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

By

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

by

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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
P1	Probe pressure (center tube)
P2	Probe pressure (side hole-facing down)
P3	Probe pressure (side hole-facing up)
P23	Average of P2 and P3
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

ϖ Mass-averaged loss coefficient

ω_{mixed} Mixed-out loss coefficient defined in Appendix E, Eq. (13)

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I would like to take this oppurtunity to thank those people who have made my time at NPS such a rewarding experience. Professor Raymond Shreeve has kept me centered on my objectives and taught me not only the principles of turbomachinery, but also the proper method of engineering research. His patience and attention to detail was a positive influence on me. Professor Garth Hobson's enthusiasm and energy provided an outstanding environment for work and learning at the Turbopropulsion Lab. I am grateful to Rick Still and Thad Best for their skill at operating the transonic cascade wind tunnel and free-jet. I would like to thank John Moulton for crafting such an excellent probe tip for use in the transonic cascade traverse system. I am also grateful to Don Harvey and Pat Hickey for their skilled advice in the design of the probe calibration apparatus. Finally, I thank my wife Rachel, whose love, support, and constant encouragement has kept me focused on my goals and the light at the end of this tunnel.

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.

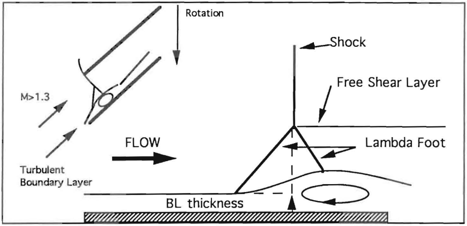

Figure 1. Shock-Boundary Layer Interaction

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.

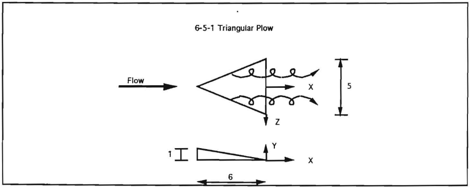

Figure 2. Low-Profile Vortex Generator

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.

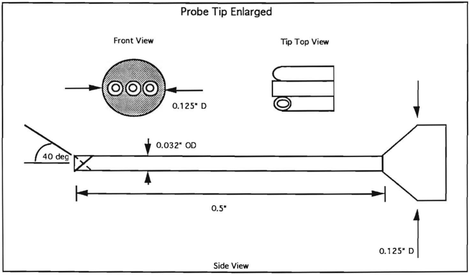

Figure 3. Probe Tip Enlarged

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" OD 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.

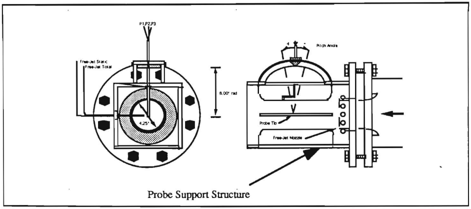

Figure 4. Free-Jet Calibration Apparatus

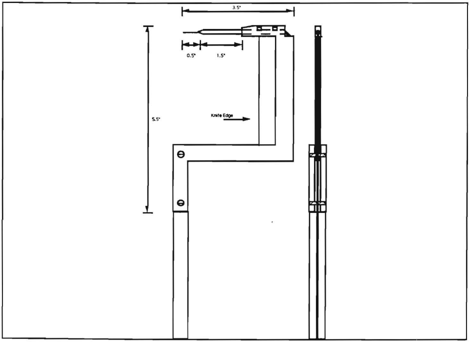

Figure 5. Probe Holder Assembly

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

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

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

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 P1 is the pressure at the center port and P2 and P3 are the pressures of the two side ports, we define the average of P2 and P3 as P23, where

$$P23 = \frac{P2 + P3}{2} \tag{2}$$

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

$$\text{Beta} = \text{B} = \frac{P1 - P23}{P1} \tag{3}$$

and

$$\text{Gamma} = \Gamma = \frac{P2 - P3}{P1 - P23} \tag{4}$$

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.

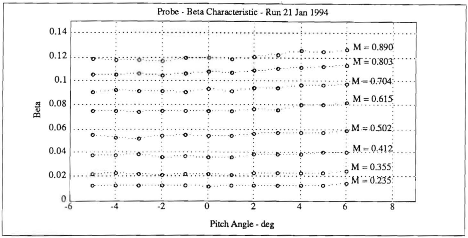

Figure 6. Beta Characteristic

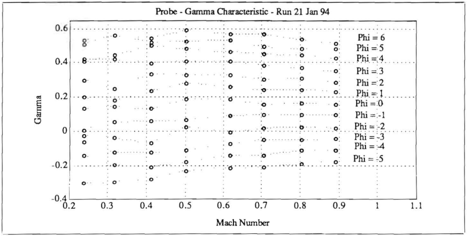

Figure 7. Gamma Characteristic

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.

$$
\begin{aligned}
X &= a_6B^6 + a_5B^5 + a_4B^4 + a_3B^3 + a_2B^2 + a_1B + a_0 \\
a_6 &= -1733913.202 \\
a_5 &= +679216.632 \\
a_4 &= -104416.881 \\
a_3 &= +8119.488 \\
a_2 &= -344.912 \\
a_1 &= +10.120 \\
a_0 &= +0.018
\end{aligned}
\tag{5}
$$

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

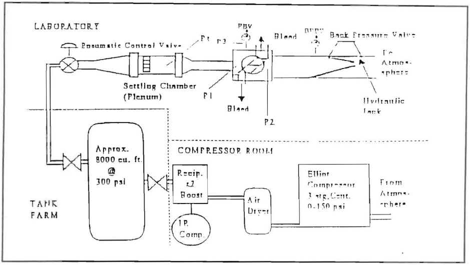

Figure 8. Wind Tunnel Facility

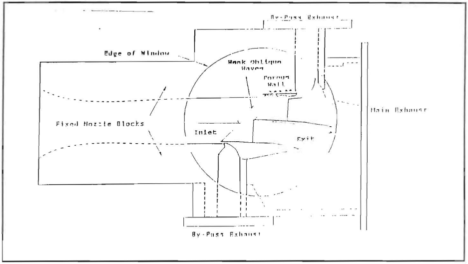

Figure 9. Transonic Cascade Model Test Section

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.

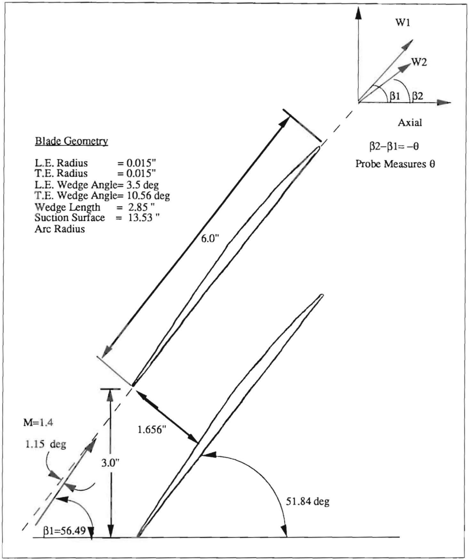

Figure 10. Cascade Blading Geometry

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 shadowraph).

- 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)	ϖ
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.

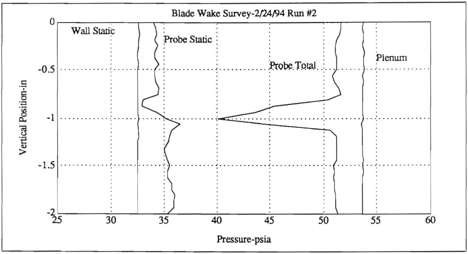

Figure 11. Blade Wake Survey: 2/24/94 Run 2

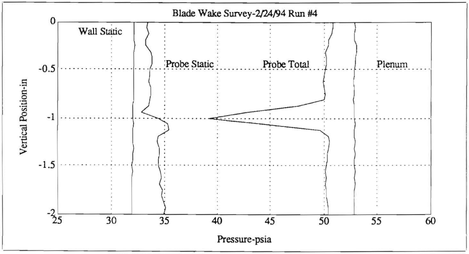

Figure 12. Blade Wake Survey: 2/24/94 Run 4

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.

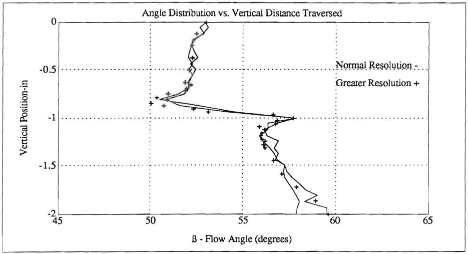

Figure 13. Angle Distribution Comparison

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.

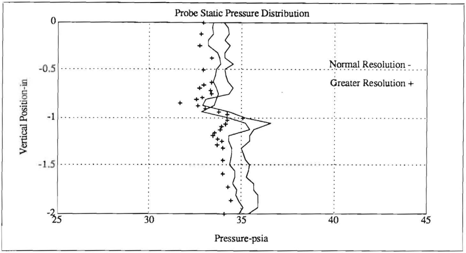

Figure 14. Probe Static Pressure Distribution

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	ϖ_{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

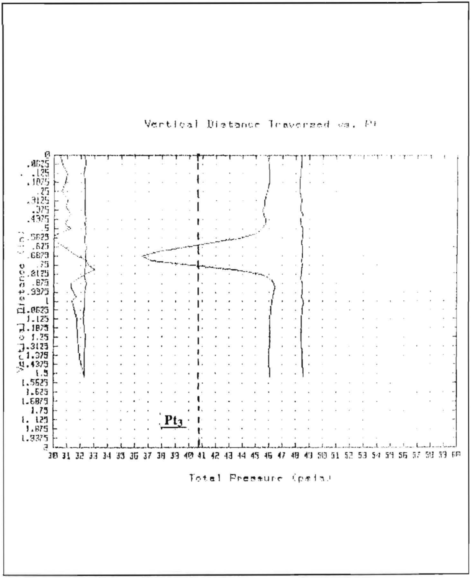

Figure 15. Baseline Blade Wake Survey: Run 1

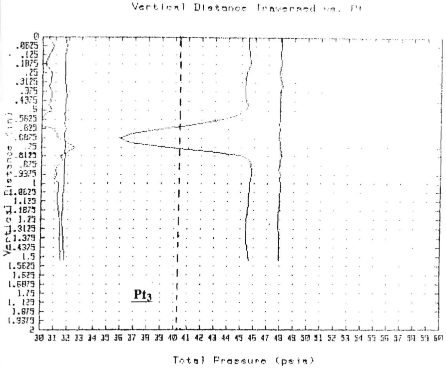

Figure 16. Baseline Blade Wake Survey: Run 2

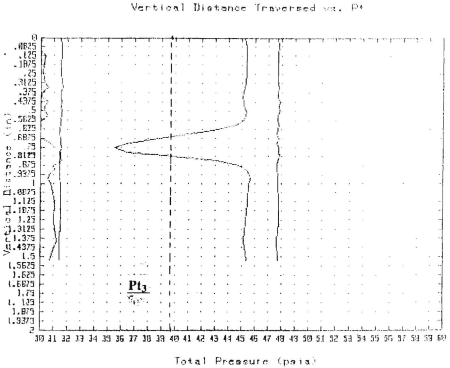

Figure 17. Baseline Blade Wake Survey: Run 3

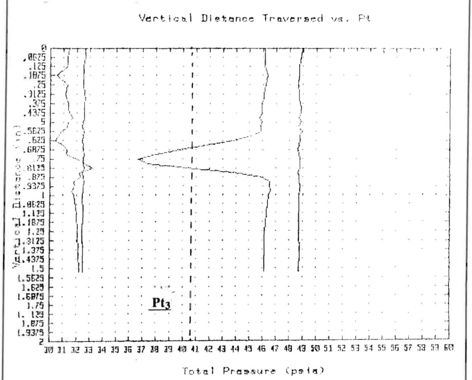

Figure 18. Baseline Blade Wake Survey: Run 4

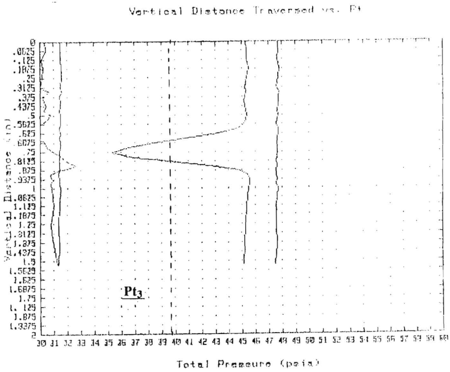

Figure 19. Baseline Blade Wake Survey: Run 5

In all cases, the calculated fully-mixed-out total pressure (Pt_3) 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:     [illegible]
30   !                [illegible] Jeff Austin
40   !LAST MODIFIED 01/[illegible]
50   !DESCRIPTION
60   !       THIS PROGRAM RECORDS AND REDUCES MEASURED [illegible]
70   !       3 PORT PNEUMATIC PROBE FOR CALIBRATION OF THE [illegible]
80   !       MACH NUMBER AND PITCH ANGLE.  THIS PROGRAM [illegible]
90   !       THE RAW DATA AT EACH DISTINCT MACH NUMBER AND [illegible]
100  !
110  !
120  !       VARIABLES [illegible] SECTION
130  !            [illegible] = DESIRED [illegible]
140  !            [illegible] = [illegible] PORT
150  !            [illegible] = S/V PORT
160  !            C = CHANNEL
170  !            V0 = DVM READING
180  !            ST = SCANNER LISTEN CODE.
190  !            S = SCANNER #
200  !            SCANIVALVE IS SET TO ADVANCE ONLY
210  !            P1,P2,P3,PAMB,PTOT,PSTAT
220  !            P1=MIDDLE PROBE HOLE (RED)
230  !            P2=LEFT PROBE HOLE (FROM TOP) [illegible]
240  !            P3=RIGHT PROBE HOLE  (GREEN)
250  !            PSTAT=STATIC PRESSURE
260  !            PTOT=TOTAL PRESSURE
270  !            PAMB=AMBIENT PRESSURE
280  !            G - 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 SCANIVALVE
350  PRINT
360  V=5
370  A=1
380  GOSUB Read
390  !*********************************************
400  PRINT "DATA ACQUISITION FOR CALIBRATION OF A THREE PORT [illegible]
410  DIM Y(20),A$[14],B$[14]
420  DIM P1(8,12),P2(8,12),P3(8,12),Pstat(8,12),Ptot(8,12),[illegible]
430  DIM Y(8,12),M2(8,12),G(8,12),B(8,12)
440  DIM Patm(8,12),Pcal(8,12)
450  INPUT "ENTER MONTH,DAY,YEAR (IE. 08,30,9[illegible]",Y[illegible]
460  PRINT USING "K,DD,""/"",DD,""/"",DD";"DATE OF RUN: ",Y(3),[illegible]
470  INPUT "ENTER RUN #:",Y(9)
480  A$="RW"&VAL$(Y(7))&VAL$(Y(3))&VAL$(Y(5))&VAL$(Y(9))
490  B$="RD"&VAL$(Y(7))&VAL$(Y(3))&VAL$(Y(5))&VAL$(Y(9))
500  CREATE ASCII A$&":,700,0,1",10        !CREATES RAW DATA FILE
```

Figure A1. Program "CAL_ACQ"

```
520    [illegible]
530    ASSIGN @Path2 TO B$&":,700,0,1"
540    PRINT
550    PRINT "RAW DATA FILE NAME:";A$
560    PRINT
570    PRINT "REDUCED DATA FILE NAME:";B$
580    PRINT
590    PRINT "MACH:0.2 TO 0.9 BY 0.1  PITCH: [illegible]
600    PRINT
610    PRINT "      SET 20 inHg  FOR SCANIVALVE CALIBRATION [illegible]
620    PRINT
630    PRINT " IN SCANIVALVE PORT #2"
640    PRINT
650    PRINT " DATA RUN" [illegible]  ENSURE MACH NUMBER AND PITCH ANGLE [illegible]
660    FOR Mach=1 TO 8
670      INPUT "ENTER AMBIENT PRESSURE IN inHg ",Pinhg
680      Pamb=Pinhg*(.4911541)
690      PRINT
700      PRINT "SET -5 deg IN PITCH"
710      PRINT
720      PRINT "****PRESS CONTINUE WHEN READY****"
730      PAUSE
740      CLEAR SCREEN
750      PRINT
760      FOR Pitch=1 TO 1[illegible]
770        V=5
780        A=1
790        GOSUB Read
800    !*******************************************************************
810    !
820    !*******************************************************************
830    !RECORD THE PRESSURE DATA FOR THIS MACH AND ANGLE
840    !
850        OUTPUT 722;"F1R1T1N0Z1"       !     SETS UP HP3456A DVM
860        V=5        !SCANIVALVE #5 DESIGNATED
870        S=1        !HP3495A SCANNER #1 DESIGNATED
880    !
890        PRINTER IS 711
900        PRINT
910        PRINT "Mach = ",Mach
920        PRINT "Pitch angle = ",Pitch
930        PRINT USING "/,5X,K,DDD,/,2X,K,15X,K,17X,K";"SCANIVALVE # ",V,"PORT","V
olts","Psi"
940        PRINT
950        PRINTER IS CRT
960    !READ THE SCANIVALVE PORTS
970        FOR A=1 TO 8
980          GOSUB 1830
990          WAIT 2.0
1000         OUTPUT 701;"C"        ! CLEARS SCANNER #1
1010         OUTPUT 701 USING "DDD";V+9!SCANNER #1 SET TO READ SCANIVALVE PORT
1020         TRIGGER 722
1030         ENTER 722;Vv
```

Figure A1. (cont) Program "CAL_ACQ"

```
1060 !      Pressures in psi
1070      IF A=1 THEN
1080        Patm(Mach,Pitch)=[illegible]*1000
1090        PRINT USING "[illegible],DDD,7X,7DD.DDDDDDDD,[illegible],7DD.DDDDD";[illegible]
itch)
1100        PRINTER IS [illegible]
1110        PRINT USING "[illegible],DDD,[illegible],7DD.DDDDDDDD[illegible]DDDDD";[illegible]
itch)
1120        PRINTER IS [illegible]
1130      END IF
1140      IF A=[illegible] THEN
1150        [illegible](Mach,Pit[illegible])=[illegible]*1000
1160        PRINT USING "[illegible],DDD,[illegible],7DD.DDDDDDDD,[illegible]DDDDD";[illegible]
itch)
1170        PRINTER IS CRT
1180        PRINT USING "[illegible]X,DDD,7X,7DD.DDDDDDDD,[illegible]DDDDD";[illegible](Mach,P
itch)
1190        PRINTER IS 711
1200      END IF
1210      IF A=4 THEN
1220        Ptot(Mach,Pitch)=(V0*1000)-Patm(Mach,Pit[illegible])[illegible]amb
1230        PRINT USING "[illegible]X,DDD,7X,7DD.DDDDDDDD,[illegible]7DD.DDDDD";[illegible](Mach,P
itch)
1240        PRINTER IS CRT
1250        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,[illegible]7DD.DDDDD";[illegible](Mach,P
itch)
1260        PRINTER IS 711
1270      END IF
1280      IF A=5 THEN
1290        Pstat(Mach,Pitch)=(V0*1000)-Patm(Mach,Pitch)[illegible]amb
1300        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible](Mach,
Pitch)
1310        PRINTER IS CRT
1320        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible]tat(Mach,
Pitch)
1330        PRINTER IS 711
1340      END IF
1350      IF A=6 THEN
1360        P1(Mach,Pitch)=(V0*1000)-Patm(Mach,Pitch)[illegible]Pamb
1370        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible],P1(Mach,Pit
ch)
1380        PRINTER IS CRT
1390        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible](Mach,Pit
ch)
1400        PRINTER IS 711
1410      END IF
1420      IF A=7 THEN
1430        P2(Mach,Pitch)=(V0*1000)-Patm(Mach,Pitch)[illegible]amb
1440        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible](Mach,Pit
ch)
1450        PRINTER IS CRT
1460        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible](Mach,Pit
ch)
1470        PRINTER IS 711
1480      END IF
1490      IF A=8 THEN
1500        P3(Mach,Pitch)=(V0*1000)-Patm(Mach,Pitch)[illegible]amb
1510        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible](Mach,Pit
ch)
1520        PRINTER IS CRT
1530        PRINT USING "2X,DDD,7X,7DD.DDDDDDDD,7X,7DD.DDDDD";[illegible](Mach,Pit
```

Figure A1. (cont) Program "CAL_ACQ"

```
1540          PRINTER IS 711
1550          P3(Mach,Pitch)=[illegible](Mach,Pitch)[illegible]
1560          G(Mach,Pitch)=[illegible](Mach,Pitch)-P3(Mach,Pitch)[illegible]
Mach,Pitch))
1570          B(Mach,Pitch)=[illegible](Mach,Pitch)[illegible]
1580          [illegible](Mach,Pitch)=[illegible]EXP(((Gamma[illegible]
Pst(Mach,Pitch)))
1590          B2(Mach,Pitch)=SQR(((2/(Gamma[illegible](Mach,Pitch)[illegible]
[illegible]
1600        END IF
1610  !****************SAVE DATA*********************************
1620        NEXT A
1630        PRINT "Mach = ";[illegible](Mach,Pitch)
1640        PRINT "Gamma   ";G(Mach,Pitch)
1650        PRINT "Beta = ";B(Mach,Pitch)
1660        PRINTER IS CRT
1670        PRINT
1680        PRINT "SET NEW PITCH ANGLE - PRESS CONTINUE WHEN READY"
1690        PRINT
1700        PAUSE
1710        CLEAR SCREEN
1720      NEXT Pitch
1730      PRINT "SET NEW MACH NUMBER - PRESS CONTINUE WHEN READY"
1740      PRINT
1750      PAUSE
1760      CLEAR SCREEN
1770  NEXT Mach
1780  GOTO [illegible]
1790  !************************END OF MAIN PROGRAM********************
1800  !
1810  !********SUBROUTINE TO POSITION AND READ S/V PORTS**************
1820  !     >>>>SCANIVALVE #1 HAS INOP HOME FEATURE
1830 Read:OUTPUT 707 USING "#,K";V
1840  P0=SPOLL(707)
1850  L=BINAND(P0,15)
1860  T1=ROTATE(P0,4)
1870  M1=BINAND(T1,7)
1880  P=10*M1+L
1890  CLEAR 707
1900  IF P=0 THEN Finish
1910  OUTPUT 701;"C"
1920  OUTPUT 701 USING "DDD";V-1
1930  OUTPUT 701;"C"
1940  WAIT .1
1950  GOTO Read
1960 Finish:RETURN
1970 !**************************************************************
1980      !**************************************************************
1990      !**********************SAVE DATA TO HARD DRIVE*****************
2000      !**********************DATA SAVED TO ":,700,0,1"**************
2010  OUTPUT @Path1;A$
2020  OUTPUT @Path2;B$
2030  OUTPUT @Path1;Patm(*),Pcnl(*),Pstat(*),P[illegible](*),P1(*),P2(*),P[illegible]
2040 !**************************************************************
2050  PRINTER IS CRT
2060  END
```

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	-0.13493724	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	15.4092	15.2139	15.212	14.8279	15.3684	15.21295	0.10453122	0.00968153	0.0127359
0	15.4059	15.2353	15.2104	14.825	15.3591	15.22285	0.1045061	0.13602841	0.01188181
1	15.4063	15.24	15.2029	14.8277	15.3615	15.22145	0.10429477	0.20070327	0.01199834
2	15.422	15.2527	15.1931	14.8292	15.3692	15.2229	0.1055302	0.29934706	0.01291013
3	15.4132	15.2574	15.174	14.8223	15.3668	15.2157	0.10538906	0.42227848	0.01281369
4	15.4128	15.2509	15.1687	14.8258	15.3484	15.2098	0.10503718	0.40492611	0.01317087
5	15.4117	15.2603	15.1581	14.8252	15.3711	15.2092	0.10499561	0.50469136	0.01313937
6	15.4224	15.2587	15.141	14.8241	15.359	15.19985	0.1060242	0.52886992	0.01443031
-5	15.8937	15.4876	15.592	14.8261	15.8155	15.5398	0.14025233	-0.29499859	0.02226668
-4	15.9035	15.5064	15.5772	14.8272	15.8343	15.5418	0.14079267	-0.19574233	0.02274342
-3	15.8946	15.528	15.5692	14.8289	15.826	15.5486	0.14012025	-0.11907514	0.0217684
-2	15.8884	15.5387	15.5504	14.8363	15.8079	15.54455	0.13922868	-0.03402647	0.02164157
-1	15.9001	15.5626	15.544	14.8282	15.8159	15.5533	0.14051266	0.05363322	0.02181118
0	15.9038	15.5764	15.5246	14.8319	15.8189	15.5505	0.1404959	0.14661761	0.02221482
1	15.8893	15.5801	15.5177	14.8373	15.817	15.5489	0.13921786	0.18331375	0.02142322
2	15.8949	15.5785	15.4869	14.842	15.8168	15.5327	0.13925374	0.25289895	0.02278718
3	15.902	15.6135	15.4591	14.8454	15.8092	15.5363	0.13947239	0.42220399	0.02299711
4	15.9012	15.6104	15.4453	14.8434	15.8202	15.52785	0.13955715	0.4422124	0.02347936
5	15.8893	15.624	15.4178	14.8423	15.8314	15.5209	0.13887839	0.5597177	0.02318541
6	15.9046	15.6245	15.4049	14.8523	16.5731	15.5147	0.13916955	0.56322134	0.02451492
-5	16.7033	15.9864	16.1623	14.8523	16.5731	16.07435	0.18166117	-0.27967247	0.03765424
-4	16.7006	16.0076	16.1363	14.8479	16.6051	16.07195	0.18176352	-0.20472441	0.03764236
-3	16.7146	16.0353	16.1104	14.8482	16.5912	16.07285	0.18238386	-0.11702376	0.03839458
-2	16.688	16.064	16.1058	14.852	16.5869	16.0849	0.18097829	-0.06930857	0.03613974
-1	16.6889	16.0893	16.0517	14.8503	16.5656	16.0705	0.18110681	0.06080207	0.03705457
0	16.6883	16.1223	16.0417	14.8521	16.5606	16.082	0.18098687	0.13293749	0.03633084
1	16.6791	16.1497	16.0074	14.8482	16.5721	16.07855	0.18076623	0.23694946	0.03600614
2	16.6949	16.1663	15.9498	14.8534	16.564	16.05805	0.18122177	0.33995446	0.03814638
3	16.6901	18.1811	15.9271	14.853	16.5387	16.0541	0.18102295	0.39937107	0.03810642
4	16.6866	16.201	15.8783	14.8537	16.5511	16.03965	0.18082678	0.49880207	0.03877063
5	16.7041	16.2095	15.863	14.8534	16.5727	18.03625	0.18164127	0.51882908	0.0399812
6	16.7016	16.2124	15.8461	14.8582	16.5701	16.02925	0.18128133	0.54480553	0.04025862
-5	17.6876	16.6005	16.8234	14.8805	17.4969	16.71195	0.21948984	-0.22846308	0.05516011
-4	17.662	16.6495	16.8131	14.8781	17.5306	16.7313	0.21869088	-0.17578167	0.05269505
-3	17.6364	16.6728	16.7724	14.8604	17.5167	16.7226	0.21852902	-0.1089954	0.0518133
-2	17.6674	16.7212	16.6948	14.8652	17.4937	16.708	0.21941922	0.0275172	0.05430341
-1	17.6858	16.742	16.6751	14.8664	17.4886	16.70855	0.22001339	0.06845741	0.05525619
0	17.6647	16.8048	16.6248	14.8668	17.5467	16.7148	0.21925774	0.18949363	0.05377391
1	17.6649	16.8319	16.5579	14.8704	17.5613	16.6949	0.21911454	0.28247423	0.05491115
2	17.6853	16.8592	16.5351	14.8728	17.5308	16.69715	0.21972978	0.32798664	0.05587409
3	17.6904	16.8903	16.4737	14.8707	17.4904	16.682	0.21999539	0.41312971	0.05700267
4	17.6673	16.9044	16.4241	14.8724	17.5039	16.66425	0.21911539	0.47883954	0.05677438
5	17.6549	16.9102	16.379	14.8718	17.5138	16.6446	0.21870422	0.52578442	0.05722491
6	17.659	16.9328	16.3267	14.875	17.5236	16.62975	0.21671483	0.58887539	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	14.8894	19.0361	17.781255	0.26532298	-0.13860068	0.07502991
-3	19.2013	17.7207	17.82441	14.8889	18.8791	17.772555	0.26475814	-0.07258818	0.07440878
-2	19.2342	17.7831	17.78981	14.8911	18.96	17.786455	0.26554165	-0.00463479	0.07526931
-1	19.2042	17.83	17.69861	14.8931	18.9864	17.764305	0.26469238	0.09124971	0.07497813
0	19.2137	17.9099	17.63951	14.8946	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	0.26060007	0.07554212
2	19.2201	17.9927	17.50731	14.9019	18.919	17.750005	0.26481125	0.33017594	0.07648738
3	19.2022	18.0347	17.43671	14.9005	18.9362	17.735705	0.2643906	0.40776818	0.0763712
4	19.2302	18.0481	17.34001	14.8987	18.9358	17.694055	0.26518222	0.46095258	0.0798819
5	19.233	18.1032	17.29101	14.9016	19.0197	17.697105	0.26515766	0.52880568	0.07985728
6	19.2463	18.115	17.22141	14.9034	18.9288	17.668205	0.26544324	0.56624601	0.08199472
-5	20.7578	18.669	19.0576	14.9191	20.5555	18.8633	0.30008337	-0.20512008	0.0912669
-4	20.7889	18.7415	19.0014	14.9199	20.5097	18.87145	0.3007079	-0.1355446	0.09223432
-3	20.7824	18.8349	18.9216	14.9235	20.5139	18.87825	0.3004684	-0.04553213	0.0916232
-2	20.7886	18.9026	18.8654	14.9229	20.5158	18.884	0.30061477	0.01953166	0.09161752
-1	20.7828	18.9754	18.7967	14.9318	20.5023	18.88605	0.30023613	0.09421379	0.09126537
0	20.8028	19.0234	18.7096	14.936	20.5472	18.8665	0.30053062	0.16206166	0.09307882
1	20.7701	19.0977	18.6358	14.9234	20.5548	18.86675	0.30021511	0.24267738	0.09163894
2	20.7921	19.134	16.538	14.9276	20.5648	18.836	0.30055141	0.3046879	0.094079
3	20.7637	19.1791	18.4286	14.941	20.41	18.80385	0.29957054	0.38293747	0.09438828
4	20.7887	19.2317	18.3189	14.9352	20.5186	18.7753	0.30026045	0.45338247	0.09685069
5	20.7678	19.251	18.2592	14.9303	20.5365	18.7551	0.2999669	0.4927709	0.09691445
6	20.7458	19.2889	18.1407	14.9357	20.4767	18.7148	0.29935007	0.56533727	0.09789933
-5	22.9389	20.299	20.7481	15.009	22.4401	20.52355	0.33781229	-0.18608988	0.10521692
-4	22.9201	20.3708	20.6378	14.9969	22.5759	20.5043	0.33783994	-0.11052239	0.10540094
-3	22.923	20.4329	20.5426	15.0066	22.6422	20.48775	0.33764505	-0.04504671	0.10623609
-2	22.9065	20.5355	20.4661	15.003	22.5493	20.5008	0.33746501	0.02884815	0.10502259
-1	22.9412	20.6033	20.3666	15.0114	22.6714	20.46495	0.33782262	0.09636641	0.1070672
0	22.9388	20.6618	20.257	15.008	22.4862	20.4594	0.33786828	0.16326531	0.10808761
1	22.9353	20.7736	20.1675	15.0053	22.6154	20.47055	0.33787852	0.24590729	0.10746535
2	22.9671	20.8613	20.0901	15.005	22.4924	20.4757	0.33840443	0.30954483	0.10847691
3	22.9706	20.9014	19.9547	14.9987	22.6625	20.42805	0.33881829	0.37234273	0.11068714
4	22.9307	20.9406	19.8011	15.0055	22.6417	20.37085	0.33779839	0.44514327	0.11163418
5	22.9279	20.9603	19.7246	15.0009	22.5477	20.34245	0.3378675	0.47794388	0.11276436
6	22.9097	21.0078	19.6188	15.0087	22.517	20.3133	0.3373749	0.5349715	0.11333191
-5	25.185	21.9479	22.461	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	0.11776157
-3	25.2069	22.1735	22.2919	15.0745	24.8858	22.2327	0.36960872	-0.03980902	0.1179915
-2	25.1828	22.2658	22.2165	15.0769	25.0103	22.24115	0.36923615	0.0167593	0.11681187
-1	25.2425	22.3807	22.0764	15.0768	24.9345	22.22855	0.37002847	0.10096385	0.11939982
0	25.23568	22.4609	21.9726	15.0715	24.994	22.21675	0.37005558	0.16174605	0.11962943
1	25.2549	22.6099	21.9043	15.0724	24.9466	22.2571	0.37028925	0.23537261	0.11870172
2	25.2329	22.6294	21.7486	15.0771	24.97	22.189	0.36989506	0.28936562	0.12063219
3	25.2277	22.6876	21.5981	15.0747	25.0219	22.14285	0.36987942	0.35317763	0.12228027
4	25.2992	22.8057	21.4402	15.0883	25.0401	22.12295	0.37052159	0.42990948	0.12554745
5	25.2022	22.8202	21.3164	15.0737	24.8398	22.0683	0.3695642	0.47984939	0.12435026
6	25.276	22.9017	21.2615	15.0831	24.7932	22.0816	0.37033101	0.51346106	0.12638076

APPENDIX C. APPLICATION OF THE CALIBRATION

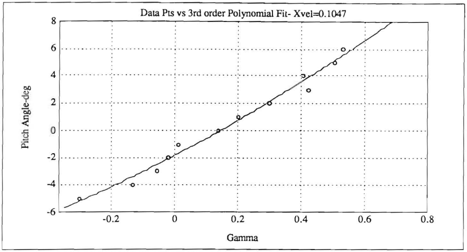

Figure C1. Pitch Angle vs. Gamma X = 0.1047

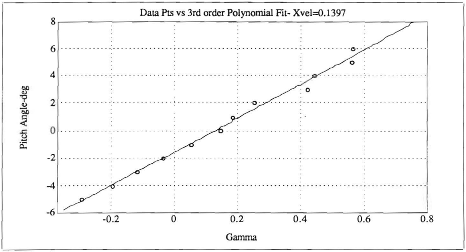

Figure C2. Pitch Angle vs. Gamma X = 0.1397

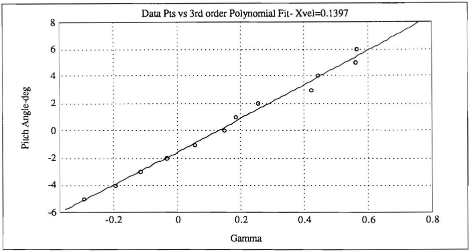

Figure C3. Pitch Angle vs. Gamma $X = 0.1812$

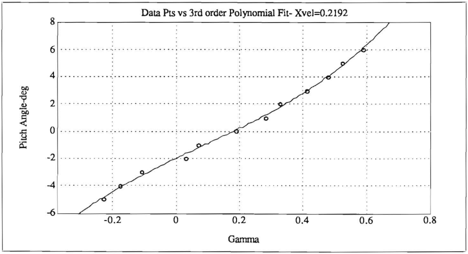

Figure C4. Pitch Angle vs. Gamma $X = 0.2192$

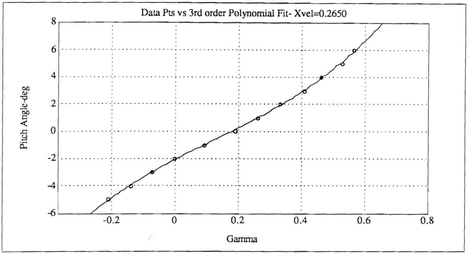

Figure C5. Pitch Angle vs. Gamma X = 0.2650

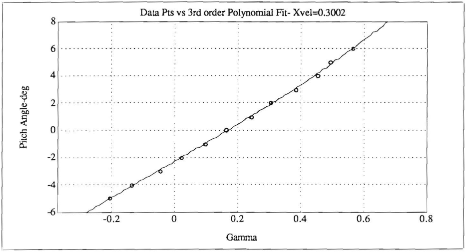

Figure C6. Pitch Angle vs. Gamma X = 0.3002

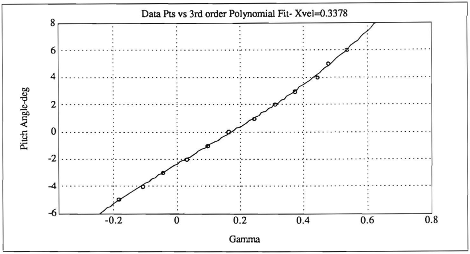

Figure C7. Pitch Angle vs. Gamma $X = 0.3378$

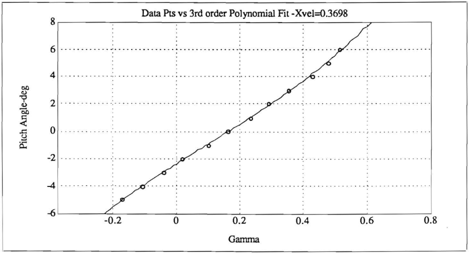

Figure C8. Pitch Angle vs. Gamma $X = 0.3698$

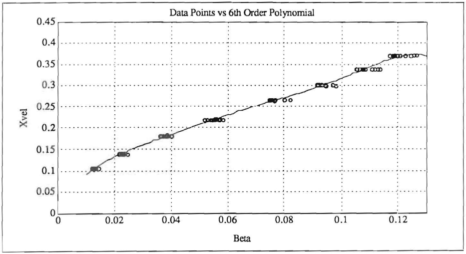

Figure C9. X vs. Beta

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	0.10538899	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	0.4676	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	0.18176341	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	-1.666	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	0.21911565	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	0.2648899	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	0.29625409	-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	2.00606283
-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	0.33725878	1.039	0.039	0.18331802
2	0.33840408	0.34005809	1.998	0.002	0.48876627
3	0.33861794	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	0.36894868	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	0.37034436	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 [illegible]
30    ! by Piet Wendland
40    ! modified by David Myre
50    ! modified 5 Nov 1992
51    ! modified 23 Feb 1991 by Jeff Austin for [illegible]
52    ! to determine dimensionless velocity and deviation angle during [illegible] probe
53    ! traverse.  Program will also determine losses calculated [illegible]
54    ! space.
60    !*****************************************************************
70     CLEAR SCREEN
80     PRINTER IS CRT
90     !Variable definition and dimension
100    COM /Plot_labels/ REAL Xo,Xf,Yo,Yf,Dx,Dy,Title$[60],X label$[50],Y label$[
60]
110    INTEGER Disk_drive,Zoc_Run,View,Sample_nto,Sample_no,Port_nit
120    INTEGER Lcrt_mer,Scan_mer_avg
130    REAL [illegible]
140    !Variable initialization
150    P_atm 11.696          !Standard day atmospheric pressure
160    Con=.491151           !Conversion from in Hg to psi
170    Gamma=1.4             !Ratio of specific heats
180    [illegible] .0925     !Sub square sizing
190    Allocated=0
200    !Dimension string variable for data location:
210    DIM Data_disc1$[23]
220    DIM Data_disc2$[23]
230    !
240    !*****************************************************************
250    !HOT KEY ROUTINES AND INITIAL SCREEN DISPLAY
260    !*****************************************************************
270    !
280    ON KEY 1 LABEL "ZOC      INPUT     " GOTO Input
300    ON KEY 3 LABEL "PRINT    DATA      " GOTO Print
320    ON KEY 5 LABEL "Pt       PLOT      " GOTO Pt
330    ON KEY 6 LABEL "                   " GOTO Hold
340    ON KEY 7 LABEL "                   " GOTO Hold
350    ON KEY 8 LABEL "EXIT     PROG      " GOTO Finish
360    !
370    !*****************************************************************
380    !INITIAL SCREEN DISPLAY
390    !*****************************************************************
400    !
410 Reset:    !
420           CLEAR SCREEN
430    PRINT
440    PRINT
450    PRINT "        READ ZOC DATA AND DISPLAY AS SHOWN"
460    PRINT
470    PRINT "        Input ZOC information and read data              F1"
490    PRINT "        Print data to CRT or PRINTER                     F3"
510    PRINT "        Plot Pt data/Print Losses                        F5"
511    PRINT "        Print out [illegible] vel and Deviation Angle
512    PRINT "        vs Vertical Distance Traversed(1 BLADE SPACE)
513    PRINT "        Determines fully mixed out loss coefficient.
520    PRINT
530    PRINT
540    PRINT "        Exit Program                                     F8
550    PRINT
560    !
570 Hold:     !
580           GOTO Hold
```

Figure D1. Program "NEW_READ_ZOC1"

```
1270  !
1280 Read:   !Reads reduced data to array.
1290         !
1300  Sample min=1                  ! First sample
1310  Sample max=Sample number      ! Last sample
1320  !
1330  FOR Scan=1 TO Scan max
1340  !
1350       FOR Port number=1 TO 32
1360       !
1370            Pa sum=0
1380            FOR Sample=Sample_min TO Sample max
1390                 Pg=Data(Sample,Port number)    ! Data read from reduced file
1400                 Pa sum=Pa sum+Pg
1410            NEXT Sample
1420            !
1430            Pa avg=(Pa sum/Sample_number)*Conv(P atm
1440            Pa(Port number,Scan)=Pa avg
1450            !
1460       NEXT Port_number
1470       Sample min=Sample min+Sample_number
1480       Sample max=Sample max+Sample_number
1490       !
1500  NEXT Scan
1510  DISP "Data read from disk and transferred to array."
1520  WAIT 2
1530  GOTO Reset
1540  !*****************************************************************
1810  !PRINTS DATA TO PRINTER OR CRT SCREEN AS DESIRED
1820  !*****************************************************************
1830  !
1840 Print:!
1850       CLEAR SCREEN
1860       !
1870  INPUT "Print results to screen or printer (0=Screen 1=Printer)",View
1880  IF View=1 THEN PRINTER IS 702
1890  !
1900  !
1910  PRINT "Data Print Out for Zoc #";Zoc;", Run #";Run;", File";Data file$
1920  PRINT TAB(5);"Period between samples (sec):";Period
1930  PRINT TAB(5);"Sample collection rate (Hz): ";Hz
1940  PRINT TAB(5);"Number of samples per port:  ";Sample number
1950  PRINT TAB(5);"Length of data run (sec):    ";Period*31*Sample number*Scan
max
1960  PRINT TAB(5);"The scan type is:            ";Scan_type
1970  PRINT TAB(5);"Number of scans/traverses:   ";Scan max
1980 !PRINT TAB(5);"Increment of traverse:       ";Increment;" Inches
1990  PRINT TAB(5);"Atmospheric pressure is:     ";P atm;" psia"
2000  PRINT TAB(5);"Tunnel Pressure Ratio is:    ";Pa(30,1)/Pa(29,1)
2010  PRINT
2020  PRINT
2030  !
2040 Format1:  IMAGE 2D,6X,2D.3D,4X,2D.3D,4X,2D.3D,4X,2D.3D,4X,2D.3D,4X,2D.3D,4X
,2D.3D
2050 Format2:  IMAGE 2D,5X,2D.3D,4X,2D.3D,4X,2D.3D,4X,2D.3D,4X,2D.3D,4X,2D.3D,4X
,2D.3D
2060  !
2070  IF Scan max>7 THEN
2260  PRINT "Scan","          Port Number"
2270  PRINT " ","01","24","25","29","30","31","32"
2280  PRINT
2290  FOR I=1 TO Scan_max
2300       PRINT USING Format1;I,Pa(1,I),Pa(24,I),Pa(25,I),Pa(29,I),Pa(30,I),Pa(3
1,I),Pa(32,I)
2310  NEXT I
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
[illegible]
2330 PRINT
2340 NEXT J
2500 !
2510 ELSE
2520 !
2530     PRINT "Port","        Scan Number"
2540     PRINT " ","1","2","3","4","5","6","7"
2550     PRINT
2560     FOR I=1 TO 32
2570         PRINT USING Format$;I,Pa(I,1) [illegible]
6),Pa(I,7)
2580     NEXT I
2590 END IF
2600 PRINTER IS CRT
2610 GOTO Reset
2620 !
2630 !
2640 !*****************************************************************
4440 !*****************************************************************
4450 !PLOT PT DATA AND LOAD INTO ARRAY(S) TO SAVE TO ASCII FILE
4460 !*****************************************************************
4470 !
4480 Pt: !
4490 !
4500 CLEAR SCREEN
4510 !
4520 PRINT "      POST PROCESSING OF TOTAL PRESSURE DATA"
4530 PRINT
4540 PRINT
4550 PRINT "      This routine will plot vertical position vs. Pt from"
4560 PRINT "      the probe impact pressure and integrate losses normalized"
4570 PRINT "      by inlet dynamic pressure to calculate a loss coefficient."
4571 PRINT "      Calculates and prints to Think-Jet the calculated X vel and"
4572 PRINT "      deviation angle and uses this information to calculate a"
4573 PRINT "      fully mixed out loss coefficient."
4580 PRINT
4590 PRINT
4600 INPUT "      Dump plots to Laser or Thinkjet (0=[illegible])",Dump
4630 PRINT "      Type F2 to continue[illegible] other inputs necessary [illegible]"
4640 PAUSE
4650 !
4660 IF Dump=1 THEN
4670    DUMP DEVICE IS 9
4680 ELSE
4690    DUMP DEVICE IS 702
4700 END IF
4710 !
4720 !Allocate all real variables
4730 !
4740 ALLOCATE INTEGER Pen2(1:Scan_max)
4750 ALLOCATE REAL P_ref(1:Scan_max)
4760 ALLOCATE REAL P_inf(1:Scan_max)
4770 ALLOCATE REAL P_exit(1:Scan_max)
4780 ALLOCATE REAL Y(1:Scan_max)
4790 ALLOCATE REAL Pt(1:Scan_max)
4800 ALLOCATE REAL M_inf(1:Scan_max)
4810 ALLOCATE REAL M_exit(1:Scan_max)
4820 ALLOCATE REAL Ma1(1:Scan_max)
4830 ALLOCATE REAL Ma2(1:Scan_max)
4840 ALLOCATE REAL Ma3(1:Scan_max)
4850 ALLOCATE REAL Ma4(1:Scan_max)
4860 ALLOCATE REAL Q(1:Scan_max)
4861 !
4862 !Begin editing of main program to determine X vel and deviation angle
4863 !Define new variables.
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
600   !************************************************************
610   !INPUT DAT INFORMATION
620   !************************************************************
630   !
640 Input:   !
650          !
660          IF Allocated=1 THEN GOSUB Deallocate
670          !
680          CLEAR SCREEN
690   INPUT "Enter Zoc # ( ,  , ), date (YYMMDD)   and run #"
700   PRINT
710   PRINT
720   PRINT
730   PRINT "Enter the disc drive where data is stored as below:
740   PRINT "       0 is HD (    ) or 700,0"
750   PRINT "       1 is LH  floppy or 700,1"
760   PRINT
770   INPUT "Enter Disc where data is located:  Disc drive
780   PRINT
790   !
800   !************************************************************
810   !FILE/DISK PATH ASSIGNED
820   !************************************************************
830   !
840   Data_file1$="ZC"&VAL$(Zoc)&Date$&VAL$(Run)
850   Data_file2$="ZB"&VAL$(Zoc)&Date$&VAL$(Run)
860   SELECT Disk_drive
870   CASE 0
880   Data_disc1$=Data_file1$&":,700,0"
890   Data_disc2$=Data_file2$&":,700,0"
900   CASE 1
910   Data_disc1$=Data_file1$&":,700,1"
920   Data_disc2$=Data_file2$&":,700,1"
930   END SELECT
940   ASSIGN @Data_path1 TO Data_disc1$
950   ASSIGN @Data_path2 TO Data_disc2$
960   !
970   !************************************************************
980   !DETERMINE NUMBER OF RECORDS AND ENTER DATA.
990   !************************************************************
1000  !
1010  STATUS @Data_path1,3;N1              ! Determine number of records
1020  STATUS @Data_path2,3;N2              ! Determine number of records
1030  ALLOCATE REAL Cal(N1-1,11)           ! Define REAL array of records
1040  ENTER @Data_path1;Cal(*)
1050  Period=Cal(0,0)
1060  R=1/Period
1070  Sample_number=Cal(0,1)
1080  Zoc=Cal(0,2)
1090  Scan_type=Cal(0,11)
1100  Scan_max=Cal(1,11)
1110  Increment=Cal(2,11)*.0000625    !Convert steps to inch
1120  P_atm=Cal(3,11)
1130  !
1140  ALLOCATE REAL Data(1:N2,0:32)    !Allocate real data array
1150  ENTER @Data_path2;Data(*)
1160  IF Scan_max<8 THEN
1170  ALLOCATE REAL Pa(1:32,1:2)
1180  ELSE
1190  ALLOCATE REAL Pa(1:32,1:Scan_max)
1200  END IF
1210  !
1220  Allocated=1          ! Allows deallocation of paths
1230  !
1240  !************************************************************
1250  !READS AVERAGE OF ALL SAMPLES TO ARRAYS
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
[illegible] ALLOCATE REAL [illegible]
4865 ALLOCATE REAL P3_r(1:Scan_max)
4866 ALLOCATE REAL P_st_p(1:Scan_max)
4868 ALLOCATE REAL P_st(1:Scan_max)
4869 ! Pt 13 P1 in the current probe.
4870 INTEGER N pts,L,K,Dev
4871 N pts=3                                !Used in Lagrange Interp [illegible]
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_p(1:Scan_max)
4877 ALLOCATE REAL Pitch_p(1:Scan_max)
4878 ALLOCATE REAL Pitch(1:Scan_max)
4879 ALLOCATE REAL Mach  p(1:Scan_max)
4880 ALLOCATE REAL X_interp(1:Scan_max)
4881 ALLOCATE REAL F_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 pt!
4894          !
4900 !Initialize plot parameters
4910 LINE TYPE 1
4920 Title$="Vertical Distance Traversed vs. Pt"
4930 X_label$="Total Pressure (psia)"
4940 Y label$="Vertical Distance (in)"
4950 Xo=30
4960 Xf=60
4970 Yo=2
4980 Yf=0
4990 Dx=30
5000 Dy=-32
5010 MAT Pen2= (-1)
5020 Pen2(1)=-2
5030 Pen2(Scan_max)=-2
5040 !
5050 CALL Plot                  !Sets up graphics environment
5060 !
5070 !Flow quantities calculated and total pressure plotted.
5080 !
5090 G=32.2
5100 Rgas=53.3
5110 !
5120 ! Read in data of new blade survey positions
5130 DATA 0,.0625,.125,.1875,.25,.3125,.34375,.375,.40625,.4375,.[illegible]
,.5625,.59375,.625,.65625,.6875,.71875,.75,.78125,.8125,.84375,.875,.90625,.9375
5131 DATA .96875,1.0,1.13125,1.2625,1.39375,1.525,1.65625
5132 DATA .96875,1.0,1.18,1.36,1.54,1.72,1.90
5134 READ Y(*)
5140 !
5150 FOR I=1 TO Scan max
5160      P_inf(I)=Pa(29,I)
5170      P_exit(I)=Pa(30,I)
5180      P_ref(I)=Pa(31,I)
5190      Pt(I)=Pa(32,I)
5200      !
5410      Q(I)=P_ref(I)-P_inf(I)
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
54[illegible]
5470      PLOT Pt(I),Y(I),Pen2(I)
5480 NEXT I
5490 !
5500 FOR I=1 TO Scan_max
5510 PLOT [illegible](I),Y(I),[illegible]
5520 NEXT I
5530 !
5540 FOR I=1 TO Scan_max
5550 PLOT [illegible](I),Y(I),[illegible]
5560 NEXT I
5561 !*** **********************
5562 !Begin calibration routine to determine X_vel and [illegible]
5563 !With errors in X_vel = [illegible](Beta probe,phi [illegible])
5564 !And errors in Phi = Phi(Gamma probe,X_vel [illegible])
5566 FOR I=1 TO Scan_max
5567 !Define needed pressure ports
5568 Pt(I)=Pa(32,I)
5569 P2_1(I)=Pa(24,I)
5570 P2_r(I)=Pa(25,I)
5572 ! calculate coefficients
5573 P23(I)=((P2_1(I)+P2_r(I))/2
5574 Beta_p(I)=(Pt(I)-P23(I))/Pt(I)
5575 Gamma_p(I)=(P2_1(I)-P2_r(I))/(Pt(I)-P23(I))
5577 !
5578 !Calculate X_vel from beta(first calibration routine
5579 X_vel(I)=-1733913.[illegible]*Beta_p(I)^6+679716.[illegible]*Beta_p(I)^5-104[illegible]*Beta_p(I)^4+8119.480*Beta_p(I)^3-[illegible]4.917*Beta_p(I)^2+10.12*Beta_p(I)[illegible]
5580 ! Mach_vel(I)=SQR((2/(Gamma-1))*X_vel(I)^2/(1-X_vel(I)^2))
5581 !
5582 P_st(I)=Pt(I)*(1-X_vel(I)^2)^(Gamma/(Gamma-1))
5584 !
5585 !Calculate angle data from calculated gamma values
5586 Phi_1(I)=-.815*Gamma_p(I)^3+3.584*Gamma_p(I)^2+12.[illegible]*Gamma_p(I)[illegible]
5587 Phi_2(I)=-.156*Gamma_p(I)^3+.412*Gamma_p(I)^2+12.[illegible]*Gamma_p(I)[illegible]
5588 Phi_3(I)=19.817*Gamma_p(I)^3-5.526*Gamma_p(I)^2+9.[illegible]*Gamma_p(I)[illegible]
5589 Phi_4(I)=13.149*Gamma_p(I)^3-3.208*Gamma_p(I)^2+11.104*Gamma_p(I)[illegible]
5590 Phi_5(I)=15.897*Gamma_p(I)^3-5.546*Gamma_p(I)^2+12.155*Gamma_p(I)[illegible]
5591 Phi_6(I)=3.438*Gamma_p(I)^3+.520*Gamma_p(I)^2+1[illegible].270*Gamma_p(I)[illegible]
5592 Phi_7(I)=11.242*Gamma_p(I)^3-2.607*Gamma_p(I)^2+13.736*Gamma_p(I)[illegible].349
5593 Phi_8(I)=11.968*Gamma_p(I)^3-3.631*Gamma_p(I)^2+14.607*Gamma_p(I)-2.[illegible]
5594 !
5595 ! X_vel average values to be used to interpolate between phi data
5596 X_avg_1=.10496059
5597 X_avg_2=.13974508
5598 X_avg_3=.1912050[illegible]
5599 X_avg_4=.21922797
5600 X_avg_5=.26502834
5601 X_avg_6=.30029142
5602 X_avg_7=.33779756
5603 X_avg_8=.36982608
5604 !
5605 ! Determine upper and lower bounds of X_vel and Phi for interpolation
5606 !
5607 IF X_vel(I)>=X_avg_1 AND X_vel(I)<=X_avg_2 THEN
5608 X_upper=X_avg_2
5609 X_lower=X_avg_1
5610 Phi_upper=Phi_2(I)
5611 Phi_lower=Phi_1(I)
5612 END IF
5613 IF X_vel(I)>=X_avg_2 AND X_vel(I)<=X_avg_3 THEN
5614 X_upper=X_avg_3
5615 X_lower=X_avg_2
5616 Phi_upper=Phi_3(I)
5617 Phi_lower=Phi_2(I)
5618 END IF
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
5619 IF X_vel(I)>=X_avg_3 AND X_vel(I)<=X_avg_4 THEN
5620 X_upper=X_avg_4
5621 X_lower=X_avg_3
5622 Phi_upper=Phi_4(I)
5623 Phi_lower=Phi_3(I)
5624 END IF
5625 IF X_vel(I)>=X_avg_4 AND X_vel(I)<=X_avg_5 THEN
5626 X_upper=X_avg_5
5627 X_lower=X_avg_4
5628 Phi_upper=Phi_5(I)
5629 Phi_lower=Phi_4(I)
5630 END IF
5631 IF X_vel(I)>=X_avg_5 AND X_vel(I)<=X_avg_6 THEN
5632 X_upper=X_avg_6
5633 X_lower=X_avg_5
5634 Phi_upper=Phi_6(I)
5635 Phi_lower=Phi_5(I)
5636 END IF
5637 IF X_vel(I)>=X_avg_6 AND X_vel(I)<=X_avg_7 THEN
5638 X_upper=X_avg_7
5639 X_lower=X_avg-6
5640 Phi_upper=Phi_7(I)
5641 Phi_lower=Phi_6(I)
5642 END IF
5643 IF X_vel(I)>=X_avg_7 AND X_vel(I)<=X_avg_8 THEN
5644 X_upper=X_avg_8
5645 X_lower=X_avg_7
5646 Phi_upper=Phi_8(I)
5647 Phi_lower=Phi_7(I)
5648 END IF
5649 !
5650 ! Lagrange interpolation to find the deviation angle
5651 Xa=X_vel(I)
5652 Yans=0
5653 X_interp(1)=X_lower
5654 X_interp(2)=X_upper
5655 F_interp(1)=Phi_lower
5656 F_interp(2)=Phi_upper
5657 FOR L=1 TO N_pts
5658 Z=1
5659 FOR K=1 TO N_pts
5660 IF L=K THEN
5661 GOTO 5661
5662 END IF
5663 Z=Z*(Xa-X_interp(K))/(X_interp(L)-X_interp(K))
5664 NEXT K
5665 Yans=Yans+(Z*F_interp(L))
5666 NEXT L
5667 Pitch(I)=6.4-Yans
5668 NEXT I
5669 !*******************************************
5670 !Put Loss coefficient calculation in this position
5671 !*******************************************
5672 ! Plot Pstatic calculated above.
5673 FOR I=1 TO Scan_max
5674 PLOT P_st(I),Y(I),Pen2(I)
5675 NEXT I
5676 PAUSE
5677 CLEAR SCREEN
5679 !Print results to Think-Jet
5680 PRINTER IS CRT
5681 INPUT "Deviation angle and X_vel data to CRT or Printer (0=CRT 1=Printer)",De
v
5682 IF Dev=1 THEN PRINTER IS 702
5683 CLEAR SCREEN
5684 !
```

Figure D1 (cont) Program "NEW_READ_ZOC1"

```
5685 PRINT USING [illegible] "Beta [illegible]
vel","P_st","Dev Angle(deg)"
5686 PRINT [illegible]

5687 FOR I=1 TO Scan_max
5688 PRINT USING "1X,SZD.5D,5X,SD.6D,3X,SD.6D,3X,SD.6D,3X,[illegible]
,Beta_p(I),Gamma_p(I),X_vel(I),[illegible](I),Pitch(I)
5689 NEXT I
5690 !****************************************
5691 ! [illegible] current [illegible]
5692 !****************************************
5693 !
5695 ! [illegible] subroutine to determine the xvel and pt [illegible]
5696 FOR I=1 TO Scan_max
5697      G_op=Gamma_p(I)
5698      B_op=Beta_p(I)
5700 CALL [illegible] poly(G_op,B_op,X_cp,P_cp)
5701      X_vel_p(I)=X_cp
5702      Pitch_p(I)=6.4-[illegible]
5703      P_st_p(I)=Pt(I)*(1-X_vel_p(I)^2)^(Gamma/(Gamma[illegible]
5704 NEXT I
5705 PRINT
5706 PRINT
5707 PRINT
5709 PRINT "Calculated Values using Newtonian Iteration"
5710 PRINT USING "/,3X,K,[illegible],7X,K,7X,K,9X,K";"Position","Beta","Gamma[illegible]
vel","P_st","Dev Angle(deg)"
5711 FOR I=1 TO Scan_max
5712 PRINT USING "1X,SZD.5D,5X,SD.6D,3X,SD.6D,3X,SD.6D,3X,[illegible]
,Beta_p(I),Gamma_p(I),X_vel_p(I),P_st_p(I),Pitch_p(I)
5713 NEXT I
5714 !
5715 PRINTER IS CRT
5716 PAUSE
5717 !
5718 INPUT "Would you like to make another plot (Y=yes,N=no)?",Go$
5719 IF Go$="Y" THEN Plot_pt
5720 !
5721 CLEAR SCREEN
5722 !
5723 PRINT
5724 PRINT
5725 DISP "Now calculating cascade loss coefficient"
5726 ! Loss calculation begins here.
5727 DEG
5728 !
5730 ALLOCATE REAL B2(1:Scan_max)
5731 ALLOCATE REAL X1_ref(1:Scan_max)
5732 ALLOCATE REAL I4_array(1:Scan_max)
5733 ALLOCATE REAL I3_array(1:Scan_max)
5734 ALLOCATE REAL I3_num(1:Scan_max)
5735 ALLOCATE REAL I3_den(1:Scan_max)
5737 ALLOCATE REAL I2_array(1:Scan_max)
5738 ALLOCATE REAL I1_array(1:Scan_max)
5739 INTEGER Hipoint1,Lowpoint1,High_t,Low_[illegible]
5740 REAL Xa_1
5741 B1=56.49        ! Beta1 in degrees
5742 FOR I=1 TO Scan_max
5743      B2(I)=B1-(6.4-Pitch(I))
5744      X1_ref(I)=SQRT(1-EXP(((Gamma-1)/Gamma)*LOG(P_inf(I)/[illegible]_ref(I)[illegible]
5745      I4_array(I)=COS(B2(I))*(Pt(I)/P_ref(I))*(X_vel(I)*(1-X_vel(I[illegible]
mma-1)))/(X1_ref(I)*(1-X1_ref(I)^2)^(1/(Gamma-1)))
5746      I1_array(I)=I4_array(I)
5747      I2_array(I)=COS(B2(I))*SIN(B2(I))*(Pt(I)/P_ref(I))*(X_vel(I)[illegible]
(I)^2)^(1/(Gamma-1)))/(X1_ref(I)^2*(1-X1_ref(I)^2)^(1/(Gamma-1)))
5748      I3_num(I)=(Pt(I)/P_ref(I))*((COS(B2(I)))^2*(2*Gamma/(Gamma-1)[illegible]
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
)^2*(1-X_vel(I)^2)^(1/(Gamma-1)))/(1-X_vel(I)^2)^(Gamma/(Gamma-1)))
5749       I3_den(I)=X1_ref(I)^2*(1-X1_ref(I)^2)^(1/(Gamma-1))
5750       I3_array(I)=I3_num(I)/I3_den(I)
5751       !
5752 NEXT I
5753 ! Begin calling subroutines to determine proper interval of integration
5754 Lowpoint1=1
5755 Hipoint1=33
5756 CALL Massflux(Lowpoint1,Hipoint1,I4_array(*),Y(*),I4_int,Posit1,Posit2,Valu
e1,Value2,High_i,Low_i)
5757 PRINT "VALUE1=";Value1
5758 PRINT "VALUE2=";Value2
5759 PRINT "I      =";High_i
5760 PRINT "I-1    =";Low_i
5762 !Returns 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
5770 PAUSE
6165 ! BOGUS VALUES TO CHECK SUBPROGRAMS
6166 ! Probe_posit=1.6345
6167 !*******************************************************************
6168 ! Begin calculations of I1,I2,I3 by calling Dat_int subprogram
6169 ! Define the upper and lower points of the integrals
6170 Lowpoint1=1
6171 CALL Dat_int(Lowpoint1,High_i,I1_array(*),Y(*),I1_int_hi)
6172 CALL Dat_int(Lowpoint1,Low_i,I1_array(*),Y(*),I1_int_lo)
6173 CALL Interpolate(Value1,Value2,I1_int_lo,I1_int_hi,I1_int,Xa_1)
6174 PRINT "I1_INT =";I1_int
6175 PAUSE
6176 !
6177 CALL Dat_int(Lowpoint1,High_i,I2_array(*),Y(*),I2_int_hi)
6178 CALL Dat_int(Lowpoint1,Low_i,I2_array(*),Y(*),I2_int_lo)
6179 CALL Interpolate(Value1,Value2,I2_int_lo,I2_int_hi,I2_int,Xa_1)
6180 PRINT "I2_INT=";I2_int
6181 PAUSE
6182 !
6183 CALL Dat_int(Lowpoint1,High_i,I3_array(*),Y(*),I3_int_hi)
6184 CALL Dat_int(Lowpoint1,Low_i,I3_array(*),Y(*),I3_int_lo)
6185 CALL Interpolate(Value1,Value2,I3_int_lo,I3_int_hi,I3_int,Xa_1)
6186 PRINT "I3_INT=";I3_int
6187 PAUSE
6188 REAL Pt_ref_avg
6190 REAL X_ref_avg
6191 REAL Q_ref_avg
6192 REAL P_ref_avg
6194 X_ref_avg=0
6195 Pt_ref_avg=0
6196 Q_ref_avg=0
6197 P_ref_avg=0
6199 FOR I=1 TO High_i
6200       X_ref_avg=X1_ref(I)+X_ref_avg
6201       Pt_ref_avg=Pt(I)+Pt_ref_avg
6202       Q_ref_avg=P_ref(I)-P_inf(I)+Q_ref_avg
6203       P_ref_avg=P_ref(I)+P_ref_avg
6205 NEXT I
6206 X_ref_avg=X_ref_avg/High_i
6207 Pt_ref_avg=Pt_ref_avg/High_i
6208 Q_ref_avg=Q_ref_avg/High_i
6209 P_ref_avg=P_ref_avg/High_i
6211 !
6212 !****using I1,I2,I3 calculate A,B,C,D,E
6213 A1=(I2_int/I1_int)*X_ref_avg
6214 B1=(I3_int/I1_int)*X_ref_avg
6215 C1=((Gamma+1)/(Gamma-1))^2
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
6216 Di=2*SQRT(Ci)*(1-((2*Gamma)/(Gamma-1))*Ai^2) Bi^2
6217 Ei=Bi^2*Ai^2+(1-((2*Gamma)/(Gamma-1))*Ai^2)^2
6219 X3_super=SQRT((-Di+SQRT(Di^2-4*Ci*Ei))/(2*Ci))
6220 X3_sub=SQRT((-Di-SQRT(Di^2-4*Ci*Ei))/(2*Ci))
6221 PRINT "X3_SUB  ="; X3_sub
6222 X3_mixed=X3_sub
6223 DEG
6224 Beta3_mixed=ASN(Ai/X3_mixed)
6225 !Pt3=(Pt_ref_avg*X_ref_avg*(1-X_ref_avg^2)^(1/(Gamma-1)))*(1_tot)/(X3_mixed*(
1-X3_mixed^2)^(1/(Gamma-1))*COS(Beta3_mixed))
6226 Pt3=(1_tot*Pt_ref_avg*X_ref_avg*(1-X_ref_avg^2)^(1/(Gamma-1)))/(COS(Beta3_
mixed)*X3_mixed*(1-X3_mixed^2)^(1/(Gamma-1)))
6228 W_mixed=(P_ref_avg-Pt3)/(Q_ref_avg)
6229 INPUT "Device to print results (0=CRT 1=PRINTER)",Dev
6230 IF Dev=1 THEN PRINTER IS 702
6231 CLEAR SCREEN
6232 PRINT "I4 UPPER = ";Value2
6233 PRINT "I4 LOWER = ";Value1
6234 PRINT "X3_mixed = ";X3_mixed
6235 PRINT "P_ref_avg= ";P_ref_avg
6236 PRINT "Pt3_mixed= ";Pt3
6237 PRINT "Beta3_mixed=";Beta3_mixed
6238 PRINT "W_mixed    =";W_mixed
6239 PAUSE
6240 !
6241 ! Plot pstatic 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(*)
6270 DEALLOCATE Ma3(*)
6280 DEALLOCATE Ma4(*)
6290 DEALLOCATE Q(*)
6300 DEALLOCATE Pt(*)
6310 DEALLOCATE Y(*)
6311 !****************************************
6312 !Deallocate added variables
6313 DEALLOCATE FZ_1(*)
6314 DEALLOCATE P_st(*)
6315 DEALLOCATE P_st_p(*)
6317 DEALLOCATE P3_r(*)
6318 DEALLOCATE Pitch(*)
6319 DEALLOCATE Pitch_p(*)
6320 DEALLOCATE X_vel_p(*)
6321 DEALLOCATE X_vel(*)
6322 DEALLOCATE Beta_p(*)
6323 DEALLOCATE Gamma_p(*)
6324 DEALLOCATE X_interp(*)
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
6325 DEALLOCATE F_interp(*)
6326 DEALLOCATE B23(*)
6327 DEALLOCATE Mach_xvel(*)
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_num(*)
6342 DEALLOCATE I3_den(*)
6343 DEALLOCATE B2(*)
6345 !*************************************************************************
6346 KEY LABELS ON
6347 PRINTER IS CRT
6348 !
6350 GOTO Reset
6360 !
6370 !*************************************************************************
6380 !EXIT PROGRAM AND DEALLOCATE ALL BUFFERS AND PATHS
6390 !*************************************************************************
6400 !
6410 Deallocate: !
6420  ASSIGN @Data_path1 TO *
6430  ASSIGN @Data_path2 TO *
6440  DEALLOCATE Cal(*)
6450  DEALLOCATE Data(*)
6460  DEALLOCATE Pa(*)
6470  RETURN
6480  !
6490 Finish: !
6500  IF Allocated=1 THEN GOSUB Deallocate
6510  PRINTER IS CRT
6520  LOAD "ZOC_MENU",10
6530  END
6540  !
6550  !*******************************************************************
6560  !SUBROUTINE TO SET UP GRAPHICS WINDOW
6570  !*******************************************************************
6580  !
6590  SUB Plot
6600  !
6610  !Subroutine to display plot screens, less the plot of any curves
6620  !For the specified variables in the COM/Plot_labels/ line.
6630  !
6640  COM /Plot_labels/ Xo,Xf,Yo,Yf,Dx,Dy,Title$,X_label$,Y_label$
6650  CLEAR SCREEN
6660  KEY LABELS OFF
6670  GINIT                                !Initialize graph routine
6680  X_range=Xf-Xo                        !Length of X-axis
6690  Y_range=Yf-Yo                        !Length of Y-axis
6700  LORG 6                               !Character ref pt:top center
6710  MOVE 100*RATIO/2,100                 !Move cursor to screen loc for labels
6720  CSIZE 3                              !Sizes labeling
6730  LABEL Title$                         !Plot title
6740  MOVE 100*RATIO/2,0                   !Move cursor to botton center screen
6750  LORG 4                               !Character ref pt:botton center
6760  LABEL X_label$                       !X-axis label
6770  DEG                                  !Desig degrees for LDIR
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
6780  LDIR 90                                  !Sets Y-axis label [illegible]
6790  LORG 5
6800  MOVE 0,50
6810  LABEL Y_label$                           !Y-axis label
6820  LDIR 0                                   !Reset label to horizontal orientation
6830  LORG 2                                   !Ch ref pt:left [illegible]
6840  VIEWPORT 10,90*RATIO,10,90               !Sets graph screen size
6850  FRAME                                    !Box around viewport
6860  WINDOW Xo,Xf,Yo,Yf              !Set axis lengths in [illegible]
6870  AXES X_range/Dx,Y_range/Dy,Xo,Yo        !Axes intersect at lower left
6880  AXES X_range/Dx,Y_range/Dy,Xf,Yf        !Axes intersect at upper right
6890  GRID X_range/Dx,Y_range/Dy,Xo,Yo,Dx,Dy,.001
6900  CLIP OFF                                 !So labels can print outside WINDOW
6910  CSIZE 3.0,.4                             !Axis label size
6920  LORG 6                                   !Number X axis
6930  FOR I=Xo TO Xf STEP X_range/Dx
6940       MOVE I,Yo-.01*Y_range
6950       LABEL USING "#,K";I
6960  NEXT I
6970  LORG 8
6980  FOR I=Yo TO Yf STEP Y_range/Dy
6990       IF ABS(I)<1.0E-5 THEN I=0.
7000       MOVE Xo-.01*X_range,I
7010       LABEL USING "#,K";I
7020  NEXT I
7030  CLIP ON
7040  !
7050  SUBEND
7060  !
7070  SUB Square(Xo,Xf,Yo,Yf,Sz)
7080  !Subroutine to plot squares around the local origin designated
7090  !by the PLOT statement.
7100  Xd=Sz*(Xf-Xo)
7110  Yd=Sz*(Yf-Yo)*RATIO
7120  RPLOT -Xd,Yd,-2
7130  RPLOT Xd,Yd,-1
7140  RPLOT Xd,-Yd,-1
7150  RPLOT -Xd,-Yd,-1
7160  RPLOT -Xd,Yd,2
7170  SUBEND
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
7700  SUB Massflux(INTEGER Lowpoint,Hipoint,REAL D(*),Pos(*),I4_int,[illegible]
2,Value1,Value2,INTEGER High_1,Low_1)
7710  OPTION BASE 1
7720  DIM A(100)
7730  DIM B(100)
7740  DIM C(100)
7750  DIM Dint(100)
7760  DIM Dafint(100)
7770  MAT A= (0)
7780  MAT B= (0)
7790  MAT C= (0)
7800  MAT Dint= (0)
7810  MAT Dafint= (0)
7811  I4_int=0
7820  N=Hipoint-1
7830  Nm1=N-1
7840  FOR I=Lowpoint+1 TO N
7850  A(I)=(1/(Pos(I+1)-Pos(I-1)))*((D(I+1)-D(I))/(Pos(I+1)-Pos(I))-(D(I)-D(I-1)
)/(Pos(I)-Pos(I-1)))
7860  B(I)=((D(I)-D(I-1))/(Pos(I)-Pos(I-1)))-((Pos(I)+Pos(I-1))*A(I))
7870  C(I)=D(I)-(A(I)*Pos(I)^2)-(B(I)*Pos(I))
7880  NEXT I
7890  Dint(1)=A(2)*(Pos(2)^3-Pos(1)^3)/3.0+B(2)*(Pos(2)^2-Pos(1)^2)/2.0+C(2)*(Po
s(2)-Pos(1))
7900  Dint(N)=A(N)*(Pos(N+1)^3-Pos(N)^3)/3.0+B(N)*(Pos(N+1)^2-Pos(N)^2)/2.0+C(N)
*(Pos(N+1)-Pos(N))
7920  FOR I=Lowpoint+1 TO Nm1
7930  Dint(I)=(A(I)+A(I+1))*(Pos(I+1)^3-Pos(I)^3)/6+(B(I)+B(I+1))*(Pos(I+1)^2-Po
s(I)^2)/4+(C(I)+C(I+1))*(Pos(I+1)-Pos(I))/2                2.0
7940  NEXT I
7950  FOR I=1 TO N
7960        I4_int=I4_int+Dint(I)
7970        IF I4_int>=1.0 THEN
7980           Posit2=Pos(I)
7990           Posit1=Pos(I-1)
8000           Value2=I4_int
8010           Value1=I4_int-Dint(I)
8011           High_1=(I)
8012           Low_1=(I-1)
8014           GOTO 8040
8020        END IF
8030  NEXT I
8031  Posit2=Pos(I)
8032  Posit1=Pos(I-1)
8033  Value2=I4_int
8034  Value1=I4_int-Dint(N)
8035  High_1=(I+1)
8036  Low_1=(I)
8040  SUBEND
```

Figure D1. (cont) Program "NEW_READ_ZOC1"

```
8050  SUB Interpolate(X_low,X_high,F_lower,F_upper,Yans_I,Xa_I)
8060  OPTION BASE 1
8061  Yans_I=0
8063  INTEGER L,K
8070  DIM X1(2)
8080  DIM F1(2)
8090  MAT X1= (0)
8100  MAT F1= (0)
8110  X1(1)=X_low
8120  X1(2)=X_high
8130  F1(1)=F_lower
8140  F1(2)=F_upper
8150  N_pt=1+2
8160  FOR L=1 TO N_pt+1
8170      Z1=1
8180      FOR K=1 TO N_pt+1
8190          IF L=K THEN
8200              GOTO 8230
8210          END IF
8220      Z1=Z1*(Xa_I-X1(K))/(X1(L)-X1(K))
8230      NEXT K
8240      Yans_I=Yans_I+(Z1*F1(L))
8250  NEXT L
8260  SUBEND
8270  SUB Dat_int(INTEGER Lowpoint,Hipoint,REAL D(*),R(*),Dat_int)
8271  ! Shreeve integration program Ref. NPS-57SF73071A
8280  OPTION BASE 1
8290  DIM A(100)
8300  DIM B(100)
8310  DIM C(100)
8320  DIM Dint(100)
8330  MAT A= (0)
8340  MAT B= (0)
8350  MAT C= (0)
8360  MAT Dint= (0)
8370  N=Hipoint-1
8380  Nm1=N-1
8390  FOR I=Lowpoint+1 TO N
8400  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)))
8410  B(I)=(D(I)-D(I-1))/(R(I)-R(I-1))-(R(I)+R(I-1))*A(I)
8420  C(I)=D(I)-A(I)*R(I)^2-B(I)*R(I)
8430  NEXT I
8440  Dat_int=0
8450  FOR I=Lowpoint+1 TO Nm1
8460  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)
)/4.0+(C(I)+C(I+1))*(R(I+1)-R(I))/2.0
8470  Dat_int=Dat_int+Dint(I)
8480  NEXT I
8490  Dint(1)=A(2)*(R(2)^3-R(1)^3)/3.0+B(2)*(R(2)^2-R(1)^2)/2.0+C(2)*(R(2)-R(1))
8500  Dint(N)=A(N)*(R(N+1)^3-R(N)^3)/3.0+B(N)*(R(N+1)^2-R(N)^2)/2.0+C(N)*(R(N+1)
-R(N))
8510  Dat_int=Dat_int+Dint(1)+Dint(N)
8520  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 .

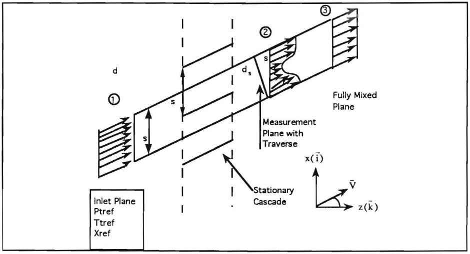

Figure E1. Fully-Mixed-Out Control Volume

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".

$$1 = \int_0^{\frac{d_s}{d_1}} \frac{X_2(1-X_2)^{\frac{1}{\gamma-1}}}{Xref(1-Xref)^{\frac{1}{\gamma-1}}} \cdot \frac{P_{T2}}{P_{T1}} \cdot \cos\beta_2 d(\frac{x}{d_1}) \qquad (1)$$

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.

$$\hat{I}_1 = \int_0^1 \frac{X_2(1-X_2)^{\frac{1}{\gamma-1}}}{Xref(1-Xref)^{\frac{1}{\gamma-1}}} \cdot \frac{P_{T2}}{P_{Tref}} \cdot \cos\beta_2 d(\frac{x}{s}) \qquad (2)$$

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

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

$$\hat{A} = Xref \cdot \frac{\hat{I}_2}{\hat{I}_1} = X_3 \sin \beta_3 \qquad (5)$$

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

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

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

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

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

where the subsonic root of X_3 is chosen

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

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

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.

$$\varpi = \frac{Ptref - Pt_3}{Ptref - Pstaticref} \tag{13}$$

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 Zoc # 1 , Run # 2 , File2P1414242
Period between samples (sec): .00303030303
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/traverses: 33
Increment of traverse: .0625 Inches
Atmospheric pressure is: 14.72 psia
Tunnel Pressure Ratio is: 2.11030215725

Scan	Port Number 1	24	25	29	30	31	32
1	15.410	47.191	45.052	15.463	32.632	53.760	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	32.662	53.750	51.550
4	15.443	46.982	44.769	15.483	32.622	53.741	51.284
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	32.567	53.750	51.198
8	15.356	47.087	44.741	15.503	32.682	53.804	51.200
9	15.421	47.096	44.684	15.513	32.542	53.885	51.312
10	15.291	46.782	44.429	15.513	32.462	53.686	50.921
11	15.356	46.915	44.543	15.513	32.552	53.759	51.055
12	15.388	47.343	44.901	15.473	32.492	53.714	51.497
13	15.387	47.428	44.910	15.463	32.502	53.677	51.607
14	15.453	46.372	43.644	15.533	32.522	53.660	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	53.732	50.625
20	15.421	46.801	45.969	15.523	32.682	53.723	51.303
21	15.367	46.744	45.522	15.523	32.532	53.823	51.246
22	15.432	46.649	45.456*	15.453	32.502	53.641	51.265
23	15.464	48.582	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	15.464	46.420	45.569	15.513	32.522	53.750	51.084
27	15.377	46.298	45.550	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	48.373	45.981	15.593	32.512	53.668	51.191
31	15.432	46.277	46.093	15.543	32.462	53.705	51.170
32	15.443	48.105	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	Beta	Gamma	X_vel	P_st	θ
+0.00000	+.106800	+.387342	+.335411	[illegible]	[illegible]
+.06250	+.105751	[illegible]	[illegible]	[illegible]	[illegible]
+.12500	+.105312	+.421933	[illegible]	[illegible]	[illegible]
+.18750	+.105462	[illegible]	[illegible]	[illegible]	[illegible]
+.25000	+.104013	[illegible]	[illegible]	[illegible]	[illegible]
+.31250	+.105232	[illegible]	[illegible]	[illegible]	[illegible]
+.37500	+.105249	[illegible]	[illegible]	[illegible]	[illegible]
+.43750	+.103383	+.443094	+.326001	[illegible]	[illegible]
+.50000	+.105674	+.444789	[illegible]	[illegible]	[illegible]
+.56250	+.104389	+.417623	+.328797	[illegible]	[illegible]
+.62500	+.104318	+.445500	+.328561	[illegible]	[illegible]
+.68750	+.104315	+.454603	+.328557	[illegible]	[illegible]
+.75000	+.105376	+.463002	+.331474	[illegible]	[illegible]
+.81250	+.102565	+.502941	+.337534	[illegible]	[illegible]
+.87500	+.091957	+.501652	+.297027	[illegible]	[illegible]
+.93750	+.072361	+.597344	+.256494	[illegible]	[illegible]
+1.00000	+.042376	+.456134	+.191402	+35.104952	[illegible]
+1.06250	+.061044	+.108396	+.233559	[illegible]	[illegible]
+1.12500	+.096599	+.206269	+.308205	+35.690539	[illegible]
+1.18750	+.089762	+.240854	+.316309	+35.473521	[illegible]
+1.25000	+.099773	+.239109	+.316337	+35.431603	[illegible]
+1.31250	+.101677	+.228894	+.321308	+35.002719	[illegible]
+1.37500	+.101110	+.206600	+.319872	+35.109605	[illegible]
+1.43750	+.100453	+.174988	+.318125	[illegible]	[illegible]
+1.50000	+.098859	+.195100	+.313958	+35.159558	[illegible]
+1.56250	+.099627	+.167338	+.315958	+35.352626	[illegible]
+1.62500	+.099679	+.146823	+.316090	+35.298159	[illegible]
+1.68750	+.090239	+.143553	+.312360	+35.030797	[illegible]
+1.75000	+.098068	+.075841	+.311923	+35.675263	[illegible]
+1.81250	+.097236	+.078715	+.309808	+35.931207	[illegible]
+1.87500	+.097407	+.036874	+.310219	+35.907320	[illegible]
+1.93750	+.097314	-.020165	+.310005	+35.900759	[illegible]
+2.00000	+.100405	+.002721	+.317999	[illegible]	[illegible]

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

Ptma1 = 53.7066520157 PSIA
Ptma2 = 50.4893345376 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 , File7D1414244
     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/traverses:    33
     Increment of traverse:        .0625  Inches
     Atmospheric pressure is:      14.715  psia
     Tunnel Pressure Ratio is:     2.0942717060
```

Scan	Port Number 1	24	25	29	30	31	32
1	15.097	46.494	44.282	15.312	32.069	52.911	50.9[illegible]
2	15.140	46.542	44.301	15.222	32.159	52.938	50.009
3	15.053	48.428	44.253	15.277	32.129	52.857	50.755
4	15.042	48.248	43.884	15.207	32.010	52.804	50.457
5	15.195	46.227	43.941	15.302	32.199	53.020	50.186
6	15.086	46.112	43.789	15.272	32.079	53.029	50.179
7	15.075	46.190	43.836	15.282	32.109	52.975	50.237
8	15.107	46.246	43.055	15.312	32.129	52.938	50.275
9	15.107	46.160	43.760	15.282	32.099	52.884	50.208
10	15.075	46.045	43.666	15.242	32.038	52.856	50.003
11	15.031	45.921	43.590	15.282	32.069	52.756	49.977
12	16.107	46.017	43.694	19.292	32.048	52.866	50.064
13	15.031	46.198	43.779	15.282	32.038	52.893	50.209
14	15.086	46.178	43.466	15.262	32.018	52.747	50.035
15	15.075	44.345	41.588	16.252	31.978	52.875	47.564
16	15.031	40.285	38.470	15.282	31.978	52.875	42.771
17	15.064	37.858	37.166	15.302	31.998	52.838	39.193
18	15.140	41.285	41.020	15.292	32.048	52.948	44.226
19	15.129	45.442	44.594	15.282	31.988	52.929	49.736
20	15.107	45.892	44.745	15.282	31.958	52.902	50.477
21	15.107	45.921	44.783	16.282	31.998	52.938	50.544
22	15.129	45.844	44.773	15.292	32.048	52.784	50.429
23	15.053	45.691	44.792	15.292	31.968	52.948	50.343
24	15.140	45.853	44.839	15.302	31.998	52.920	50.367
25	15.107	45.566	44.707	15.292	31.908	52.838	50.277
26	15.107	45.490	44.868	15.323	31.958	52.938	50.208
27	15.053	45.403	45.000	15.292	31.918	52.838	50.227
28	15.064	45.375	44.971	15.312	31.868	53.011	50.218
29	15.003	45.375	45.075	15.312	31.928	52.902	50.227
30	15.097	45.365	45.141	15.282	31.908	52.975	50.295
31	15.107	45.348	45.320	16.302	31.868	51.893	50.347
32	15.184	45.375	45.565	16.302	31.888	52.911	50.458
33	15.086	45.231	45.548	16.302	31.858	52.713	50.410

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

Position	Beta	Gamma	X_Vel	P_st	θ
+0.00000	+.106918	+.407205	+.335743	+33.439232	+3.548
+.06250	+.107439	+.409964	+.337187	+33.355166	+3.612
+.12500	+.106677	+.401569	+.335075	+33.454211	+3.445
+.18750	+.107047	+.437265	+.336100	+33.174569	+4.077
+.25000	+.107011	+.423172	+.336001	+33.195939	+3.877
+.31250	+.104200	+.444342	+.326237	+33.870156	+4.100
+.37500	+.103900	+.452525	+.327415	+33.790172	+4.233
+.43750	+.103921	+.457597	+.327471	+33.801073	+4.324
+.50000	+.104520	+.457256	+.329117	+33.613029	+4.341
+.56250	+.104380	+.455215	+.328732	+33.562786	+4.299
+.62500	+.104488	+.446434	+.329029	+33.468191	+4.147
+.68750	+.104038	+.445915	+.327794	+33.631022	+4.122
+.75000	+.103950	+.463457	+.327553	+33.748783	+4.430
+.81250	+.104172	+.520485	+.328161	+33.579769	+5.509
+.87500	+.096681	+.599904	+.308411	+33.523559	+6.705
+.93750	+.079337	+.534907	+.270226	+32.801343	+5.317
+1.00000	+.042896	+.411459	+.192636	+34.331537	+3.083
+1.06250	+.069498	+.086222	+.250835	+35.228939	-1.055
+1.12500	+.094875	+.179722	+.303954	+35.426325	+.090
+1.18750	+.102192	+.222420	+.322772	+34.344858	+.668
+1.25000	+.102727	+.219231	+.324218	+34.265020	+.628
+1.31250	+.101532	+.209210	+.320999	+34.465525	+.487
+1.37500	+.101325	+.176241	+.320444	+34.454286	+.050
+1.43750	+.101580	+.159021	+.321127	+34.408583	.176
+1.50000	+.101350	+.168822	+.320512	+34.369556	.048
+1.56250	+.100172	+.123711	+.317386	+34.624414	.626
+1.62500	+.100061	+.080332	+.317094	+34.662676	-1.175
+1.68750	+.100457	+.079940	+.318137	+34.566756	-1.185
+1.75000	+.099596	+.059878	+.315874	+34.766883	-1.429
+1.81250	+.100239	+.044425	+.317563	+34.668833	-1.633
+1.87500	+.099511	+.005169	+.315652	+34.865673	-2.121
+1.93750	+.098856	-.038082	+.313950	+35.091164	-2.663
+2.00000	+.099613	-.062773	+.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 , FileZR1414245
    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:     33
    Increment of traverse:         .0625  Inches
    Atmospheric pressure is:       14.71  psia
    Tunnel Pressure Ratio is:      2.1263124713
```

Scan	Port Number 01	24	25	29	30	31	
1	14.958	46.017	43.932	14.931	31.747	52.292	50.367
2	14.901	45.873	43.537	14.991	31.767	[illegible]	50.108
3	14.890	45.576	43.185	14.961	31.677	52.292	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	52.218	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	49.807
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	[illegible]
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	31.506	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	52.356	49.396
21	14.858	45.326	44.211	14.971	31.626	52.255	49.887
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	44.302	15.001	31.596	52.293	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	52.283	49.916
28	14.869	45.230	44.240	14.991	31.596	52.264	49.810
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	52.218	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 vel	[illegible]	$6.4° - \theta$
+0.00000	+.100061	+.401499	+.338902	[illegible]	[illegible]
+.12500	+.107021	[illegible]	[illegible]	[illegible]	[illegible]
+.25000	+.107102	[illegible]	[illegible]	[illegible]	[illegible]
+.37500	+.104235	[illegible]	+.328334	[illegible]	[illegible]
+.50000	+.105848	+.459306	+.337760	[illegible]	[illegible]
+.62500	+.104095	[illegible]	[illegible]	[illegible]	[illegible]
+.65625	+.106081	+.455454	[illegible]	[illegible]	[illegible]
+.68750	+.107499	[illegible]	+.337551	[illegible]	[illegible]
+.71875	+.104209	+.473635	+.328263	[illegible]	[illegible]
+.75000	+.103370	[illegible]	+.325966	[illegible]	[illegible]
+.78125	+.103999	[illegible]	+.327688	[illegible]	[illegible]
+.81250	+.099897	+.538371	+.316630	[illegible]	[illegible]
+.84375	+.096630	+.589125	+.308205	[illegible]	[illegible]
+.87500	+.076380	+.550406	+.264387	[illegible]	[illegible]
+.90625	+.057994	+.487897	+.227039	+32.992700	+2.161
+.93750	+.043291	+.422427	+.193574	[illegible]	+2.986
+.96875	+.050223	+.167186	+.209724	+31.171847	[illegible]
+1.00000	+.066294	+.074027	+.244407	[illegible]	+2.591
+1.03125	+.092627	+.143426	+.298597	[illegible]	[illegible]
+1.06250	+.099986	+.153376	+.315897	+34.099767	[illegible]
+1.09375	+.102590	+.217048	+.323946	+33.851257	[illegible]
+1.12500	+.102928	+.196521	+.324753	[illegible]	+5.079
+1.15625	+.104184	+.206836	+.320193	[illegible]	+5.934
+1.18750	+.104871	+.210690	+.330083	+33.417217	+5.878
+1.21875	+.103263	+.207073	+.325674	+33.894407	+5.735
+1.25000	+.102192	+.194471	+.322773	+33.917013	+6.108
+1.28125	+.103496	+.200981	+.326310	+33.659203	+6.017
+1.31250	+.101882	+.195161	+.321938	+33.962206	+6.109
+1.45000	+.101374	+.160414	+.320575	+33.953279	[illegible]
+1.58750	+.101646	+.125889	+.321303	[illegible]	[illegible]
+1.72500	+.100792	+.062604	+.319025	[illegible]	+7.899
+1.86250	+.100422	-.016691	+.318046	+34.106121	+8.820
+2.00000	+.102052	-.067175	+.322395	+34.040963	+9.529

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

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