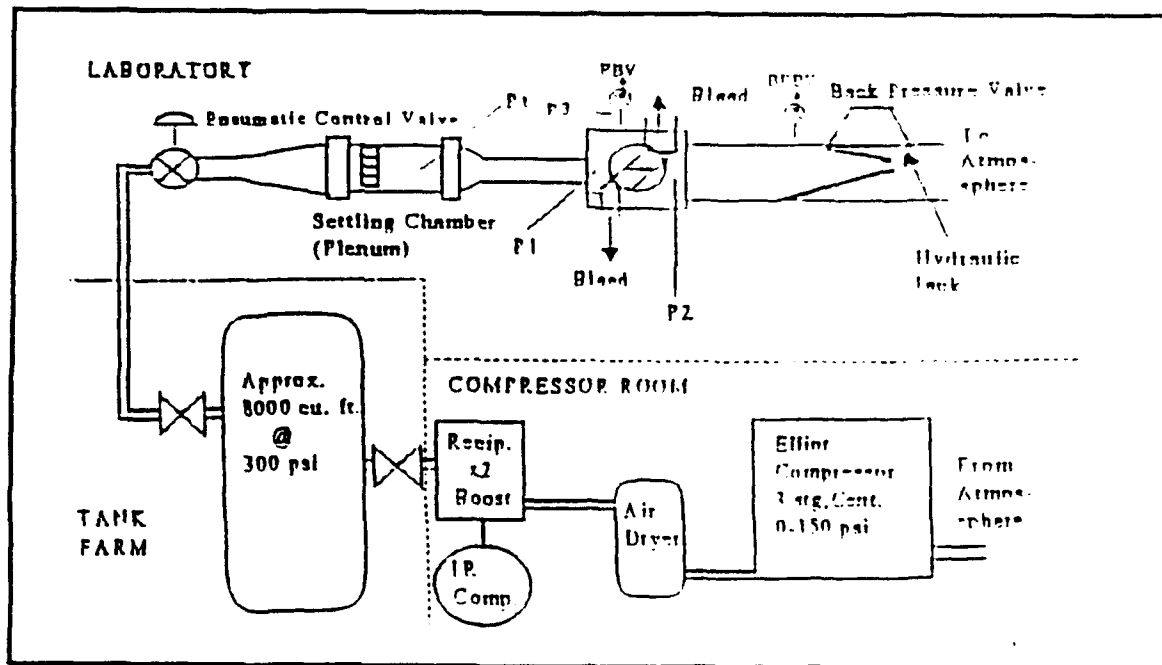


Figure 8. Wind Tunnel Facility

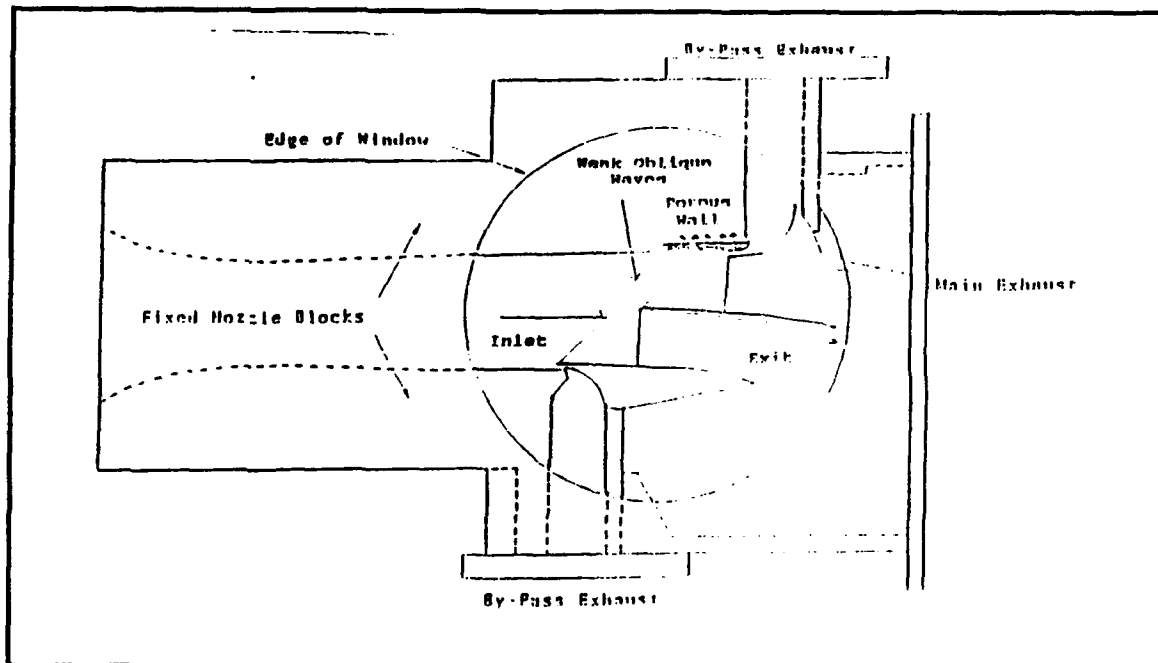


Figure 9. Transonic Cascade Model Test Section

structure at the design incidence were set using the "Back-Pressure Valve (BPV)". A "Back-Pressure Bleed Valve (BPBV)" was used for fine adjustments in setting the proper shock structure (Figure 8).

2. Data Acquisition System

The data acquisition system utilized in the present study was used previously by Tapp [Ref. 6]. One ± 50 psid ZOC-14 enclosure was used to record the three pressures of the traversing probe. Plenum and wall reference pressures were also recorded. The data acquisition program "NEW_SCAN_ZOC" [Ref. 5] was modified slightly to allow the probe-traverse mechanism to increment in smaller steps through the wake, in order to improve the spatial resolution. To change the increment step size required a change in only a single line of code. The initial starting point of the probe-traverse assembly was also changed by a single entry.

The data reduction program "READ_ZOC2" [Ref. 5] was modified for use in the current study and renamed "NEW_READ_ZOC1". The principal change was the application of the routine to return dimensionless velocity and flow angle from the three pressure measurements. The calculation of the fully-mixed-out condition was also calculated in the program. The program is listed in Appendix D and the calculation of the fully-mixed-out condition is summarized in Appendix E. A complete derivation of the method for calculating the fully-mixed-out dimensionless velocity, flow angle, and total pressure is contained in Reference 12.

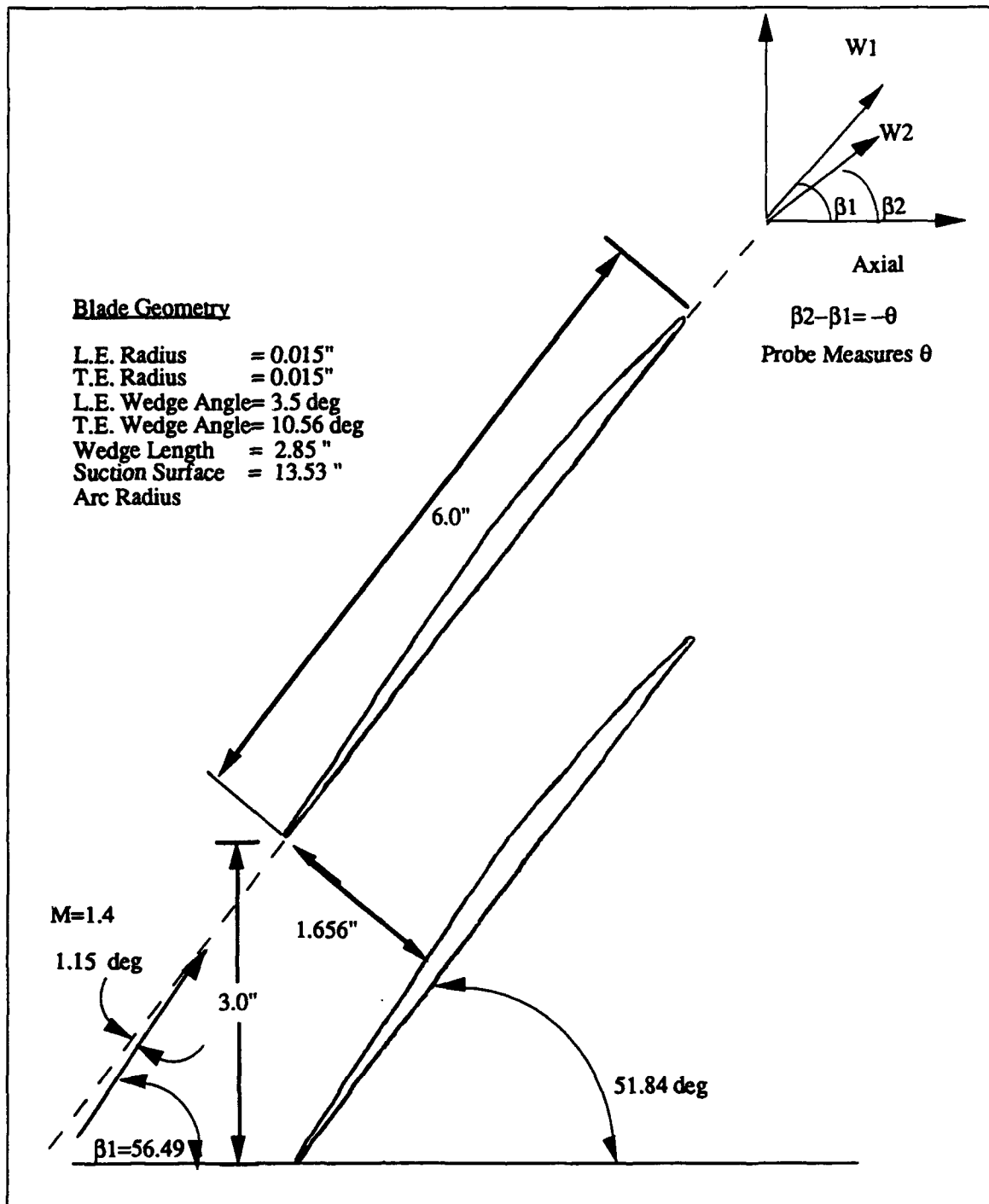


Figure 10. Cascade Blading Geometry

III. EXPERIMENTAL PROGRAM, RESULTS AND DISCUSSION

A. EXPERIMENTAL PROGRAM

The experimental program consisted of a series of initial runs with equal-increment probe traverses through the center blade wake. These tests were used to refine the operation of the pressure valves in setting the shock structure, to become familiar with the data acquisition procedures, and to verify the revised coding of the data reduction program "NEW_READ_ZOC1". Repeatability tests were then conducted to verify that the impact probe measurements compared with previous results reported by Myre [Ref. 5] and Tapp [Ref. 6]. Once these tests were completed the number of data points in the blade wake was increased to provide better resolution through the wake. These tests were used to examine probe-derived static pressure and angle distributions through the wake. Finally, five tests were conducted to provide baseline data and to establish the fully-mixed-out condition for use in studies to assess the effect of vortex generating devices. In all the tests, the shocks in the upper and lower passages were repeatedly set to the expected on-design position, using the following procedure:

- 1. The tunnel was allowed to become steady at a plenum pressure of 33 psig.
- 2. While carefully monitoring the shadowgraph, the BPV was closed by four smooth movements of the hydraulic jack handle.

- 3. A fifth movement of the jack handle (done smoothly) was stopped just as the lower passage shock was in position at a mark on the tunnel side plate (visible in the shadowgraph).
- 4. The BPBV was closed until the upper passage shock was in the corresponding position. Its position was monitored visually throughout the data acquisition during the probe traverse.

B. REPEATABILITY TESTS

These tests were run to compare the mass-averaged loss coefficient results obtained with the new probe and those obtained by Myre [Ref. 5] and Tapp [Ref. 6], using an equal-increment traverse procedure, across a distance of two inches. The probe tip was approximately 1 1/8 inches downstream of the trailing edge of the middle blade with the probe starting its traverse 1.0 inch above the level of the blade trailing edge. Figures 11 and 12 show the blade-wake pressures vs. vertical position during the traverse. Table 2 summarizes the results of tests in which tunnel supply conditions were held reasonably constant.

TABLE 2. REPEATABILITY TESTS: 2/24/94 RUN 2 AND RUN 4

Run #	Patm (psia)	P2/P1	T _T (R)	$\bar{\omega}$
2	14.72	2.11	514.5	0.0842
4	14.715	2.09	513.0	0.0847

The raw pressure data for the complete test program are listed in Appendix F. The mass-averaged losses compared well (to within three percent) with previous results [Ref. 5 & 6] with similar tunnel conditions. The data confirmed that the

probe, data acquisition system, and data reduction process were operating properly.

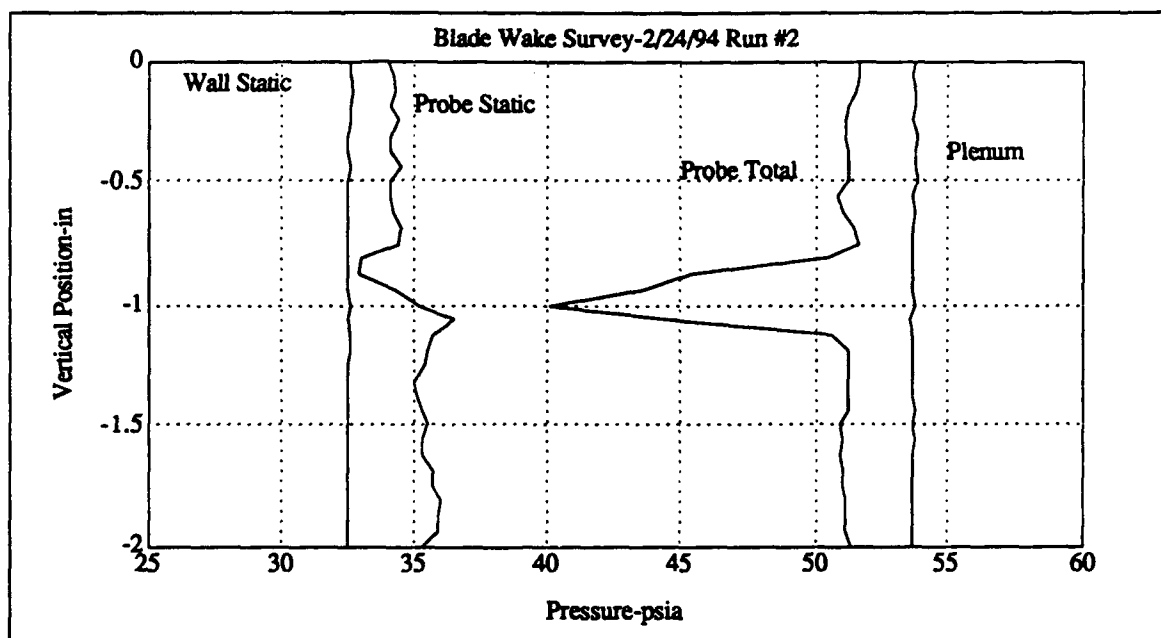


Figure 11. Blade Wake Survey: 2/24/94 Run 2

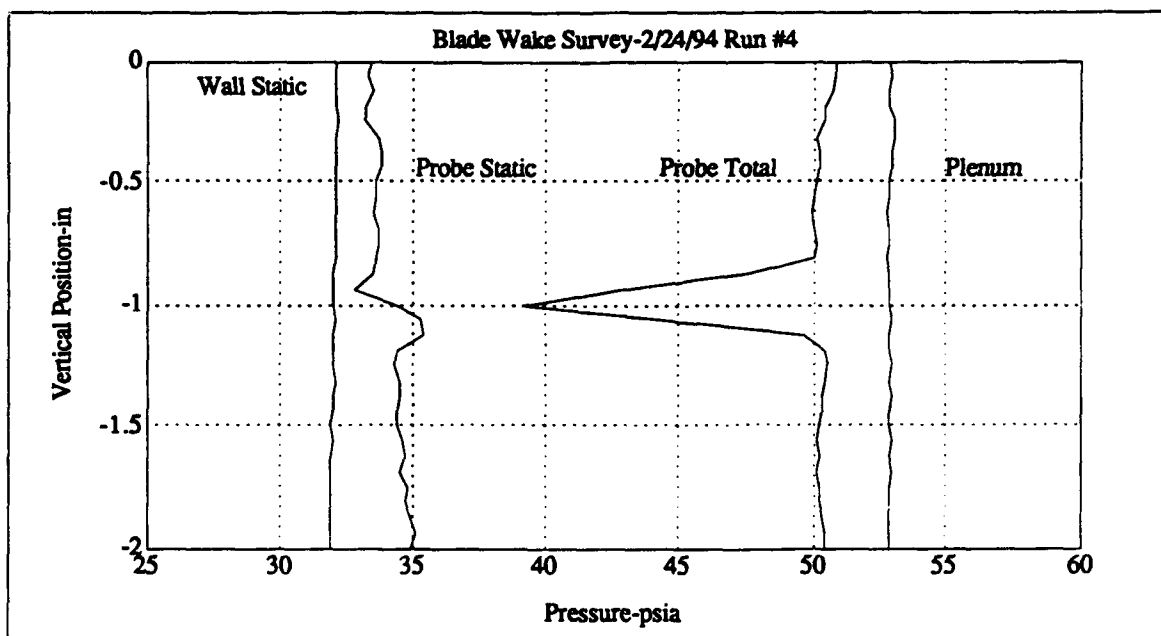


Figure 12. Blade Wake Survey: 2/24/94 Run 4

Probe-derived static pressure profiles are shown in Figures 11 and 12. It is seen that the static pressure on the suction side of the blade was lower than that on the pressure side, implying a higher velocity in that portion of the upper passage. A change in static pressure through the wake can clearly be seen. Both runs show a reasonably periodic condition in the cascade model based only on the measured total pressure.

C. TURNING ANGLE DISTRIBUTION

Figure 13 shows the distribution of the flow angle derived from probe measurements in three similar tests.

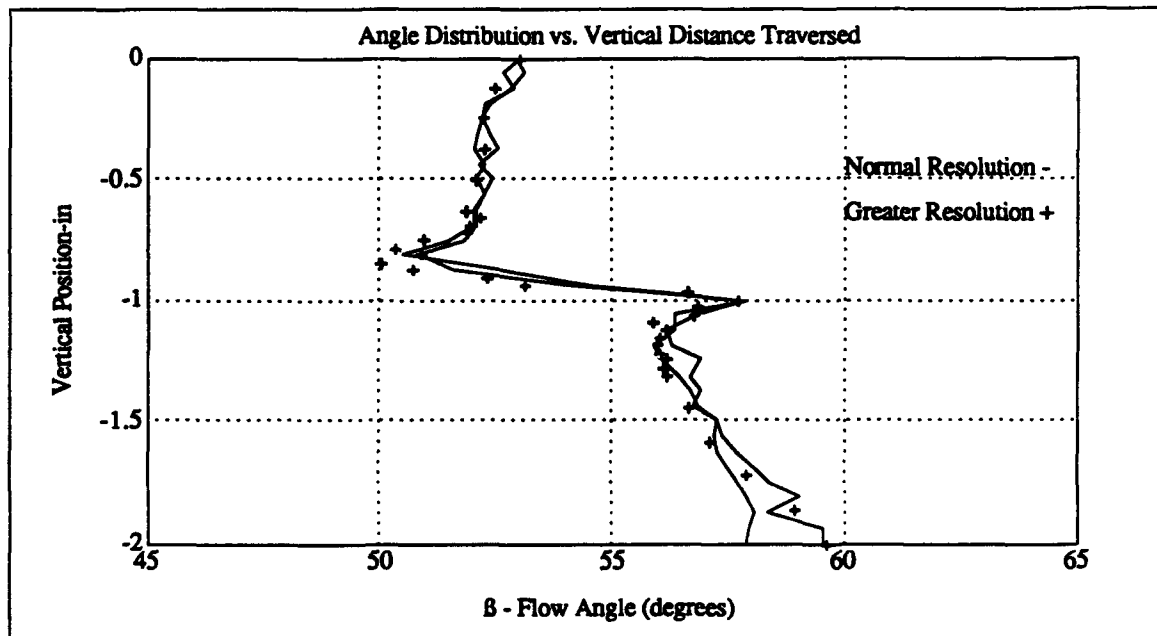


Figure 13. Angle Distribution Comparison

Figure 13 contains data from Runs 2, 4, and 5 of 2/24/94. As presented previously, Runs 2 and 4 were equal-increment surveys for a two inch traverse. Run 5 was a survey which stepped 0.03125 inches per increment through 22 points just prior to, and through the blade wake, providing better spatial

resolution. The start and end points remained the same for all three runs. The data are seen to be similar for all runs. The angle distribution is characterized by increased values of outlet flow angle (β_2) from the upper portion of the lower passage (less turning). The value of β_2 from the upper passage approaches that of the design value of 50 degrees. The flow angle behaves similarly to the static pressure through the turbulent blade wake. Without further measurements, the differences in flow angle and dimensionless velocity cannot be explained definitively. The higher turning angle in the upper passage and lower turning angle in the lower passage is most probably the result of the significant differences in the wakes of the center and lower blades. The center blade is a true blade wake, the lower blade wake is a mixing layer, with entrainment from the test section cavity. In viewing the probe distributions, it should be remembered that the traverse was not parallel to the blade trailing edges so that the lower part of the traverse is further downstream of the blading than is the upper part. The data do show that the angle distributions through the passages were repeatable.

D. PROBE STATIC PRESSURE DISTRIBUTION

Figure 14 shows a comparison of probe-derived static pressure for the same tests as in Figure 13. The static pressure distributions all have the same form, and were reasonably repeatable. The improved resolution blade-wake surveys clearly show a steep decline in static pressure as the probe entered the blade wake, then a sharp rise through the wake. The static pressure rises slightly again on the pressure side of the blade wake, then stabilizes at a value above that of the upper passage.

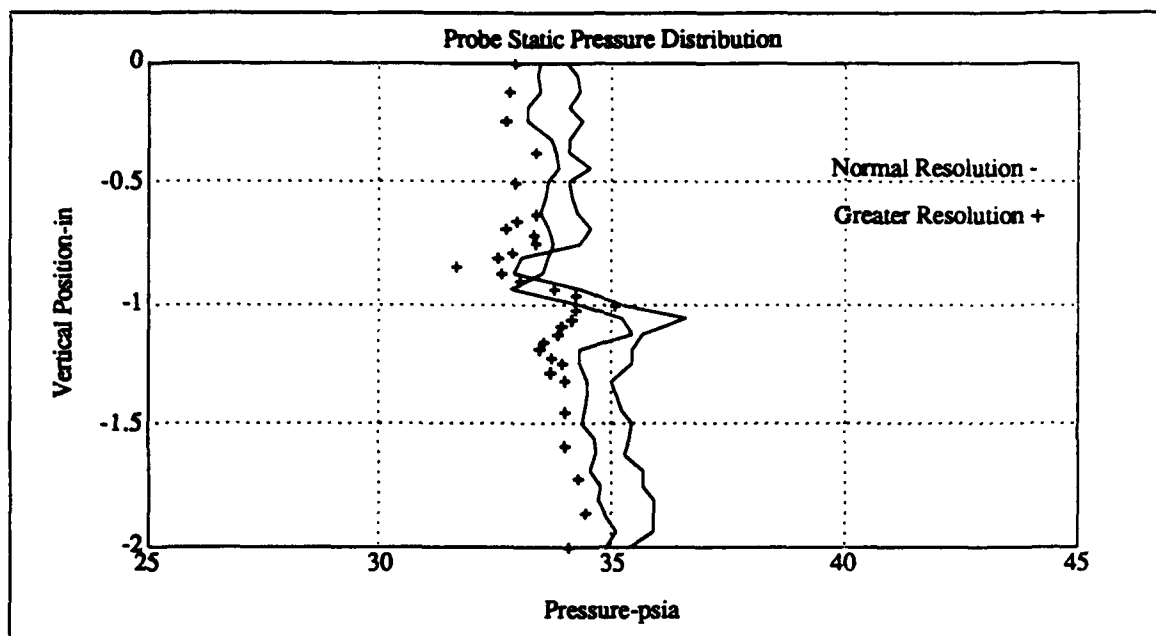


Figure 14. Probe Static Pressure Distribution

E. MODEL BASELINE MEASUREMENTS

The model baseline measurements were made using a survey distance of 1.656 inches (equal to the staggered-passage width, Figure 10) with the probe starting position located 0.75 inches above the level of the middle blade trailing edge. ZOC 1 was used for the probe surveys with the measured pressures and their associated ports listed in Table 3. Table 4 lists the probe positions relative to the starting point with point 1 being the beginning of the traverse above the middle blade. Five runs were made to determine the flow profiles and the baseline loss coefficient using the fully-mixed-out conditions calculated as shown in Appendix E. Table 5 lists the tunnel conditions for the five runs and Table 6 lists the results of the fully-mixed-out calculations. Figures 15 through 19 show the blade wake survey results output by the data reduction program "NEW_READ_ZOC1".

TABLE 3. MEASURED PRESSURES AND PORTS ASSIGNED

Measured Pressure psia	Port Assigned
Atmospheric	1
P1	32
P2	24
P3	25
Upstream Static	29
Downstream Static	30
Plenum	31

TABLE 4. PROBE TRAVERSE POSITON

Point	Relative Position-in	Point	Relative Position-in	Point	Relative Position-in
1	0	12	0.50	23	0.84375
2	0.0625	13	0.53125	24	0.875
3	0.125	14	0.5625	25	0.90625
4	0.1875	15	0.59375	26	0.9375
5	0.25	16	0.625	27	0.96875
6	0.3125	17	0.65625	28	1.00
7	0.34375	18	0.6875	29	1.13125
8	0.375	19	0.71875	30	1.2625
9	0.40625	20	0.75	31	1.39375
10	0.4375	21	0.78125	32	1.525
11	0.46875	22	0.8125	33	1.65625

TABLE 5. BASELINE TUNNEL CONDITIONS

Run #	Upstream Static-psia	P2/P1	T _T (R)	Plenum- psia	Mass Flux Integral
1	15.279	2.09	518.7	48.45	0.9143
2	15.128	2.08	519.7	47.94	0.9140
3	15.379	2.08	518.2	48.76	0.9196
4	15.043	2.07	518.2	47.75	0.9218
5	15.047	2.09	517.7	47.65	0.9227

TABLE 6. BASELINE FULLY-MIXED-OUT CONDITIONS

Run #	X ₃	Pt ₃ - psia	β_3 -deg	$\bar{w}_{mixed}$
1	0.3115	40.73	55.14	0.2328
2	0.3118	40.31	55.15	0.2327
3	0.3100	40.58	54.73	0.2450
4	0.3159	39.76	55.05	0.2443
5	0.3143	39.73	54.92	0.2432
AVERAGE	0.3127	40.22	55.00	0.2396

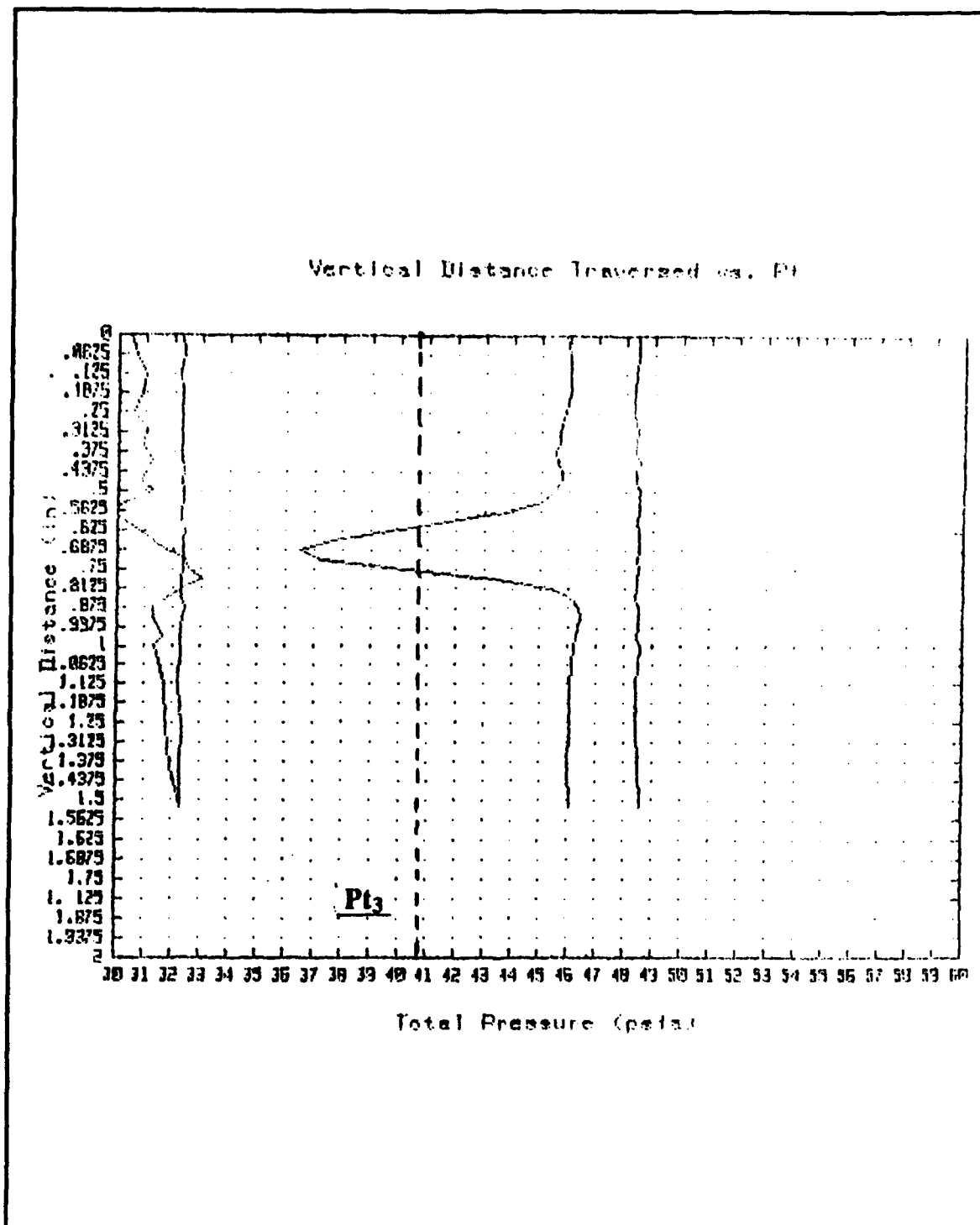


Figure 15. Baseline Blade Wake Survey: Run 1

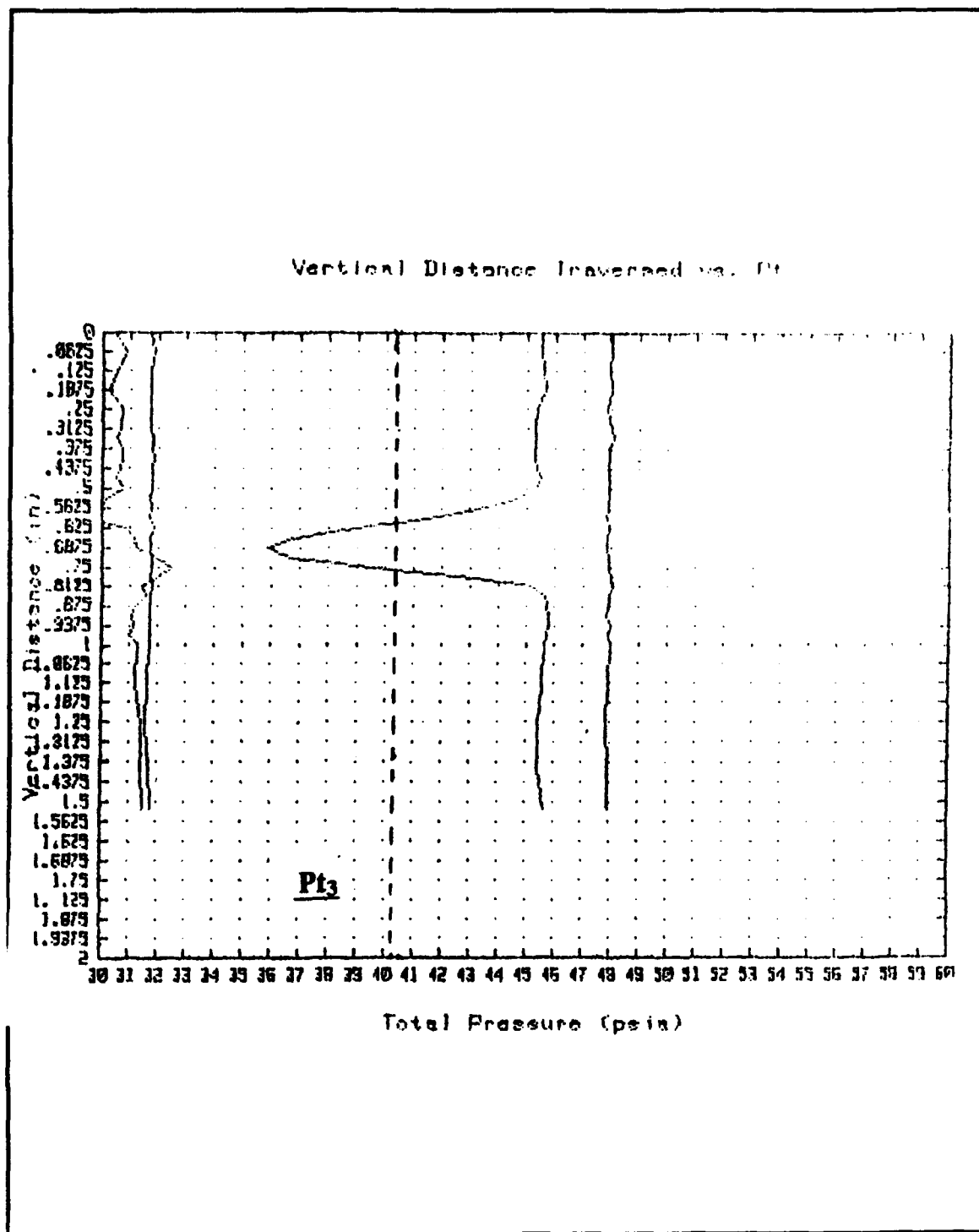


Figure 16. Baseline Blade Wake Survey: Run 2

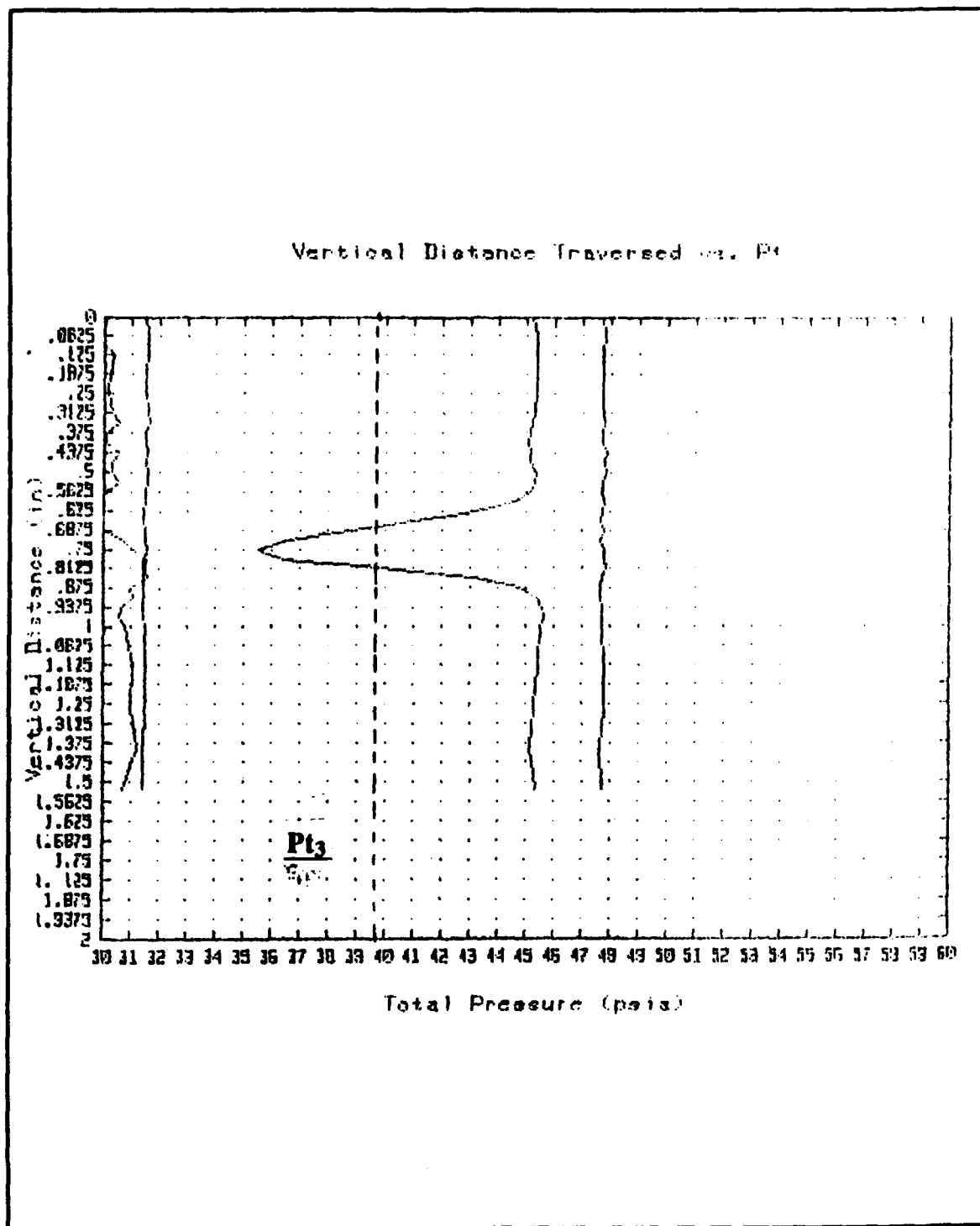


Figure 17. Baseline Blade Wake Survey: Run 3

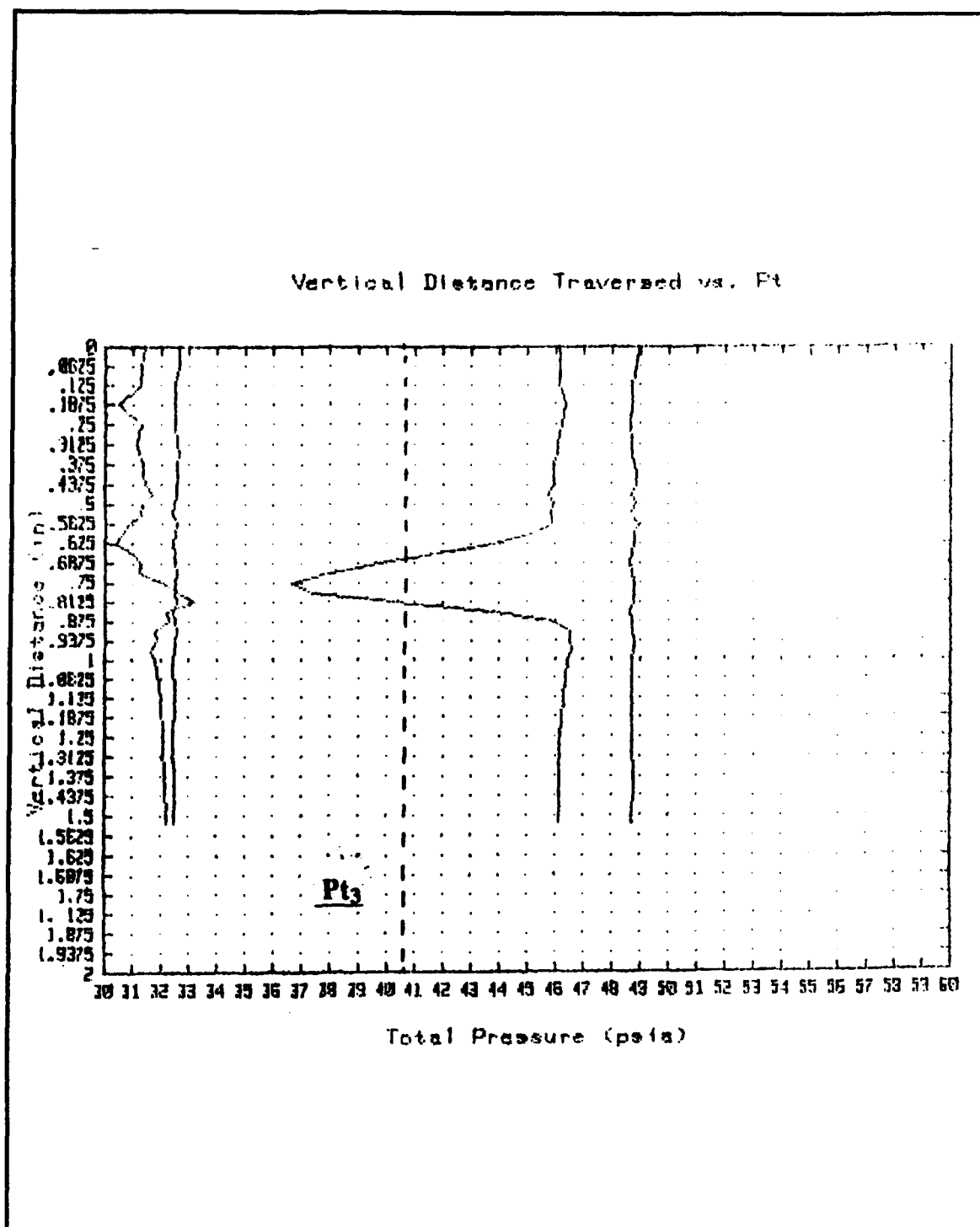


Figure 18. Baseline Blade Wake Survey: Run 4

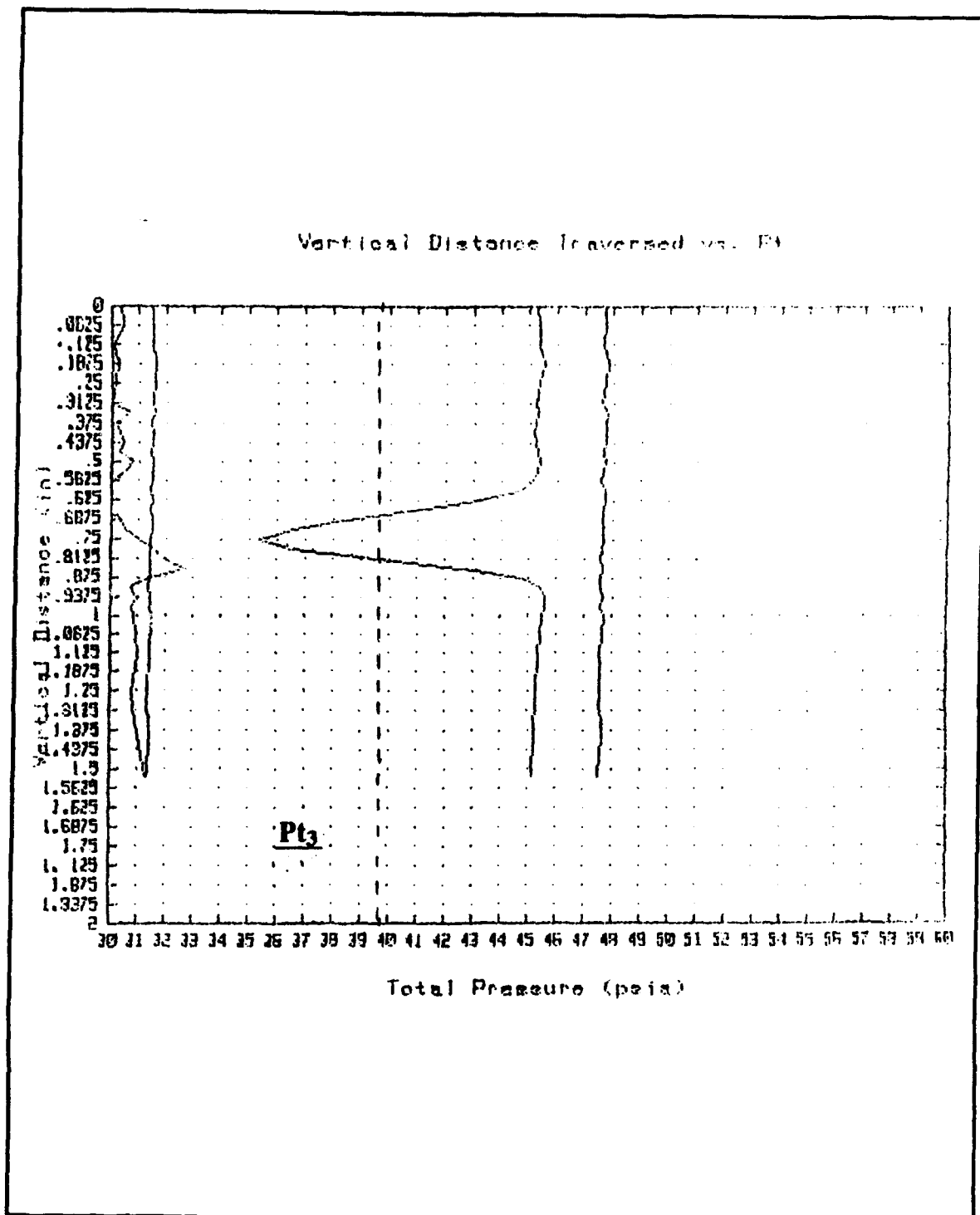


Figure 19. Baseline Blade Wake Survey: Run 5

In all cases, the calculated fully-mixed-out total pressure (P_{t3}) was repeatable and qualitatively showed a low but not unreasonable value when compared to probe-measured total pressure distribution, which was reasonably periodic. The probe-derived static pressure distributions were also repeatable, and followed the trends of the previously discussed results. The calculated fully-mixed-out loss coefficient was more than twice the mass-averaged loss coefficient as presented in Table 2. The fully-mixed-out calculation subprogram in "NEW_READ_ZOC1" was verified by programming a known test case used by Armstrong [Ref. 12]. It is noted that the test case was at low Mach number, rather than the high subsonic range of the present measurements. However, it is also noted that Armstrong also reported that much higher values were obtained for the fully-mixed-out loss coefficient than for the mass-averaged loss coefficient, when reducing cascade-flow survey data.

IV. CONCLUSIONS AND RECOMMENDATIONS

In the present study, the velocity and flow angle distributions, and the fully-mixed-out losses due to the shock-boundary layer interaction in the transonic fan-blade cascade model, were measured at the design incidence angle. The measured flow field and flow losses provide baseline values for planned measurements with low-profile vortex generator devices installed. The fully-mixed-out loss values were more than twice the mass-averaged loss values reported by Myre [Ref. 5] and Tapp [Ref. 6] and repeated in the present study. The measurements of pressure and flow angle distributions were repeatable. The three-port probe, designed for the present study, gave excellent results in measurements of static pressure, dimensionless velocity and flow angle, at velocities greater than $M = 0.4$.

The following specific conclusions were drawn:

- Shock placement using the Back Pressure Valve (BPV), Back Pressure Bleed Valve (BPBV), Porous Bleed Valve (PBV), and in-line shadowgraph system was quick, and gave repeatable results.
- The calculated fully-mixed-out flow losses were significantly higher than mass-averaged results. This may have been due to the probe not traversing parallel to the trailing edge, but a more detailed analysis of how this would effect the calculation needs to be made.
- The probe-derived static pressure in the flow from the suction side of the center blade was lower than that from the pressure side, indicating a higher velocity in the upper passage.

- Angle distributions obtained in the surveys were repeatable and showed less flow turning from the pressure side of the middle blade than from the suction side.
- The probe in its present location, traversing normal to inlet velocity, could not determine the degree of periodicity in the two-passage fan-blade model.
- The probe design had excellent characteristics at medium to high Mach numbers and had the ability to measure accurately in the wake shear layers. Measurements of static pressure and flow angle through the blade wake were consistent with previous experience at lower Mach numbers [Ref. 13].

The following recommendations are made concerning the present pilot and follow-on research program:

- Use the same probe design but increase the range of the angle calibration from -6 degrees to +12 degrees.
- Design and build an apparatus to calibrate the probe in the probe holder while still attached to the motor-controller assembly and utilizing the ZOC system for data acquisition.
- Make more measurements with the current system and validate the calculation of the fully-mixed-out loss .
- Install the 6-5-1 Triangular Plow Vortex Generator Devices and compare the loss measurements and the flow field to the baseline results.

- Once these pilot experiments are complete, proceed to a larger apparatus in which Mach number and cascade geometry can be varied. In the larger apparatus, design the traverse to be parallel to the blade trailing edge.
- The larger apparatus should incorporate three blades to improve the ability to simulate periodicity.

APPENDIX A. PROGRAM "CAL_ACQ"

```

10  FILE NAME:      CAL.ACQ
20  DISK LABEL:     CAL.ACQ
30  FILE DATE:      Austin
40  FILE MODIFIED:  01/19/84
50  DESCRIPTION
60  THIS PROGRAM RECORDS AND REDUCES MEASURED PROBE PRESSURES
70  FROM A THREE-PORT PROBE FOR CALIBRATION OF THE PROBE TO DETERMINE
80  MACH NUMBER AND PITCH ANGLE. THIS PROGRAM ACQUIRES
90  THE RAW DATA AT EACH DISTANCE, MACH NUMBER AND PITCH ANGLE.
100
110
120  VARIABLES FOR SECTION
130  D = DISTANCE
140  P = PRESSURE
150  A = ANGLE
160  C = CHANNEL
170  UP = DATA READING
180  ST = STATION MASTER CODE
190  S = SAMPLE NO.
200  SCANTIME = IS SET TO ADVANCE ONLY
210  P1=P2=P3=PAMB,P101,PSTAT
220  P1=MIDDLE PROBE HOLE (RED)
230  P2=LEFT PROBE HOLE (FROM TOP) (GREEN)
240  P3=RIGHT PROBE HOLE (GREEN)
250  PSTAT=STATIC PRESSURE
260  P101=TOTAL PRESSURE
270  PAMB=AMBIENT PRESSURE
280  S = PITCH SENSITIVE PRESSURE COEFFICIENT
290  B = MACH SENSITIVE PRESSURE COEFFICIENT
300
310  OPTION BASE 1
320  GAMMA=1.4
330  CLEAR SCREEN
340  DISP "PLEASE WAIT WHILE RESETTING SCANTIME"
350  PRINT
360  V=5
370  A=1
380  BUSY Read
390  .....
400  PRINT "DATA ACQUISITION FOR CALIBRATION OF A THREE-PORT PROBE"
410  DIM Y(120),AS(141),HS(141)
420  DIM P1(8,12),P2(8,12),P3(8,12),Pstat(8,12),P101(8,12),PAMB(8,12)
430  DIM Y1(8,12),M2(8,12),B(8,12),B1(8,12)
440  DIM Pstat(8,12),P101(8,12)
450  INPUT "ENTER MONTH, DAY, YEAR (IE. 08, 20, 1984):", Y(1), Y(2), Y(3)
460  PRINT USING "K, DD, / MM, / YY, DATE OF RUN: ", Y(1), Y(2), Y(3)
470  INPUT "ENTER RUN #": Y(4)
480  AS=THIRDS(KVAL$(Y(1))KVAL$(Y(2))KVAL$(Y(3))KVAL$(Y(4)))
490  B=THIRDS(KVAL$(Y(1))KVAL$(Y(2))KVAL$(Y(3))KVAL$(Y(4)))
500  CREATE ASCII ASK(1,200,0.1,10)

```

Figure A1. Program "CAL_ACQ"

Figure A1. (cont) Program "CAL_ACO"

[illegible]

Figure A1. (cont) Program "CAL_ACQ"

Figure A1. (cont) Program "CAL_ACQ"

APPENDIX B. PROBE CALIBRATION RAW DATA

TABLE B1. PROBE CALIBRATION RAW DATA X = 0.10 - 0.22

ANGLE (deg)	P1 (psia)	P2 (psia)	P3 (psia)	PSTAT (psia)	PTOT (psia)	P2 & P3 avg	X	GAMMA	BETA
-5	15.4069	15.1831	15.2424	14.8421	15.3841	15.21275	0.1030245	-0.30543394	0.0126015
-4	15.4051	15.201	15.2268	14.8217	15.359	15.2139	0.10473662	-0.13483724	0.01241147
-3	15.412	15.2172	15.228	14.8271	15.365	15.2226	0.10484925	-0.05702218	0.01228913
-2	15.413	15.2133	15.2176	14.83	15.3644	15.21545	0.104673	-0.02176664	0.0128171
-1	15.4082	15.2139	15.212	14.8279	15.3684	15.21295	0.10453122	0.00968153	0.0127359
0	15.4088	15.2353	15.2104	14.825	15.3591	15.22285	0.1045061	0.13602841	0.01188181
1	15.4063	15.24	15.2028	14.8277	15.3615	15.22145	0.10428477	0.20070327	0.01198834
2	15.422	15.2527	15.1931	14.8282	15.3682	15.2229	0.1055302	0.28934708	0.01291013
3	15.4132	15.2574	15.174	14.8223	15.3668	15.2157	0.10538808	0.42227848	0.01281369
4	15.4128	15.2509	15.1887	14.8258	15.3484	15.2098	0.10503718	0.40482611	0.01317087
5	15.4117	15.2603	15.1581	14.8252	15.3711	15.2092	0.10489581	0.50489138	0.01313937
6	15.4224	15.2587	15.141	14.8241	15.359	15.19985	0.1060242	0.52886992	0.01443031
-5	15.6837	15.4878	15.592	14.8261	15.8155	15.5388	0.14025233	-0.29489859	0.02228886
-4	15.9035	15.5084	15.5772	14.8272	15.8343	15.5418	0.14078267	-0.19574233	0.02274342
-3	15.8946	15.528	15.5692	14.8289	15.826	15.5488	0.14012025	-0.11907514	0.0217684
-2	15.8884	15.5387	15.5504	14.8383	15.8079	15.54455	0.13922888	-0.03402647	0.02184157
-1	15.9001	15.5628	15.544	14.8282	15.8159	15.5533	0.14051286	0.05363322	0.02181118
0	15.9038	15.5764	15.5248	14.8318	15.8188	15.5505	0.1404858	0.14681781	0.02221482
1	15.8893	15.5891	15.5177	14.8373	15.817	15.5488	0.13921788	0.18331375	0.02142322
2	15.8949	15.5785	15.4889	14.842	15.8188	15.5327	0.13925374	0.25288895	0.02276718
3	15.902	15.6135	15.4581	14.8454	15.8082	15.5383	0.13947238	0.42220389	0.02288711
4	15.9012	15.6104	15.4453	14.8434	15.8202	15.52785	0.13955715	0.4422124	0.02347938
5	15.8893	15.624	15.4178	14.8423	15.8314	15.5288	0.13987839	0.5587177	0.02318541
6	15.9048	15.6245	15.4049	14.8523	15.5731	15.5147	0.13918855	0.58322134	0.02451482
-5	16.7033	15.8884	16.1823	14.8523	16.5731	16.07435	0.18188117	-0.27867247	0.03765424
-4	16.7006	16.0078	16.1363	14.8478	16.8051	16.07185	0.18178352	-0.20472441	0.03784238
-3	16.7148	16.0353	16.1104	14.8482	16.5812	16.07285	0.18238388	-0.11702378	0.03839458
-2	16.688	16.064	16.1058	14.852	16.5888	16.0848	0.18097829	-0.06930857	0.03813874
-1	16.6889	16.0893	16.0517	14.8503	16.5858	16.0705	0.18110681	0.06880207	0.03705457
0	16.6883	16.1223	16.0417	14.8521	16.5808	16.082	0.18098887	0.13293749	0.03633084
1	16.6791	16.1497	16.0074	14.8482	16.5721	16.07855	0.18078823	0.23884946	0.03600814
2	16.6949	16.1663	15.9488	14.8534	16.564	16.05805	0.18122177	0.33995446	0.03814838
3	16.6901	16.1811	15.8271	14.853	16.5387	16.0541	0.18102295	0.38837107	0.03810642
4	16.6888	16.201	15.8783	14.8537	16.5511	16.03985	0.18082878	0.48880207	0.03877063
5	16.7041	16.2095	15.863	14.8534	16.5727	16.03825	0.18164127	0.51882988	0.0398812
6	16.7016	16.2124	15.8481	14.8582	16.5701	16.02925	0.18128133	0.544880553	0.04025882
-5	17.6878	16.8005	16.8234	14.8805	17.4989	16.71185	0.21848884	-0.22848308	0.05516011
-4	17.682	16.8495	16.8131	14.8781	17.5308	16.7313	0.21889088	-0.17578187	0.05268505
-3	17.6384	16.8728	16.7724	14.8804	17.5167	16.7228	0.21852902	-0.1088954	0.0518133
-2	17.6874	16.7212	16.8848	14.8852	17.4837	16.708	0.21941822	0.0275172	0.05430341
-1	17.6858	16.742	16.8751	14.8864	17.4888	16.70855	0.22001339	0.06845741	0.05525619
0	17.6847	16.8048	16.8248	14.8888	17.5487	16.7148	0.21925774	0.18848383	0.05377391
1	17.6849	16.8319	16.5579	14.8704	17.5813	16.6949	0.21911454	0.28247423	0.05481115
2	17.6853	16.8592	16.5351	14.8728	17.5308	16.69715	0.21872878	0.32798864	0.05587408
3	17.6904	16.8903	16.4737	14.8707	17.4804	16.682	0.21999539	0.41312971	0.05700267
4	17.6873	16.9044	16.4241	14.8724	17.5039	16.68425	0.21811539	0.47883954	0.05877438
5	17.6548	16.9102	16.379	14.8718	17.5138	16.6448	0.21870422	0.52578442	0.05722491
6	17.659	16.9328	16.3287	14.875	17.5238	16.62975	0.21871483	0.58887538	0.05828473

TABLE B2. PROBE CALIBRATION RAW DATA X = 0.26 - 0.37

ANGLE (deg)	P1 (psia)	P2 (psia)	P3 (psia)	PSTAT (psia)	PTOT (psia)	P2 & P3 avg	X	GAMMA	BETA
-5	19.2303	17.6324	17.93781	14.9019	19.0151	17.785105	0.26507724	-0.21132788	0.07515197
-4	19.2236	17.6813	17.88121	14.8884	19.0361	17.781255	0.26532298	-0.13860068	0.07502891
-3	19.2013	17.7207	17.82441	14.8889	18.8791	17.772558	0.26475814	-0.07258818	0.07440876
-2	19.2342	17.7831	17.78981	14.8911	18.98	17.788455	0.26554165	-0.00463478	0.07526931
-1	19.2042	17.83	17.8881	14.8931	18.9864	17.784305	0.26489238	0.09124971	0.07497813
0	19.2137	17.9099	17.83851	14.8948	18.9402	17.774705	0.26488997	0.18790197	0.07489422
1	19.221	17.9582	17.57981	14.8948	19.0205	17.769005	0.26507365	0.28060007	0.07554212
2	19.2201	17.9927	17.50731	14.9019	18.919	17.750005	0.26481125	0.33017584	0.07648738
3	19.2022	18.0347	17.43671	14.9005	18.9382	17.735705	0.26439806	0.40776818	0.0763712
4	19.2302	18.0481	17.34001	14.8987	18.9358	17.694055	0.26518222	0.48095258	0.0798819
5	18.233	18.1032	17.28101	14.9019	19.0187	17.697105	0.26515786	0.52880568	0.07985728
6	19.2483	18.115	17.22141	14.9034	18.9288	17.688205	0.26544324	0.56824601	0.08199472
-5	20.7578	18.988	19.0578	14.9191	20.5555	18.8833	0.30008337	-0.20512008	0.0912669
-4	20.7889	18.7415	19.0014	14.9189	20.5097	18.87145	0.3007079	-0.1355446	0.09223432
-3	20.7824	18.8349	18.9218	14.9235	20.5139	18.87825	0.3004884	-0.04553213	0.0916232
-2	20.7888	18.9026	18.8854	14.9229	20.5158	18.884	0.30061477	0.01953184	0.09181752
-1	20.7828	18.9754	18.7987	14.9318	20.5023	18.88805	0.30023813	0.09421379	0.09128537
0	20.8028	19.0234	18.7096	14.938	20.5472	18.8865	0.30053062	0.18208166	0.09307882
1	20.7701	19.0977	18.6358	14.9234	20.5548	18.88875	0.30021511	0.24267738	0.09183894
2	20.7821	19.134	18.538	14.9278	20.5648	18.838	0.30055141	0.3046879	0.094079
3	20.7837	19.1791	18.4888	14.941	20.41	18.80388	0.29957054	0.38293747	0.09438828
4	20.7887	19.2317	18.3189	14.9352	20.5188	18.7753	0.30028045	0.45338247	0.09885088
5	20.7878	19.261	18.2582	14.9383	20.5385	18.7551	0.2998688	0.4927709	0.09881445
6	20.7458	19.2889	18.1407	14.9357	20.4787	18.7148	0.29835007	0.56533727	0.09789933
-5	22.8369	20.289	20.7481	15.008	22.4401	20.52355	0.33781229	-0.18888888	0.10521892
-4	22.8201	20.3708	20.6378	15.0088	22.5759	20.5043	0.33783994	-0.11052239	0.10540094
-3	22.823	20.4329	20.5426	15.0088	22.8422	20.48775	0.33784505	-0.04504671	0.10623608
-2	22.9085	20.5355	20.4881	15.003	22.5493	20.5006	0.33746501	0.02884815	0.10502258
-1	22.8412	20.6033	20.3888	15.0114	22.8714	20.48485	0.33782282	0.09838841	0.1070072
0	22.9388	20.6818	20.257	15.008	22.4882	20.4584	0.33788828	0.18328531	0.10808761
1	22.8353	20.7739	20.1675	15.0053	22.8154	20.47055	0.33787852	0.24580729	0.10748535
2	22.8671	20.8613	20.0901	15.005	22.4924	20.4757	0.33840443	0.30854483	0.10847891
3	22.9706	20.9014	19.9547	15.0087	22.8825	20.48805	0.33861829	0.37234273	0.11068714
4	22.9307	20.9408	19.8011	15.0085	22.8417	20.37085	0.33779839	0.44514327	0.11183418
5	22.9279	20.9603	19.7248	15.0009	22.5477	20.34245	0.3378875	0.47784388	0.11278436
6	22.8887	21.0078	19.6188	15.0087	22.517	20.3133	0.3373748	0.5348715	0.11333181
-5	25.185	21.8479	22.481	15.0729	24.9006	22.20445	0.36935398	-0.17214944	0.11834624
-4	25.1712	22.0485	22.3655	15.0751	24.8853	22.207	0.36912206	-0.10694285	0.11778157
-3	25.2089	22.1735	22.2919	15.0745	24.8858	22.2327	0.36908072	-0.03980902	0.1179915
-2	25.1828	22.2658	22.2185	15.0789	25.0103	22.24115	0.36923815	0.0187593	0.11881187
-1	25.2425	22.3807	22.0764	15.0788	24.9345	22.22855	0.37002847	0.10088385	0.11939882
0	25.23588	22.4809	21.8728	15.0715	24.994	22.21875	0.37005558	0.16174805	0.11962943
1	25.2548	22.6099	21.9043	15.0724	24.9486	22.2571	0.37028825	0.23537281	0.11870172
2	25.2329	22.6294	21.7488	15.0771	24.87	22.189	0.36989508	0.28936582	0.12063219
3	25.2277	22.6878	21.5981	15.0747	25.0219	22.14285	0.36987842	0.35317783	0.12228027
4	25.2882	22.8057	21.4402	15.0883	25.0401	22.12295	0.37052159	0.42990848	0.12554745
5	25.2022	22.8202	21.3164	15.0737	24.8398	22.0883	0.3695642	0.47984939	0.12435026
6	25.278	22.8917	21.2815	15.0831	24.7932	22.0818	0.37033101	0.51348108	0.12938076

APPENDIX C. APPLICATION OF THE CALIBRATION

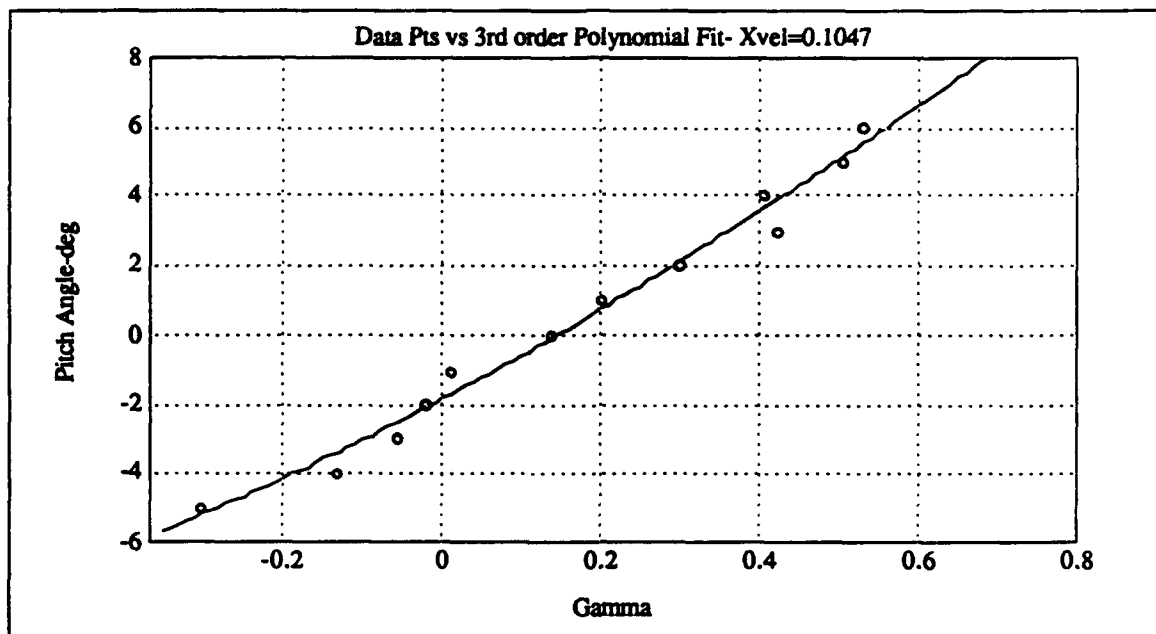


Figure C1. Pitch Angle vs. Gamma X = 0.1047

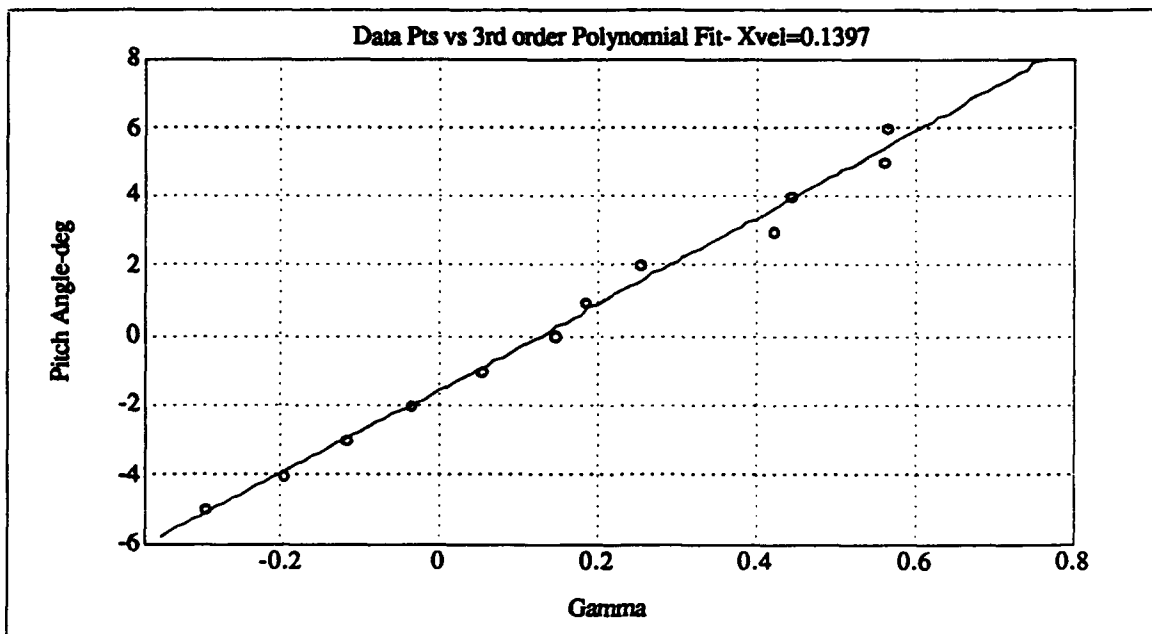


Figure C2. Pitch Angle vs. Gamma X = 0.1397

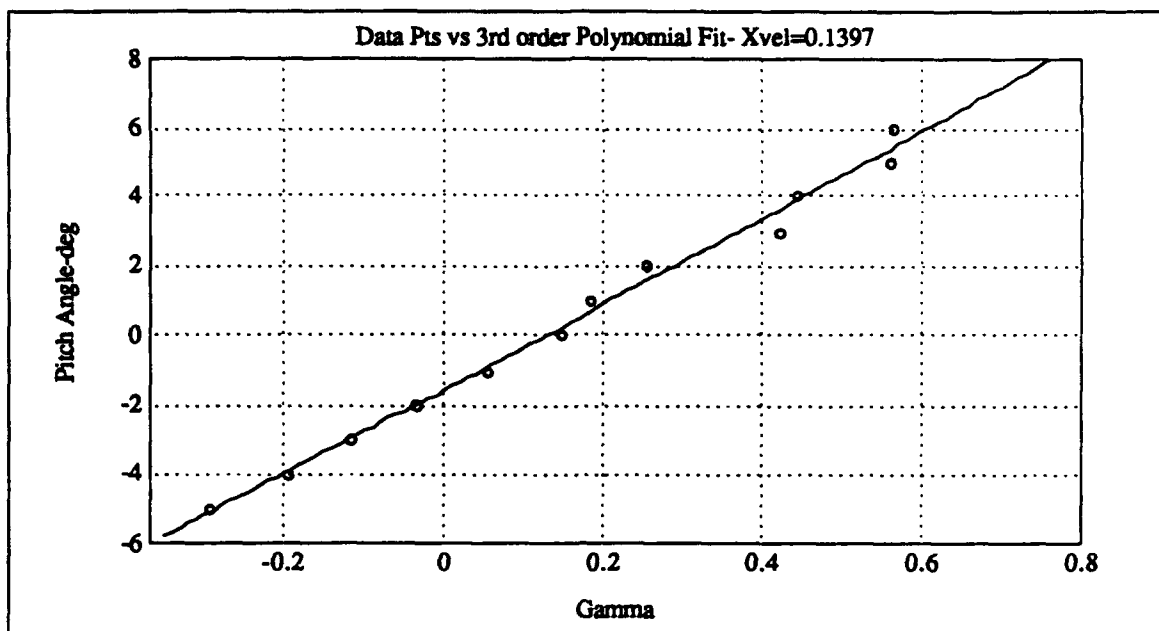


Figure C3. Pitch Angle vs. Gamma $X = 0.1812$

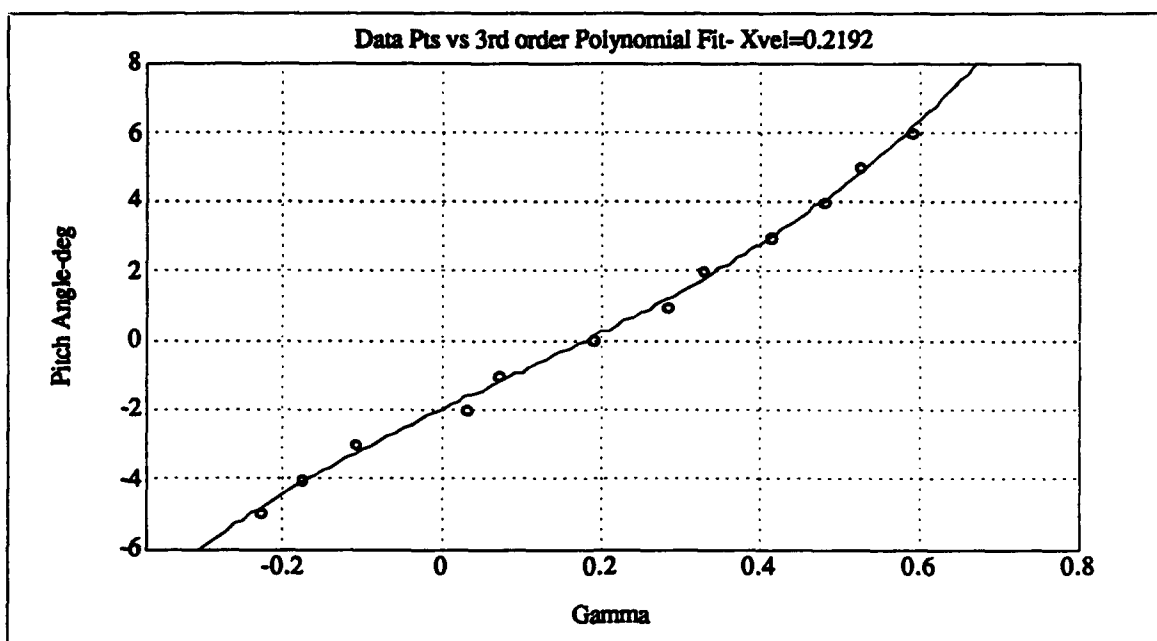


Figure C4. Pitch Angle vs. Gamma $X = 0.2192$

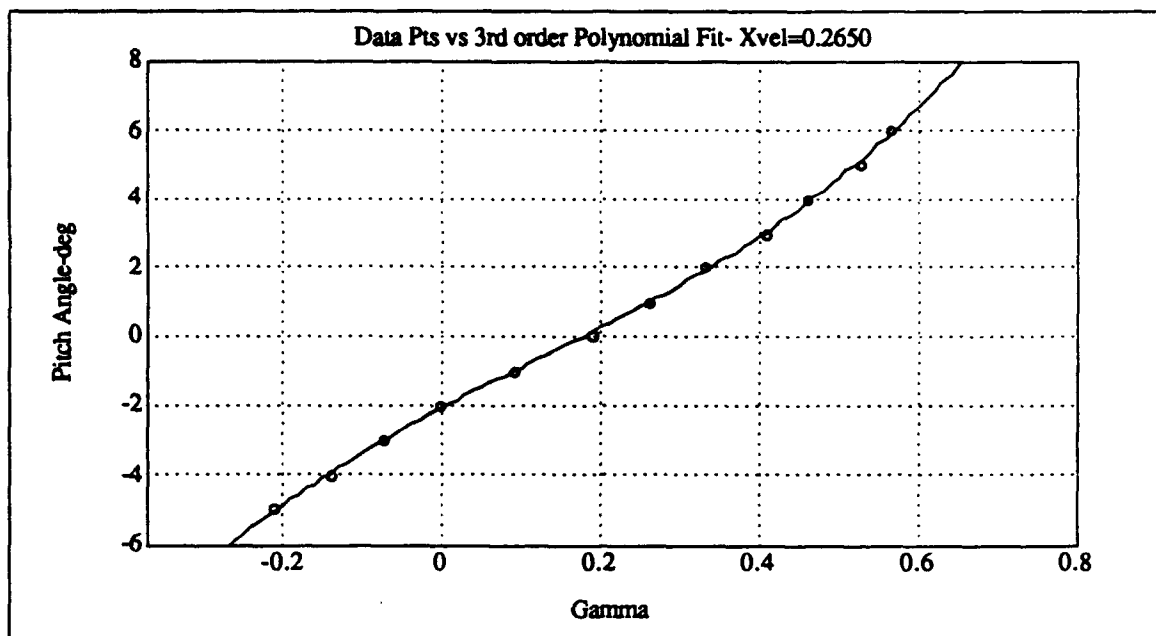


Figure C5. Pitch Angle vs. Gamma $X = 0.2650$

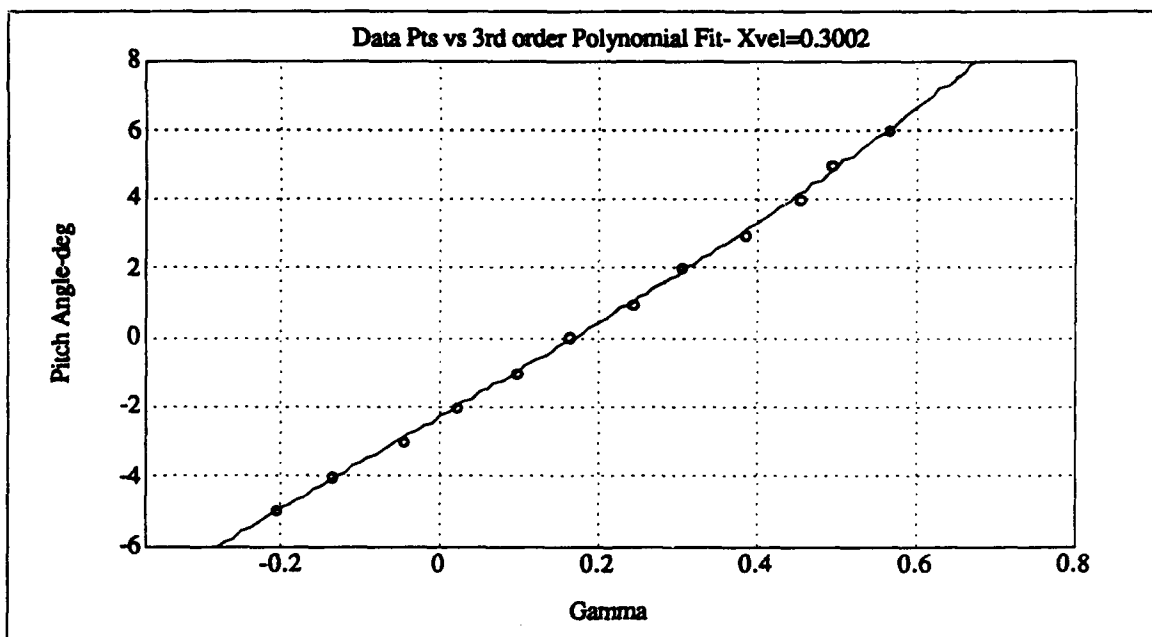


Figure C6. Pitch Angle vs. Gamma $X = 0.3002$

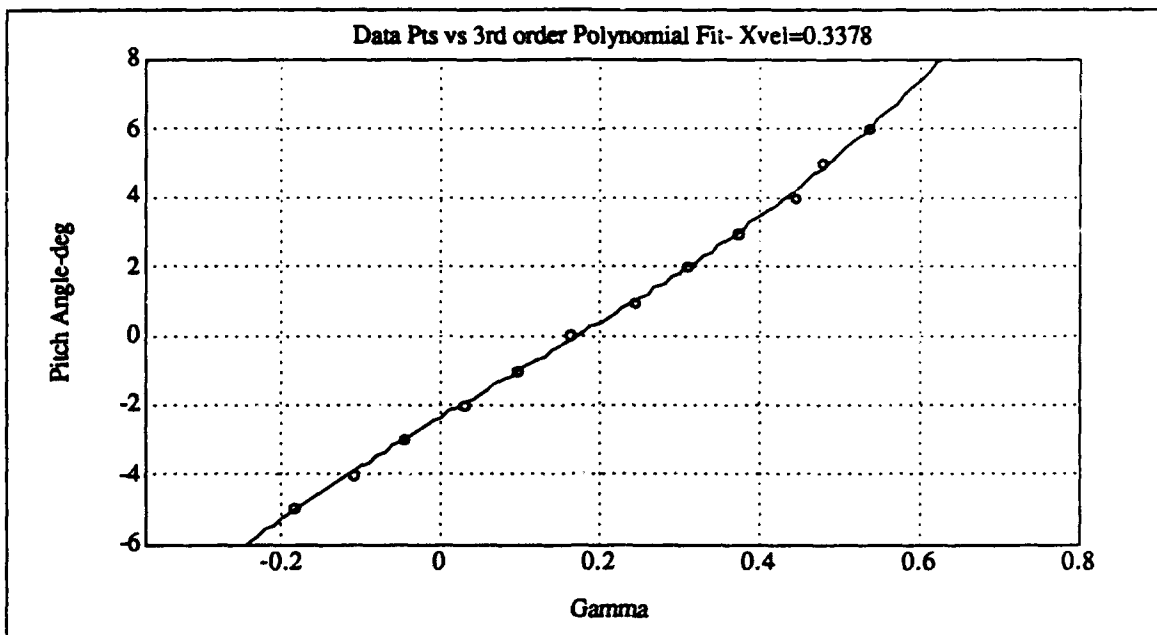


Figure C7. Pitch Angle vs. Gamma $X = 0.3378$

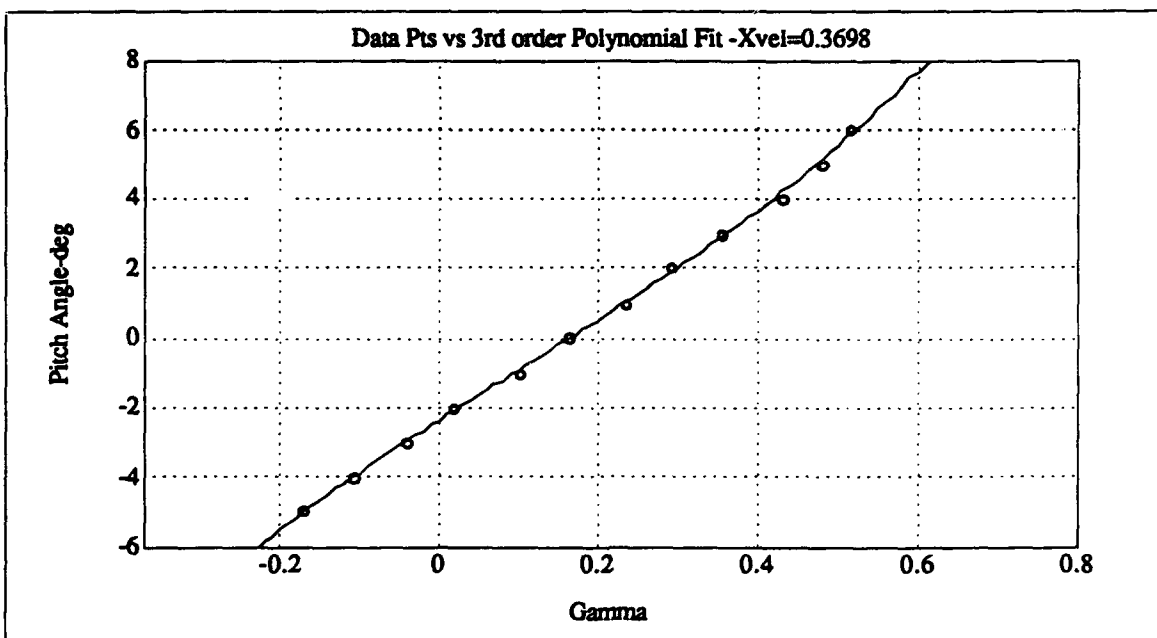


Figure C8. Pitch Angle vs. Gamma $X = 0.3698$

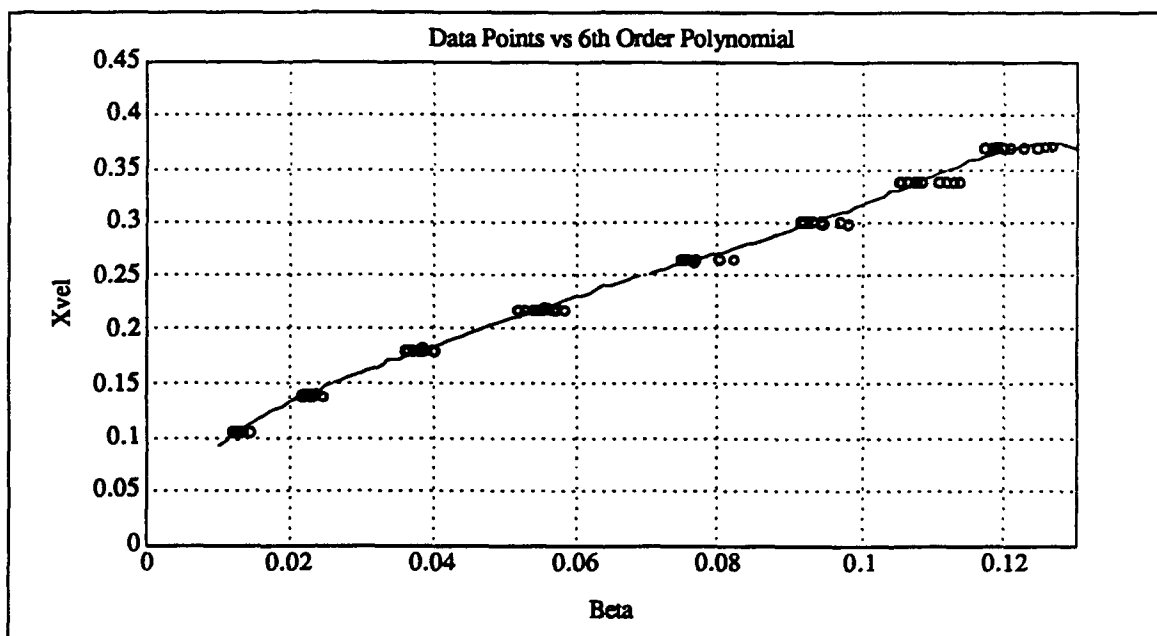


Figure C9. X vs. Beta

TABLE C1. CALIBRATION METHOD RESULTS X = 0.10 - 0.22

ANGLE (deg)	ACTUAL X	CALIBRATED X	CALIBRATED ANGLE	Angle Difference	X % Difference
-5	0.10302443	0.10457949	-5.271	0.271	1.50940746
-4	0.10473655	0.10371192	-3.4375	0.5625	0.97829573
-3	0.10484919	0.10314849	-2.529	0.471	1.62203994
-2	0.10467293	0.10555298	-2.103	0.103	0.84075906
-1	0.10453115	0.10518767	-1.716	0.716	0.62805825
0	0.10450603	0.10124488	-0.109	0.109	3.12053738
1	0.1042947	0.10179391	0.759	0.241	2.39780855
2	0.10553013	0.10596948	2.15	0.15	0.41632236
3	0.10538999	0.10553766	3.93	0.93	0.14107116
4	0.10503711	0.10712581	3.678	0.322	1.98853771
5	0.10499554	0.10698696	5.167	0.167	1.89667253
6	0.10602413	0.11249207	5.517	0.483	6.10044264
-5	0.14025224	0.13980665	-5.09	0.09	0.31770656
-4	0.14079258	0.14122875	-3.91	0.09	0.30979645
-3	0.14012016	0.1382986	-3.01	0.01	1.29999554
-2	0.13922859	0.13791107	-1.988	0.012	0.94630291
-1	0.14051257	0.13841175	-0.919	0.081	1.49511339
0	0.14049581	0.13965073	0.2365	0.2365	0.60149886
1	0.13921777	0.13724023	0.6768	0.3232	1.42046589
2	0.13925365	0.13925365	1.5324	0.4678	2.5998E-06
3	0.1394723	0.1419776	3.647	0.647	1.7962704
4	0.13955706	0.1433869	3.902	0.098	2.74428123
5	0.1388783	0.1443133	5.265	0.265	3.9134965
6	0.13916946	0.14635418	5.55	0.45	5.16257237
-5	0.18166106	0.18007618	-5.124	0.124	0.87243932
-4	0.18178341	0.1800474	-3.92	0.08	0.94408982
-3	0.18238375	0.1818669	-2.749	0.251	0.28338434
-2	0.18097817	0.17639308	-2.231	0.231	2.53350638
-1	0.1811067	0.17862118	-0.8679	0.1321	1.37240608
0	0.18098676	0.1768594	-0.1508	0.1508	2.28047625
1	0.18076612	0.17606679	0.9432	0.0568	2.5996715
2	0.18122165	0.18126723	2.077	0.077	0.02514951
3	0.18102283	0.18117063	2.913	0.087	0.08164354
4	0.18082666	0.18277423	4.608	0.608	1.07703754
5	0.18164116	0.18568528	4.997	0.003	2.22643459
6	0.18128121	0.18634556	5.535	0.465	2.79364135
-5	0.2194901	0.22083929	-4.858	0.142	0.61469162
-4	0.21869114	0.21533631	-4.038	0.038	1.53405034
-3	0.21852929	0.21334476	-3.145	0.145	2.37246331
-2	0.21941948	0.2189379	-1.668	0.334	0.21948013
-1	0.22001366	0.22098927	-1.215	0.215	0.44343307
0	0.219258	0.21775675	0.1151	0.1151	0.68469612
1	0.2191148	0.22028799	1.2	0.2	0.53542175
2	0.21973005	0.22241454	1.789	0.211	1.22172576
3	0.21999565	0.22488684	3.007	0.007	2.22331157
4	0.21911585	0.22438852	4.066	0.066	2.40643095
5	0.21870449	0.22530943	4.899	0.101	3.0200314
6	0.21867328	0.22766856	6.191	0.191	4.11356991

TABLE C2. CALIBRATION METHOD RESULTS X = 0.26 - 0.37

ANGLE (deg)	ACTUAL X	CALIBRATED X	CALIBRATED ANGLE	Angle Difference	X % Difference
-5	0.26507717	0.2619759	-5.013	0.013	1.1699502
-4	0.26532291	0.26173636	-3.889	0.111	1.35176715
-3	0.26475806	0.26051754	-2.977	0.023	1.60165967
-2	0.26554158	0.26220618	-2.125	0.125	1.25607285
-1	0.26469231	0.26163475	-0.9976	0.0024	1.15513717
0	0.2646899	0.26147008	0.1185	0.1185	1.29103287
1	0.26507358	0.26274165	0.99788	0.00212	0.87972867
2	0.26481118	0.26459853	1.908	0.092	0.08030137
3	0.26439052	0.26437015	3.039	0.039	0.00770505
4	0.26518215	0.27131254	3.981	0.019	2.31176687
5	0.26515759	0.27126343	5.206	0.206	2.30272106
6	0.26544316	0.27555841	5.9705	0.0295	3.81070088
-5	0.30008337	0.29543526	-4.997	0.003	1.54894039
-4	0.3007079	0.29766971	-4.053	0.053	1.01034686
-3	0.3004684	0.29625408	-2.846	0.154	1.40258162
-2	0.30061477	0.296241	-1.9896	0.0104	1.45494093
-1	0.30023613	0.29543177	-1.004	0.004	1.60019508
0	0.30053062	0.29964959	-0.091	0.091	0.29315864
1	0.30021511	0.29629037	1.001	0.001	1.30730965
2	0.30055141	0.3020306	1.921	0.079	0.49215954
3	0.29957054	0.30277494	3.09	0.09	1.06966512
4	0.30026045	0.30883693	4.23	0.23	2.85634722
5	0.2999669	0.30899709	4.889	0.111	3.0103945
6	0.29935007	0.31149122	6.2	0.2	4.05583392
-5	0.33781195	0.33103523	-5.013	0.013	2.00608283
-4	0.33783959	0.33154321	-3.888	0.112	1.86372124
-3	0.33764471	0.33385295	-2.965	0.035	1.12300352
-2	0.33746466	0.33049924	-1.944	0.056	2.06404389
-1	0.33782227	0.3361555	-1.037	0.037	0.49338794
0	0.33786794	0.33898174	-0.123	0.123	0.32965667
1	0.33787817	0.33725078	1.039	0.039	0.18331802
2	0.33640408	0.34005809	1.998	0.002	0.48876627
3	0.33661794	0.34611675	3.037	0.037	2.21453438
4	0.33779804	0.3486671	4.32	0.32	3.21762102
5	0.33786715	0.35165497	4.95	0.05	4.08084063
6	0.33737456	0.35312697	6.103	0.103	4.66911618
-5	0.36936742	0.36484632	-4.995	0.005	1.22401028
-4	0.36912224	0.36361324	-3.942	0.058	1.49245984
-3	0.3696089	0.36409248	-2.931	0.069	1.49250252
-2	0.36923632	0.36155338	-2.114	0.114	2.08076611
-1	0.37002864	0.36684095	-0.9156	0.0844	0.86147213
0	0.3700547	0.36725096	-0.0529	0.0529	0.75765544
1	0.37028942	0.36552042	1.007	0.007	1.28791266
2	0.36989523	0.36894668	1.839	0.161	0.25643867
3	0.3698796	0.37124174	2.87	0.13	0.36826666
4	0.37052177	0.37356432	4.209	0.209	0.82115315
5	0.36956438	0.3731039	5.1418	0.1418	0.95775437
6	0.37034438	0.37357425	5.808	0.192	0.87213134

APPENDIX D. PROGRAM "NEW_READ_ZOC1"

```

10  ! Program: NEW_READ_ZOC1
20  ! Description: Reads specified data compiled from program NEW_READ_ZOC1
30  ! by Paul Wendland
40  ! modified by David Myer
50  ! modified 15 May 1997
51  ! modified 23 Feb 1991 by Jeff Austin for 700 program data
52  ! to determine dimensionless velocity and deviation angle for two sample
53  ! traverses. Program will also determine losses calculated from blade
54  ! spacing.
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999 !
1000 !

```

Figure D1. Program "NEW_READ_ZOC1"

```

1290  $P_{avg} = (P_{avg} + reduced\_data) / 2$ ; array.
1290  $P_{avg} = P_{avg} / 2$ 
1300 Sample_min = Sample_min - 1 First sample
1310 Sample_max = Sample_max + 1 Last sample
1320  $P_{avg} = P_{avg} / 2$ 
1330 FOR Scan = 1 TO Scan_max
1340  $P_{avg} = P_{avg} / 2$ 
1350 FOR Port = 1 TO 32
1360  $P_{avg} = P_{avg} / 2$ 
1370  $P_{avg} = P_{avg} / 2$ 
1380 FOR Sample = Sample_min TO Sample_max
1390  $P_{avg} = P_{avg} / 2$ 
1400  $P_{avg} = P_{avg} / 2$ 
1410  $P_{avg} = P_{avg} / 2$ 
1420  $P_{avg} = P_{avg} / 2$ 
1430  $P_{avg} = P_{avg} / 2$ 
1440  $P_{avg} = P_{avg} / 2$ 
1450  $P_{avg} = P_{avg} / 2$ 
1460  $P_{avg} = P_{avg} / 2$ 
1470  $P_{avg} = P_{avg} / 2$ 
1480  $P_{avg} = P_{avg} / 2$ 
1490  $P_{avg} = P_{avg} / 2$ 
1500 NEXT Scan
1510 DISK "Data read from disk and transferred to array."
1520 WAIT 2
1530 GOTO Reset
1540  $P_{avg} = P_{avg} / 2$ 
1550 PRINTS DATA TO PRINTER OR CRT SCREEN AS DESIRED
1560  $P_{avg} = P_{avg} / 2$ 
1570  $P_{avg} = P_{avg} / 2$ 
1580  $P_{avg} = P_{avg} / 2$ 
1590  $P_{avg} = P_{avg} / 2$ 
1600  $P_{avg} = P_{avg} / 2$ 
1610  $P_{avg} = P_{avg} / 2$ 
1620  $P_{avg} = P_{avg} / 2$ 
1630  $P_{avg} = P_{avg} / 2$ 
1640  $P_{avg} = P_{avg} / 2$ 
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1660  $P_{avg} = P_{avg} / 2$ 
1670  $P_{avg} = P_{avg} / 2$ 
1680  $P_{avg} = P_{avg} / 2$ 
1690  $P_{avg} = P_{avg} / 2$ 
1700  $P_{avg} = P_{avg} / 2$ 
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1780  $P_{avg} = P_{avg} / 2$ 
1790  $P_{avg} = P_{avg} / 2$ 
1800  $P_{avg} = P_{avg} / 2$ 
1810  $P_{avg} = P_{avg} / 2$ 
1820  $P_{avg} = P_{avg} / 2$ 
1830  $P_{avg} = P_{avg} / 2$ 
1840  $P_{avg} = P_{avg} / 2$ 
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1860  $P_{avg} = P_{avg} / 2$ 
1870  $P_{avg} = P_{avg} / 2$ 
1880  $P_{avg} = P_{avg} / 2$ 
1890  $P_{avg} = P_{avg} / 2$ 
1900  $P_{avg} = P_{avg} / 2$ 
1910  $P_{avg} = P_{avg} / 2$ 
1920  $P_{avg} = P_{avg} / 2$ 
1930  $P_{avg} = P_{avg} / 2$ 
1940  $P_{avg} = P_{avg} / 2$ 
1950  $P_{avg} = P_{avg} / 2$ 
1960  $P_{avg} = P_{avg} / 2$ 
1970  $P_{avg} = P_{avg} / 2$ 
1980  $P_{avg} = P_{avg} / 2$ 
1990  $P_{avg} = P_{avg} / 2$ 
2000  $P_{avg} = P_{avg} / 2$ 
2010  $P_{avg} = P_{avg} / 2$ 
2020  $P_{avg} = P_{avg} / 2$ 
2030  $P_{avg} = P_{avg} / 2$ 
2040  $P_{avg} = P_{avg} / 2$ 
2050  $P_{avg} = P_{avg} / 2$ 
2060  $P_{avg} = P_{avg} / 2$ 
2070  $P_{avg} = P_{avg} / 2$ 
2080  $P_{avg} = P_{avg} / 2$ 
2090  $P_{avg} = P_{avg} / 2$ 
2100  $P_{avg} = P_{avg} / 2$ 
2110  $P_{avg} = P_{avg} / 2$ 
2120  $P_{avg} = P_{avg} / 2$ 
2130  $P_{avg} = P_{avg} / 2$ 
2140  $P_{avg} = P_{avg} / 2$ 
2150  $P_{avg} = P_{avg} / 2$ 
2160  $P_{avg} = P_{avg} / 2$ 
2170  $P_{avg} = P_{avg} / 2$ 
2180  $P_{avg} = P_{avg} / 2$ 
2190  $P_{avg} = P_{avg} / 2$ 
2200  $P_{avg} = P_{avg} / 2$ 
2210  $P_{avg} = P_{avg} / 2$ 
2220  $P_{avg} = P_{avg} / 2$ 
2230  $P_{avg} = P_{avg} / 2$ 
2240  $P_{avg} = P_{avg} / 2$ 
2250  $P_{avg} = P_{avg} / 2$ 
2260  $P_{avg} = P_{avg} / 2$ 
2270  $P_{avg} = P_{avg} / 2$ 
2280  $P_{avg} = P_{avg} / 2$ 
2290  $P_{avg} = P_{avg} / 2$ 
2300  $P_{avg} = P_{avg} / 2$ 
2310  $P_{avg} = P_{avg} / 2$ 

```

Figure D1. (cont) Program "NEW_READ_ZOC1"


```

600
610 ***** DAT INFORMATION *****
620 *****
630 *****
640 Input: 1
650 *****
660 *****
670 *****
680 *****
690 *****
700 *****
710 *****
720 *****
730 *****
740 *****
750 *****
760 *****
770 *****
780 *****
790 *****
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850 *****
860 *****
870 *****
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890 *****
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1000 *****
1010 *****
1020 *****
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1190 *****
1200 *****
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1220 *****
1230 *****
1240 *****
1250 *****

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

4864 ALLOCATE REAL P2(1:Scan_max)
4865 ALLOCATE REAL P3(1:Scan_max)
4866 ALLOCATE REAL P4(1:Scan_max)
4867 ALLOCATE REAL P5(1:Scan_max)
4868 ! P1 IS P1 in the current probe.
4869 INTEGER N_pts,L,K,Dev
4870 !
4871 ! p1=3 !Used in Lagrange Interpolation
4872 ALLOCATE REAL P23(1:Scan_max)
4873 ALLOCATE REAL Beta_p(1:Scan_max)
4874 ALLOCATE REAL Gamma_p(1:Scan_max)
4875 ALLOCATE REAL X_vel(1:Scan_max)
4876 ALLOCATE REAL X_vel_or(1:Scan_max)
4877 ALLOCATE REAL Pitch_p(1:Scan_max)
4878 ALLOCATE REAL Pitch_or(1:Scan_max)
4879 ALLOCATE REAL Hach_p(1:Scan_max)
4880 ALLOCATE REAL X_interp(1:Scan_max)
4881 ALLOCATE REAL P_interp(1:Scan_max)
4882 ALLOCATE REAL Phi_1(1:Scan_max)
4883 ALLOCATE REAL Phi_2(1:Scan_max)
4884 ALLOCATE REAL Phi_3(1:Scan_max)
4885 ALLOCATE REAL Phi_4(1:Scan_max)
4886 ALLOCATE REAL Phi_5(1:Scan_max)
4887 ALLOCATE REAL Phi_6(1:Scan_max)
4888 ALLOCATE REAL Phi_7(1:Scan_max)
4889 ALLOCATE REAL Phi_8(1:Scan_max)
4890 !
4891 !.....
4892 !
4893 !Plot p1:
4894 !
4895 !Initialize plot parameters
4896 LINE TYPE 1
4897 Title="Vertical Distance Traversed vs. P1"
4898 X_label="Total Pressure (psia)"
4899 Y_label="Vertical Distance (in)"
4900 X0=10
4901 Xf=60
4902 Y0=2
4903 Yf=0
4904 Ox=30
4905 Oy=32
4906 MAT Pen2= (-1)
4907 Pen2(1)= 2
4908 Pen2(Scan_max)= -2
4909 !
4910 CALL Plot !Sets up graphics environment
4911 !
4912 !Flow quantities calculated and total pressure plotted.
4913 !
4914 Go=30.2
4915 Foes=93.3
4916 !
4917 ! Read in data of new blade survey positions
4918 DATA 0.,.0625,.125,.1875,.25,.3125,.375,.4375,.500,.5625,.625,.6875,.75,.8125,.875,.9375
4919 DATA .96875,1.0,1.13125,1.2025,1.39375,1.525,1.65625
4920 DATA .96875,1.0,1.19,1.36,1.54,1.72,1.90
4921 READ Y(*)
4922 !
4923 FOR I=1 TO Scan_max
4924 P_inf(I)=Pa(29,I)
4925 P_ref(I)=Pa(30,I)
4926 P_ref(I)=Pa(31,I)
4927 P(I)=Pa(32,I)
4928 !
4929 O(I)=P_ref(I)-P_inf(I)

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

5470      F101=PI(1),V(1),P0(1)
5480 NEXT I
5490 I=1
5500 FOR J=1 TO Scan_max
5510 F101=1+Cos(1),V(1),P0(1)
5520 NEXT J
5530 J=1
5540 FOR I=1 TO Scan_max
5550 F101=Cos(1),V(1),P0(1)
5560 NEXT I
5570 I=1+Scan_max
5580 *****
5590 *****calibration routine to determine x_val from phi data*****
5600 *****convert to X_val from phi data in che,phi*****
5610 *****convert in Phi to Phi/Gamma probe,X_val*****
5620 FOR I=1 TO Scan_max
5630 *****define needed previous points*****
5640 P1=P(1),P2=P(2),I
5650 P2=P(2),P3=P(3),I
5660 P3=P(3),P4=P(4),I
5670 *****calculate coefficients*****
5680 P12=P1*(P2-P1)+P2*(P1-P2)
5690 P13=P1*(P3-P1)+P3*(P1-P3)
5700 Gamma_p(I)=P12*(P3-P1)+P13*(P2-P1)
5710 *****
5720 *****calculate x_val from BetaFirst calibration routine*****
5730 X_val(I)=1733913.00*Beta_p(I)+5678216.83*Beta_p(I)+104410.00*Beta_p(I)+49119.48*Beta_p(I)+7724.91*Beta_p(I)+2410.12*Beta_p(I)+810
5740 *****
5750 *****Hash_val(I)=SOR((Gamma_p(I)+X_val(I)*Gamma_p(I))/Gamma_p(I))
5760 *****
5770 *****
5780 *****
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9980 *****
9990 *****
10000 *****

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

5615 IF X_val(I) < X_avg_3 THEN X_val(I) = X_avg_3
5616 X_upper = X_avg_4
5617 X_lower = X_avg_3
5618 Phi_upper = Phi_4(I)
5619 Phi_lower = Phi_3(I)
5620 END IF
5621 IF X_val(I) < X_avg_4 AND X_val(I) > X_avg_5 THEN
5622 X_upper = X_avg_5
5623 X_lower = X_avg_4
5624 Phi_upper = Phi_5(I)
5625 Phi_lower = Phi_4(I)
5626 END IF
5627 IF X_val(I) > X_avg_5 AND X_val(I) < X_avg_6 THEN
5628 X_upper = X_avg_6
5629 X_lower = X_avg_5
5630 Phi_upper = Phi_6(I)
5631 Phi_lower = Phi_5(I)
5632 END IF
5633 IF X_val(I) > X_avg_6 AND X_val(I) < X_avg_7 THEN
5634 X_upper = X_avg_7
5635 X_lower = X_avg_6
5636 Phi_upper = Phi_7(I)
5637 Phi_lower = Phi_6(I)
5638 END IF
5639 IF X_val(I) > X_avg_7 AND X_val(I) < X_avg_8 THEN
5640 X_upper = X_avg_8
5641 X_lower = X_avg_7
5642 Phi_upper = Phi_8(I)
5643 Phi_lower = Phi_7(I)
5644 END IF
5645 ! Lagrange interpolation to find the deviation angle
5646 Yns = X_val(I)
5647 Yns = 0
5648 X_interp(1) = X_lower
5649 X_interp(2) = X_upper
5650 F_interp(1) = Phi_lower
5651 F_interp(2) = Phi_upper
5652 FOR I = 1 TO N_pts
5653 Z = 1
5654 FOR K = 1 TO N_pts
5655 IF I = K THEN
5656 Z = Z * (Yns - X_interp(K)) / (X_interp(L) - X_interp(K))
5657 NEXT K
5658 Yns = Yns * (Z * F_interp(1))
5659 NEXT I
5660 Fns = Yns
5661 Fns = Fns * 6.4 - Yns
5662 ! Put loss coefficient calculation in this position
5663 ! Plot static calculated above.
5664 FOR I = 1 TO Scan_max
5665 FLOT Fns(I), Y(I), Pen2(I)
5666 NEXT I
5667 PAUSE
5668 CLEAR SCREEN
5669 ! Print results to Think-Jel
5670 PRINT# 15 CR1
5671 INPUT "Deviation angle and X_vel data to CRT or Printer (0-CRT 1-Printer) : " Dev
5672 IF Dev = 1 THEN PRINT# 15 Dev
5673 CLEAR SCREEN
5674 !

```

Figure D1 (cont) Program "NEW_READ_ZOC1"

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

      X_val(I)=X_val(I)/(Gamma+1)+X_val(I)/(Gamma-1)
5749      I3_den(I)=X1_ref(I)*2*(1-X1_ref(I)*2)/(Gamma+1)
5750      I3_array(I)=I3_num(I)/I3_den(I)
5751      I
5752 NEXT I
5753 ! Begin calling subroutines to determine proper interval of integration
5754 Lowpoint1=1
5755 Highpoint1=33
5756 CALL GaussPlus(Lowpoint1,Highpoint1,I3_array(*),Y(*),I3_int_Finite,Value1,Value2,High_1,Low_1)
5757 PRINT "VALUE1=";Value1
5758 PRINT "VALUE2=";Value2
5759 PRINT "I      "=";High_1
5760 PRINT "I-1    "=";Low_1
5762 !Return the index values to interpolate between when calculating I1,I2,I3
5763 !Interpolate to find proper traverse position for one blade space
5764 Xa_1=1.0
5765 PAUSE
5767 CALL Interpolate(Value1,Value2,Posit1,Posit2,Probe_posit,Xa_1)
5768 PRINT "Probe position for one blade space =";Probe_posit
5769 PAUSE
5770 ! BOGUS VALUES TO CHECK SUBPROGRAMS
5771 ! Probe posit=1.6345
5772 !.....
5773 ! Begin calculations of I1,I2,I3 by calling Dat_int subprogram
5774 ! Define the upper and lower points of the integrals
5775 Lowpoint1=1
5776 CALL Dat_int(Lowpoint1,High_1,I1_array(*),Y(*),I1_int_hi)
5777 CALL Dat_int(Lowpoint1,Low_1,I1_array(*),Y(*),I1_int_lo)
5778 CALL Interpolate(Value1,Value2,I1_int_lo,I1_int_hi,I1_int,Xa_1)
5779 PRINT "I1_INT=";I1_int
5780 PAUSE
5781 !
5782 CALL Dat_int(Lowpoint1,High_1,I2_array(*),Y(*),I2_int_hi)
5783 CALL Dat_int(Lowpoint1,Low_1,I2_array(*),Y(*),I2_int_lo)
5784 CALL Interpolate(Value1,Value2,I2_int_lo,I2_int_hi,I2_int,Xa_1)
5785 PRINT "I2_INT=";I2_int
5786 PAUSE
5787 !
5788 CALL Dat_int(Lowpoint1,High_1,I3_array(*),Y(*),I3_int_hi)
5789 CALL Dat_int(Lowpoint1,Low_1,I3_array(*),Y(*),I3_int_lo)
5790 CALL Interpolate(Value1,Value2,I3_int_lo,I3_int_hi,I3_int,Xa_1)
5791 PRINT "I3_INT=";I3_int
5792 PAUSE
5793 REAL Pt_ref_avg
5794 REAL X_ref_avg
5795 REAL Q_ref_avg
5796 REAL P_ref_avg
5797 X_ref_avg=0
5798 Pt_ref_avg=0
5799 Q_ref_avg=0
5800 P_ref_avg=0
5801 FOR I=1 TO High_1
5802     Y_ref_avg=X1_ref(I)+X_ref_avg
5803     Pt_ref_avg=Pt(I)+Pt_ref_avg
5804     Q_ref_avg=Q_ref(I)+Q_ref_avg
5805     P_ref_avg=P_ref(I)+P_ref_avg
5806 NEXT I
5807 X_ref_avg=X_ref_avg/High_1
5808 Pt_ref_avg=Pt_ref_avg/High_1
5809 Q_ref_avg=Q_ref_avg/High_1
5810 P_ref_avg=P_ref_avg/High_1
5811 !
5812 !.....using I1,I2,I3 calculate A,B,C,D,E
5813 A=(I2_int/I1_int)*X_ref_avg
5814 B=(I3_int/I1_int)*X_ref_avg
5815 C=((Gamma+1)/(Gamma-1))*2

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

6216 D1=7*SQRT(C1)/(1-((2*Gamma)/(Gamma-1))*A1/2) R1=7
6217 F1=B1/2*A1/2*(1-((2*Gamma)/(Gamma-1))*A1/2)/2
6218 X3_super=SQRT(1-D1*SQRT(D1/2-4*C1+E1))/(2*C1)
6220 X3_sub=SQRT((-D1-SQRT(D1/2-4*C1+E1))/(2*C1))
6221 PRINT "X3 SUB =" ; X3_sub
6222 X3_mixed=X3_sub
6223 DEF
6224 Beta3_mixed=ASN(A1/X3_mixed)
6225 P13=(P1_ref_avg*X_ref_avg/(1-X_ref_avg))^((1/(Gamma-1))*11,10)X3_mixed
1-X3_mixed))^((1/(Gamma-1))*0.05/Beta3_mixed))
6226 P13=(11-Int(P1_ref_avg*X_ref_avg/(1-X_ref_avg))^((1/(Gamma-1))*0.05/Beta3_
mixed)*X3_mixed*(1-X3_mixed)^((1/(Gamma-1)))
6228 M_mixed=(P_ref_avg-P13)/(P_ref_avg)
6229 INPUT "Device to print results (0=CRT 1=PRINTER) to
6230 IF Dev=1 THEN PRINTER IS 702
6231 CLEAR SCREEN
6232 PRINT "14 UPPER = " ; Value2
6233 PRINT "14 LOWER = " ; Value1
6234 PRINT "X3_mixed = " ; X3_mixed
6235 PRINT "P_ref_avg = " ; P_ref_avg
6236 PRINT "P13_mixed = " ; P13
6237 PRINT "Beta3_mixed = " ; Beta3_mixed
6238 PRINT "M_mixed = " ; M_mixed
6239 PAUSE
6240 !
6241 ! Plot static that was calculated by Newtonian Iteration
6242 !
6243 CLEAR SCREEN
6244 PRINTER IS CRT
6245 CALL Plot
6246 FOR I=1 TO Scan_max
6247   PLOT P_exit(I),Y(I),Pen2(I)
6248 NEXT I
6249 FOR I=1 TO Scan_max
6250   PLOT P_st_p(I),Y(I),Pen2(I)
6251 NEXT I
6252 PAUSE
6253 !Deallocate all real variables
6254 !
6255 DEALLOCATE Pen2(*)
6256 DEALLOCATE P_inf(*)
6257 DEALLOCATE P_exit(*)
6258 DEALLOCATE P_ref(*)
6259 DEALLOCATE M_inf(*)
6260 DEALLOCATE M_exit(*)
6261 DEALLOCATE Ma1(*)
6262 DEALLOCATE Ma2(*)
6263 DEALLOCATE Ma3(*)
6264 DEALLOCATE Ma4(*)
6265 DEALLOCATE Q(*)
6266 DEALLOCATE P1(*)
6267 DEALLOCATE Y(*)
6268 !.....
6269 !Deallocate added variables
6270 DEALLOCATE F2_1(*)
6271 DEALLOCATE P_st(*)
6272 DEALLOCATE P_st_p(*)
6273 DEALLOCATE P3_r(*)
6274 DEALLOCATE Pitch(*)
6275 DEALLOCATE Pitch_p(*)
6276 DEALLOCATE X_vel_p(*)
6277 DEALLOCATE X_vel(*)
6278 DEALLOCATE Beta_p(*)
6279 DEALLOCATE Gamma_p(*)
6280 DEALLOCATE X_interp(*)

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

6325 DEALLOCATE P_interpol
6326 DEALLOCATE P23(*)
6327 DEALLOCATE Mech_vel(*)
6328 DEALLOCATE Phi_1(*)
6329 DEALLOCATE Phi_2(*)
6330 DEALLOCATE Phi_3(*)
6331 DEALLOCATE Phi_4(*)
6332 DEALLOCATE Phi_5(*)
6333 DEALLOCATE Phi_6(*)
6334 DEALLOCATE Phi_7(*)
6335 DEALLOCATE Phi_8(*)
6336 DEALLOCATE X1_ref(*)
6337 DEALLOCATE I4_array(*)
6338 DEALLOCATE I3_array(*)
6339 DEALLOCATE I2_array(*)
6340 DEALLOCATE I1_array(*)
6341 DEALLOCATE I3_out(*)
6342 DEALLOCATE I3_den(*)
6343 DEALLOCATE R2(*)
6345 .....
6346 KEY LABELS ON
6347 PRINTER IS CRT
6348 I
6350 GOTO Pass1
6351 I
6352 .....
6380 EXIT PROGRAM AND DEALLOCATE ALL BUFFERS AND DATA
6381 .....
6400 I
6410 Deallocate: I
6420 ASSIGN #Data_path1 TO *
6430 ASSIGN #Data_path2 TO *
6440 DEALLOCATE Cal(*)
6450 DEALLOCATE Data(*)
6460 DEALLOCATE Pa(*)
6470 RETURN
6480 I
6490 Finish: I
6500 IF allocated=1 THEN GOSUB Deallocate
6510 PRINTER IS CRT
6520 LOAD "ZOC_MENU",10
6530 END
6540 I
6550 .....
6560 (SUBROUTINE TO SET UP GRAPHICS WINDOW
6570 .....
6580 I
6590 SUB Plot
6600 I
6610 (Subroutine to display plot screens, less the plot of any curves
6620 (for the specified variables in the COM/Plot_labels/ line.
6630 I
6640 COM /Plot_labels/ X0,Xf,Y0,Yf,Dx,Dy,Title,X_label,Y_label
6650 CLEAR SCREEN
6660 KEY LABELS OFF
6670 GINIT
6680 X_range=Xf-X0
6690 Y_range=Yf-Y0
6700 LOG6 6
6710 MOVE 100*RATIO/2,100
6720 CSIZE 3
6730 LABEL Title$
6740 MOVE 100*RATIO/2,0
6750 LOG6 4
6760 LABEL X_label$
6770 DEF

```

```

Initialize graph routine
(Length of X-axis
(Length of Y-axis
(Character ref plot center
(Move cursor to screen top for labels
(Sizes labeling
(Plot title
(Move cursor to bottom center screen
(Character ref plot bottom center
(X-axis label
(Design degrees for LOG6

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

6770 RETURN
6780 LOG 5
6800 MOVE 0,50
6810 LABEL Y_Label3
6820 LOOP 0
6830 LOG 0
6840 VIEWPORT 10,90+PATIO,10,90
6850 FRAME
6860 MOVE(Xo,Xf,Yo,Yf)
6870 AXES X range/Dx,X range/Dy,Xo,Yo
6880 AXES X range/Dx,X range/Dy,Xf,Yf
6890 PLOT X range/Dx,X range/Dy,Xo,Yo,Dx,Dy,001
6900 PLOT 001
6910 PLOT X,0,.4
6920 LOG 0
6930 FOR I=Yo TO Yf STEP Y range/Dy
6940     MOVE I,Yo+.01*Y range
6950     LABEL USING "R,I,I"
6960 NEXT I
6970 LOG 0
6980 FOR J=Xo TO Xf STEP X range/Dx
6990     IF ABS(J)/1.0E-5 THEN I=0,
7000     MOVE Xo+.01*X range,I
7010     LABEL USING "R,I,I"
7020 NEXT J
7030 PLOT 001
7040
7050 SUBROUT
7060
7070 SUB Square(Xo,Xf,Yo,Yf,Se)
7080 Subroutine to plot squares around the focal or top destroyed
7090 by the PLOT statement.
7100 Xd=Se+(Xf-Xo)
7110 Yd=Se+(Yf-Yo)*PATIO
7120 PLOT Xd,Yd,-2
7130 PLOT Xd,Yd,-1
7140 PLOT Xd,Yd,-1
7150 PLOT Xd,Yd,-1
7160 PLOT Xd,Yd,2
7170 SUBEND

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

7700 SUB PosFus (INTEGER Lowpoint, Hpoint, REAL DC*, Pos(1:14), Int(1:14), Value1, Value2, INTEGER High(1:14), Low(1:14))
7710 OPTION BASE 1
7720 DIM A(100)
7730 DIM B(100)
7740 DIM C(100)
7750 DIM Dint(100)
7760 DIM Datint(100)
7770 DAT A= (0)
7780 DAT B= (0)
7790 DAT C= (0)
7800 DAT Dint= (0)
7810 DAT Datint= (0)
7820 I4_int=0
7830 B-Hpoint-1
7840 Dat=0
7850 FOR I=Lowpoint+1 TO H
7860 A(I)=C/(Pos(I+1)-Pos(I-1))*((D(I+1)-D(I))/(Pos(I+1)-Pos(I))+D(I)-D(I-1))/2*(Pos(I)-Pos(I-1)))
7870 B(I)=(D(I)-D(I-1))/(Pos(I)-Pos(I-1))*((Pos(I)+Pos(I-1)+A(I))/2*(Pos(I)-Pos(I-1))-B(I))/2*(Pos(I)-Pos(I-1))
7880 NEXT I
7890 Dint(1)=A(2)*(Pos(2)-3-Pos(1)+3)/3.0+B(2)*(Pos(2)-3-Pos(1)+3)/2.0+D(1)*(Pos(2)-Pos(1))
7900 Dint(N)=A(N)*(Pos(N)+3-Pos(N)+3)/3.0+B(N)*(Pos(N)+3-Pos(N)+3)/2.0+D(N)*(Pos(N)+3-Pos(N))
7910 FOR I=Lowpoint+1 TO H
7920 Dint(I)=(A(I)+A(I+1))*(Pos(I+1)+3-Pos(I)+3)/6.0+(B(I)+B(I+1))*(Pos(I+1)+3-Pos(I)+3)/4.0+(C(I)+C(I+1))*(Pos(I+1)-Pos(I))/2
7930 NEXT I
7940 FOR I=1 TO N
7950 I4_int=I4_int+Dint(I)
7960 IF I4_int=1.0 THEN
7970 Posit2=Pos(I)
7980 Posit1=Pos(I-1)
7990 Value2=I4_int
8000 Value1=I4_int-Dint(I)
8010 High_1=(I)
8020 Low_1=I+1
8030 GOTO 8040
8040 END IF
8050 NEXT I
8060 Posit2=Pos(I)
8070 Posit1=Pos(I-1)
8080 Value2=I4_int
8090 Value1=I4_int-Dint(N)
8100 High_1=(I+1)
8110 Low_1=(I)
8120 RETURN

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```

0000 SUB Interpolate(X_low,X_high,F_lower,F_upper,Yana_1,Xa_1)
0010 OPTION BASE 1
0020 Yana_1=0
0030 INTEGER L,K
0040 DIM X(100)
0050 DIM F(100)
0060 MAT X= (0)
0070 MAT F= (0)
0080 X(L)=X_low
0090 X(H)=X_high
0100 F(L)=F_lower
0110 F(H)=F_upper
0120 H=H+1
0130 FOR L=1 TO H-1
0140     F(L)=F
0150     IF F(L)=F THEN
0160         GO TO 8230
0170     END IF
0180     Z1=Z1+(Xa_1-X(L)*F)/(X(H)-X(L))
0190     NEXT L
0200 Yana_1=Yana_1+(Z1+F(L))
0210 NEXT F
0220 SUBEND
0230 SUB Dat_int(INTEGER Lowpoint,Hipoint,REAL B(X),P(X),B(X))
0240 ! Shreeve Integration program Ref. NPS-575F73B71A
0250 OPTION BASE 1
0260 DIM A(100)
0270 DIM B(100)
0280 DIM C(100)
0290 DIM Dint(100)
0300 MAT A= (0)
0310 MAT B= (0)
0320 MAT C= (0)
0330 MAT Dint= (0)
0340 N=Hipoint-1
0350 N=Lowpoint+1
0360 FOR I=Lowpoint+1 TO N
0370     A(I)=(1.0/(R(I+1)-R(I-1)))*((D(I+1)-D(I))/(R(I+1)-R(I)))+(D(I)-D(I-1))/(R(I)-R(I-1)))
0380     B(I)=(D(I)-D(I-1))/(R(I)-R(I-1))-(R(I)+R(I-1))*A(I)
0390     C(I)=(D(I)-A(I))*P(I)^2-R(I)*R(I)
0400     NEXT I
0410 Dat_int=0
0420 FOR I=Lowpoint+1 TO N
0430     Dint(I)=(A(I)+A(I+1))*R(I+1)^3-R(I)^3)/6.0+(B(I)+B(I+1))*R(I+1)^2-R(I)^2)/2.0
0440     Dat_int=Dat_int+Dint(I)
0450     NEXT I
0460 Dint(N)=(A(N)+A(N+1))*R(N+1)^3-R(N)^3)/3.0+(B(N)+B(N+1))*R(N+1)^2-R(N)^2)/2.0+(C(N)+C(N+1))-R(N))
0470 Dat_int=Dat_int+Dint(N)
0480 SUBEND

```

Figure D1. (cont) Program "NEW_READ_ZOC1"

APPENDIX E. MIXED-OUT LOSS CALCULATION

The calculation of the total pressure loss coefficient in the fan-blade cascade model required the calculation of fully-mixed-out-flow conditions. This requirement was difficult due to the probe not traversing parallel to the trailing edge of the blades, and the use of uneven spacings. Figure E1 shows the fully-mixed-out control volume for the analysis, and the location of the traverse in the fan blade cascade model.

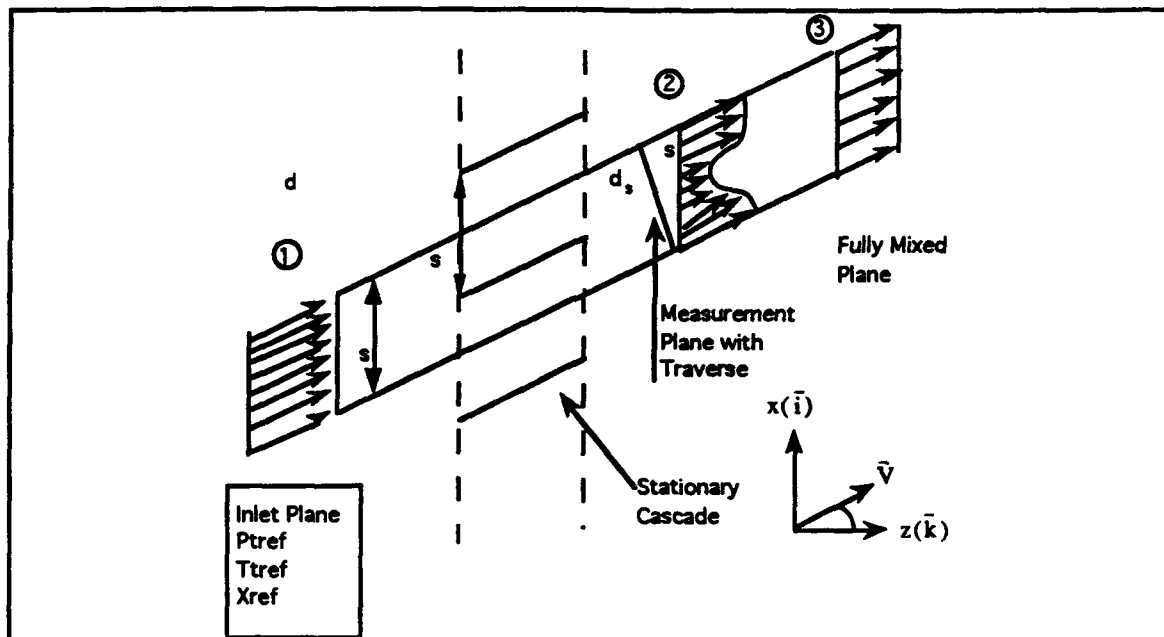


Figure E1. Fully-Mixed-Out Control Volume

The equations for the analysis, reported by Armstrong [Ref. 12], were programmed in HP Basic and are part of the data reduction program "NEW_READ_ZOC1" listed in Appendix D. The analysis required that the probe data be taken over a single blade space. Due to the probe traverse not traversing parallel to the trailing edge, it was required that the program calculate when the

probe had measured the same integrated mass flux at position 2 as had entered at position 1(where nozzle free-stream conditions were known). The integral in equation 1 was programmed as a subprogram labeled "Mass_flux".

$$1 = \int_0^{\frac{d_s}{d_1}} \frac{X_2(1-X_2)^{\frac{1}{\gamma-1}}}{X_{ref}(1-X_{ref})^{\frac{1}{\gamma-1}}} \cdot \frac{P_{T2}}{P_{T1}} \cdot \cos \beta_2 d\left(\frac{x}{d_1}\right) \quad (1)$$

where d_1 is the staggered passage width of 1.656 inches and d_s is the blade traverse distance required for the analysis. By computing the integral at every point in the traverse, the distance d_s was determined where the integral became unity. Once the proper blade space distance was known the following equations could be calculated using the subprogram "Dat_int" which was an integration scheme designed to integrate a function over non-equispaced points.

$$\hat{I}_1 = \int_0^1 \frac{X_2(1-X_2)^{\frac{1}{\gamma-1}}}{X_{ref}(1-X_{ref})^{\frac{1}{\gamma-1}}} \cdot \frac{P_{T2}}{P_{Tref}} \cdot \cos \beta_2 d\left(\frac{x}{s}\right) \quad (2)$$

$$\hat{I}_2 = \int_0^1 \frac{X_2^2(1-X_2^2)^{\frac{1}{\gamma-1}}}{X_{ref}^2(1-X_{ref}^2)^{\frac{1}{\gamma-1}}} \cdot \frac{P_{T2}}{P_{Tref}} \cdot \cos \beta_2 \sin \beta_2 d\left(\frac{x}{s}\right) \quad (3)$$

$$\hat{I}_3 = \int_0^1 \frac{\left[(1-X_2^2)^{\frac{\gamma}{\gamma-1}} + \left(\frac{2\gamma}{\gamma-1} \right) \cdot X_2^2 (1-X_2^2)^{\frac{1}{\gamma-1}} \cdot \cos^2 \beta_2 \right]}{X_{ref}^2 (1-X_{ref}^2)^{\frac{1}{\gamma-1}}} \cdot \frac{P_{T2}}{P_{Tref}} \cdot d\left(\frac{x}{s}\right) \quad (4)$$

$$\hat{A} = X_{ref} \cdot \frac{\hat{I}_2}{\hat{I}_1} = X_3 \sin \beta_3 \quad (5)$$

$$\hat{B} = X_{ref} \cdot \frac{\hat{I}_3}{\hat{I}_1} = \frac{\left[(1-X_3^2) + \left(\frac{2\gamma}{\gamma-1} \right) X_3^2 \cos^2 \beta_3 \right]}{X_3 \cos \beta_3} \quad (6)$$

$$C = \left(\frac{\gamma+1}{\gamma-1} \right)^2 \quad (7)$$

$$D = 2 \left(\frac{\gamma+1}{\gamma-1} \right) \left[1 - \left(\frac{2\gamma}{\gamma-1} \right) \hat{A}^2 \right] - \hat{B}^2 \quad (8)$$

$$E = \left[1 - \left(\frac{2\gamma}{\gamma-1} \right) \hat{A}^2 \right]^2 + \hat{A}^2 \hat{B}^2 \quad (9)$$

$$X_3^2 = \frac{-D \pm \sqrt{D^2 - 4CE}}{2C} \quad (10)$$

where the subsonic root of X_3 is chosen

$$\beta_3 = \sin^{-1} \left(\frac{\hat{A}}{X_3} \right) \quad (11)$$

$$P_{T3} = \frac{X_{ref} \left(1 - X_{ref}^2 \right)^{\frac{1}{\gamma-1}} P_{Tref} \hat{I}_1}{X_3 \left(1 - X_3 \right)^{\frac{1}{\gamma-1}} \cos \beta_3} \quad (12)$$

The fully-mixed-out loss coefficient could be then be calculated using the inlet total pressure, the fully-mixed-out total pressure, and inlet static pressure in Equation 13.

$$\varpi = \frac{P_{tref} - P_{t3}}{P_{tref} - P_{staticref}} \quad (13)$$

When the above procedure was followed using the baseline test data, the values obtained for d_s were significantly greater than 1.656 inches. In reducing the baseline data, the fully-mixed-out condition was calculated using Eq. (2) - Eq.(12), with the full survey distance (s), which was 1.656 inches.

APPENDIX F. SELECTED RAW DATA

Data Print Out for Loc # 1 , Run # 2 , File 70141424.
 Period between samples (sec): .0030303030303
 Sample collection rate (Hz): 330
 Number of samples per port: 10
 Length of data run (sec): 33
 The scan type is: 3
 Number of scans/traverses: 33
 Increment of traverse: .0625 inches
 Atmospheric pressure is: 14.72 psia
 Tunnel Pressure Ratio is: 2.1103821572%

Scan	Port Number						
	1	24	25	29	30	31	32
1	15.410	47.191	45.052	15.463	32.632	53.769	51.636
2	15.410	47.276	45.023	15.483	32.642	53.714	51.607
3	15.388	47.267	44.976	15.473	32.652	53.750	51.650
4	15.443	46.982	44.769	15.483	32.622	53.741	51.204
5	15.399	46.982	44.712	15.533	32.582	53.659	51.170
6	15.399	46.906	44.562	15.543	32.562	53.849	51.112
7	15.377	47.001	44.618	15.483	32.562	53.750	51.199
8	15.356	47.087	44.741	15.503	32.682	53.804	51.200
9	15.421	47.096	44.884	15.513	32.542	53.885	51.312
10	15.291	46.782	44.429	15.513	32.482	53.698	50.921
11	15.356	46.915	44.543	15.513	32.552	53.750	51.055
12	15.388	47.343	44.901	15.473	32.492	53.714	51.493
13	15.387	47.428	44.910	15.463	32.502	53.672	51.602
14	15.453	46.372	43.644	15.533	32.522	53.650	50.433
15	15.399	42.269	40.175	15.503	32.552	53.641	45.396
16	15.410	41.344	39.461	15.493	32.542	53.632	43.554
17	15.432	38.783	38.008	15.463	32.582	53.741	40.095
18	15.346	41.919	41.825	15.483	32.532	53.569	44.488
19	15.399	46.239	45.230	15.523	32.582	53.722	50.625
20	15.421	46.801	45.959	15.523	32.582	53.723	51.303
21	15.367	46.744	45.522	15.523	32.532	53.623	51.246
22	15.432	46.649	45.456	15.453	32.502	53.641	51.265
23	15.464	46.582	45.612	15.533	32.472	53.723	51.227
24	15.356	46.497	45.597	15.543	32.512	53.706	51.189
25	15.410	46.439	45.456	15.563	32.482	53.632	50.988
26	15.484	46.420	45.589	15.513	32.522	53.750	51.084
27	15.377	46.298	45.650	15.543	32.552	53.695	51.007
28	15.443	46.382	45.662	15.533	32.482	53.632	51.036
29	15.399	46.229	45.850	15.483	32.502	53.632	51.046
30	15.399	46.373	45.981	15.593	32.512	53.668	51.191
31	15.432	46.277	46.083	15.543	32.462	53.705	51.170
32	15.443	46.105	46.206	15.543	32.522	53.695	51.131
33	15.421	46.210	46.196	15.513	32.442	53.650	51.360

Figure F1. Run 2 2/24/94 Raw Data

Position	Data	Gamma	X_vel	U_st	θ
+0.00000	1.105800	1.387342	+1.325411	131.001066	17.120
+0.06250	1.105751	1.411936	1.325411	131.001066	17.120
+0.12500	1.105312	1.421953	1.321130	131.001066	17.120
+0.18750	1.105462	1.429357	1.321130	131.001066	17.120
+0.25000	1.104013	1.436401	1.325411	131.001066	17.120
+0.31250	1.105232	1.436061	1.325411	131.001066	17.120
+0.37500	1.105249	1.441005	1.325411	131.001066	17.120
+0.43750	1.103393	1.442094	1.326001	131.001066	17.120
+0.50000	1.105674	1.444789	1.327790	131.001066	17.120
+0.56250	1.104389	1.447623	1.328797	131.001066	17.120
+0.62500	1.104318	1.445500	1.328561	131.001066	17.120
+0.68750	1.104315	1.454603	1.328567	131.001066	17.120
+0.75000	1.105376	1.453002	1.331474	131.001066	17.120
+0.81250	1.107565	1.502941	1.337531	131.001066	17.120
+0.87500	1.091957	1.501652	1.297027	131.001066	17.120
+0.93750	1.072361	1.597344	1.256494	131.001066	17.120
+1.00000	1.042378	1.456134	1.191401	131.001066	17.120
+1.06250	1.061044	1.108396	1.233550	131.001066	17.120
+1.12500	1.096589	1.206269	1.300205	131.001066	17.120
+1.18750	1.089762	1.240854	1.316309	131.001066	17.120
+1.25000	1.099773	1.239109	1.316307	131.001066	17.120
+1.31250	1.101677	1.228894	1.321394	131.001066	17.120
+1.37500	1.101110	1.206600	1.319872	131.001066	17.120
+1.43750	1.100453	1.174988	1.318125	131.001066	17.120
+1.50000	1.098859	1.195100	1.313959	131.001066	17.120
+1.56250	1.099627	1.167338	1.315958	131.001066	17.120
+1.62500	1.099679	1.146823	1.316090	131.001066	17.120
+1.68750	1.090239	1.143553	1.312360	131.001066	17.120
+1.75000	1.098068	1.075841	1.311923	131.001066	17.120
+1.81250	1.097236	1.078715	1.309808	131.001066	17.120
+1.87500	1.097407	1.036874	1.310210	131.001066	17.120
+1.93750	1.097314	1.020165	1.310005	131.001066	17.120
+2.00000	1.100405	1.002721	1.317999	131.001066	17.120

The cascade loss coefficient based on inlet
dynamic pressure as calculated using
mass averaged quantities as shown below.

Ptma1 = 53.7056520157 PSIA

Ptma2 = 50.4993345376 PSIA

Pt1-P1 = 38.1956451806 PSIA

Ttavg = 514.5 deg R

W_bar = .084206392192

Figure F1. (cont) Run 2 2/24/94 Raw Data

Data Print Out for Zoc # 1, Run # 4, File Z01414244
 Period between samples (sec): .0030303030303
 Sample collection rate (Hz): 330
 Number of samples per port: 10
 Length of data run (sec): 31
 The scan type is: 3
 Number of scans/traverse: 33
 Increment of traverse: .0625 inches
 Atmospheric pressure is: 14.713 psia
 Tunnel Pressure Ratio is: 2.09427170691

Scan	Port Number					
	1	24	25	29	30	31
1	15.097	46.494	44.282	15.312	32.060	52.911
2	15.140	46.542	44.301	15.222	32.159	52.930
3	15.053	46.428	44.253	15.277	32.129	52.897
4	15.042	46.248	43.984	15.202	32.010	52.904
5	15.195	46.227	43.941	15.302	32.199	53.020
6	15.086	46.112	43.789	15.272	32.079	52.929
7	15.076	46.198	43.836	15.282	32.109	52.979
8	15.107	46.246	43.859	15.312	32.129	52.938
9	15.107	46.160	43.760	15.282	32.099	52.884
10	15.075	46.045	43.666	15.242	32.070	52.896
11	15.031	45.921	43.590	15.282	32.060	52.756
12	15.107	46.017	43.694	15.292	32.040	52.866
13	15.031	46.198	43.779	15.282	32.038	52.893
14	15.086	46.178	43.468	15.262	32.018	52.747
15	15.075	44.345	41.588	15.252	31.978	52.876
16	15.031	40.285	38.470	15.282	31.978	52.876
17	15.064	37.858	37.166	15.302	31.998	52.838
18	15.140	41.285	41.020	15.292	32.048	52.948
19	15.129	45.442	44.694	15.282	31.988	52.929
20	15.107	45.892	44.745	15.282	31.958	52.902
21	15.107	45.921	44.783	15.282	31.998	52.938
22	15.129	45.844	44.773	15.292	32.048	52.784
23	15.053	45.691	44.792	15.292	31.988	52.948
24	15.140	45.853	44.839	15.302	31.998	52.920
25	15.107	45.666	44.707	15.292	31.988	52.838
26	15.107	45.498	44.868	15.323	31.958	52.938
27	15.053	45.403	45.000	15.292	31.918	52.838
28	15.064	45.375	44.971	15.312	31.868	53.011
29	15.089	45.375	45.075	15.312	31.920	52.902
30	15.097	45.365	45.141	15.282	31.908	52.876
31	15.107	45.348	45.320	15.302	31.868	52.893
32	15.184	45.375	45.565	15.302	31.888	52.911
33	15.086	45.231	45.548	15.302	31.858	52.793

Figure F2. Run 4 2/24/94 Raw Data

Position	Beta	Gamma	Delta	Epsilon	Theta
+0.00000	+1.06918	+4.07205	+3.35743	+33.439232	+3.548
+0.06250	+1.07439	+4.09964	+3.37187	+33.355166	+3.612
+0.12500	+1.06677	+4.01569	+3.35075	+33.454211	+3.445
+0.18750	+1.07047	+4.37265	+3.36100	+33.174569	+4.077
+0.25000	+1.07011	+4.23172	+3.36001	+33.195939	+3.827
+0.31250	+1.04200	+4.44342	+3.326237	+33.070156	+4.100
+0.37500	+1.03900	+4.452525	+3.327415	+33.790172	+4.233
+0.43750	+1.03921	+4.457597	+3.327471	+33.801077	+4.324
+0.50000	+1.04520	+4.457256	+3.329117	+33.613029	+4.341
+0.56250	+1.04380	+4.455215	+3.328732	+33.562784	+4.299
+0.62500	+1.04488	+4.446434	+3.329029	+33.468191	+4.147
+0.68750	+1.04038	+4.445915	+3.327794	+33.631022	+4.122
+0.75000	+1.03950	+4.463457	+3.327553	+33.748783	+4.430
+0.81250	+1.04172	+4.520485	+3.328161	+33.579769	+4.509
+0.87500	+0.96691	+4.599904	+3.300411	+33.523559	+6.705
+0.93750	+0.979337	+4.534907	+2.270226	+33.801343	+5.317
+1.00000	+0.942896	+4.411459	+1.92636	+34.331537	+3.023
+1.06250	+0.969499	+4.086222	+1.250835	+35.228939	+1.054
+1.12500	+0.994875	+4.179722	+1.303954	+35.426323	+0.090
+1.18750	+1.02182	+4.222420	+1.322772	+34.344859	+0.660
+1.25000	+1.02727	+4.219231	+1.324218	+34.265020	+0.628
+1.31250	+1.01532	+4.209210	+1.320999	+34.465523	+0.487
+1.37500	+1.01325	+4.176241	+1.320444	+34.454286	+0.050
+1.43750	+1.01580	+4.159021	+1.321127	+34.408583	+0.176
+1.50000	+1.01350	+4.168822	+1.320512	+34.369556	+0.048
+1.56250	+1.00172	+4.123711	+1.317386	+34.624414	+0.626
+1.62500	+1.00061	+4.080332	+1.317094	+34.652676	+1.175
+1.68750	+1.00457	+4.079940	+1.318137	+34.566756	+1.185
+1.75000	+0.99596	+4.059878	+1.315874	+34.766803	+1.429
+1.81250	+1.00239	+4.044425	+1.317563	+34.668833	+1.633
+1.87500	+0.99511	+4.005169	+1.315652	+34.865673	+2.121
+1.93750	+0.998856	+4.038082	+1.313950	+35.091164	+2.663
+2.00000	+0.999613	+4.062773	+1.315918	+34.889373	+3.004

The cascade loss coefficient based on inlet dynamic pressure as calculated using mass averaged quantities as shown below.

Ptma1 = 52.8913362148 PSIA

Ptma2 = 49.7055979741 PSIA

Pt1-P1 = 37.6061947212 PSIA

Ttavg = 513 deg R

W_bar = .0847131241109

Figure F2. (cont) Run 4 2/24/94 Raw Data

Data Print Out for Zoc # 1 , Run # 5 , FileZRI414245

Period between samples (sec): .0030303030303

Sample collection rate (Hz): 330

Number of samples per port: 10

Length of data run (sec): 31

The scan type is: 4

Number of scans/traverses: 13

Increment of traverse: .0625 Inches

Atmospheric pressure is: 14.71 psia

Tunnel Pressure Ratio is: 0.1263124713

Scan	01	Port Number 24	25	29	30	31	
1	14.958	46.017	43.932	14.931	31.747	52.192	50.367
2	14.901	45.873	43.537	14.991	31.767	52.171	50.100
3	14.880	45.576	43.185	14.961	31.677	52.297	49.704
4	14.880	45.643	43.299	15.001	31.717	52.319	49.546
5	14.858	45.518	43.109	14.961	31.667	52.219	49.559
6	14.880	45.681	43.223	14.991	31.727	52.319	49.617
7	14.814	45.614	43.214	15.001	31.677	52.301	49.681
8	14.880	45.768	43.280	14.971	31.636	52.237	49.907
9	14.803	45.662	43.214	14.931	31.596	52.191	49.607
10	14.782	45.624	42.937	14.991	31.646	52.209	49.395
11	14.880	45.182	42.364	15.041	31.667	52.273	49.854
12	14.847	43.819	41.089	15.011	31.636	52.264	47.054
13	14.880	41.840	39.284	14.981	31.646	52.301	44.900
14	14.869	39.703	37.904	14.981	31.677	52.301	42.012
15	14.814	37.954	36.831	14.961	31.586	52.283	39.695
16	14.869	37.259	36.537	14.921	31.687	52.292	39.568
17	14.782	38.152	37.826	15.011	31.586	52.292	39.998
18	14.825	40.715	40.501	14.951	31.536	52.118	43.491
19	14.836	43.348	42.718	14.931	31.576	52.246	47.426
20	14.880	44.826	44.069	14.971	31.667	52.256	49.396
21	14.858	45.326	44.211	14.971	31.626	52.255	49.987
22	14.890	45.326	44.316	14.961	31.616	52.191	49.964
23	14.912	45.288	44.211	15.021	31.566	52.118	49.954
24	14.880	45.345	44.240	14.971	31.616	52.319	50.040
25	14.869	45.269	44.202	15.001	31.596	52.283	49.997
26	14.901	45.249	44.259	14.991	31.636	52.264	49.848
27	14.912	45.269	44.230	14.981	31.556	52.263	49.916
28	14.869	45.230	44.240	14.991	31.596	52.264	49.910
29	14.836	44.999	44.192	14.981	31.586	52.246	49.627
30	14.901	44.961	44.325	15.001	31.546	52.219	49.694
31	14.956	44.990	44.675	15.051	31.667	52.401	49.858
32	14.901	44.913	44.997	15.061	31.536	52.200	49.973
33	14.912	44.711	45.053	15.011	31.566	52.209	49.983

Figure F3. Run 5 2/24/94 Raw Data

Position	Beta	Gamma	X val	P val	6.4° - θ
+0.00000	+1.108061	+1.401449	+1.338900	133.001400	13.0000
+1.12500	+1.107821	+1.402116	+1.337944	133.003754	13.0000
+1.25000	+1.107102	+1.402102	+1.336854	133.006054	13.0000
+1.37500	+1.104235	+1.402075	+1.328534	133.008354	13.0000
+1.50000	+1.105849	+1.400306	+1.332780	133.010650	13.0000
+1.62500	+1.104095	+1.425026	+1.327040	133.012950	13.0000
+1.65625	+1.106091	+1.455454	+1.333420	133.015250	13.0000
+1.68750	+1.107499	+1.443000	+1.337551	133.017550	13.0000
+1.71875	+1.104209	+1.473635	+1.328264	133.019850	13.0000
+1.75000	+1.103370	+1.520242	+1.325966	133.022150	13.0000
+1.78125	+1.103999	+1.554629	+1.327698	133.024450	13.0000
+1.81250	+1.099897	+1.538371	+1.316630	133.026750	13.0000
+1.84375	+1.096630	+1.580125	+1.309200	133.029050	13.0000
+1.87500	+1.076380	+1.560406	+1.264397	133.031350	13.0000
+1.90625	+1.057994	+1.487897	+1.227039	133.033650	13.0000
+1.93750	+1.043291	+1.432427	+1.193574	133.035950	13.0000
+1.96875	+1.050223	+1.167186	+1.209724	133.038250	13.0000
+1.00000	+1.066294	+1.074027	+1.244407	133.040550	13.0000
+1.03125	+1.092627	+1.143426	+1.290597	133.042850	13.0000
+1.06250	+1.099986	+1.153326	+1.315897	133.045150	13.0000
+1.09375	+1.102590	+1.217840	+1.323946	133.047450	13.0000
+1.12500	+1.102928	+1.196521	+1.324763	133.049750	13.0000
+1.15625	+1.104184	+1.206836	+1.320193	133.052050	13.0000
+1.18750	+1.104871	+1.210590	+1.330083	133.054350	13.0000
+1.21875	+1.103263	+1.207073	+1.325674	133.056650	13.0000
+1.25000	+1.102192	+1.194471	+1.322773	133.058950	13.0000
+1.28125	+1.103496	+1.200981	+1.326310	133.061250	13.0000
+1.31250	+1.101882	+1.195161	+1.321938	133.063550	13.0000
+1.45000	+1.101374	+1.160414	+1.320575	133.065850	13.0000
+1.58750	+1.101646	+1.125889	+1.321303	133.068150	13.0000
+1.72500	+1.100792	+1.062604	+1.319025	133.070450	13.0000
+1.86250	+1.100422	+1.015691	+1.318046	133.072750	13.0000
+2.00000	+1.102052	+1.067175	+1.322395	133.075050	13.0000

Figure F3. (cont) Run 5 2/24/94 Raw Data

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