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# Model fan passage flow simulation

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# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

# THESIS

MODEL FAN PASSAGE
FLOW SIMULATION

by

David D. Myre

December, 1992

Thesis Advisor: Raymond P. Shreeve

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# Model Fan Passage Flow Simulation

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

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December, 1992

## ABSTRACT

Two-dimensional experimental and numerical simulations of a transonic fan blade passage were conducted at a Mach number of 1.4 to provide baseline data for the study of the effects of vortex generating devices on the suction surface shock-boundary layer interaction. In the experimental program, a probe and traverse system were designed and constructed. A new data acquisition system was adapted to record data from probe surveys and multiple scans of static pressure ports. Impact pressure behind two model fan passages and static pressures across the shock-boundary layer interaction were measured for a design incidence and one off-design incidence in a blow-down wind tunnel. The passage shocks were positioned in similar locations by rotating the model to a decreased flow incidence. Fan passage losses were obtained by integrating the probe measurements. The losses compared favorably with a numerical Navier-Stokes solution and one engineering model. Static pressure distributions were also found to compare favorably with numerical results.

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# I. INTRODUCTION

## A. SHOCK-BOUNDARY LAYER INTERACTION

The demand for higher levels of thrust and the desire to limit the physical size of turbofan engines have combined to drive fan and leading compressor stage relative Mach numbers higher into the supersonic range. A shock system is inevitable in a transonic stage and "... the design principle is not the avoidance of shocks, but control of their locations and strengths so as to minimize aerodynamic losses." [Ref. 1] At operating conditions in such a stage, a shock forms at the leading edge of each blade and impinges on the suction side boundary layer of the adjacent blade. The resulting flow structure is illustrated in Figure 1. The subsonic portion of the boundary layer may not be able to negotiate the steep pressure gradient in the neighborhood of the shock and may separate locally and reattach at some point downstream. This results in a shock structure called a lambda-foot where the original normal shock branches into two oblique shocks near the wall. In a fan passage, reattachment must take place in a very small percentage of the chord to allow further diffusion to the design pressure ratio.

Characterization of the opposing loss mechanisms present in this flow regime are of interest to the designer. The size of the interaction will determine the normal shock losses and the behavior of the boundary layer. As the interaction is suppressed, high normal shock losses dominate. If the interaction region is large then the boundary layer will thicken, mixing losses will increase and the design flow turning angles will not be achieved.

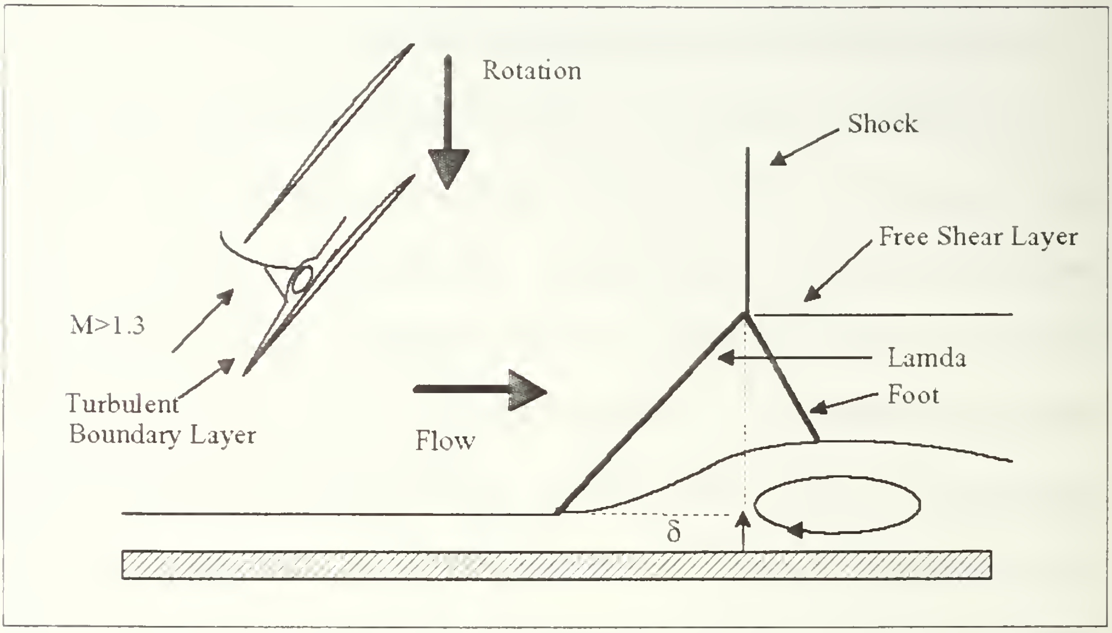
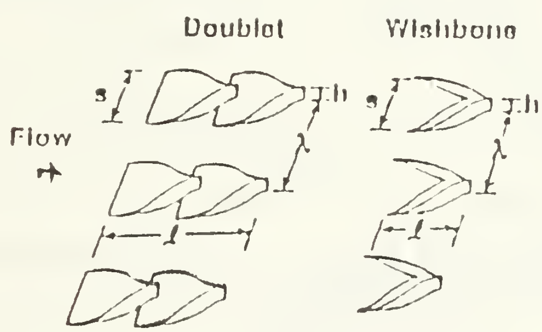



**Figure 1.** Shock-Boundary Layer Interaction

## B. BOUNDARY LAYER CONTROL

Several promising methods for controlling the shock-boundary layer interaction have been examined recently [Ref. 2]. Among these are vortex generator jets (VGJ's), low-profile vortex generators and the passive cavity. The first two devices energize the low momentum flow nearest the wall with higher momentum flow via streamwise vortices. This provides the inner layer with enough momentum to overcome the adverse pressure gradient transmitted forward through the subsonic layer. The passive cavity induces suction downstream of the shock and injection upstream of the shock which reduces the separation region while increasing boundary layer thickness [Ref. 3].

Conventional vane-type vortex generators have been studied since the nineteen fifties. NACA first investigated their usefulness for controlling flow separation and shock-boundary layer interactions. The low-profile vortex generator is relatively new and offers promise of reducing separation with less parasitic drag than conventional vortex generators [Ref. 3]. Examples of such devices are the "Wheeler Doublet" [Ref. 4] and the "wishbone" profile low-profile vortex generators both examined by Linn, et al and shown in Figure 2 [Ref. 2]. These vortex generators are submerged in the boundary




Doublet

| h | ℓ | s | λ |
|---|---|---|---|
| 0.11" | 1.25" | 0.42" | 0.50" |
| 0.125" | 1.60" | 0.80" | 1.00" |
| 0.15" | 1.65" | 0.56" | 0.75" |
| 0.50" | 3.35" | 1.62" | 2.00" |

Wishbone

| h | ℓ | s | λ |
|---|---|---|---|
| 0.11" | 0.35" | 0.25" | 0.50" |
| 0.25" | 0.84" | 0.70" | 1.00" |
| 0.50" | 1.88" | 1.60" | 2.00" |

**Figure 2.** Low profile Vortex Generators [Ref. 2]

layer many boundary layer thicknesses upstream of the shock-boundary layer interaction. For external flows over surfaces and internal flow in diffusers these wedge shapes would be easy to apply, but there may be more difficulty in applying them to fan blades with adequate precision.

VGJ's, shown in Figure 3, have been studied extensively by Johnston and Nishi as well as Johnston and Compton [Ref 5, 6]. VGJ's are pitched and skewed to the streamwise direction and can be passively or actively operated. In studies completed in subsonic flows they provide the largest vorticity when pitched at about forty-five degrees and yawed between forty-five and ninety degrees. These jets can be implemented in the fan application simply by drilling holes through blading. In passive operation the jet

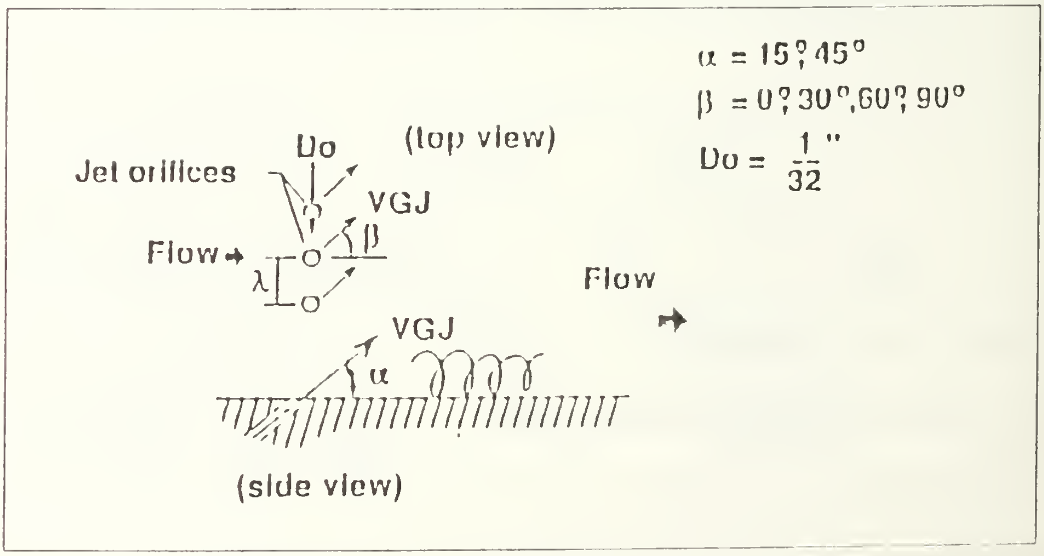



**Figure 3.** Vortex Generating Jets [Ref. 2]

would pass high pressure air from the pressure surface to the suction surface. An alternative approach would be to actively provide air to the jets through the blade only in the transonic range of operation. In both cases blade strength would be an issue and in the active case, mechanical complexity would be added.

The passive cavity is illustrated in Figure 4. Passive cavity operation is described as follows. "The pressure rise across the shock induces a passive suction downstream of the shock, which tends to close down the separation bubble, and an injection of flow upstream of the shock, causing a series of compression waves to form (resulting in more isentropic compression) and the pressure rise to spread over a larger axial distance (which tends to suppress separation)." [Ref. 3]

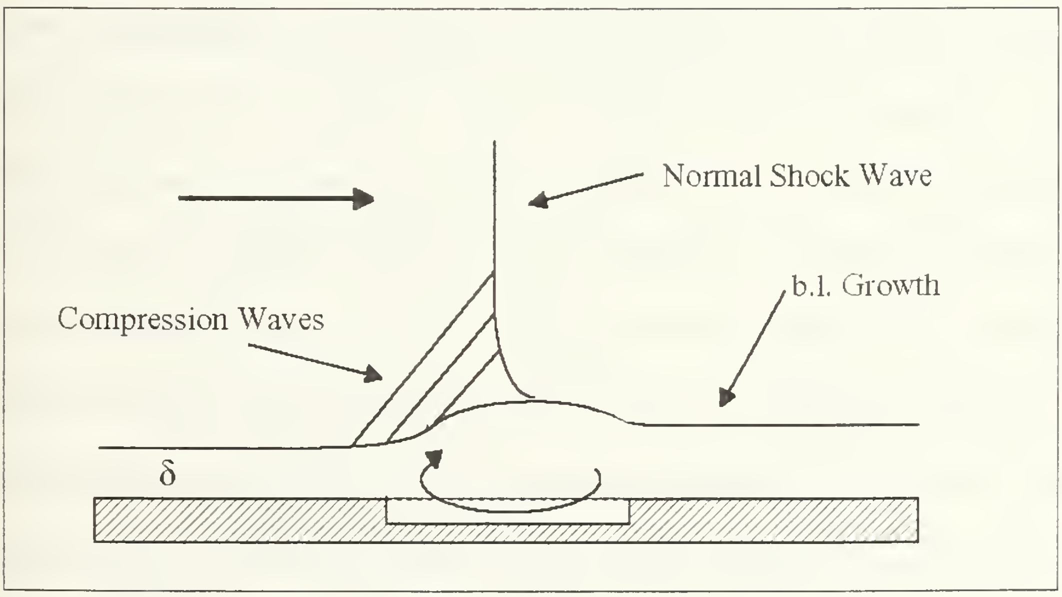



**Figure 4.** Passive Cavity Operation

## C. 2-D FAN PASSAGE SIMULATION

The effects of various flow control devices, including vortex generators, on the shock-boundary layer interaction have been examined by McCormick [Refs. 3, 7] in a round tube geometry. In the present work, it is planned to examine the most promising configurations shown in McCormick's results in a model simulation of the flow in a fan passage. The present work is an extension of studies performed by Golden [Ref. 8] and Collins [Ref. 9]. The wind tunnel used in the present work was designed by Demo [Ref. 10] and first used for blading studies by Hegland [Ref. 11]. The data acquisition system designed by Wendland [Ref. 12] was adapted and implemented in the course of the present study.

The geometry of the model was intended to generate a 2-D simulation of the relative flow on a stream surface through an advanced fan rotor at approximately 63% of the span. The geometry of the model is shown in Figure 5. The blade profile was approximated very closely as a wedge arc for ease of manufacture, and since streamline contraction could not be simulated in the experiment. Measurements made by Golden showed the flow through the model passage to be acceptably two dimensional [Ref. 8].

In the current study, an impact pressure probe and vertical traverse were designed and manufactured, and the "Zero Operate and Calibrate" (ZOC) Data Acquisition System (DAS) developed by Wendland [Ref. 12] was adapted to acquire data from probe surveys and multiple scans of static pressure ports in order to establish a baseline performance of the unmodified blade. This system was then implemented on the wind tunnel. With the

Blade Geometry

| | |
|---|---|
| L.E. Radius | = 0.015 in |
| T.E. Radius | = 0.015 in |
| Wedge Angle | = 3.5° |
| Wedge Length | = 2.85 in |
| Suction Surface Arc Radius | = 13.53 in |

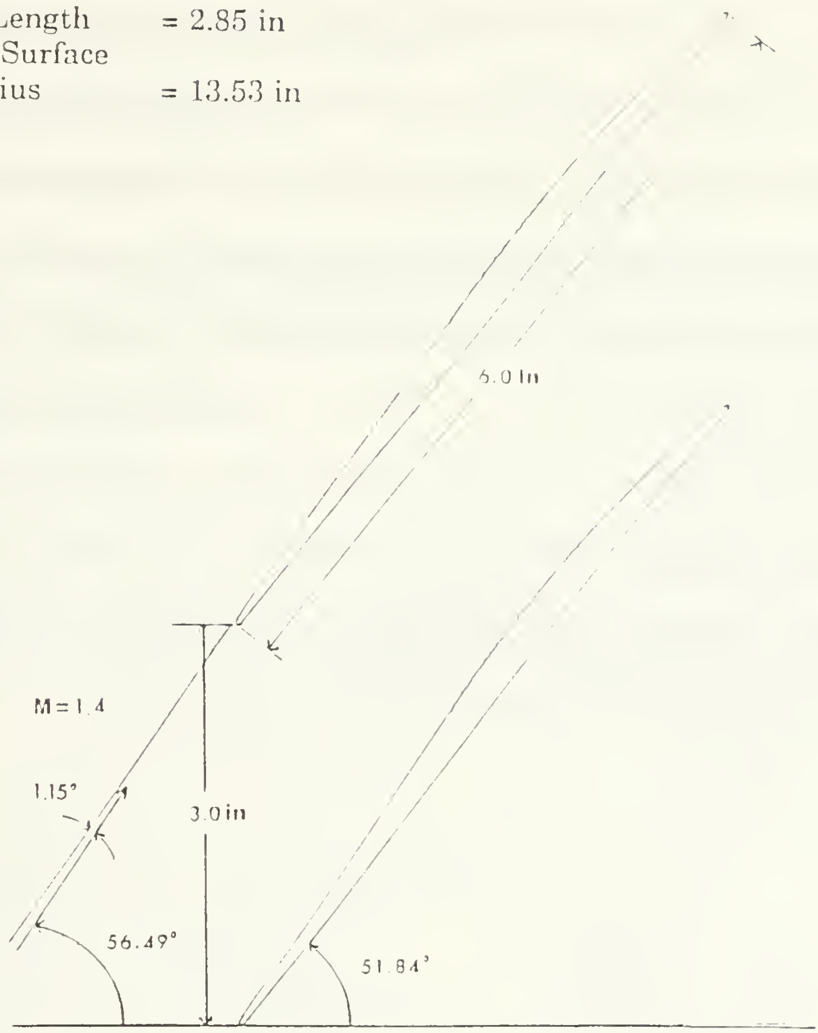



**Figure 5.** Transonic Cascade Blade Geometry

model at design incidence, surface pressure distributions and impact pressure distributions impact pressure distributions behind the lower and middle blade were measured. Cascade losses were obtained by integrating the probe measurements. When it was discovered that similar shock locations in the two passages could be obtained by rotating the model to a decreased flow incidence, static and impact pressure profiles were obtained at this condition. The measured behavior was analyzed and comparisons were made with computational simulations and one engineering loss model.

In the present report, the wind tunnel and model simulation, the probe design and DAS modification are described in Chapter II. In Chapter III, the experimental program and results are presented. A computational simulation of the blade geometry is presented in Chapter IV and in Chapter V, the experimental and numerical results are compared. Chapter VI provides conclusions based on the progress of the current study and recommendations for future work.

# II. EXPERIMENTAL SIMULATION

## A. TRANSONIC CASCADE WIND TUNNEL

### 1. Wind Tunnel Description

The wind tunnel used was a blow-down apparatus located in the Gas Dynamics Laboratory (Bldg. 216) at the Naval Postgraduate School. A schematic of the facility is shown in Figure 6. A schematic of the wind tunnel and a photograph of the tunnel are shown in Figures 7 and 8, respectively.

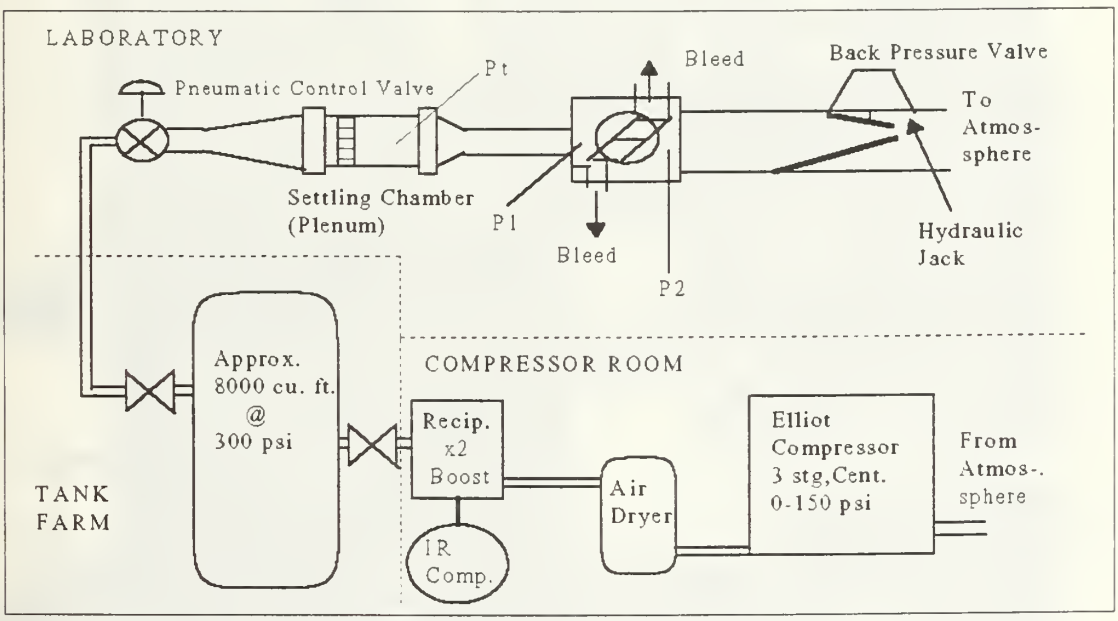



**Figure 6.** Wind Tunnel Laboratory Schematic

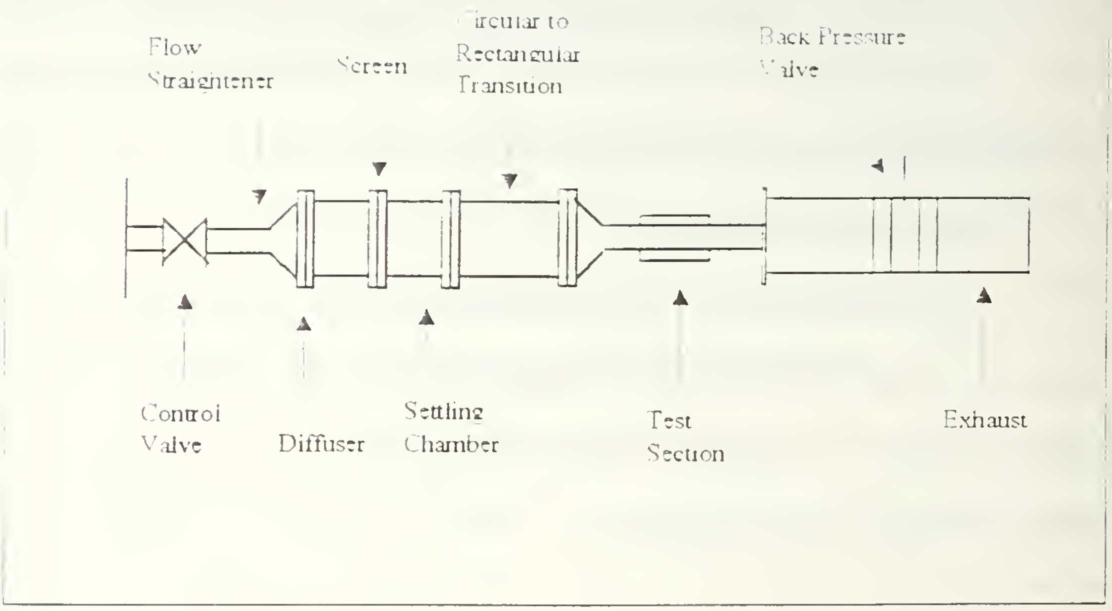



**Figure 7.** Schematic of the Transonic Wind Tunnel

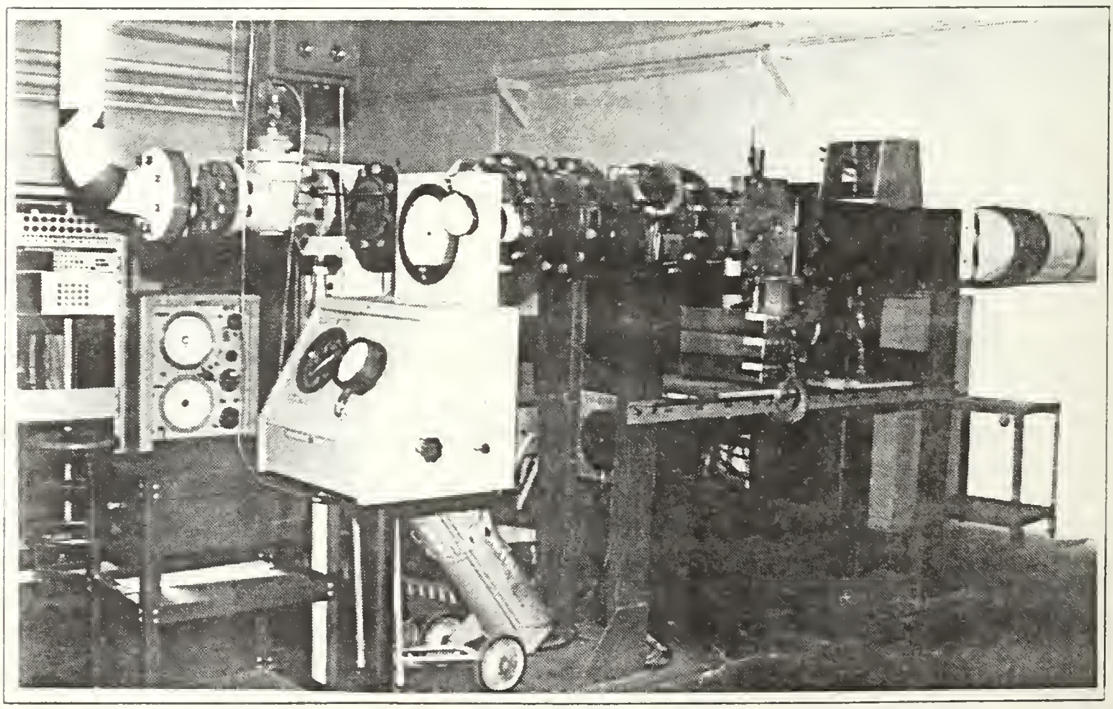


**Figure 8.** Transonic Wind Tunnel

The wind tunnel inlet pressure was maintained by a pneumatically operated control valve. The test section back pressure required to simulate fan pressure ratios was adjusted using a hand-operated hydraulic flap valve mounted aft of the test section. The valve is shown in Figure 9. A convergent-divergent nozzle provided a Mach 1.4 flow to the test section inlet. A test section schematic and photograph are shown in Figures 10 and 11 respectively. Boundary layer scoops were provided on the upper and lower as

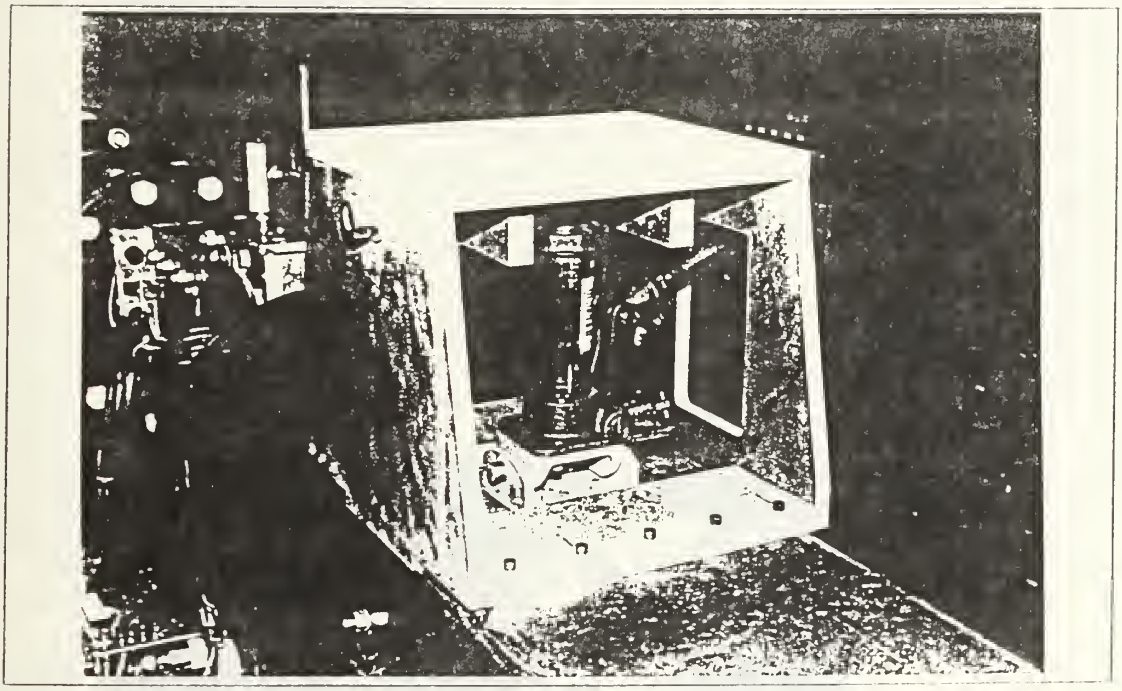


**Figure 9.** Back Pressure Valve

well as right and left sides of the test section in order to divert the boundary layers from the model. The test section modeled two fan passages, between three fan blades. The middle blade in the model was the only complete blade, while the upper and lower sections were half blades, modeling only lower and upper surfaces respectively. The incidence of the model could be varied. The blade upper surface was inclined 1.15

degrees to the freestream flow at the design condition, while the blade wedge angle was 3.5 degrees. Further details of the wind tunnel can be found in Ref. 9. Details of the back pressure valve design are contained in Ref. 8.

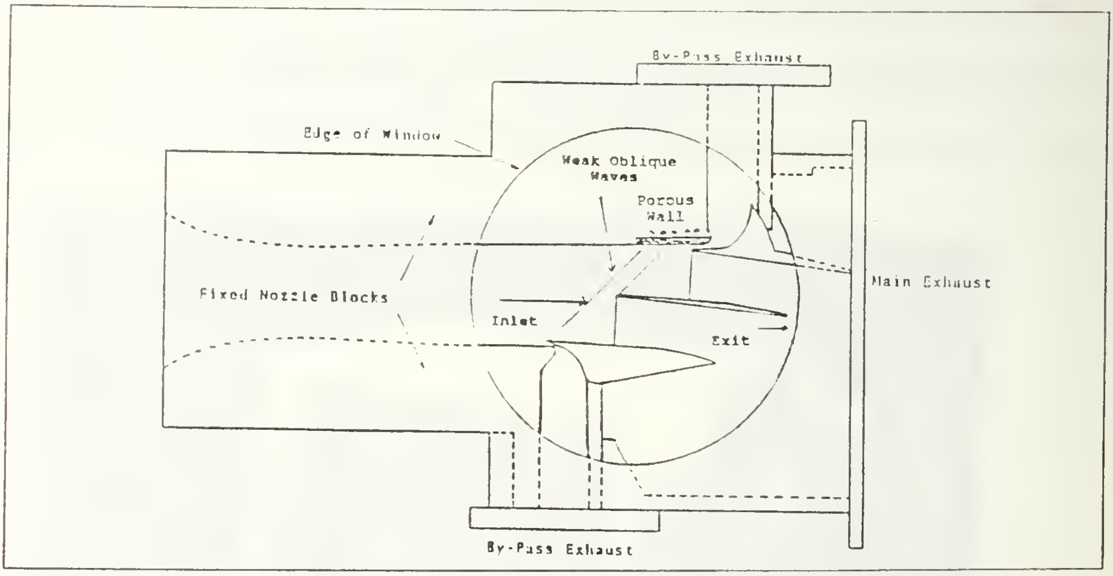



**Figure 10.** Test Section Schematic

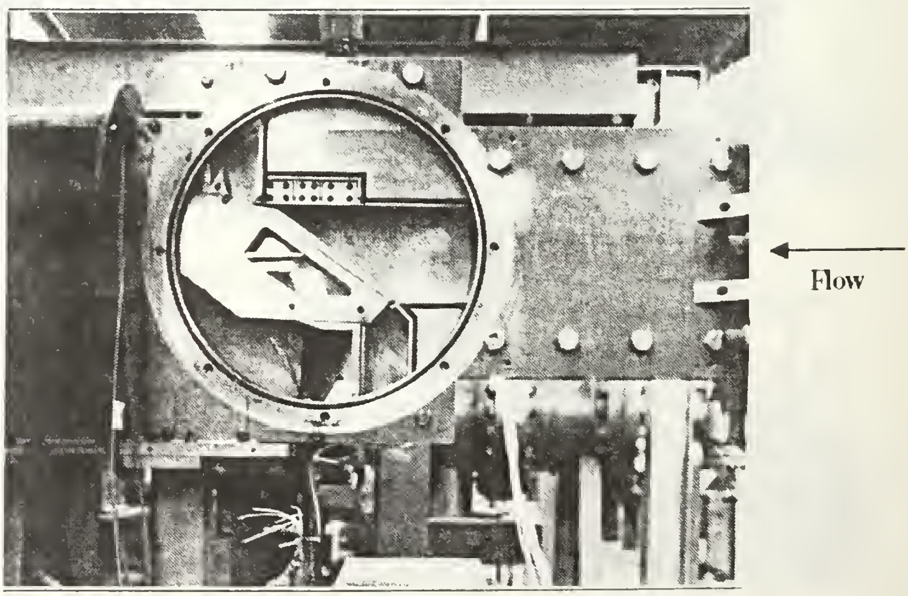



**Figure 11.** Test Section

## 2. Optical system

The optical system provided both schlieren and shadowgraph capabilities. A diagram of the arrangement used is shown in Figure 12. A continuous or spark light source was available from a combination unit. A parabolic lense collimated the light, directing it through the test section and into a parabolic mirror where the beam was reflected into the camera. Shadowgraph photos were made during selected tunnel runs to record the shock position and shock structure.

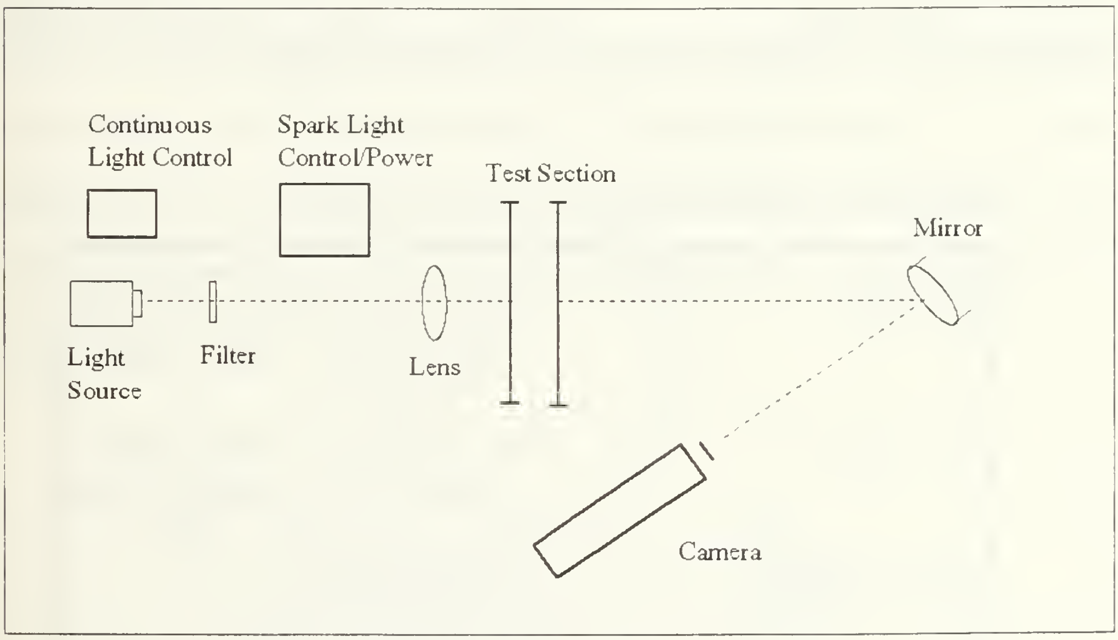



**Figure 12.** Optical System

## B. TEST SECTION INSTRUMENTATION

### 1. Static Pressure Taps

Pressure taps were provide on side plates, window blanks and the lower blade as described by Golden [Ref. 8]. Two side plate pressure taps were used to measure the inlet and exit static pressures. The lower blade centerline pressure taps were used to measure the static pressures across the shock-boundary layer interaction region as well as to measure possible flow field disturbance caused by probe surveys. Aluminum window replacement blanks were instrumented in a fashion that would provide similar information to that of the lower blade. Table I summarizes the pressure tap locations. Drawings of the instrumented components are given in Appendix A.

**TABLE I.** STATIC PRESSURE TAP LOCATIONS

| **Section** | **Ports** | **Location** | **Purpose** |
|---|---|---|---|
| Side Plates | 2 | Upstream/down-stream of test section | Measure cascade pressure ratio |
| Lower Blade | 25 | Centerline of blade surface | Measure static pressure through shock |
| Window Blanks | 8 | Close to blade surface | " |
| Plenum | 1 | Plenum, aft of screen | Provide tunnel Reference pressure |

### 2. Impact Probe and Vertical Traverse

A probe was designed and mounted in a vertical traverse for conducting pressure surveys downstream of the cascade model. The probe was an impact tube with 0.02 inch internal diameter and a 0.032 inch external diameter. It was mounted in a probe holder designed to cause minimum disturbance to the flow. The probe and holder are shown in Figures 13 and 14. The probe holder was mounted on a solid shaft that passed out of the test section through a bearing surface and connected to a mounting block. This mounting block was then bolted to the mounting block of a VELMEX UNISLIDE Motor Driven Assembly. The entire assembly is shown Figure 15. The assembly consisted of a hardened aluminum dovetail base with an aluminum sliding element fitted with bonded bearing pads. A high precision lead screw converted rotational motion to linear motion for up to 6.6 inches of travel. Further details are given in Reference 13. Drawings for the probe and UNISLIDE assembly are contained in Appendix B.

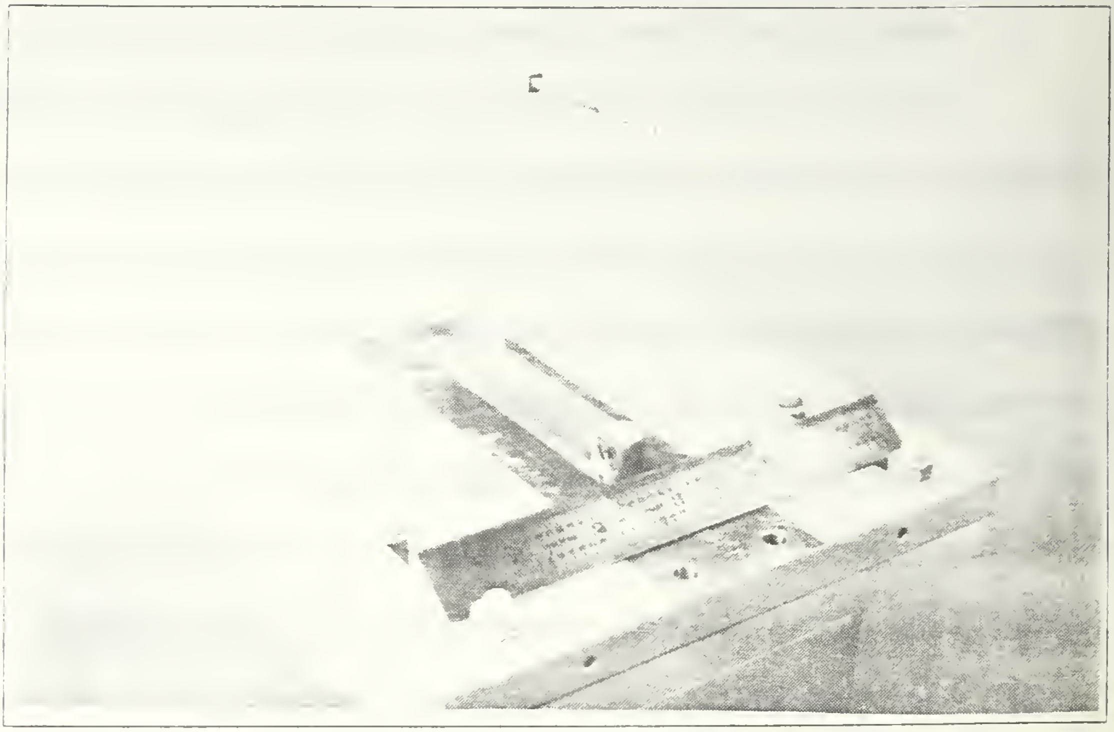


**Figure 13.** Impact Probe and Probe Holder

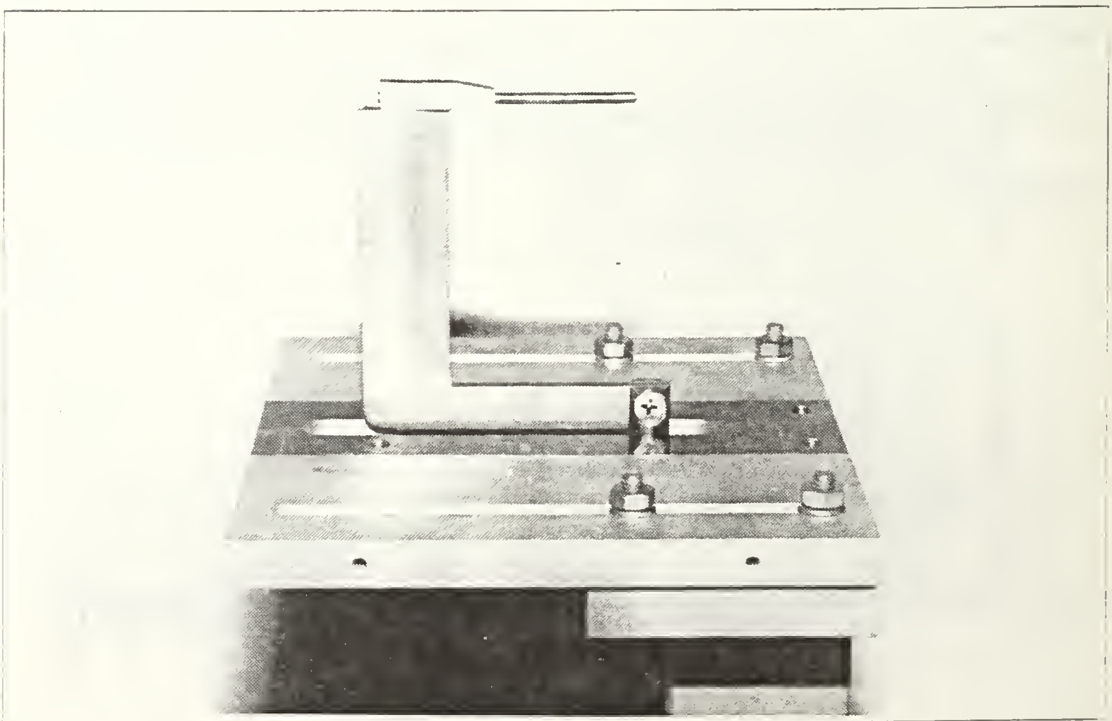


**Figure 14.** Impact Probe and Probe Holder

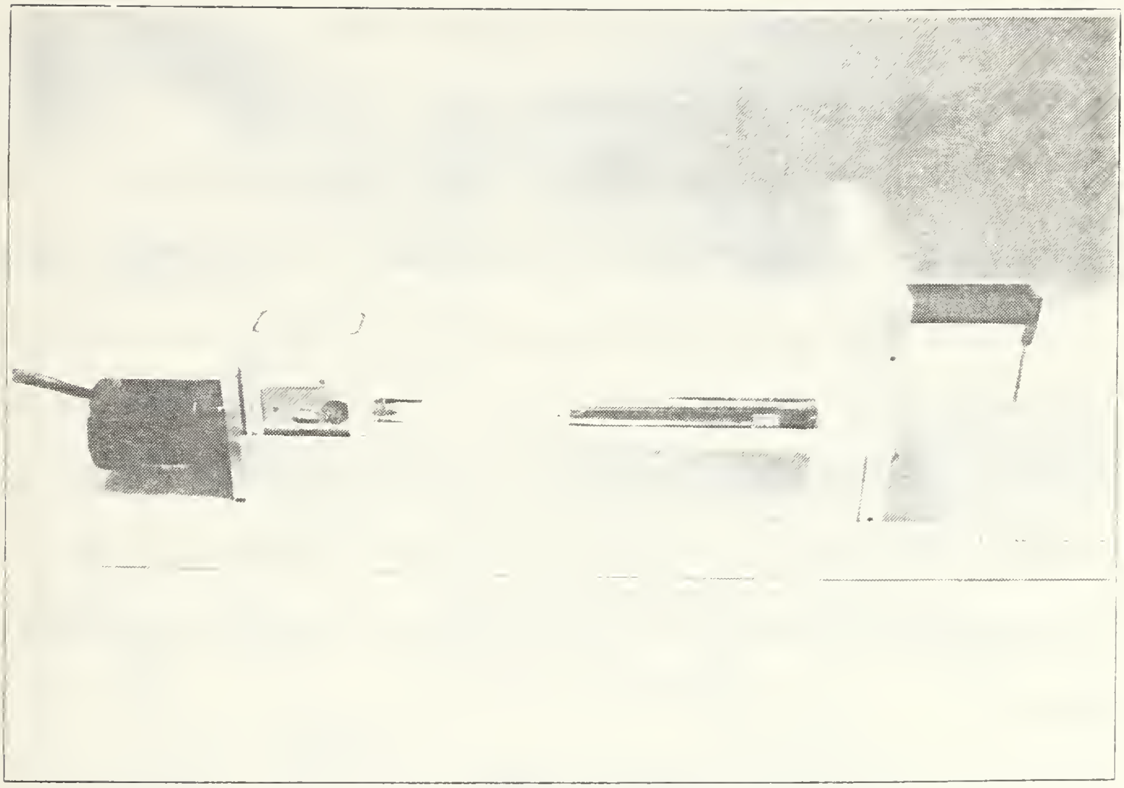


**Figure 15.** Probe Traverse Assembly

## C. DATA ACQUISITION AND ANALYSIS SYSTEM

### 1. Pressure Measurement System

The pressure measurement system consisted of three main elements; namely the "Zero Operate and Calibrate" (ZOC-14) Data Acquisition System (DAS) for recording pressure data, a continuous pressure monitoring system for setting pressure ratio prior to data taking and the VELMEX NF90 Stepper Motor Controller which operated the UNISLIDE Motor Driven Assembly to provide probe surveys behind the test section blading. A schematic of the pressure measurement system is shown in Figure 16. The present application of this system was an extension of the work done by Wendland [Ref. 12].

#### *a. ZOC-14 Data Acquisition System*

The Zero Operate and Calibrate (ZOC) Data Acquisition System (DAS) consisted of the HP9000 Series 300 Desk Top Computer System, three Scanivalve ZOC-14 Electronic Scanning Modules, the CALSYS2000 calibration standard and the HP6944A Multiprogrammer. The HP 9000 Series 300 Desktop Computer acted as the master controller for the system as well as a data storage and processing tool. Extensive documentation provided with this language is described further in Reference 12. The HP9000 is equipped with 10 mega-bytes of Random Access Memory and a 40 mega-byte hard drive as well as a 1.44 mega-byte floppy drive. HP Basic version 5.13 software was used. A comprehensive guide to the system is given in Reference 12.

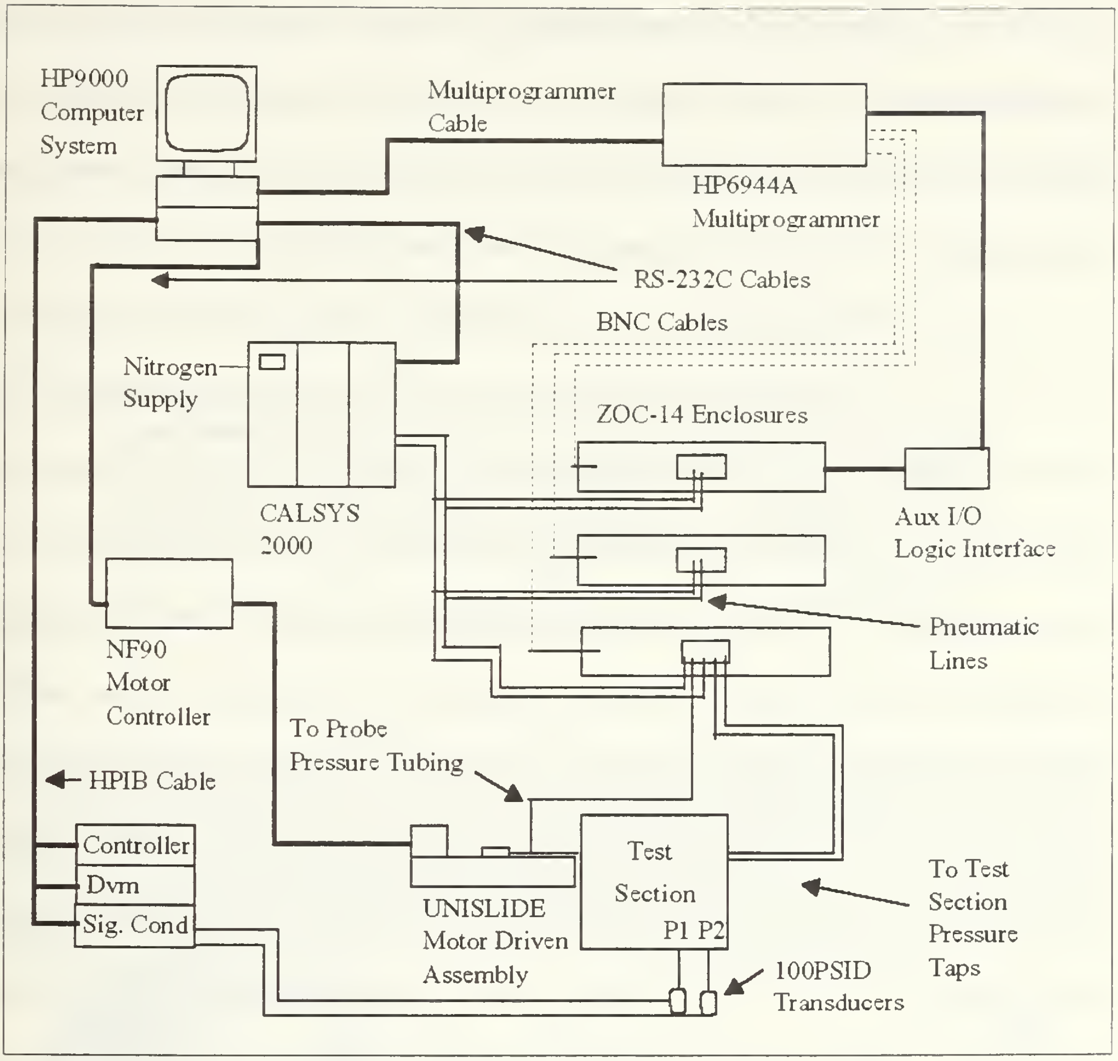



**Figure 16.** Data Acquisition System Schematic

#### *b. Pressure Monitoring System*

The Pressure Monitoring System allowed the tunnel operator to set the pressure ratio across the cascade prior to recording data by providing a continuous display of the test section inlet (P1) pressure, exit pressure (P2) and exit to inlet pressure ratio (P2/P1) to the screen of the HP9000. This was implemented using two 100 PSID transducers, multi-port signal conditioner, a Digital Voltmeter (HP3455A), Data Acquisition/Control Unit (HP3497A) and the HP9000 Series 300 Computer. The HP9000 provided program control for the controller and the voltmeter. Details on the programming of these devices are contained in Reference 14 and 15.

*c. NF90 Stepping Motor Controller/Unislide Motor Driven Assembly*

The VELMEX Stepping Motor Controller and the UNISLIDE Motor Driven Assembly provided a fully programmable and highly precise traverse mechanism. The NF90 Stepper Motor Controller could operate in a "stand alone" mode or an "interactive mode". A three wire serial RS-232C port allowed the host controller to enter commands and data, poll for status and read position information. It was capable of operating up to three stepper motors as well as being daisy-chained with multiple NF90's. It had a 400 step (0.9 degree) resolution, which equated to a 0.025 inch linear resolution for the lead screw that was used. Other features of interest in the present study were its programmable baud rate, speed control, poll for status, and return to zero position commands. Further details concerning the NF90 Stepping Motor Controller are contained in Reference 16. Though provided with IBM compatible controller software it was fully compatible with the HP9000 equipped with an RS-232C port. The serial port used was separate from the port used for the CALSYS2000 and was made available by installing the Asynchronous Serial Interface (HP98644A) expansion card into the HP9000 [Ref. 17].

The UNISLIDE Motor Drive Assembly was model number MB2509P40J with a Bodine #2010 (2410) Drive Motor. A precision roll-formed lead screw held by preloaded ball bearings drove a low friction, adjustable anti-backlash nut. The lead screw provided in the model P40J allowed capabilities outlined in Table II. Installation and maintenance instructions for the VELMEX UNISLIDE are contained in Reference 13. The NF90 and UNISLIDE are shown in Figure 17.

**Table II.** UNISLIDE LEAD SCREW PARAMETERS

| UNISLIDE Lead Screw | Advance/ Revolution | Advance/ Step | Speed at 1000 Steps/Second |
|---|---|---|---|
| P40.C | 0.025 inches | 0.0000625 inches | 0.0625 inches/second |

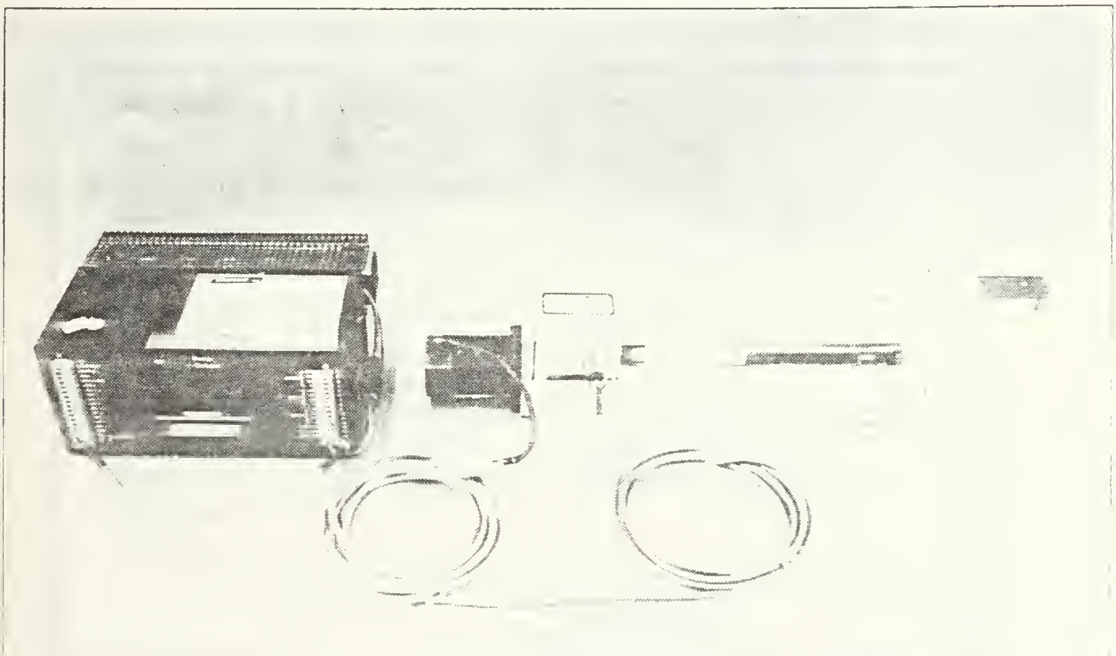


**Figure 17.** NF90 and VELMEX UNISLIDE

## 2. Data Acquisition and Analysis Programs

### *a. The Data Acquisition Program "SCAN_ZOC_06"*

Program "SCAN_ZOC_06" was developed to provide the data acquisition options shown in Table III. The program was an adaptation and extension of the "SCAN_ZOC_05" program developed by Wendland [Ref. 12]. The extensions involved adding commands to provide continuous monitoring of the cascade pressure ratio prior to acquiring data with the ZOC system and commands to control the probe traverse. The development and description of the new software, program listing and operating manual are given in Appendix C.

**Table III.** SCAN TYPES AVAILABLE

| Scan Type | Purpose | Options | Comments |
|---|---|---|---|
| 0 | Single Scan of all ZOC's | Number of Samples up to 1021 | Original SCAN_ZOC_05 operation |
| 1 | Multiple Scans of all ZOC's | Number of Samples Avail. based on 1021/#Scans | Allows multiple Successive Observations |
| 2 | Probe Survey of Lower Blade | Scans = 33 Samples =10 | Parameters "hard wired" to avoid probe damage |
| 3 | Probe Survey of Middle Blade | " | " |

#### *b. The "READ_ZOC2" Data Reduction Program*

The "READ_ZOC2" program was an adaptation of the "READ_ZOC" utility program given in Reference 12. The previous version was developed to examine ZOC data to verify the ZOC-14 DAS performance. The current version was specifically developed to analyze data taken from the Transonic Cascade Wind Tunnel. "READ_ZOC2" converted the acquired ZOC voltage data to pressures in psia. It provided a print out of data indexed to each port and scan taken, saved pressure data to an ASCII file, plotted surface pressures normalized by inlet total pressure versus percent of chord, plotted displacement versus probe survey pressure and calculated the mass averaged loss coefficient. This program is listed in Appendix D. Output from this program is shown in Appendix E and referred to in Chapter III.

# III. EXPERIMENTAL PROGRAM AND RESULTS

## A. EXPERIMENTAL PROGRAM

The program of tests is summarized in Table VI. After initial tests to verify the probe and traverse mechanism, and data acquisition and control program operation, probe and surface pressure measurements were acquired with the model at design incidence and with incidence increased by 2 degrees. The latter condition was found to give similar shock patterns in the upper and lower passages at the design pressure ratio. Useful test data are given in Appendix E.

### 1. Initial Tests

Eleven preliminary tests were conducted with the model set at the design incidence. The shadowgraph system was adjusted optimally and experience was gained in operating the back pressure control valve to position the passage shocks in the model. Data acquisition procedures using the ZOC-14 DAS were exercised and verified by comparing with measurements reported in Reference 8. Also, multiple scans of blade surface taps revealed less than 1% uncertainty (see Figure E1, page 124). When shocks were positioned and data were taken, the pressure ratio across the blading was approximately two. The probe and traverse proved to be very rigid and no noticeable vibrations could be sensed external to the test section. The traverse was programmed to step 32 times and a probe measurement was recorded at each stop. At each stop, during a pause of one second, all 32 ZOC pressure ports were scanned ten times. One minute and

13 seconds were required to complete the traverse. Surveys were conducted at the exit of the lower passage while using the instrumented lower blade to provide surface static pressures across the passage normal shock. This shock was placed at the "design" location using a pressure ratio of approximately 2.04. Observation and measured data revealed that no significant disturbances or additional unsteadiness of the shock structure was present during probe surveys. Four such surveys were completed and a representative data set, together with a sample data reduction, is given in Appendix E.

### 2. Probe Surveys at Design Incidence (1.15 degrees)

Seven tunnel runs were conducted to survey across a full passage centered on the middle blade. The cascade was operated at a pressure ratio of approximately 2.14, at which the upper passage normal shock was located at the "design" location and the lower passage shock was slightly ahead of this location. The two shocks were within ten percent of chord of the same axial location on the blade suction surface. A typical data set is given in Appendix E. These and all subsequent surveys were taken at one inch downstream of the blade trailing edge.

### 3. Probe Surveys at -0.85 Degree Incidence

Five tunnel runs were conducted to examine various off-design incidence angles. The cascade model was rotated such that the incidence to the suction surface was varied by plus or minus 2 degrees. The setting which resulted in a suction surface incidence of -0.85 degrees caused the upper and lower passage normal shocks to move into approximately the same position within the passage at the same pressure ratio. Rotation in the opposite direction (increased incidence) had the opposite effect. Two complete center blade surveys were conducted at -0.85 degrees incidence to examine the changes in the losses as well as in the blade surface pressure distributions. A set of survey data is given in Appendix E together with sidewall pressure measurements. Shadowgraph photographs of the flow at -0.85 degrees using continuous and spark light sources are shown in Figures 18 and 19 respectively.

**TABLE IV.** EXPERIMENTAL PROGRAM

| Date | Runs | Measured | Purpose | Appendix E pages |
|---|---|---|---|---|
| 4 Nov 92 | 1-4 | Plenum, P2/P1, Blade Surface Static | DAS Testing | |
| 6 Nov 92 | 1-7 | Plenum, P2/P1, Blade Surface Static | DAS Testing | |
| 16 Nov 92 | 1-4 | Plenum, Impact P2/P1,Blade Surface Static | DAS/Probe tests and Preliminary Data | 1-7 (Run 3) |
| 19 Nov 92 | 1-5 | Plenum, Impact P2/P1,Blade Surface Static | Center Blade Survey at Design $i_{ss}$ | 8-14 (Run 4) |
| 25 Nov 92 | 1-5 | P2/P1,Blade Static | Vary $i_{ss}$ | |
| 1 Dec 92 | 1-2 | Plenum, Impact P2/P1,Blade Surface Static, Plenum Temperature | Survey Center Blade at Off-Design $i_{ss} = -0.85$ deg | 15-21 (Run 2) |
| 7 Dec 92 | 1-3 | Plenum, Impact P2/P1,Blade Surface and Side-wall Static, Plenum Temperature | Survey Center Blade at Off-Design $i_{ss} = -0.85$ deg | 22-29 (Run 1) |

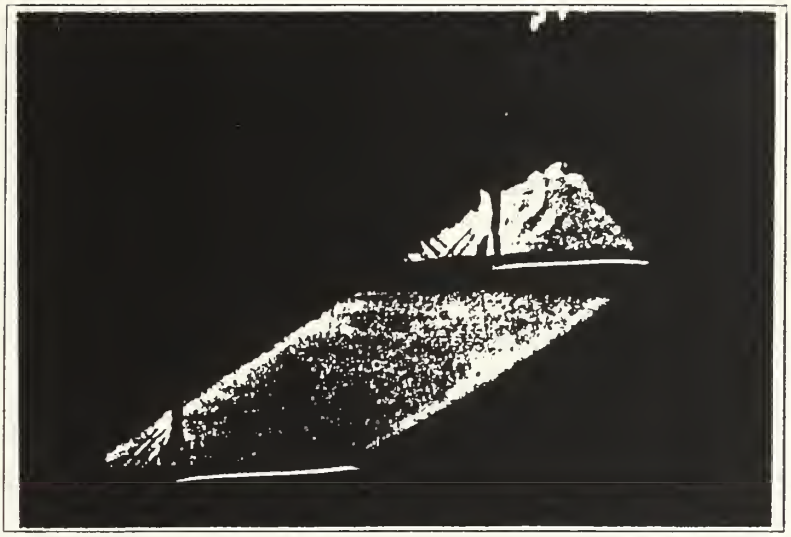


**Figure 18.** Continuous Light Shadowgraph

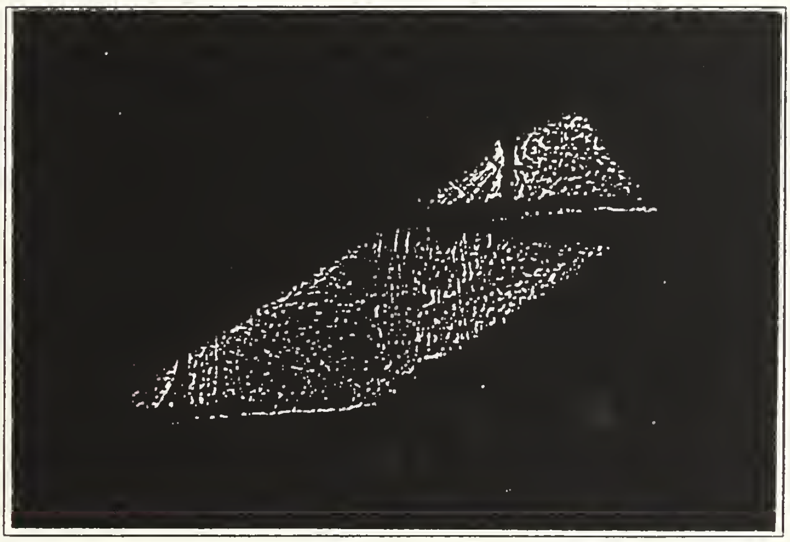


**Figure 19.** Spark Light Shadowgraph

## B. EXPERIMENTAL RESULTS

### 1. Measurements at Design Incidence

The suction surface pressure distribution at a pressure ratio of 2.04, normalized by inlet total pressure, is shown in Figure 20. A very gradual expansion is seen as the flow approaches the shock-interaction region. The interaction is centered at approximately 40% chord and steady diffusion continues toward the trailing edge of the blade. It is significant to note that pressure ratios used to place shocks in the upper and lower passage (2.04 and 2.14 respectively) at design incidence did not change with the installation of the probe and the suction surface static pressure distribution was unaffected by the probe movement. At design incidence, shocks could not be positioned in the same location on the blade suction surface in the two passages. The upper passage normal shock was positioned in the design location (approximately 40% chord) at a pressure ratio of 2.14. The lower passage shock was then centered at 30% chord as determined by the surface pressure measurements. The lower blade surface pressure distribution at a pressure ratio of 2.14 is shown in Figure 21.

The loss distribution resulting from the probe survey conducted downstream of the center blade at a pressure ratio of 2.14 is shown in Figure 22 Exit static and plenum pressures during the probe survey are shown (dashed lines) with the impact pressure measurements against displacement. The shock losses experienced in the upper passage are higher than those experienced in the lower passage. The increased losses may be due to the lower passage normal shock which is now forward of the center blade leading edge. In addition, a slight reduction in loss is present just above the wake region, which

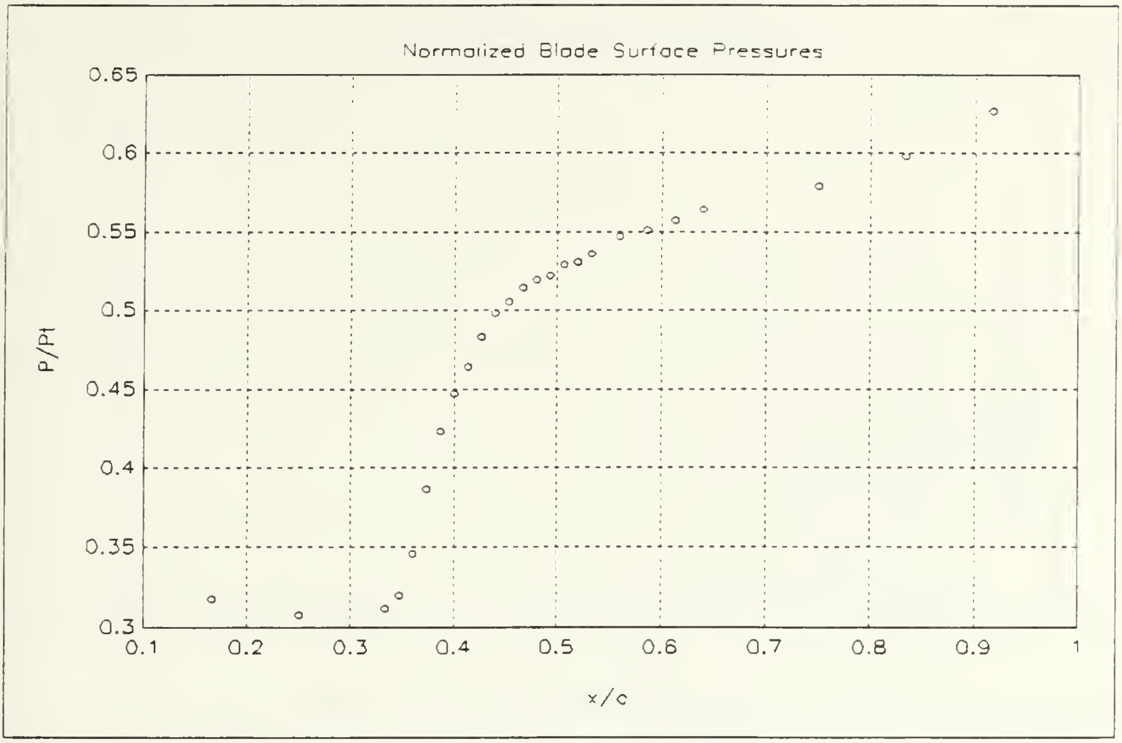



**Figure 20.** Lower Blade Surface Pressure Distribution (P2/P1 = 2.04)

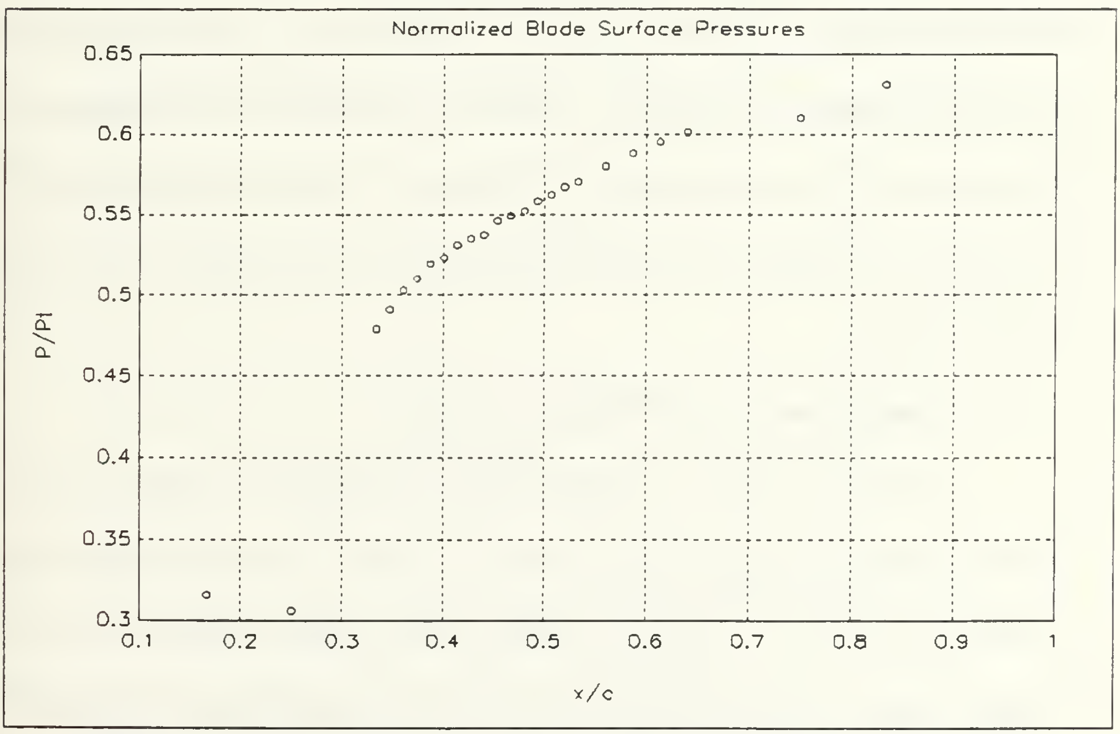



**Figure 21.** Lower Blade Surface Pressure Distribution (P2/P1 = 2.14)

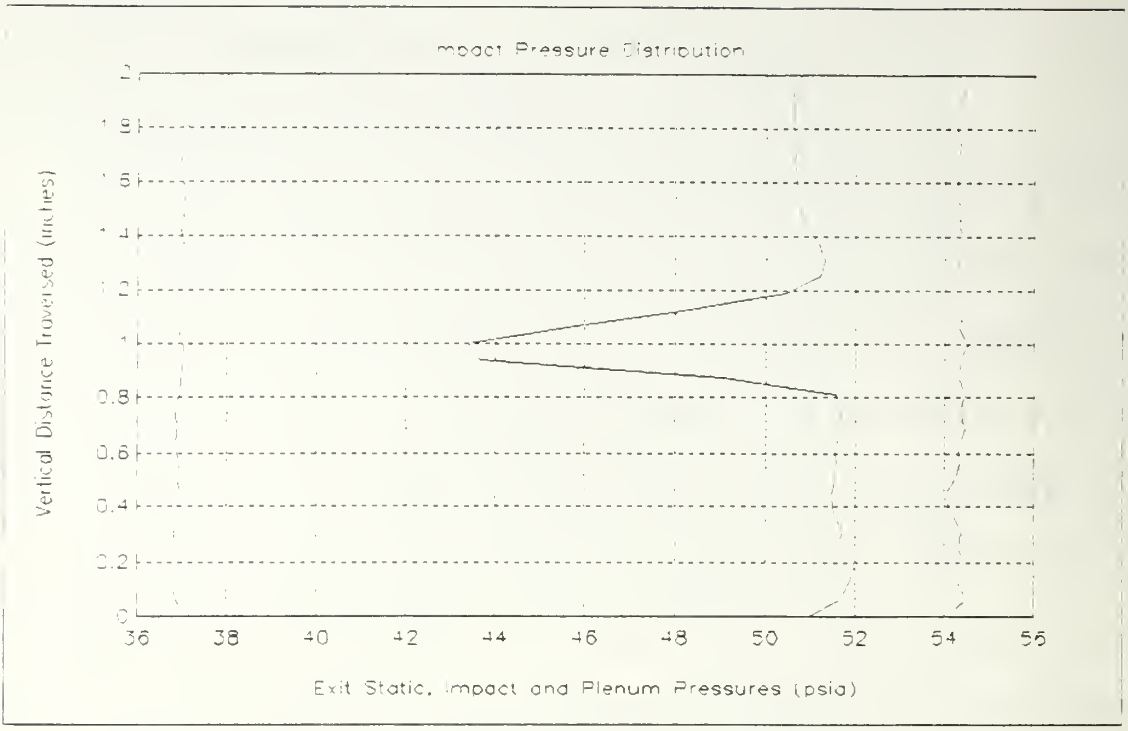



**Figure 22.** Loss Distribution at Design Incidence (1.15 degrees)

may be attributed to the shock-boundary layer interaction. This effect was also present in the lower passage (see Figure E1). The wake is mixed out to some degree as revealed by the level of the test section exit static pressure. The mass averaged loss coefficient, calculated by integration of the distribution across one blade space, was 0.10065 for the design incidence.

### 2. Measurements at -0.85 Degree Incidence

As can be seen by the shadowgraph photographs in Figure 18 and 19, the passage normal shocks were in approximately the same location in the two passages at a pressure ratio of 2.14. The lower blade surface pressure distribution and an upper passage sidewall pressure distribution are shown in Figures 23 and 24 respectively. These

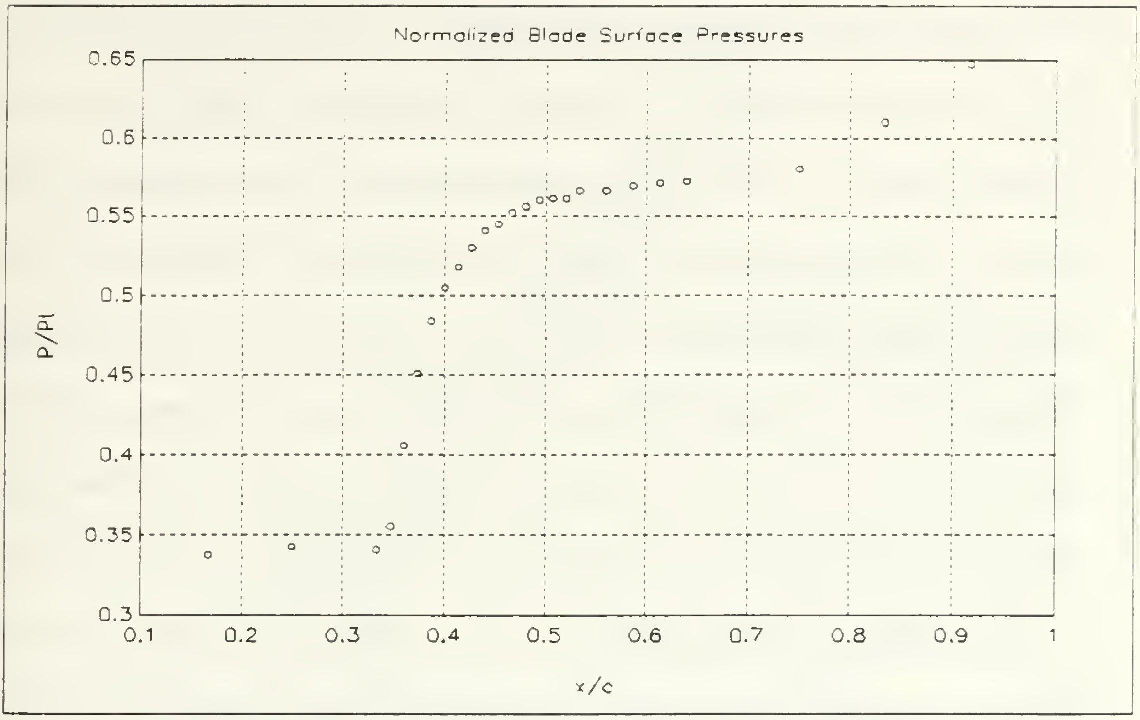



**Figure 23.** Lower Blade Surface Pressure Distribution (-0.85 degrees)

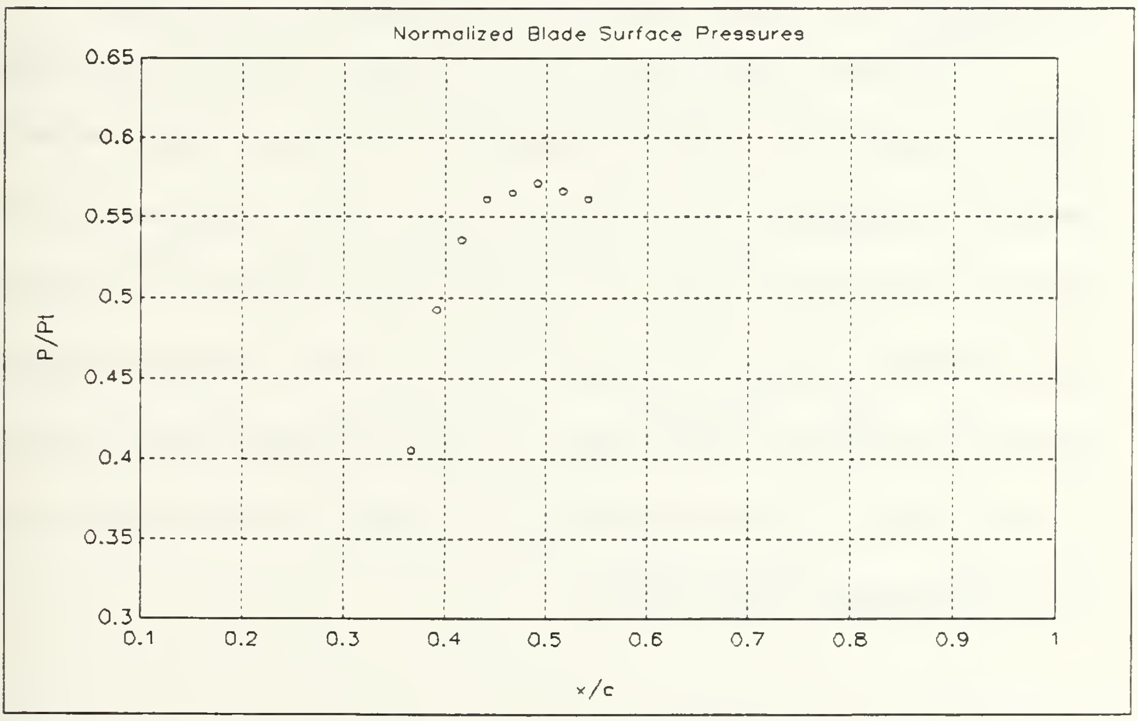



**Figure 24.** Middle Blade Side Plate Pressure Distribution (-0.85 degrees)

data indicate that the shocks differed in position by no more than 2% of chord. The blade surface pressure distributions for the design cases showed a small acceleration prior to the shock interaction region. At the negative incidence, no such expansion is apparent. Also, the level of pressure prior to the shock in this case is 5-10% higher than for the design incidence, suggesting the presence of an oblique shock at the blade leading edge. Though the flow is eventually diffused to the same pressure in both cases, in the reduced incidence case the shock interaction region is reduced in length. The reduced incidence case shows the shock pressure rise occurring over approximately 15% of chord compared to 30% of chord at design incidence. This is consistent with having a lower Mach number at the shock (higher pressure) and a reduced region of separation and associated lambda structure.

The impact pressure survey shown in Figure 25 indicates that the wake was shed at a higher vertical location, as should be the case since the higher incidence was arrived at by rotating the test section. Shock losses for the two passages were closer to the same value and losses were in fact less overall for this incidence. The mass averaged loss coefficient for this case was calculated to be 0.07393. The loss distribution just above the wake (from the lambda interaction on the suction side) appears in Figure 25 to be quite similar to the design incidence case in Figure 22, but the passage shock loss above this interaction is not as uniform.

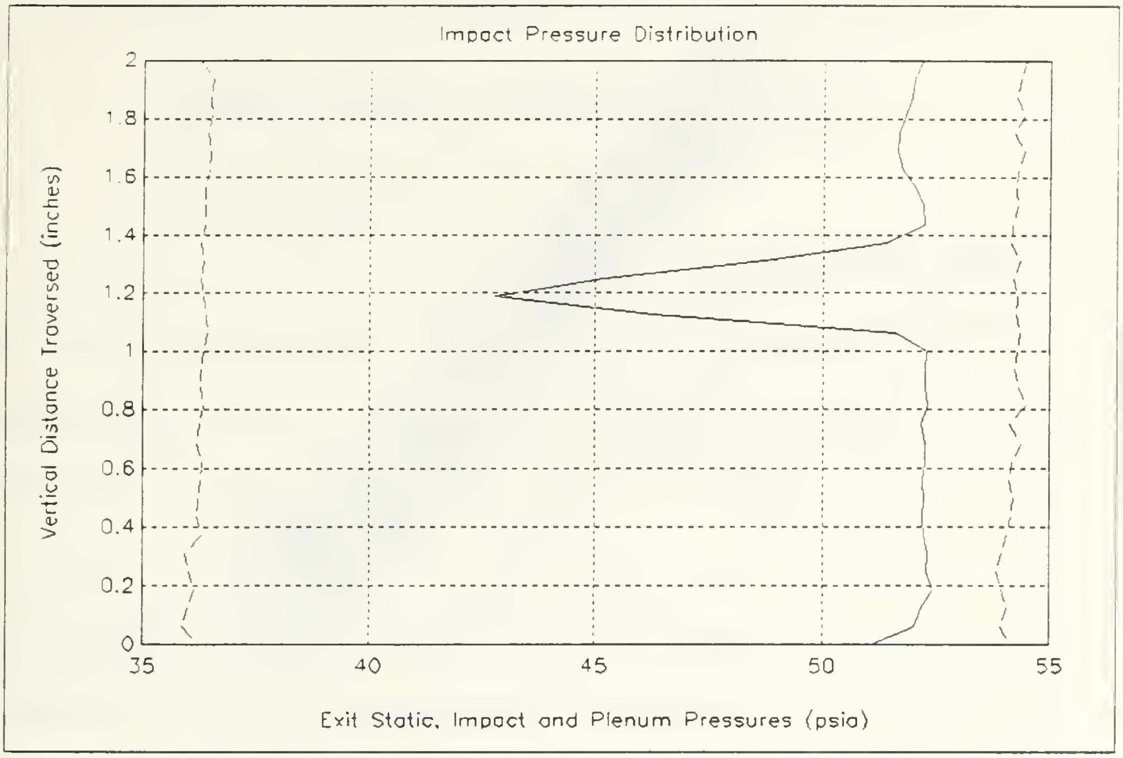



**Figure 25.** Loss Distribution at Off-Design Incidence (-0.85 degrees)

# IV. NUMERICAL SIMULATION

## A. GRID GENERATION

The numerical simulation was carried out on a C-grid generated with the GRAPE grid generation program. GRAPE (GRids about Airfoils using Poisson's Equation) was written by Sorenson [Refs. 18, 19] and revised by Chima [Ref. 20] to accommodate periodic cascades for turbomachinery. A flow solution was obtained on a grid of 250 x 49 points generated by Golden [Ref. 8]. This grid was non-dimensionalized for use in the latest version of the flow solver. The grid is shown in Figures 26 through 28. The existing grid has been optimized for this particular flow regime by adding more points at the leading and trailing edges and a finer grid at the walls to improve resolution of shocks and boundary layers.

## B. COMPUTATIONAL SCHEME

### 1. The Solution Method

The numerical scheme used was RVCQ3D (Rotor Viscous Code Quasi-3D) developed by Roderick Chima at NASA Lewis Research Center in Cleveland, Ohio. RVCQ3D was specifically designed for the analysis of blade to blade flows in turbomachinery [Ref. 21]. The code is an explicit multistage Runge-Kutta scheme which solves either the Euler or Navier-Stokes (thin-layer) equations and features the following:

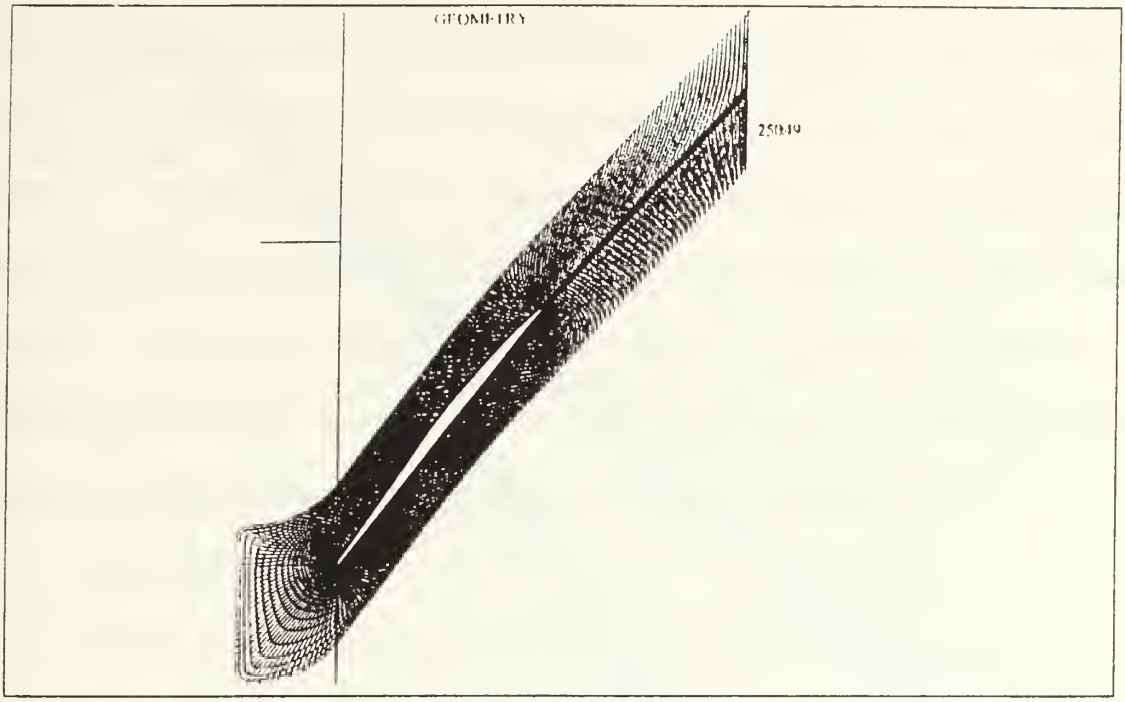



**Figure 26.** Viscous Grid

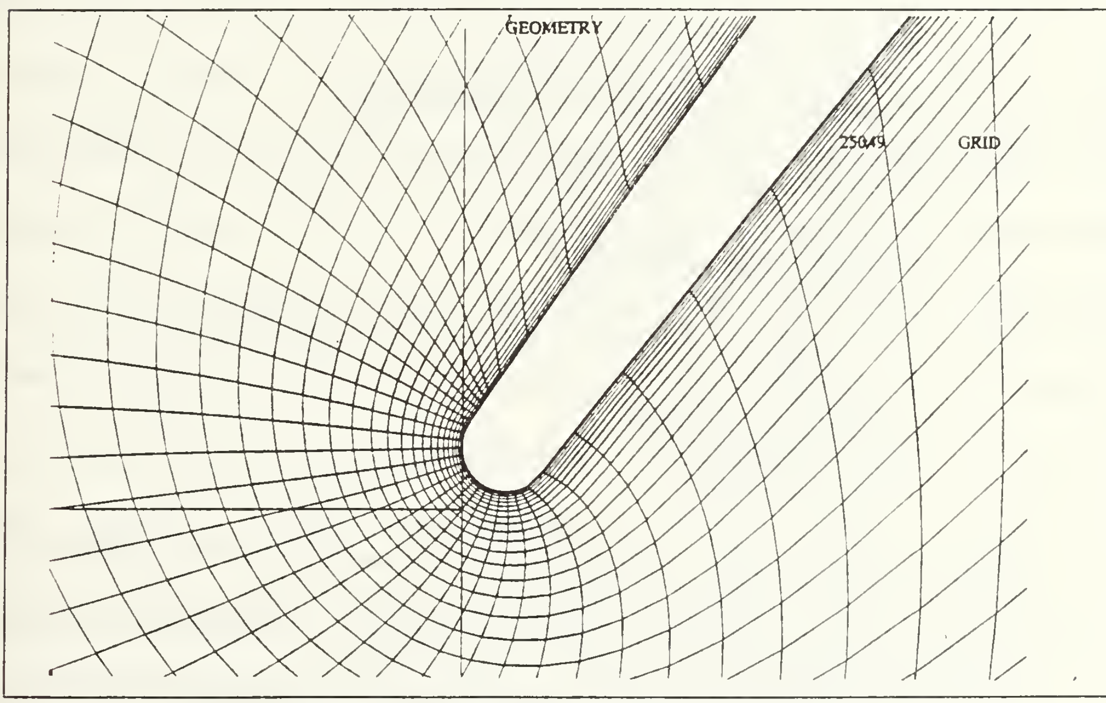



**Figure 27.** Viscous Grid Leading Edge

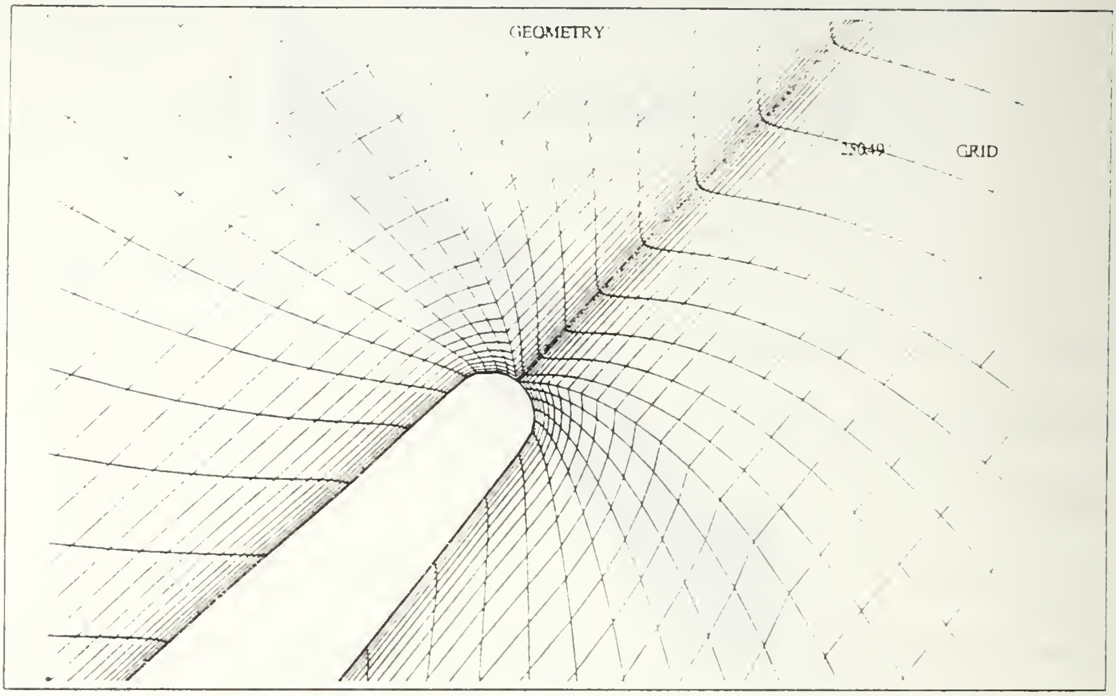



**Figure 28.** Viscous Grid Trailing Edge

- A spatially varying time step
- Second and fourth order artificial viscosity
- Implicit residual smoothing
- An ideal gas assumption
- A Baldwin-Lomax or Cebeci-Smith turbulence model
- Stream tube variation
- Rotation effects

A thin layer approximation is employed such that derivatives in the streamwise direction are dropped while calculating viscous derivatives. The Baldwin-Lomax turbulence model was used in all calculations. The code uses an initial guess and time marches to a steady-state solution. The code is second-order accurate in space due to central differencing and has been used up to a fifth-stage Runge-Kutta format providing fifth-order accuracy in time. All calculations herein were completed using a four-stage scheme. Version 3.7 of the code was used for the most current work. This version allows for almost completely dimensionless inputs and provides a powerful restart capability. This version was updated by Dan Tweedt of NASA Lewis [Ref. 22]. A complete mathematical description of RVCQ3D is contained in Reference 23 and a comparison of this scheme to other multigrid codes is given in Reference 24.

### 2. RVCQ3D Inputs

In the current simulation only 2-D cascade flow effects with no rotation, were modeled. An adiabatic wall temperature boundary condition was imposed. Reynolds number based on chord length and total conditions was input using a total temperature of 520 deg R or 15 deg C. A Courant number of 4.5 was used and allowed convergence in 7000 iterations (5.78 hours on a Silicon Graphics Iris Indigo). Residual smoothing was increased as much as 100% above recommended amounts early in the solution and reduced to the recommended values as the solution converged. A ratio of outlet static pressure to inlet total pressure was required. It was initially set above design to accelerate placement of shocks and reduced to an approximate design value as the solution converged. Further details concerning RVCQ3D inputs are contained in Reference 21. The restart capability now included in RVCQ3D allowed optimization of the quantities previously discussed, which saved time and improved performance. A sample RVCQ3D input file listing and a summary of restart inputs used to obtain the solution is contained in Appendix F.

## C. COMPUTATIONAL SOLUTION

### 1. Summary of Previous Numerical Results

An "unsteady" solution was obtained by Golden [Ref . 8] in 4000 iterations. In this solution the "normal shock merges with the leading edge bow shock on the pressure surface and with the turbulent boundary layer on the suction surface." [Ref. 8] The lambda foot was not predicted, but some increase in boundary layer thickness was present. Boundary layer transition was predicted to be at ten percent chord and the flow incidence angle to the suction surface was predicted to be 2.53 degrees. (design incidence was 1.15 degrees) The results were "unsteady" because the convergence history showed that residuals increased late in the solution process and a steady state solution was not realized.

### 2. Current Numerical Solution

The inputs to the code represented conditions in the test section that gave a Reynolds number of about 8 million, and a nominal back pressure was specified (P2/Pt1 = 0.7). The inlet Mach number was set at 1.4 and the inlet flow angle to the "machine" axis (normal to the leading edge plane) was set for the design incidence case of 56.49 degrees. A constant CFL of 4.5 was used. The shock system was moved to the "on-design" condition by increasing the back pressure to about 0.76 of inlet stagnation pressure. The convergence history in Figure 29 shows a three order of magnitude drop in RMS density residuals in 7000 iterations. Other solution outputs such as incidence angle, Mach number, continuity and energy conservation are summarized below in Table V.

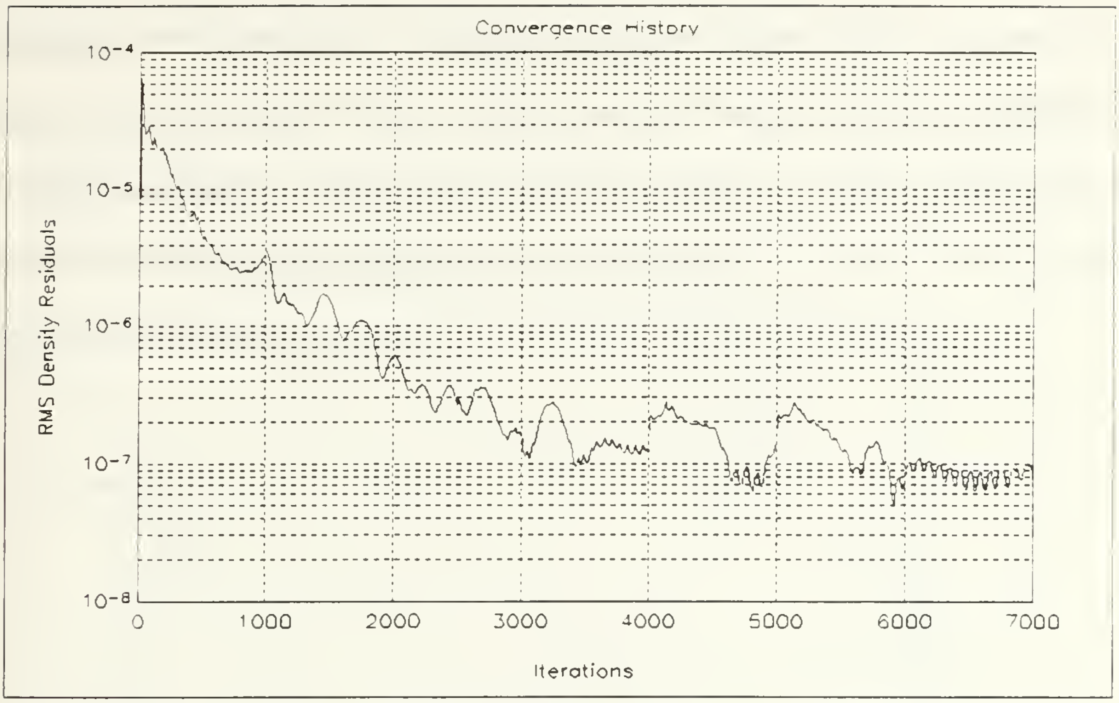



**Figure 29.** RMS Density Residuals

**TABLE V.** SUMMARY OF SOLUTION OUTPUTS

| Quantity | Inlet | Exit | Global | Comments |
|---|---|---|---|---|
| Mach Number | 1.378 | 0.633 | | For M1 guess = 1.4 |
| $\beta$ (deg) | 57.518 | 52.609 | | For $i_{SS}$ = 2.178 |
| Loss Coefficient | | | 0.1123 | Mass Averaged |
| Mass Conservation | | | -0.0011 | 1-Mdot(out)/Mdot(in) |
| Energy Conservation | | | 0.00091 | 1-Ht(out)/Ht(in) |

### 3. Computational Results

#### *a. Suction Surface Pressure Profile*

The static pressure distribution given by RVCQ3D is shown in Figure 30. The current solution predicted the suction surface shock interaction starting at 30% chord extending to 55% chord. The flow expanded very slightly as it approached the interaction region, dipped after the shock induced compression and continued to subsonically diffuse across the remainder of the blade after the interaction region.

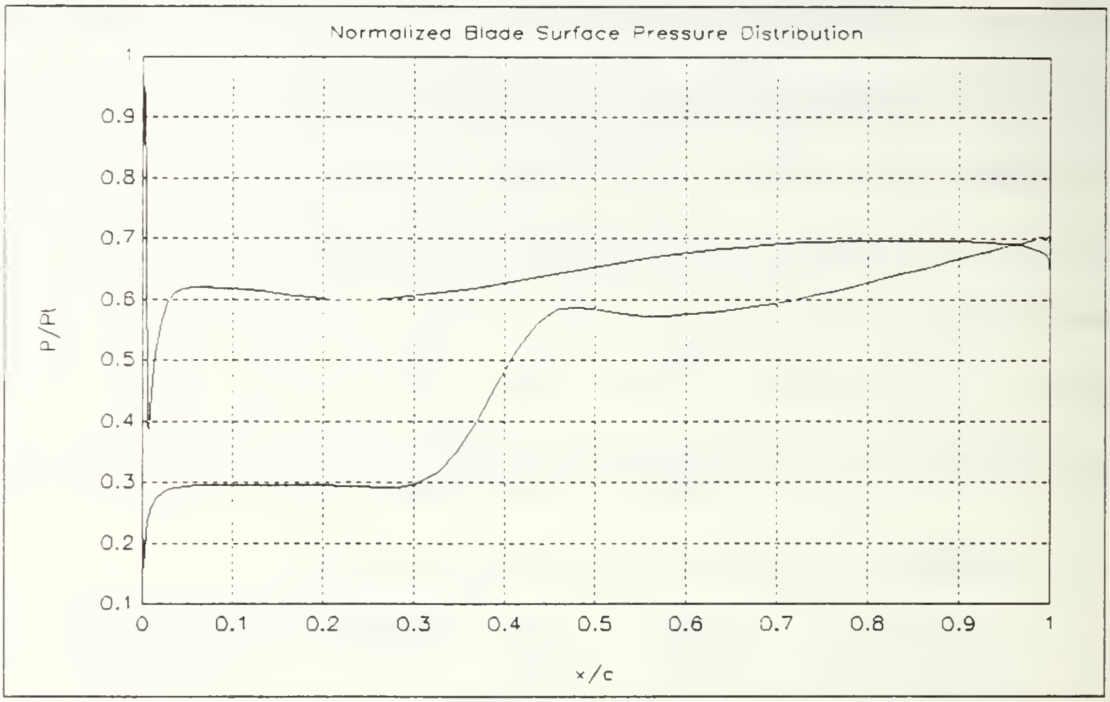



**Figure 30.** Blade Surface Pressure Distribution

### *b. Flow Separation*

Separation was predicted at the leading edge, in the neighborhood of the shock and at the trailing edge. Figure 31 shows the skin friction coefficient distribution and Figure 32 shows the boundary layer in the normal shock region. Transition to turbulent flow was predicted to occur at about 5% chord. Flow detachment was predicted at 38% and reattachment at 45% chord. This separation was associated with the shock-boundary layer interaction. The trailing edge separation was predicted to start at 99% chord and was caused by the adverse pressure gradient caused by further diffusion through the passage. The leading edge separation "bubble" was confined to very few points. Figure 33 shows a particle trace at the location of the shock induced separation. It shows a very flattened separation region which is a function of the turbulent shock-boundary layer interaction, but may also be caused by the inadequate boundary layer resolution afforded by the Baldwin-Lomax turbulence model.

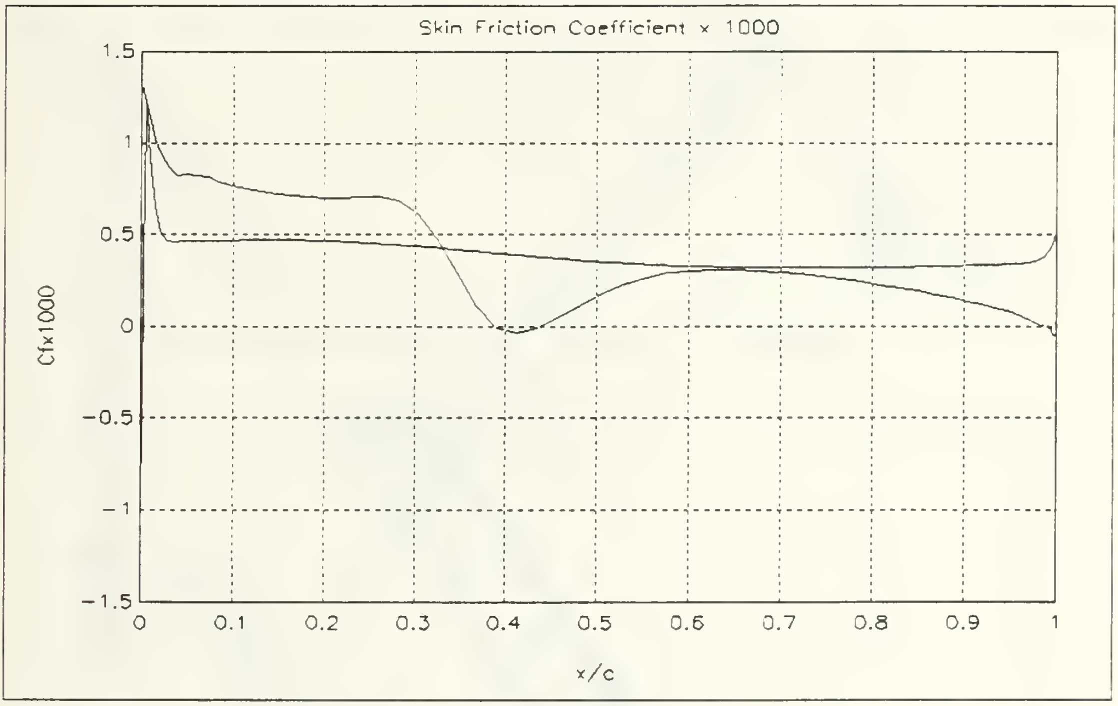



**Figure 31.** Skin Friction Coefficient Distribution (x1000)

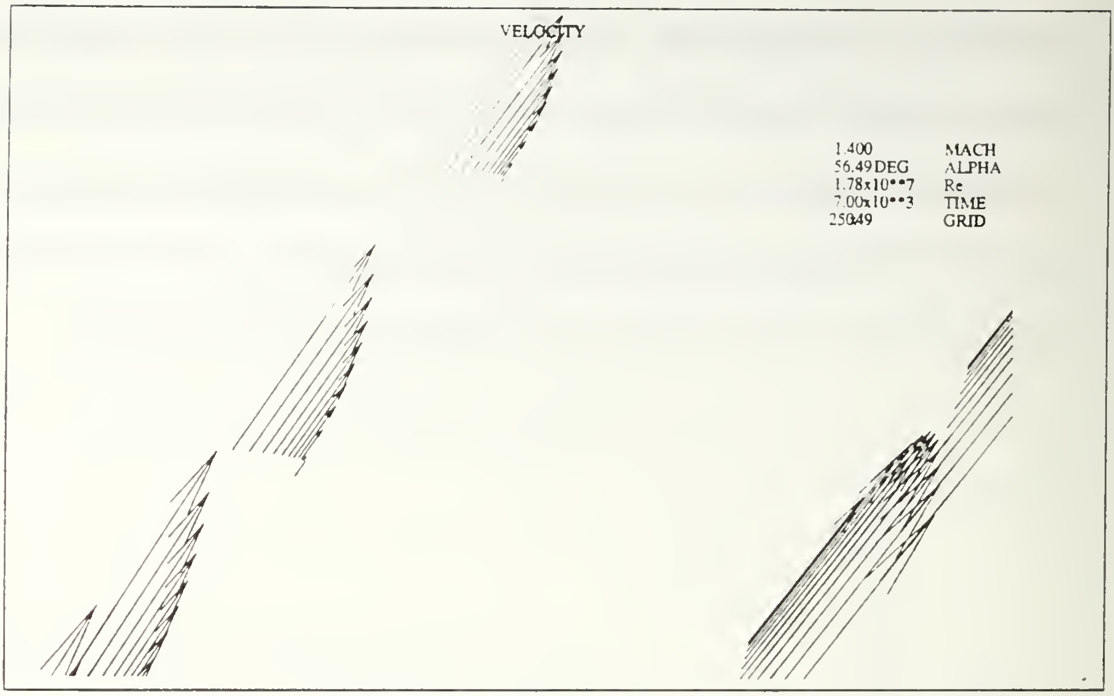



**Figure 32.** Velocity Profile at Shock Induced Separation

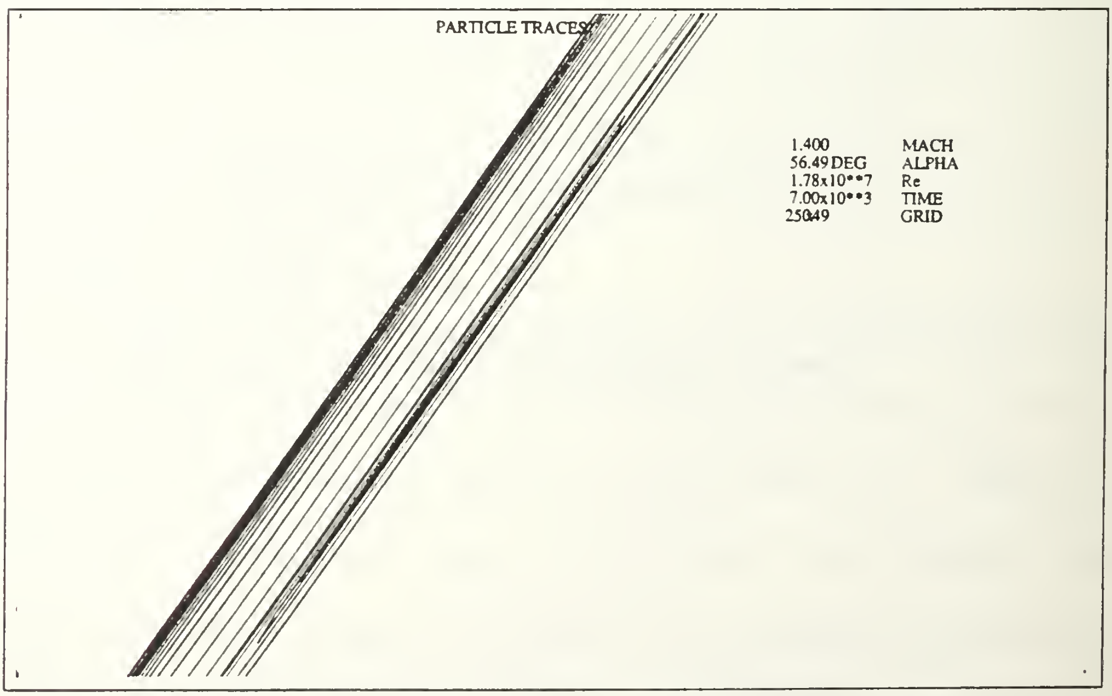



**Figure 33.** Particle Trace at Shock Induced Separation

### *c. Shock Resolution*

Mach number contours are shown in Figure 34. The normal shock merges with the leading edge bow shock on the pressure surface causing the attendant separation bubble previously described. This configuration is similar to that observed in the experiment and would appear to be the "design condition".

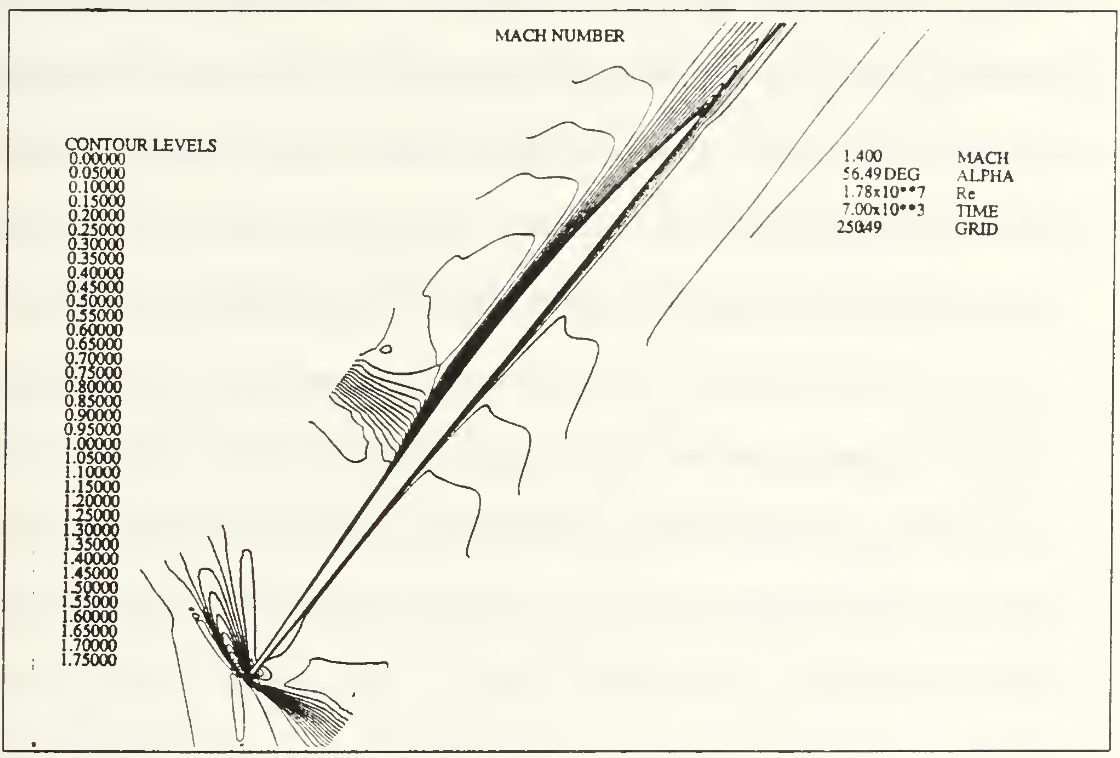



**Figure 34.** Mach Number Contours

### *d. Loss Calculation*

RVCQ3D predicted a mass averaged loss coefficient of 0.1123. This prediction will be compared to mass averaged losses calculated from experimental data as well as with a currently accepted empirical loss model.

# V. DISCUSSION OF RESULTS

## A. BLADE SURFACE PRESSURE DISTRIBUTIONS

The experimental and computational results for the surface pressure distribution on the blade suction side are shown in Figure 35. The numerical solution predicts the interaction region to be located about 2% chord upstream of where it was measured to be at the design incidence. The experimental results show a somewhat reduced Mach number upstream of the shock interaction and the shock induced compression does not reach the same peak value downstream as is shown in the numerical solution. However, the slope of the pressure rise in the interaction region and in the subsonic diffusion after the shock-boundary layer interaction compare favorably in the two simulations. It should be noted that the computational scheme generates a solution for what the inlet flow angle should be for the specified inlet Mach number (to allow periodic conditions through the cascade geometry). Thus the inlet air angle for the computation was 57.656 degrees, whereas it was 56.49 degrees in the experiment. Also, the outlet static-to-inlet total pressure was 0.704 in the computation and 0.68 in the experiment. A further difference between the experiment and computation was the unavoidable presence of side-walls in the experiment. While the RVCQ3D code has provisions for streamline contraction, in the experiment, determination of streamline contraction was not possible with the presently available instrumentation.

At the -0.85 degree incidence (an inlet flow angle of 54.49 degrees), which is further from the angle output by the computational solution than the design setting, the slope of the pressure rise across the shock is higher than for the design case. The sharper rise is followed by a near plateau through the passage throat and then a steeper rise over the curved surface. Since the pressure ahead of the shock is higher, corresponding to a lower Mach number, the steep rise through the shock suggests less or even the absence of separation. This contrasts with the design incidence case, at which the shock pressure rise (and interaction) is spread over 30% chord. The significant difference between the boundary layers entering the subsonic diffusion passage in the two cases, as deduced from the wake measurements, could account for the different rate of pressure rise.

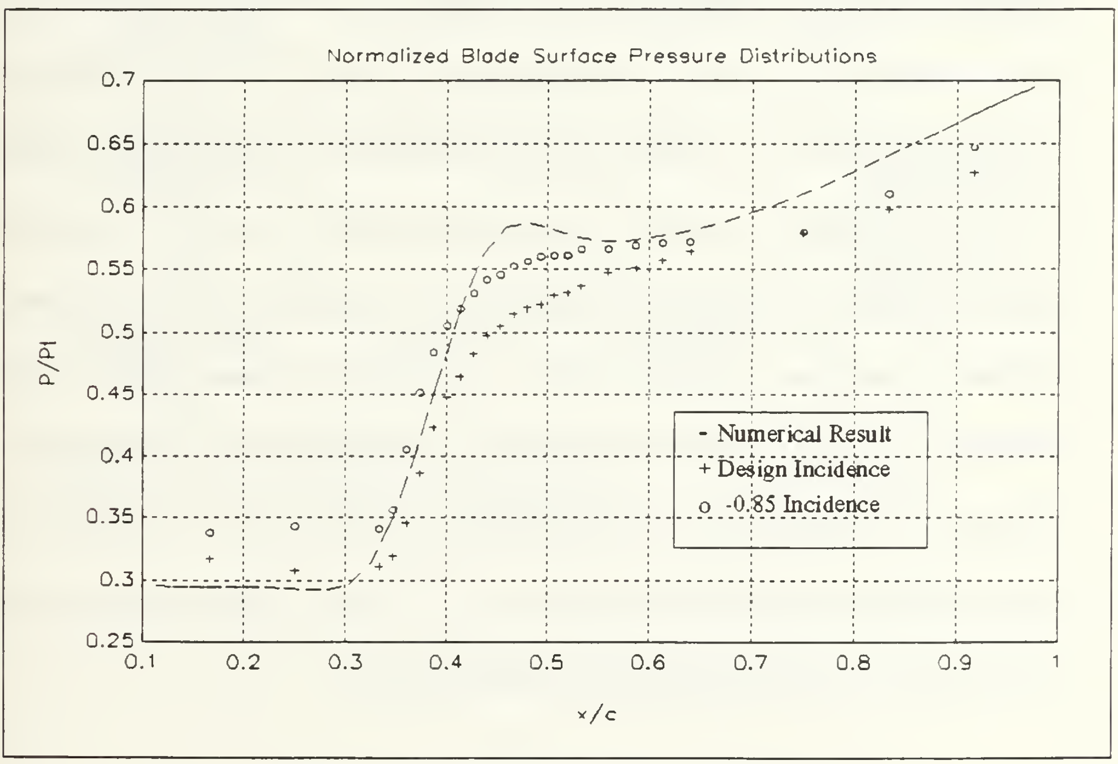



**Figure 35.** Surface Pressure Distributions

## B. CASCADE LOSS ESTIMATION

Mass-averaged pressures and losses derived from probe surveys are summarized in Table VI. It was of interest to compare these loss values with the predictions of current loss models, and with the losses predicted by the numerical simulation.

**TABLE VI.** MASS AVERAGED QUANTITIES AND LOSSES

| Case | Pt1ma (psia) | Pt2ma (psia) | Pt1-P1 (psia) | Ttave (deg R) | ω_ma |
|---|---|---|---|---|---|
| Design | 54.334 | 50.612 | 36.983 | 511 | 0.1006 |
| Off-design | 54.204 | 51.478 | 36.865 | 507.5 | 0.0739 |

The Koch and Smith method [Ref. 25] was selected since it was recommended in a recent review sponsored by AGARD [Ref. 26]. This empirical method can provide an estimate of the design point efficiency potential of a multistage compressor, taking into account viscous loss, shock and leading edge bluntness losses as well as end-wall and part-span shroud losses. The intent here was to use only the relevant parts of this model, inputting experimental conditions and estimating those unavailable from the data. A sample calculation is contained in Appendix G. Only profile, shock and leading edge bluntness losses were appropriate for the present cascade flow. Both the design and off-design incidence cases were examined. Deviation angle was estimated using Equation 3.5 of Reference 25 in combination with Figure 160 of Reference 27 and by using Equations 268 and 269 of Reference 27. Table VII gives the inputs (and their sources) to the loss calculation and the predicted losses.

**TABLE VII.** LOSS MODEL INPUTS AND PREDICTED LOSSES

| **Parameter** | **Design** | **Off-design** | **Comments** |
|---|---|---|---|
| Modified Carter Deviation (deg) | 2.48 | 2.48 | Based on Stagger Angle (used in loss estimate) |
| NASA SP-36 Deviation (deg) | 2.11 | 2.07 | Function of β1, Solidity, Shape and Thickness |
| Inlet Flow Angle β1 (deg) | 56.49 | 54.49 | Set in Test Section to 0.1 Degree |
| Outlet Flow Angle β2 (deg) | 49.402 | 49.402 | Function of Metal Angle and Deviation |
| Average Outlet Velocity V2(ft/sec) | 717.183 | 753.384 | Based on Measured Pt2, P2 Tt1 |
| Average Inlet Mach Number M1 | 1.389 | 1.387 | Based on Pt1, P1 |
| Momentum Thickness to Chord θc | 0.00656 | 0.00525 | Corrected for Equivalent Diffusion, M1 and Surface Roughness |
| Trailing Edge Form Factor $H_{TE}$ | 2.414 | 2.229 | " |

(TABLE VII. is continued on the next page)

TABLE VII. (continued)

| Parameter | Design | Off-Design | Comments |
|---|---|---|---|
| Shock Inlet Mach Number | 1.4 | 1.36 | Based on Surface Pressures |
| Profile Losses | 0.02608 | 0.0225 | |
| Normal Shock Losses | 0.065 | 0.05 | Based on Shock Inlet Mach number |
| L.E. Bluntness Losses | 0.00855 | 0.0081 | |
| Loss Coefficient | 0.0996 | 0.0806 | |

A summary of the losses obtained by measurement, by the application of the Koch and Smith method and from the numerical simulation, is provided in Table VIII. There is seen to be a reasonable agreement between the measurements and the Koch and Smith model at both incidence angles. The slightly higher loss from the numerical simulation is consistent with there being a slightly higher Mach number at the shock.

TABLE VIII. COMPARISON OF LOSS ESTIMATES

| Case | Measured | Koch and Smith | Numerical |
|---|---|---|---|
| **Design** | 0.1006 | 0.0996 | 0.1123 |
| **Off-Design** | 0.0739 | 0.0806 | |

# VI. CONCLUSIONS AND RECOMMENDATIONS

In the present study, the losses due to the shock-boundary layer interaction in a simulated fan blade passage were measured at design and one off-design flow angle. The results were compared with the losses predicted using the Koch and Smith loss model. Also, numerical results were obtained using a 2-D thin layer Navier-Stokes flow solver for blade-to-blade flows. Both surface pressure distribution through the interaction and losses predicted by the code were compared with the experimental results. A new data acquisition system and programmable probe and traverse system were implemented to obtain the measurements.

The following conclusions were drawn:

- The new data acquisition system was very successful and provided repeatable and accurate measurements. This was determined by comparing pressure levels to those measured in Reference 8 and by examining multiple scans of blade surface pressures.

- The new probe and traverse mechanism provided precise positional accuracy and pressure survey measurements

- As the back pressure was increased at the design incidence (a suction surface incidence of 1.15 degrees) the lower passage shock entered the cascade first and could be placed no closer than 10% chord to the upper passage shock.

- At a suction surface incidence of -0.85 degrees the upper and lower passage shocks were placed at approximately the same location at the same pressure ratio (P2/P1=2.1).

- At design incidence angle, blade surface pressures showed the shock-boundary layer interaction to be spread over 30% of chord. The slopes of the early shock compression and subsonic diffusion compared favorably with numerical predictions.

- At the reduced incidence angle blade surface pressures revealed a reduced Mach number prior to the shock, steep shock compression and a pressure plateau for 25% chord followed by a more rapid pressure rise over the back of the blade. The absence of significant separation would explain this change in behavior.

- Mass averaged losses were calculated from impact pressure measurements for both incidence angles and compared to predictions using the Koch and Smith loss model. The results compared favorably and each gave a twenty percent reduction in losses at the reduced incidence angle.

- The loss measurements at design incidence angle compared reasonably well with those given by the computational simulation.

Conclusions concerning the numerical simulation are:

- The flow solution is highly grid dependent. Repeated attempts to increase grid size to obtain more precise viscous solutions resulted in shock patterns, incidence angles and losses that did not reflect reality.

- The current numerical solution, using the latest version of RVCQ3D, predicted separation in the shock-boundary layer interaction region. It also predicted a small separation bubble on the leading edge and a slightly larger separated region at the trailing edge. On a similar grid, using the previous version of the code, separation was not predicted.

- The new version of the code demonstrated more rapid convergence on the present geometry than was observed previously with the earlier version. Placement of shocks at a desired location could be accelerated by slightly increasing back pressure above anticipated levels. The restart feature in the present code is a very powerful aide in obtaining solutions.

The following recommendations are made concerning the apparatus and instrumentation:

- Obtain an additional CALMOD 2000 such that lower pressure (15PSID) ZOC-14 scanning modules can be calibrated concurrently with higher pressure (50PSID) modules, but with equal accuracy.
- Expand the ZOC-14 DAS to enable more test section pressures to be measured in one test.
- Acquire pressure data from the instrumented side plates ahead of the test section to more fully examine the upstream flow as incidence angle is changed.
- Systematically replace all model sections exposed to the flow with parts made of harder steel since erosion due to contamination is severe.
- Do not exceed plus or minus two degrees of rotation from the design incidence because of potential damage to the lower blade pressure tubing.
- Design a three sensor pressure probe for the present traverse apparatus and calibrate it to return Mach number and pitch angle.

Based on the understanding gained in the present program, the following steps are proposed to achieve the stated goals of the project:

- Verify the absence of separation at the negative incidence using a surface injection technique.

- Experiment with "tailboards" to achieve similar flows (with separation) within the two passages at positive flow incidence angles.

- Obtain reference blade wake surveys at selected incidence angles using displacement increments of 1/32 inch (currently 1/16).

- Install a center blade with VGJ's and repeat the surveys with flow visualization.

- Install Wheeler Doublets on the lower and center blade (separately and then together), and repeat the surveys with flow visualization.

- Evaluate the results.

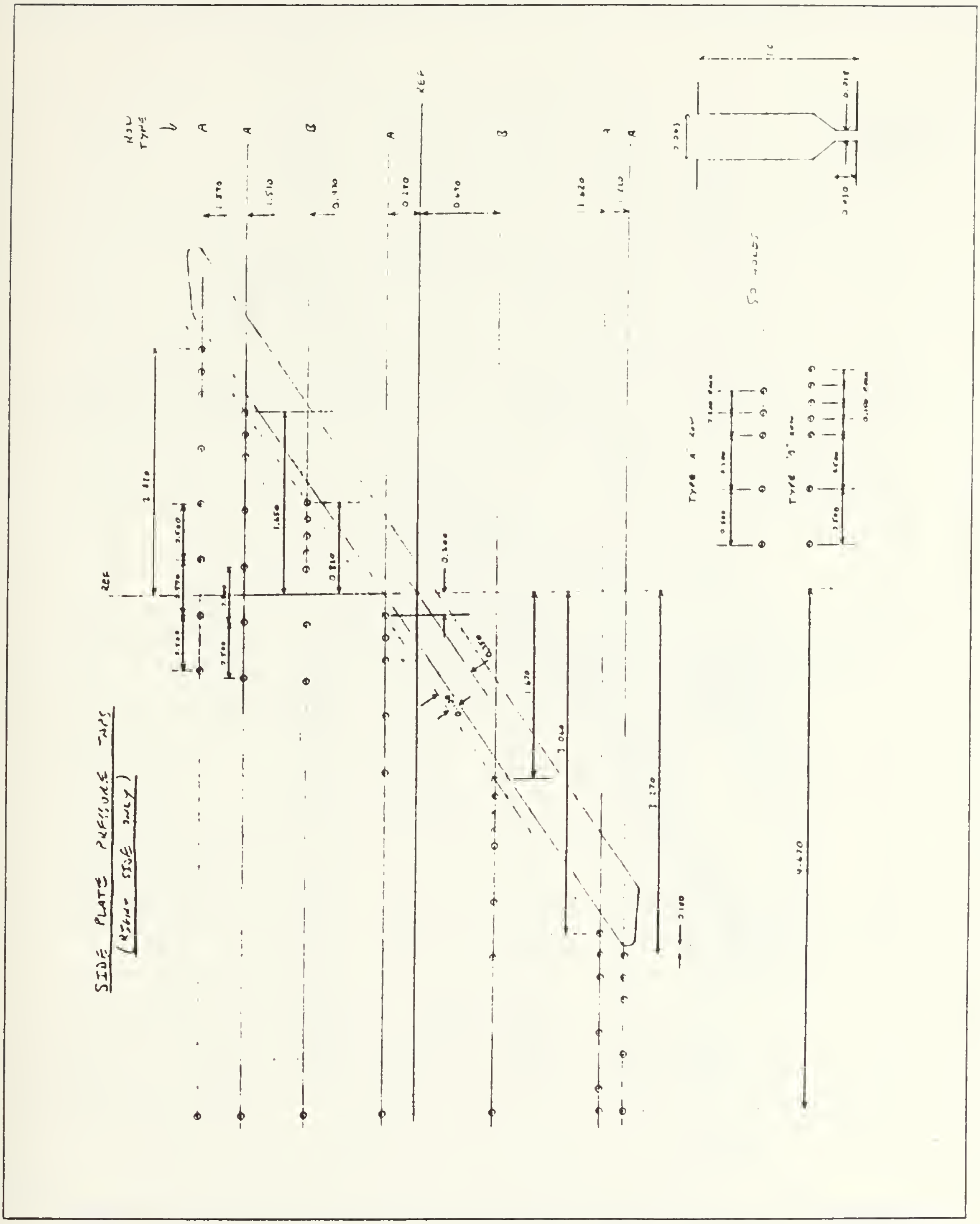



**Figure A1.** Side Plate Instrumentation (Right Side)

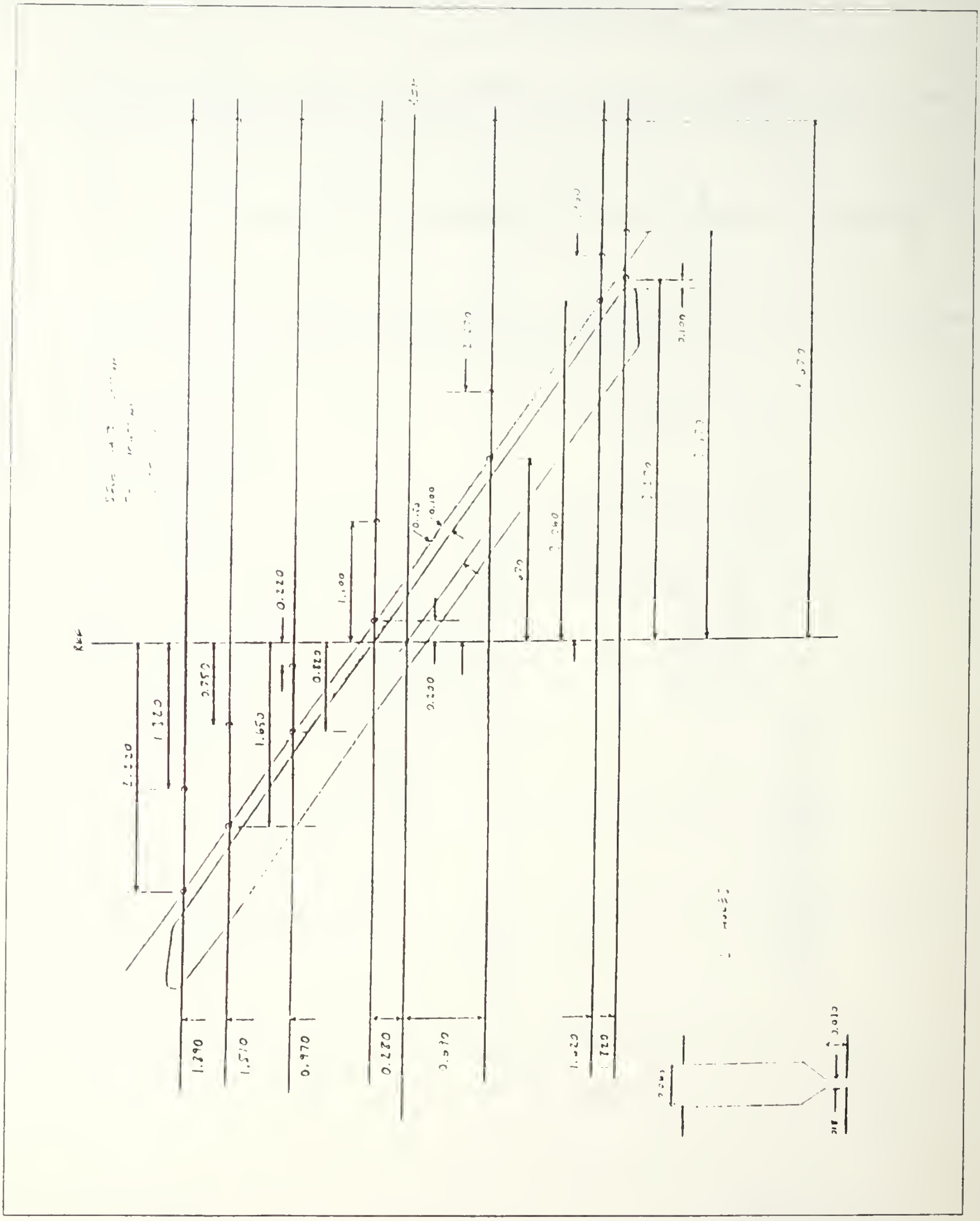


**Figure A1.** Side Plate Instrumentation (Left Side)

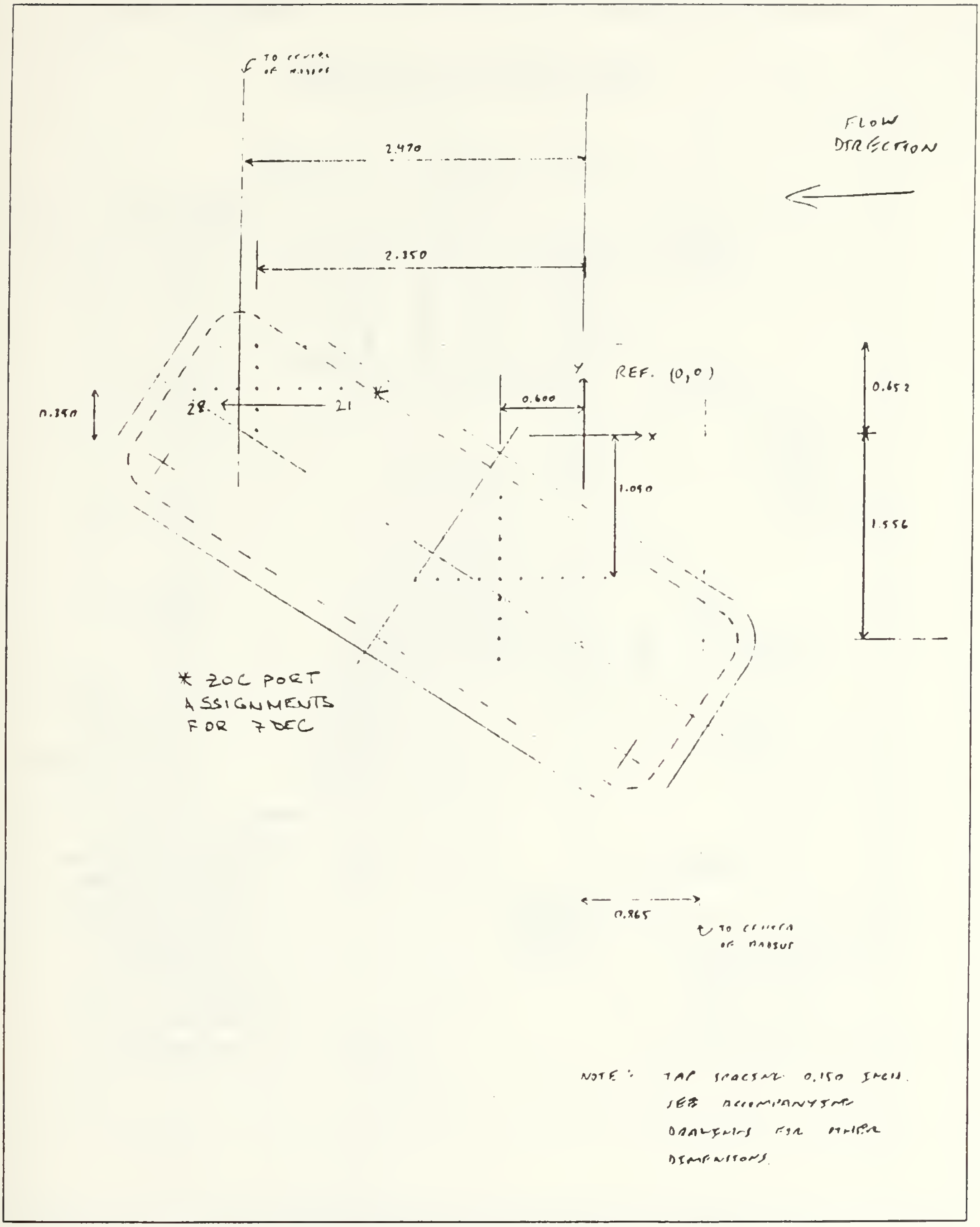



**Figure A2.** Window Blank Instrumentation (Left Side)

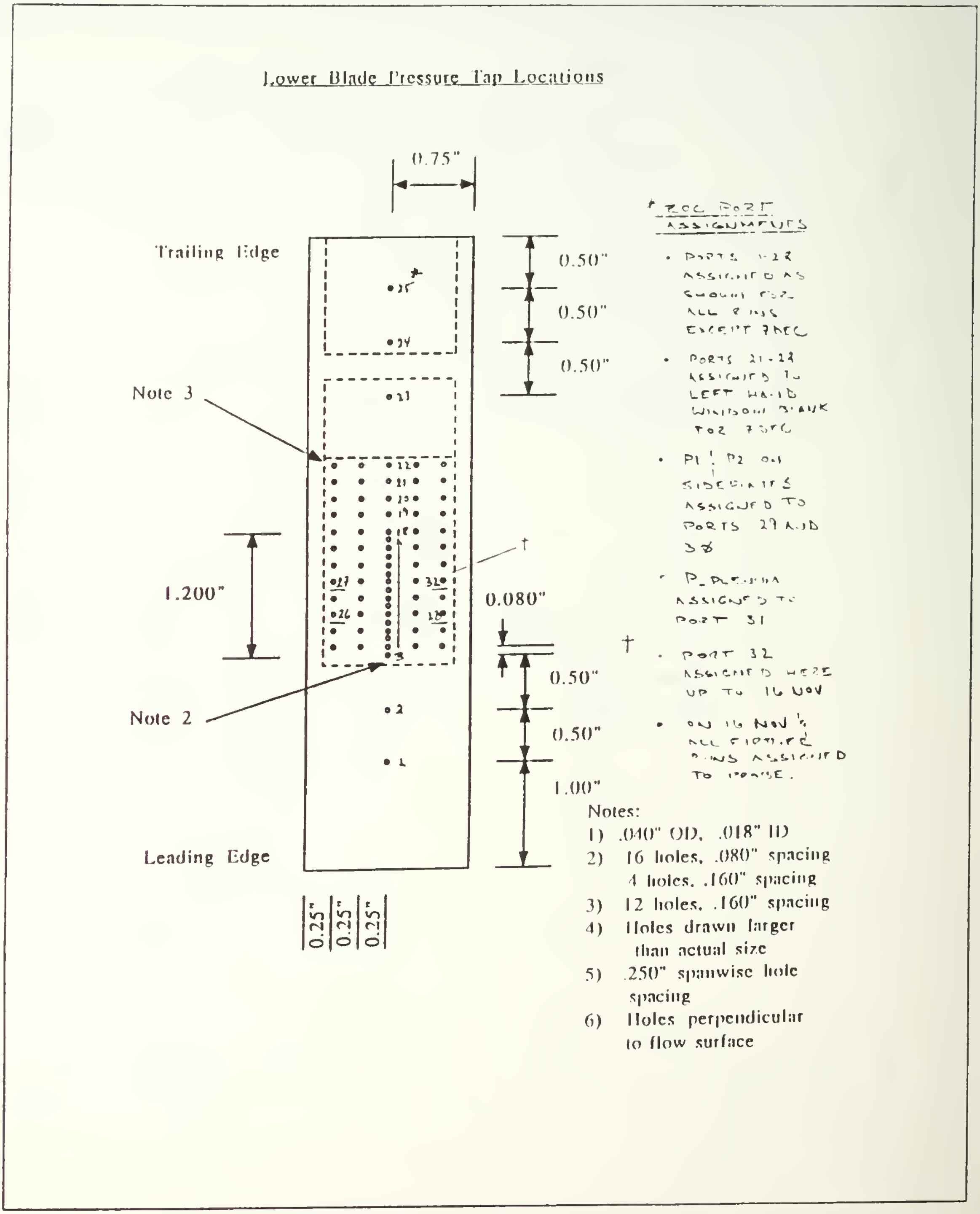



**Figure A3.** Lower Blade Instrumentation

# APPENDIX B. PROBE AND TRAVERSE DESIGN

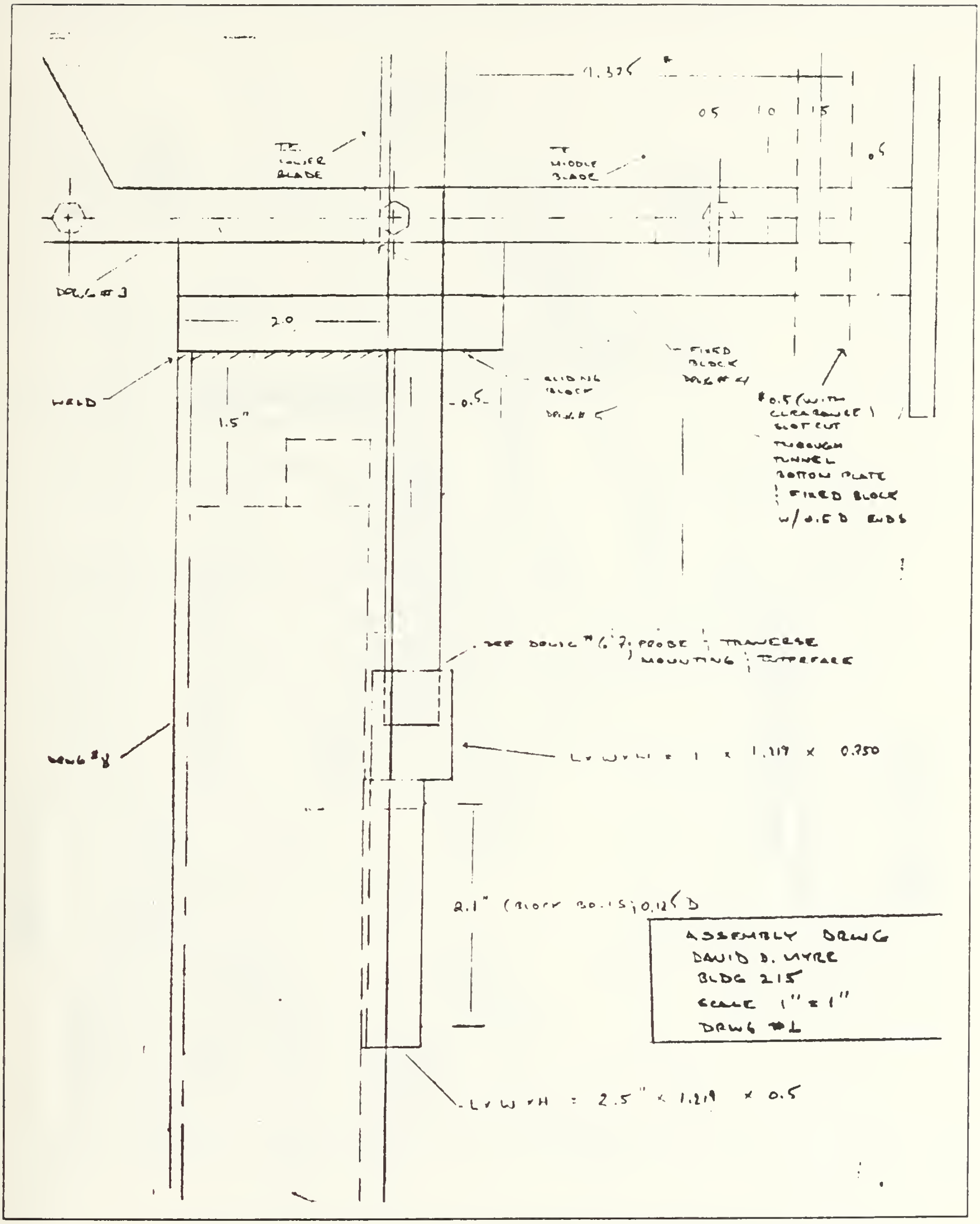


**Figure B1.** Probe Traverse Assembly Drawing

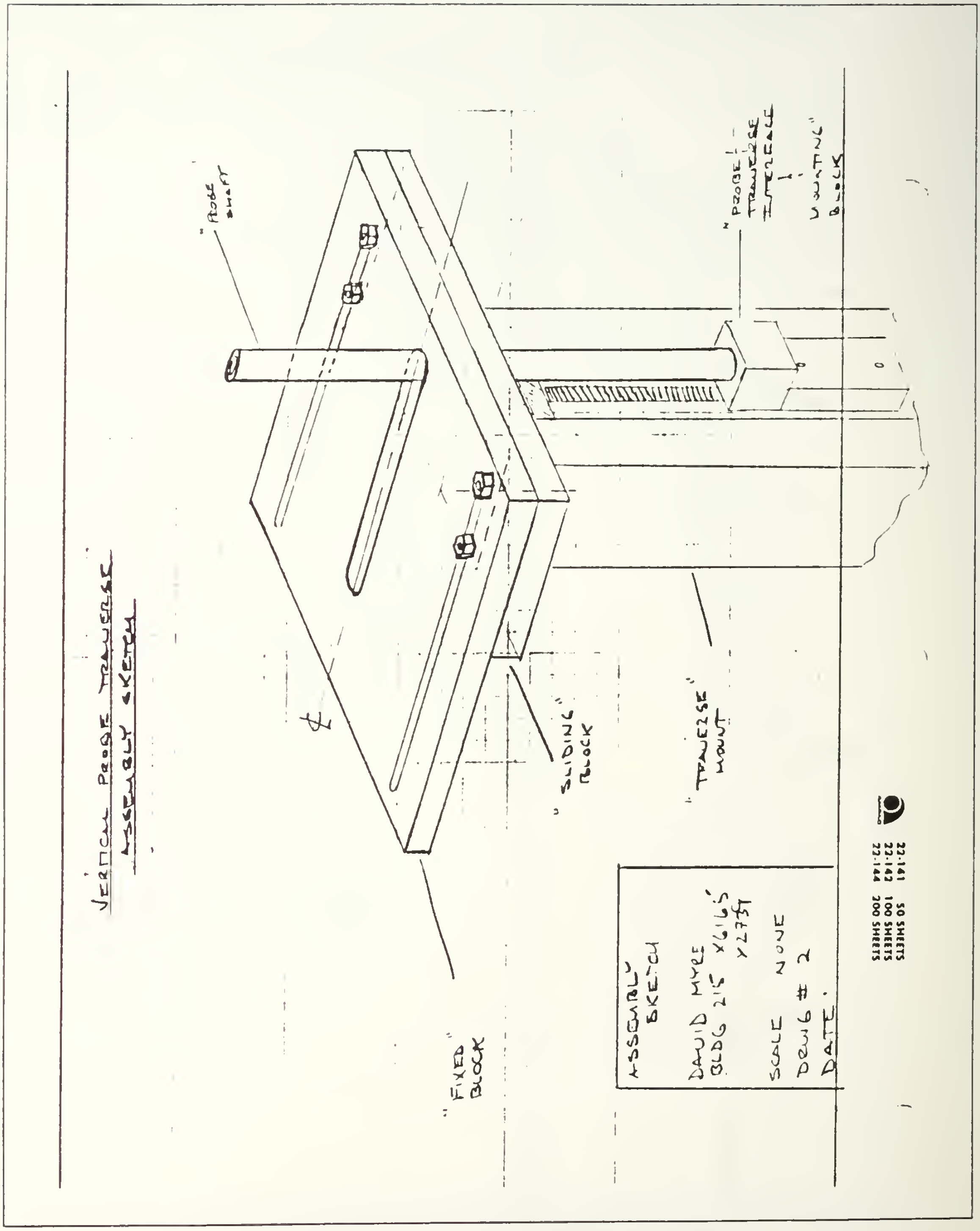



**Figure B2.** Probe Traverse Assembly Drawing

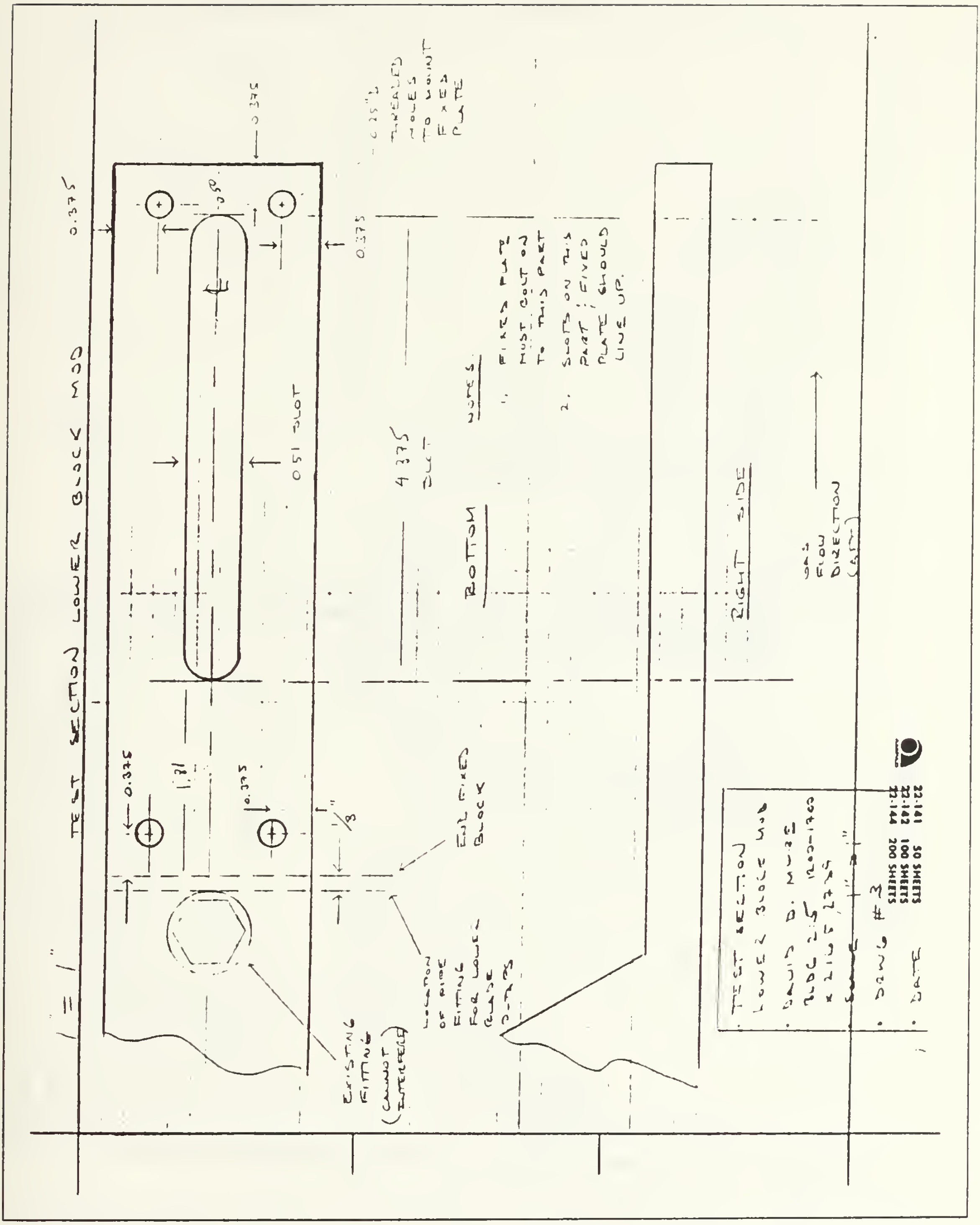



**Figure B3.** Test Section Lower Block Modification

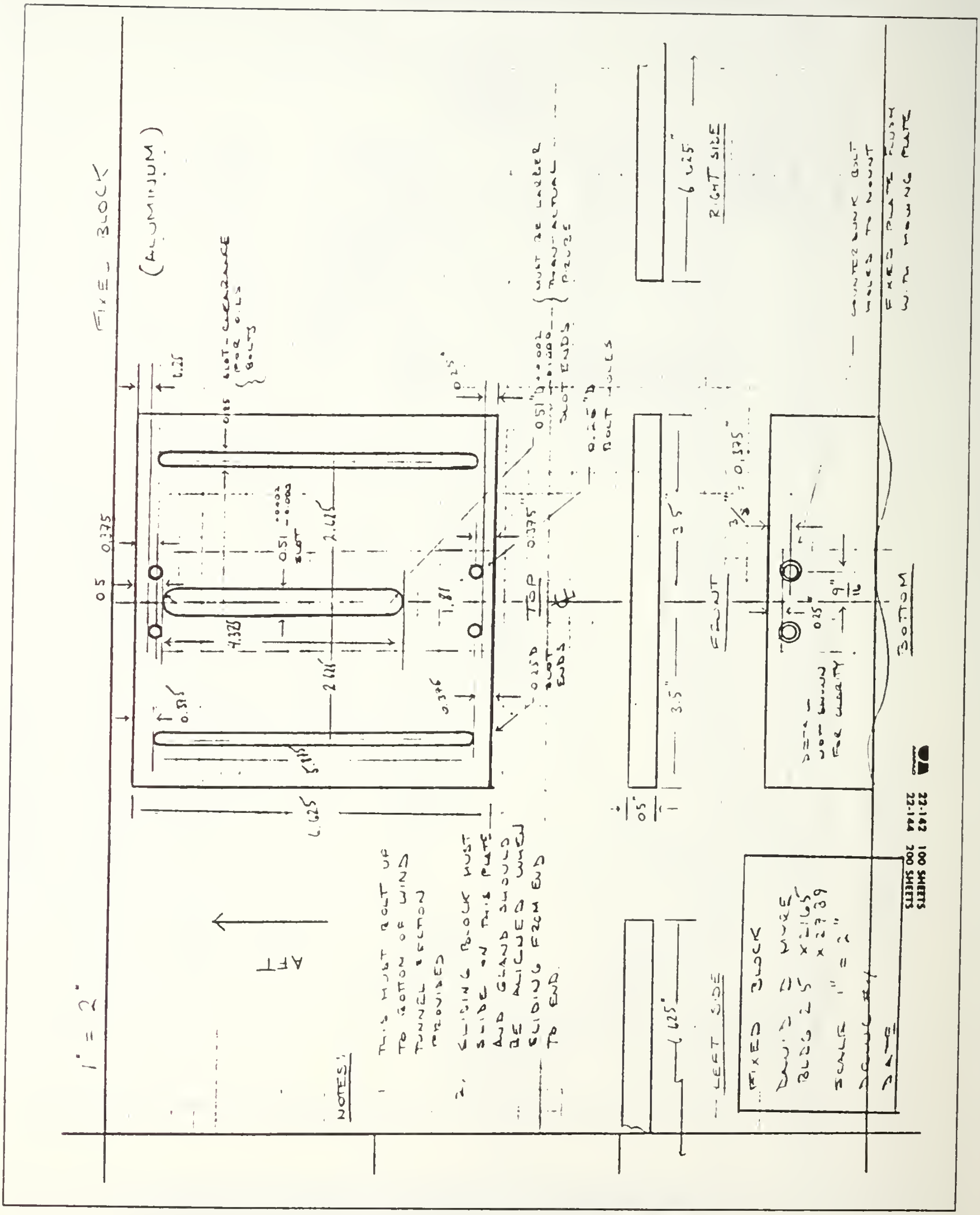



**Figure B4.** Fixed Block

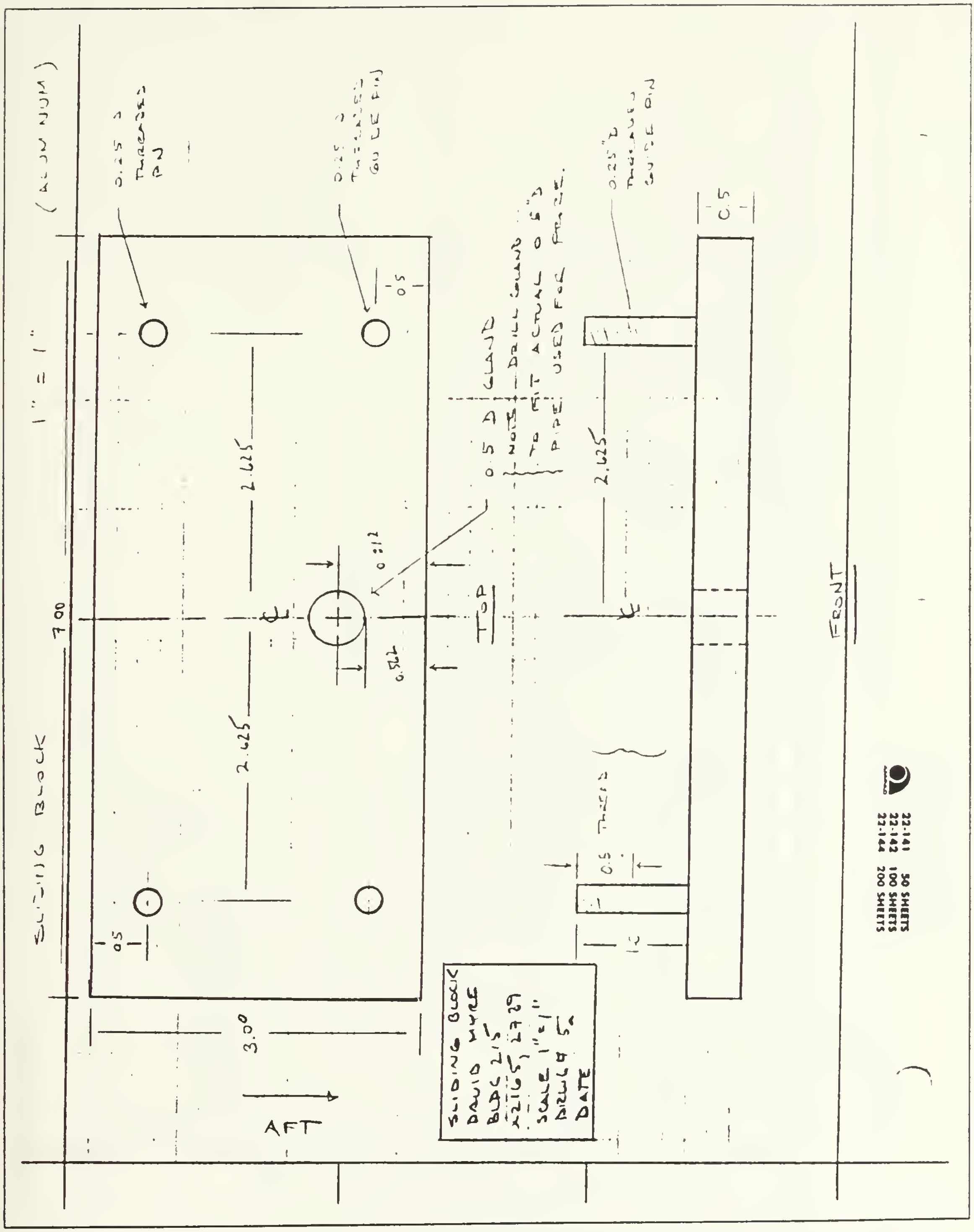



**Figure B5.** Sliding Block

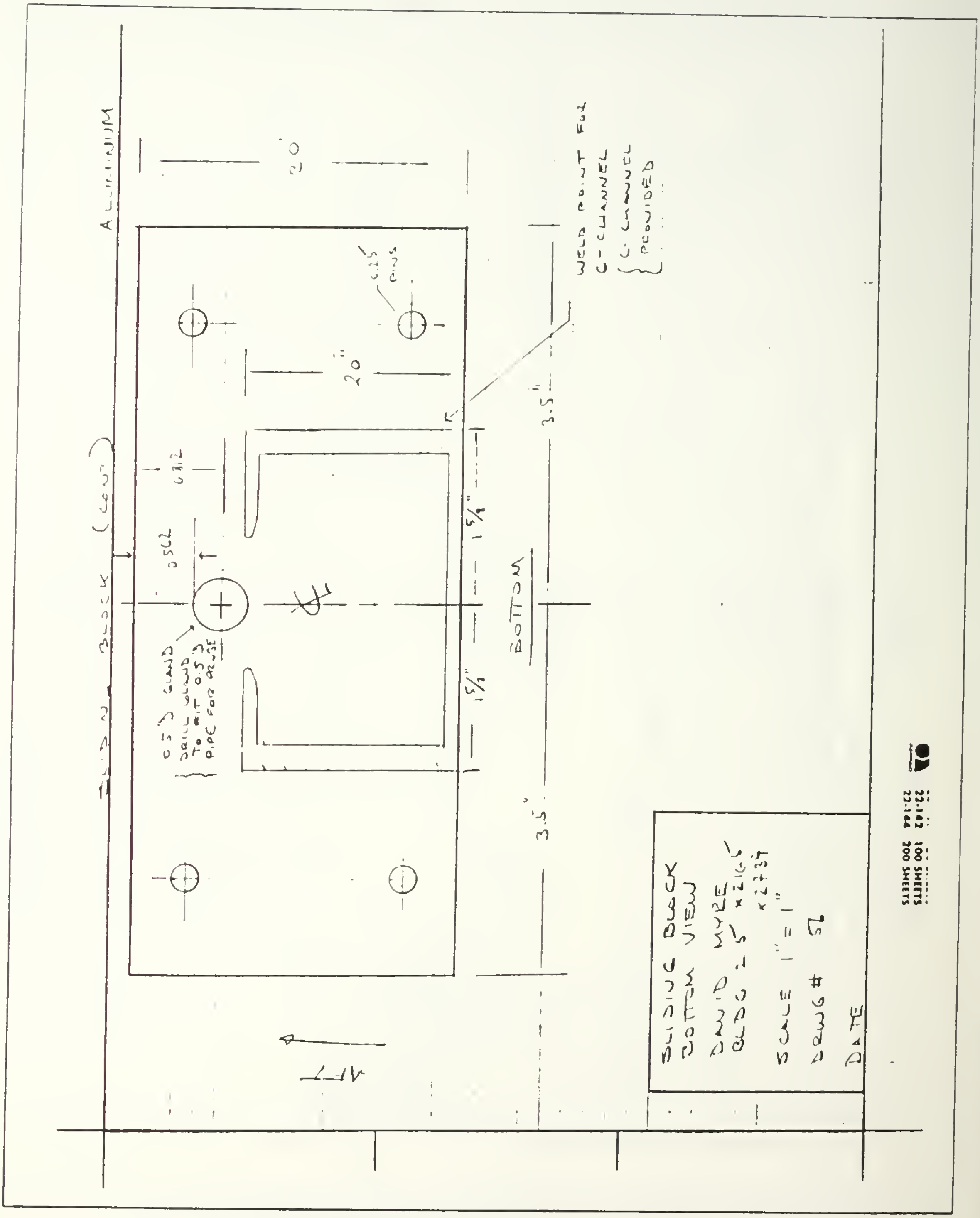



**Figure B5.** Sliding Block (Bottom View)

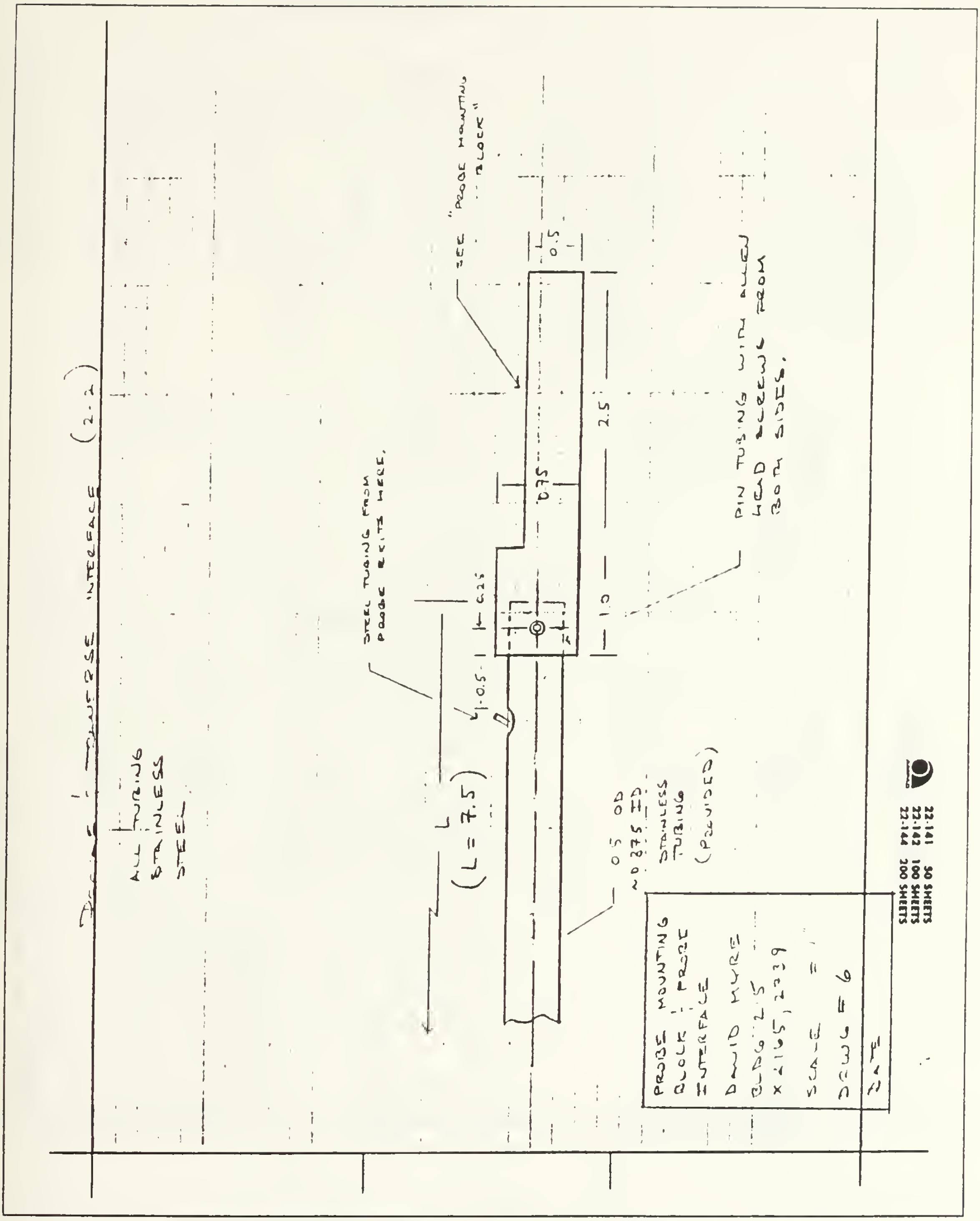



**Figure B6.** Probe and Traverse Interface

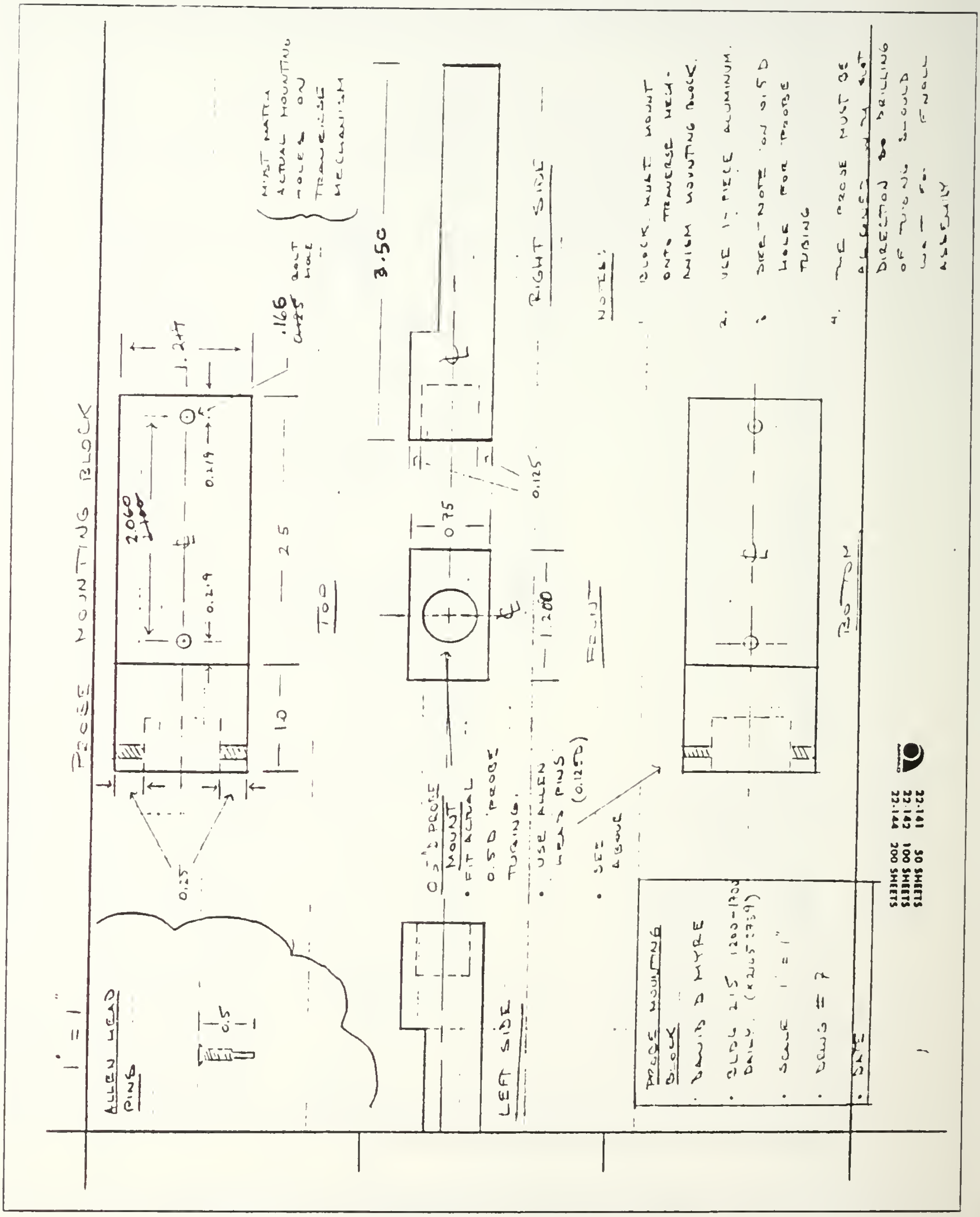



**Figure B7.** Probe Mounting Block

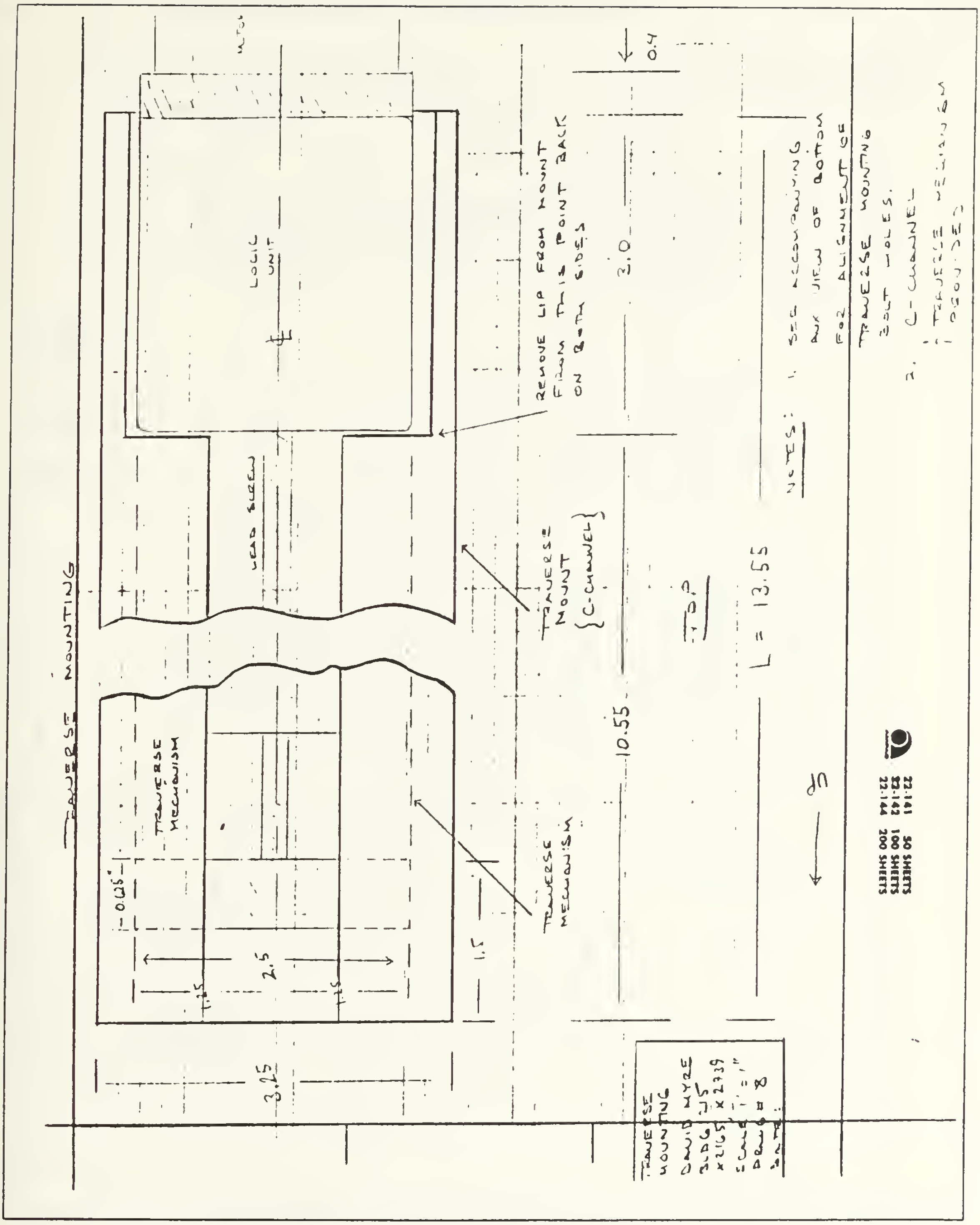



**Figure B8.** Traverse Mounting

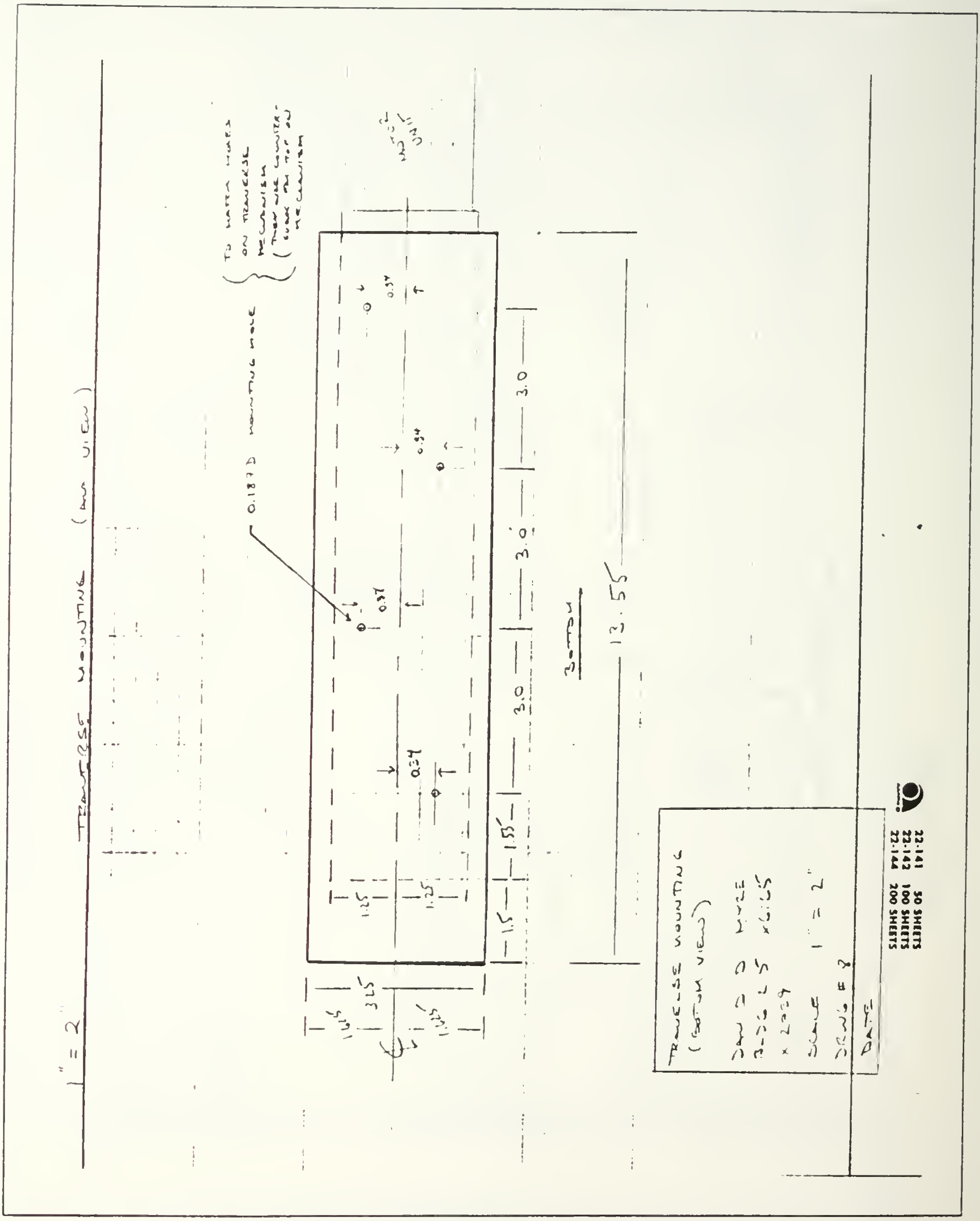


**Figure B8.** Traverse Mounting (Auxiliary View)

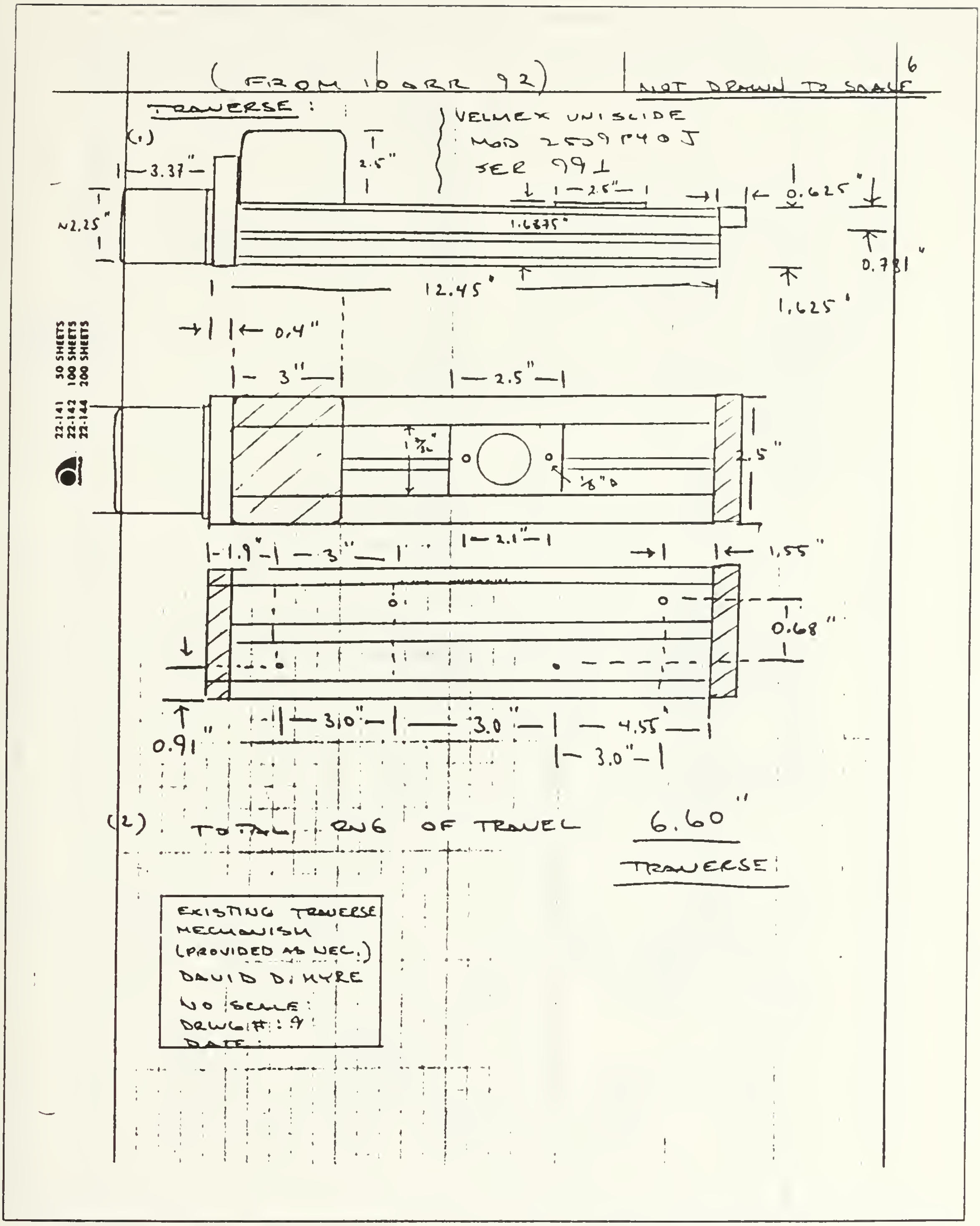



Figure B9. VELMEX UNISLIDE

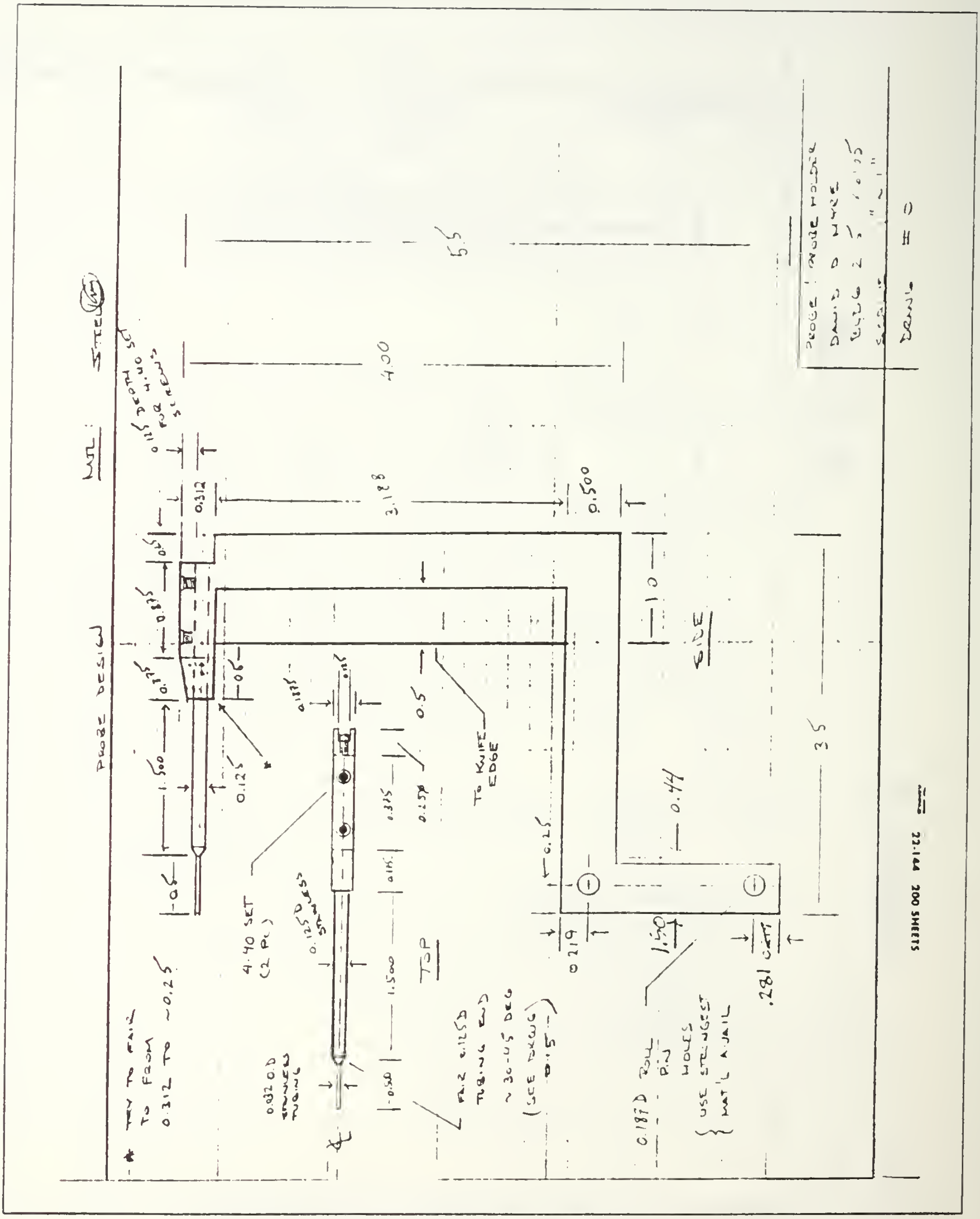



**Figure B10.** Probe and Probe Holder

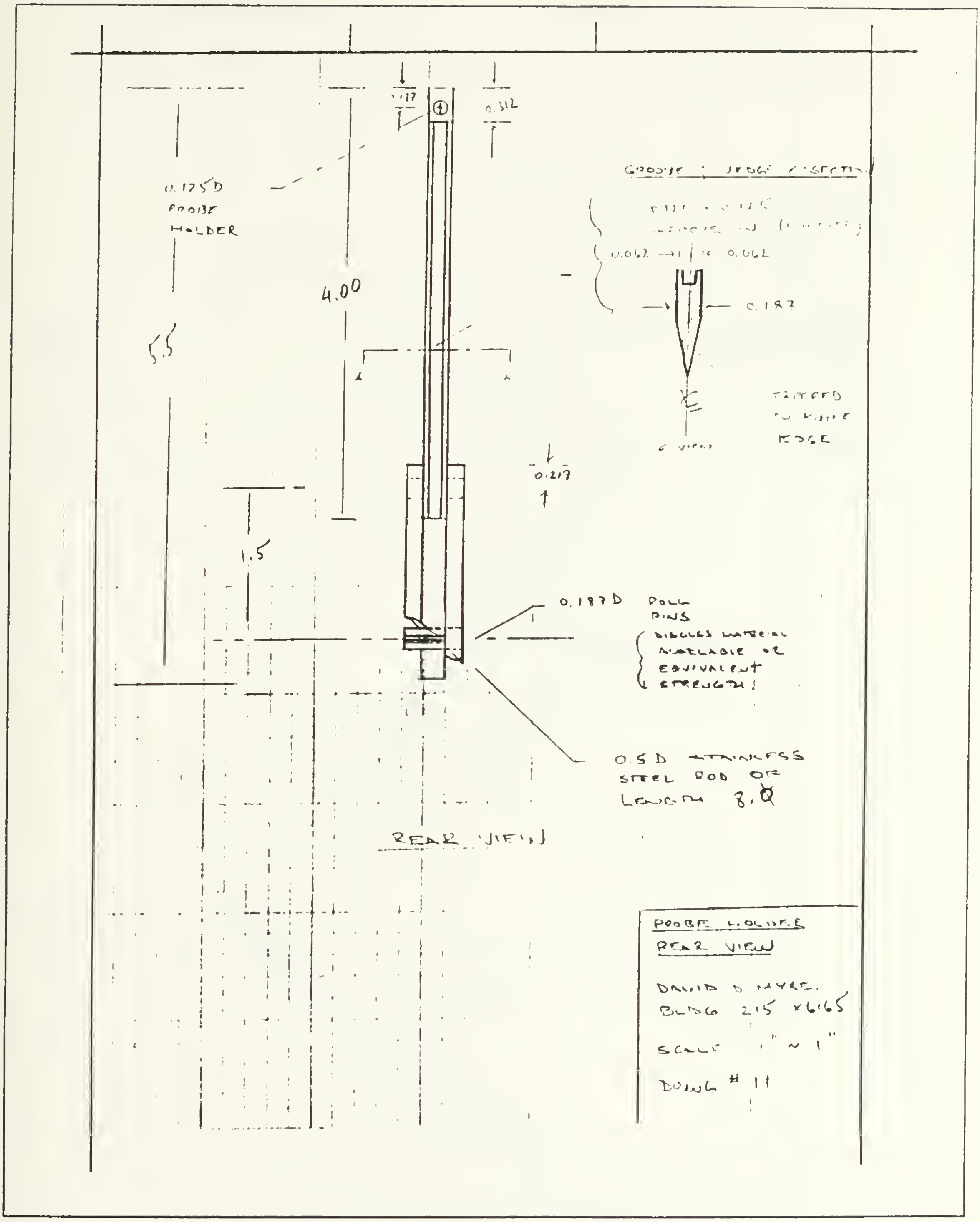



**Figure B10.** Probe and Probe Holder (Rear View)

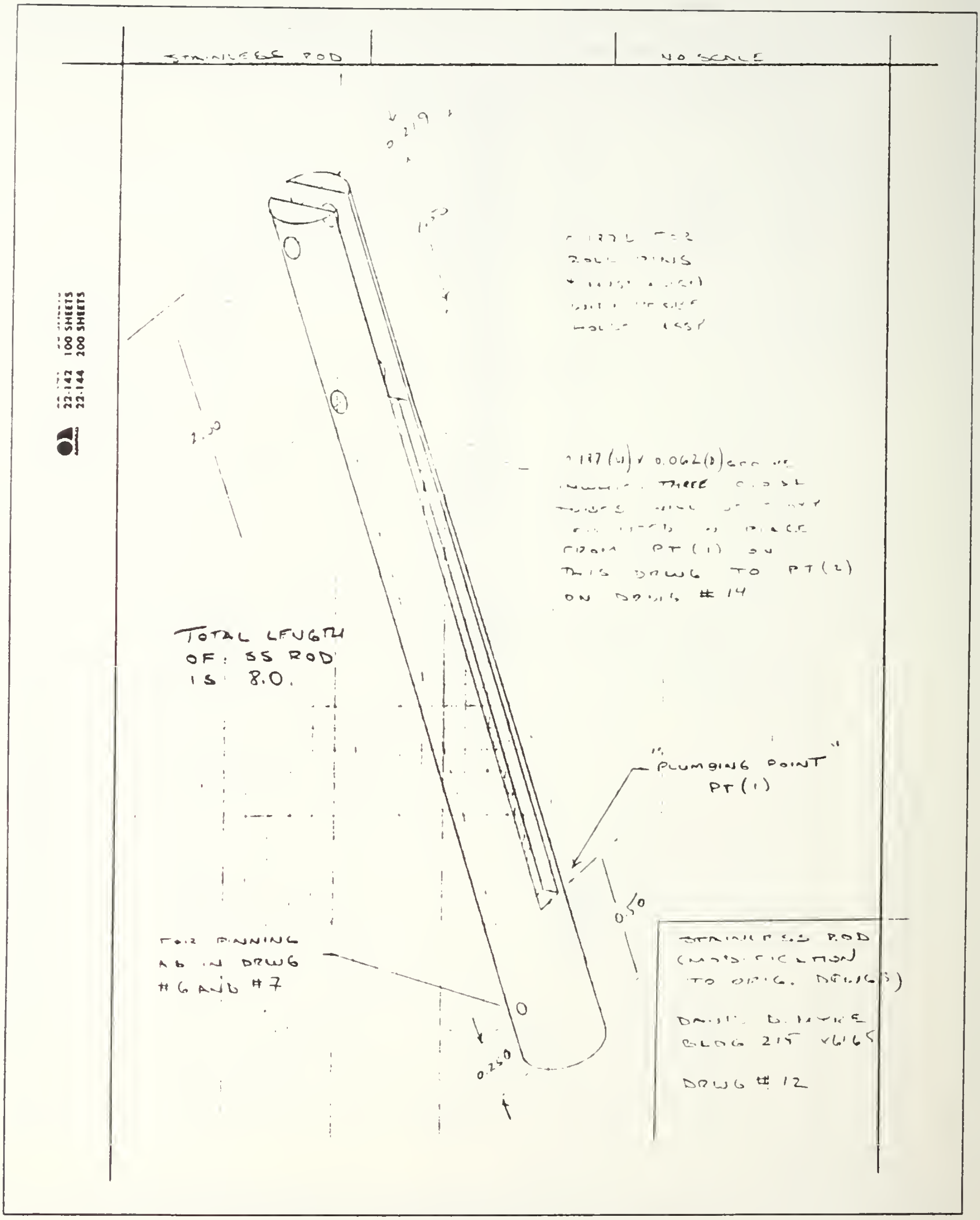



**Figure B11.** Stainless Rod

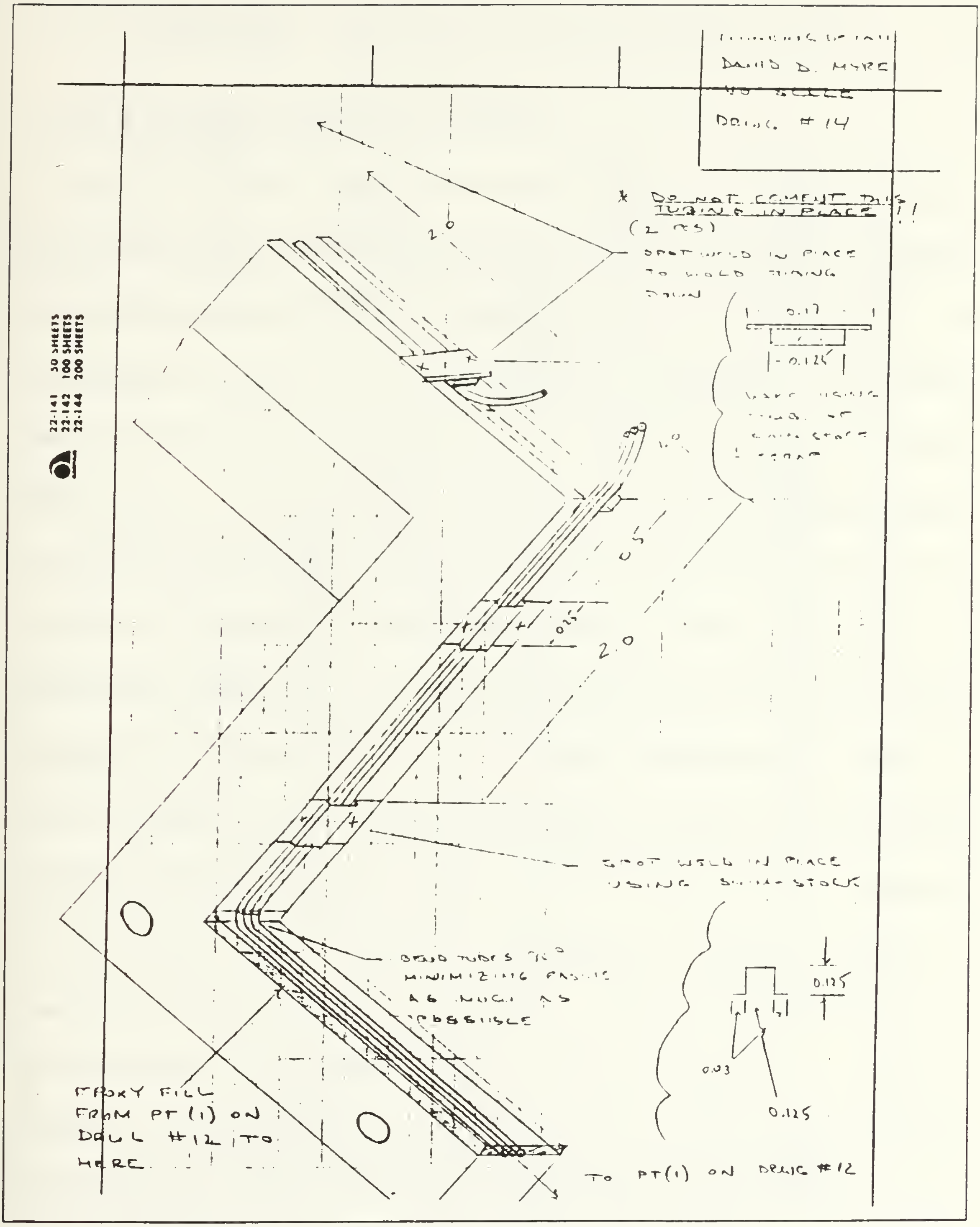



**Figure B12.** Plumbing Detail

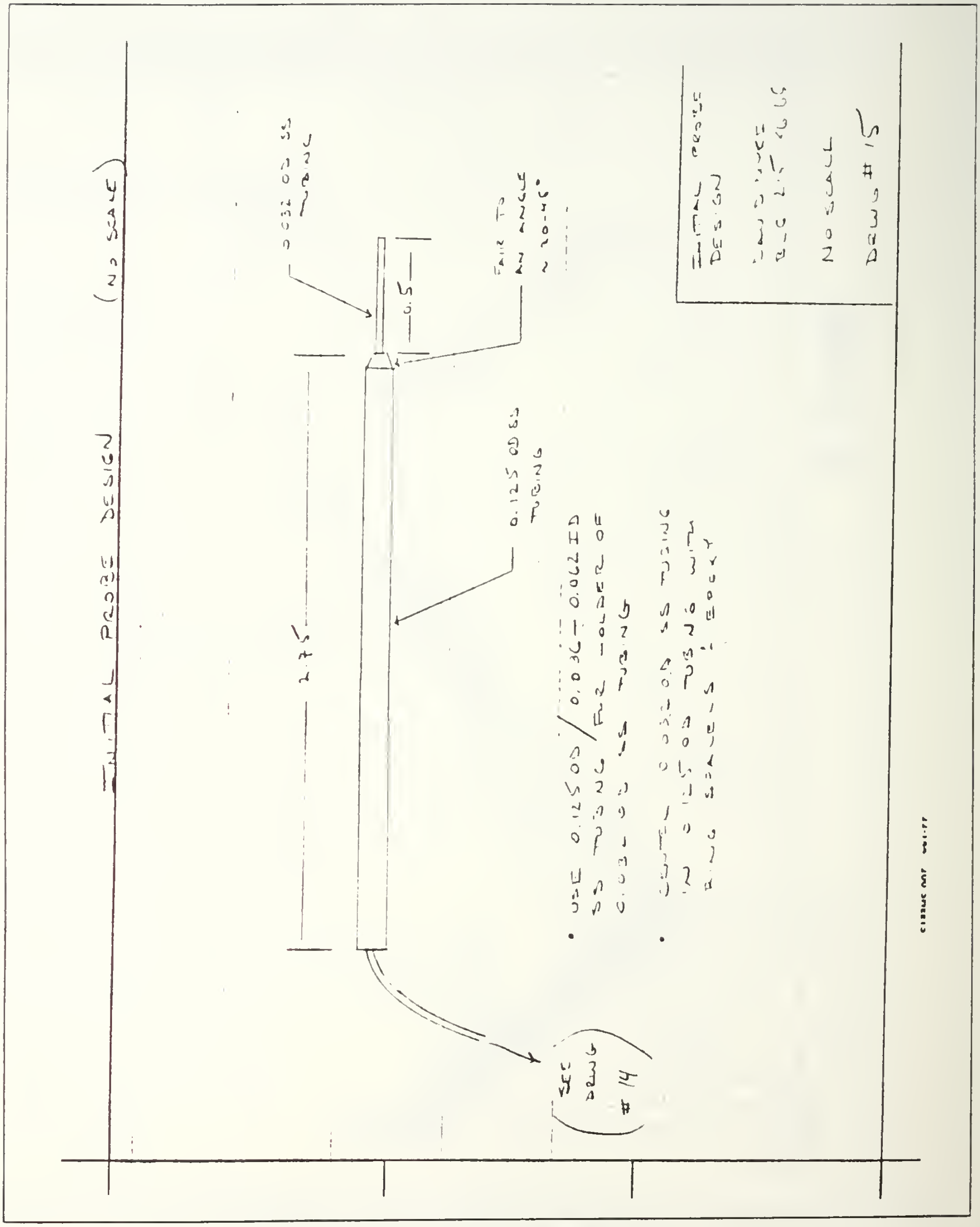
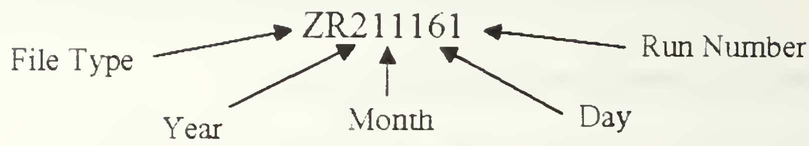



**Figure B13.** Initial Probe Design

# APPENDIX C. ZOC-14 DAS SOFTWARE DEVELOPMENT

## 1. Data Acquisition Program SCAN_ZOC_05

The ZOC-14 DAS software development integrated the ZOC-14 modules, CALSYS2000 and the HP6944A Multiprogrammer with the HP9000 series 300 Desktop Computer System and the HP6944A Computer Aided Test (CAT) software package. All programming was done in HP BASIC version 5.13. The HP6944A CAT software package provided software and documentation to configure and operate the HP6944A Multiprogrammer. This package formed the framework around which the main program, "SCAN_ZOC_05", was written. The CAT software provided routines which allow the programmer to integrate the operation of individual Multiprogrammer cards into powerful data acquisition tools. The A/D cards and Memory cards have been combined to operate as a data buffer and the Pacer and Counter cards combined to operate as a timer. The buffer stored raw strain gauge voltages in extremely fast RAM during acquisition and thus did not require transfer to the HP9000 RAM and finally to disk until the data run was complete. The timer function provided a square wave pulse at a prescribed pulse width and number of repetitions. The pulse width determined the scanning frequency and the number of repetitions (always a multiple of 32) determined the number of samples taken per scan of the 32 ZOC ports. The program generated three files for storage of raw data (prefix "ZW"), calibration data (prefix "ZC") and reduced data (prefix "ZR"). The files were labeled by the program in a fashion that is very useful as illustrated below. With its file management system, multiple data runs could be




completed without stopping to reduce the data until tunnel operations were complete. The program made use of multiple subprograms and user defined functions for repetitive tasks affording a "top down" program structure. Further details on "SCAN_ZOC_05" program development are contained in reference 12.

### 2. Modified ZOC-14 DAS Software ("SCAN_ZOC_06")

"SCAN_ZOC_05" was modified to provide continuous monitoring of cascade pressure ratios prior to data acquisition, operate a probe traverse for cascade surveys and conduct a complete scan of all ZOC's at each new probe position. This version of the program was designated "SCAN_ZOC_06". The purpose of this section is to document modifications to the original program. The new program listing is contained in Figure C1. An updated operating procedure for the system including hardware interface is also contained in Appendix C. Changes from the previous operational procedures found in reference 12 are indicated.

The initial setup routine was modified to include options available in the new version of the program. These included the current day atmospheric pressure and the type of scan or "scan type". The options are illustrated below in Table III. The program is menu driven with additional user inputs clearly prompted by the program.

Other selections which include the frequency of data acquisition, ZOC's to be operated and CALMOD utilized have been retained.

**Table IX.** SCAN TYPES AVAILABLE

| Scan Type | Purpose | Options | Comments |
|---|---|---|---|
| 0 | Single Scan of all ZOC's | Number of Samples up to 1021 | Original SCAN_ZOC_05 operation |
| 1 | Multiple Scans of all ZOC's | Number of Samples Avail. based on 1021/#Scans | Allows multiple Successive Observations |
| 2 | Probe Survey of Lower Blade | Scans = 33 Samples =10 | Parameters "hard wired" in to avoid probe damage |
| 3 | Probe Survey of Middle Blade | " | " |

The operation of the Transonic Cascade Wind Tunnel required knowledge of the pressure ratio across the test section prior to data acquisition. A routine was adapted from the program "SCAN" listed in reference 8 to provide a continuous display of the inlet (P1), exit (P2) and exit to inlet pressure ratio (P2/P1). The routine initialized both the HP3497A Data Acquisition/Control Unit and the HP3455A Digital Voltmeter. It then repetitively commanded the HP3497A to set the correct signal conditioner port and triggered the voltmeter to read the voltage across the transducers connected to the signal conditioner. It input this data to variables, scaled them appropriately and printed out the two pressures in psia followed by the P2/P1 ratio. This process began upon pressing the function key F4 which initiated the "Data Preps" routine. Prior to the start of the continuous cascade of pressure ratios the probe traverse moved to its initial position (if "scan_type" was greater than 1) and the CALMOD was initialized.

Routines to operate the NF90 Stepping Motor Controller were added to the software such that a probe mounted on the VELMEX UNISLIDE Motor Driven Assembly could be initially positioned prior to taking data, survey behind a cascade passage and finally return to its original position. As mentioned above the NF90 would be placed on line and the probe would move to its initial position during the "Data Preps" phase of ZOC operations, provided a scan type of 2 (Lower Blade) or 3 (Middle Blade) was chosen. When the cascade pressure ratio was at the appropriate value the function key F5 was pressed to begin collecting data. After each scan (after the subprogram "Scan_zocs" was called) was completed the subroutine "Traverse" was called which stepped the traverse a preset linear distance that was "hard-wired" into the program (a program edit was required to change this parameter) to avoid inadvertent damage to the probe. The probe moved after each pressure measurement, but ceased to move after the final measurement. The system completed 33 scans causing the probe to move 32 times at 0.0625 inches each time for a total of two inches traversed. More detailed surveys could be completed by changing the number of steps per scan (currently 1000) to a smaller value. After pressure measurements were completed another routine included in the "Collect Data" phase of the program moved the probe back to its starting position out of the flow and placed the NF90 off-line. A summary of the ASCII commands transmitted to the NF90 via the serial RS-232C port is provided in Table IV.

**Table X.** NF90 COMMANDS USED IN SCAN_ZOC_06

| Command | Definition | Purpose | Comments |
|---|---|---|---|
| "FN" | On-line & Zero Motors | Place NF90 on-line | Used at the beginning of traverse ops |
| "Q" | Quit | Take NF90 off-line | Used at the completion of traverse ops |
| "C" | Command | Alerts NF90 to new command | Used at the beginning of each command |
| "S1M1000" | Speed of Motor One at 1000 Steps/Second | Set motor speed | 1000 steps/sec is the optimum speed of operation |
| "I1M1000" | Index Motor One 1000 steps | Moves UNISLIDE 1000 steps | 500 steps is equivalent to 1/32 inches |

In making first time probe surveys in the Transonic Cascade Wind Tunnel, measurements were required to determine the significance of disturbances caused by the probe itself. The procedure was modified so that it was possible to measure a portion of the cascade pressure field at each survey point. "SCAN_ZOC_05" was modified such that it would perform one scan of all ZOC's for each new position of the probe. This required the addition of the traverse routines described above and the modification of the following routines listed in Table V. These changes essentially added a "global loop" around the entire acquisition process (with the exception of the transfer of data to the HP9000, gathering of calibration data and final data reduction) thus enabling the system to scan all ZOC pressure ports, including the port reserved for the probe, multiple times while still taking multiple samples. These operations were limited by the HP6944A buffer space such that the number of scans times the number of samples times 32 ZOC ports had to be less than 32,672.

**Table XI.** ROUTINES MODIFIED IN SCAN_ZOC_O6

| Routine | Purpose | Modifications | Comments |
|---|---|---|---|
| Initialize_spac | Initializes variables | 1. Added parameter "Itrav" for total number of scans/traverse points<br>2. Added one column to "Zoc_cal" arrays for storage of additional program inputs | See "Collect_data" for more on "Itrav" |
| Key_menu | Prints ZOC operating menu | 1. Changed "F4" selection to "Final Checklist and P2/P1 Cascade" | |
| Input | Provides Program inputs | 1. Added input for Atmospheric Pressure and Type of scan desired.<br>2. Replaced LIF Hard Drive selection with LIF Floppy Drive for data storage | Inputs stored in Zoc_cal array and Cal file in "Initial_cal" |
| Data_prep | Initializes CALMOD and probe traverse and prints out pressure ratio | 1. Added routine to preposition the probe traverse depending on "Scan_type" selected in "Input"<br>2. Added routine that prints continuous cascade of pressure ratios (P2/P1) | "P2p1" routine starts after probe is in position. |

(TABLE XI. is continued on the next page)

**TABLE XI.** (continued)

| Routine | Purpose | Modifications | Comments |
|---|---|---|---|
| Collect_data | Scans ZOC's desired number of times | 1. The variable "Iscan" is now passed to SUB "Scan_zocs" . When Iscan is greater than one the HP6944A buffer will not reinitiate such that data from all scans will be stored.<br>2. SUB "Traverse" is now called after each measurement and moves the probe vertically down at a set increment. | See SUB "Scan_zocs" for use of variable "Iscan" and also see SUB "Traverse" |
| | | 3. At completion of measurements a routine returns the probe to its initial position. | |
| Initial_cal | Initializes arrays necessary for storage of calibration data | 1. Additional program inputs are now stored in "Zoc_cal" arrays for current data run.<br>2. New inputs included are "Scan_type", number of scans ("Itrav"), traverse "Increment" and atmospheric pressure.<br>3. Variable "Iscan" is reset to one so that buffers initiate for storage of calibration data. | All inputs are stored in the calibration file which is read later during data analysis. |
| Collect_cal_dat | Collects raw calibration data for each CALSYS pressure | 1. Variable "Iscan" added to call of SUB "Scan_zocs".<br>2. Since Iscan reset to one the HP6944A buffer initializes to store calibration data only. | |
| Reduce_data | Reduces raw calibration and measured data | 1. Replaced LIF Hard Drive option with LIF Floppy Drive . | SEE SUB "Raw_red_ dat" |

(TABLE XI. is continued on the next page)

TABLE XI. (continued)

| Routine | Purpose | Modifications | Comments |
|---|---|---|---|
| View_files | Displays filenames from storage media | 1. Replaced LIF Hard Drive option with LIF Floppy Drive . | |
| SUB Scan_zocs | Operates HP6944A for scanning ZOC's | 1. Program passes additional variable "Iscan" . 2. Conditional "IF" statement skips reinitiating of HP6944A buffer if Iscan greater than one. | |
| SUB Traverse | Steps probe traverse a preset distance when "Scan_type" is greater than one | 1. Increments for upper and middle blade survey can be varied with program edit. 2. Routine verifies probe movement complete by awaiting "^" character from NF90 Stepping Motor Controller. | Survey increment "hard-wired" into program to avoid probe damage |
| SUB Raw_dat | Collects raw data from memory for storage on disk drive | 1. The number records read into the HP9000 memory and stored on disk drive were multiplied by the factor "Itrav". 2. CREATE BDAT, Input_iblock and CONTROL statements were affected. | "Itrav" is the total number of scans. |
| SUB Cal_dat | Stores calibration data on disk drive | 1. Data file size and size of file buffer were increased to account for additional column in Zoc_cal array. 2. CREATE BDAT and CONTROL statements were changed. | Zoc_cal array size increased to hold amplifying information. |
| SUB Raw_red_dat | Loads raw data and cal data from disk, reduces data and stores on drive | 1. Add outer loop to account for multiple scans now implemented. 2. Repetitively set read pointer to second element of each scan in raw data file. | |

## OPERATING THE ZOC-14 DAS PROGRAM

### 1. Start-up

- Turn on HP6944A, CALSYS2000, ZOC Enclosures, HP3497A, HP3455A, NF90, and HP9000.

- Verify traverse assembly is in correct position for desired survey if applicable. Also, ensure lead screw is lubricated to avoid motor stall.

- From main menu shown type F7 and set time and date in the following format: Time 10:25:45 (hours:minutes:seconds); Date 17 Dec 1992. If entries are correct enter "Y" when prompted.

- Type F2 to enter HP6944A directory menu.

### 2. Calibration

- From this menu type F2 again to calibrate individual transducers. 100PSID transducers 1 and 2 are on ports 0 and 4 of the signal conditioner. Set zero calibration and then range scale calibration using test pressure. Set range to one-half (1/2) actual test pressure for 100PSID transducers.

- Type an out of range value in calibration menu to reenter HP6944A menu.

- Type F1 to proceed to ZOC-14 Modules menu.

- Ensure the nitrogen gas supply is connected to the CALSYS2000 and 90 psi is set on the regulator.

- CALSYS2000 regulators: Set the high, medium and low pressure regulators over a range of pressures to be measured. If specific levels are known, set regulators close to those levels.

- **WARNING:** Do not over pressurize ZOC's that are not rated for the higher pressures such as the 15PSID ZOC's.

- CALSYS2000 verification: Select F4 from the ZOC Modules menu and verify pressure settings.

- **NOTE:** This should always be completed when the CALSYS2000 is first energized to ensure the RS-232C line is clear and ZOC's are initialized.

- Type F2 to return to ZOC menu.

**3. SCAN_ZOC_06 Set Up**

- Type F1 to load and run "SCAN_ZOC_06". **NOTE:** HP6944A must be energized to run this program.

- An introduction screen is displayed which indicates the program is waiting for a function key input. Function key options are listed at the bottom of the screen. Typing F1 displays the introduction screen again. Typing F2 will display a menu screen with same function key options listed at the bottom the screen.

- **NOTE:** Typing F4 or F5 at this time results in an error.

- Type F3 to supply set-up inputs to the program. All inputs are prompted and a list of these inputs is provided below:

  a. Input atmospheric pressure in psia.

  b. Select data storage drive (0 is HFS hard drive ":,700,0" and 1 is LIF floppy drive " :,700,1")

  c. Select "Scan_type" as described in Table IX above. The number of samples available is determined by this selection.

  d. Select the number of samples based on selection of "Scan_type".

  e. Select the number of ZOC's (1-3) for recording data.

  f. Select the CALMOD assigned to each ZOC by entering 1 or 2 when prompted. (currently only one is available).

**4. Data Collection Preparations ("Final Checklist and P2/P1 Cascade")**

- Verify nitrogen is supplied to CALSYS2000 at 90 psi.

- Verify wind tunnel is prepared for operation:

  a. Back pressure valve is wide open.

b. Control air is supplied to the pneumatic regulator valve.

- **NOTE:** The next step is to type F4 for final preparations and checklist, but the outcome will vary depending on Scan_type selected.

- If Scan_type 0 or 1 is chosen, type F4 prior to commencing wind tunnel operations. This will provide a continuous display of tunnel pressure ratio.

- If Scan_type 2 or 3 is selected, type F4 just prior to opening tunnel inlet valve by coordinating with the operator. This will avoid placing probe in unsteady initial tunnel flow and save run time by positioning probe in an expeditious manner.

- **WARNING:** Probe motion is "hard-wired" into program. Ensure probe is positioned such that current settings will not damage the probe or traverse.

**5. Data Collection**

- When prompted, and when tunnel pressure ratio is at desired level, type F5 to commence data collection. The HP9000 will display "Collecting raw pressure data."

- The HP9000 will display "Raw data collection complete." and then store raw data to the disk drive selected. At this time the wind tunnel can be secured if desired. The HP9000 will also take and store raw calibration data at this time and display all filenames for raw data and raw calibration data storage.

- At this point there are several options available. Type F4 to repeat the previous data run. Type F3 to reset program set up. Type F6 to reduce the current day raw data, or F8 to exit program.

**6. Data Reduction and File Listing**

- Typing F7 will list all current day data files on the storage drive. The program prompts the user if copying files to the floppy drive (":,700,1") is desired.

- Type F6 to reduce current day raw data. It is recommended that all data be reduced the day it is taken.

- **NOTE:** Data reduction of large data files (multiple scans required for probe surveys) takes several minutes.

- Type F8 to exit the program and return to the ZOC menu.

7. **Data Analysis with READ_ZOC2**

- Typing F2 enters the program "READ_ZOC2" for data analysis.

- A menu is displayed with various choices for data analysis. Typing F1 prompts the user for the ZOC number, date (YMMDD) and run number from that day. It then prompts the user for the storage drive where this data is saved (must be the HFS hard drive or LIF floppy drive). This will read the reduced pressure and calibration data from the files generated by "SCAN_ZOC_06".

- **NOTE:** All other function key selections will result in an error before entering the ZOC data (typing F1).

- Functions available by typing the function key shown are as follows:

  F1 Read ZOC data stored on disk drives

  F2 Save pressure data array in psia to an ASCII file

  F3 Print pressure data to CRT or printer

  F4 Plot P/Pt and Mach number distributions and print out P/Pt and Mach number for multiple scans.

  F5 Plot vertical displacement against probe pressures and calculate mass averaged losses.

  F8 Exit READ_ZOC2

- **NOTE:** ASCII file size is "hard-wired" into the program and must be changed with a program edit.

- The program is currently configured to read the first 25 ZOC ports into the arrays for plotting surface pressure and Mach number distributions. Other distributions are possible with a simple program edit.

```
10    ! Program: SCAN_ZOC_06
20    ! by Richard Wendland
30    ! modified for traverse operations by David Hire
40    !
50    ! Description: Application program to operate HP69440 collecting pressure
60    !              readings from 1-3 ZOC-14 32 port modules using the CALSYS
70    !              2000 to provide calibration data, reduce raw pressure data
80    !              and store data to the hard drive.
90    !
100   ! Hardware:  (1) HP6944A Multi-processors
110   !              - (3) 500 kHz A/D Cards (HP69759A)
120   !                (3) High Speed Memory Cards (HP69791A)
130   !              - (1) Timer/Pacer Card (HP69736A)
140   !              - (1) Counter Card (HP69775A)
150   !            (1) HIScan CALSYS 2000 Calibration Module
160   !            (3) ZOC-14 32 port Electronic Pressure Scanning Modules
170   !            (4) VELMEX NF90 series stepping motor controller
180   !
190   ! Notes: 1. This program utilizes up to three (3) Zoc Modules storing data
200   !         of each Zoc into a seperate buffer Memory System (HP69791A).
210   !         2. COM /Names/ line and BDAT file ZOC_CONFIG_04 must match for
220   !         this program to operate.
230   !         3. CALSYS2000 requires a short period to stabilize before reading
240   !         the pressure valves.  The Pause for statement sets (line 470) this
250   !         wait period in seconds.  Adjustment of the variable my be required
260   !         as additional Zocs are integrated into the Data Acquisition System
.
270   !         4. CALSYS2000 currently configured for one (1) calibrator.  This
280   !         program is written to operate one (1) or two (2) calibrators.
290   !
300   ! Buffer Memory: 65536 16-bit data words in HP69791A per system
310   ! Timer: Maximum 32676 counts for one HP69775A
320   ! Max speed of HP system is Period=0.000002 sec. or 500 kHz.
330   !
340    COM /Issacom/ INTEGER X(1:1106)
350    COM /Isss_heap/ Isss_heap(1000)
360    COM /Names/ Buffer1,Adc1,Buffer2,Adc2,Buffer3,Adc3,Timer
370    Configure("Menu_off","ZOC_CONFIG_05")
380   !Configure("Ask_me","ZOC_CONFIG_05")
390   !
400 Key_label: !------ KEY LABEL ASSIGNMENT ------------------------------------
410           !
420    KEY LABELS ON
430    ON KEY 1 LABEL "Intro" GOTO Intro
440    ON KEY 2 LABEL "Key      Menu" GOTO Key_menu
450    ON KEY 3 LABEL "Set-up" GOTO Input
460    ON KEY 4 LABEL "Data     Preps" GOTO Data_prep
470    ON KEY 5 LABEL "Collect Data" GOTO Collect_data
480    ON KEY 6 LABEL "Reduce  Data" GOTO Reduce_data
490    ON KEY 7 LABEL "List    Copy" GOTO View_files
500    ON KEY 8 LABEL "Exit" GOTO Finish
510    !
520 Initialize_spac:  !----- ASSIGN MEMORY SPACE ----------------------------
530    Pause_for=1.5                          ! Wait time for CALSYS2000 stabilizatio
n
540   ! COM assigns calibration data array for 32 Zoc ports and standard values.
550    COM /Zoc_dat/ REAL Zoc_cal1(33,11) BUFFER,Zoc_cal2(33,11) BUFFER,Zoc_cal3(
33,11) BUFFER
560    COM /Stats/ REAL Pulse,Sample_number,Pause_for,INTEGER Cal_mod_id(3),Date$
[6],Run,Itrav
570    COM /Files/ File$(1:99,1:9)[14],Data_drive$[24] !Data file & storage drive
```

**Figure C1.** Program "SCAN_ZOC_06"

```
580   !
590    DIM Command_mode$(1:7)[2]
600    Command_mode$(1)="NH"
610    Command_mode$(2)="NM"
620    Command_mode$(3)="NL"
630    Command_mode$(4)="ZO"
640    Command_mode$(5)="PL"
650    Command_mode$(6)="PM"
660    Command_mode$(7)="PH"
670    !
680    Run=0
690    Data_reduced=0
700    !
710 Intro: !----- INTRODUCTION SCREEN -----------------------------------------
720    !
730    CLEAR SCREEN
740    PRINT "Introduction.  Program SCAN_ZOC_05:"
750    PRINT
760    PRINT "  - Scans 1-3 Zoc-14 Modules simultaneously (32 pressure sensing po
rts each)."
770    PRINT "  - Uses Zero Operate Calibrate (ZOC) principal:"
780    PRINT "      - Collects raw pressure data (Zero Operate)"
790    PRINT "      - Collects calibration data (Calibrate)"
800    PRINT "      - Reduces and stores data on selected hard or floppy drive."
810    PRINT "  - CALSYS2000 Calibration Module used for the reference pressure s
tandard."
820    PRINT "  - Raw pressure data reduced using calibration data from CALSYS200
0"
830    PRINT "    and Zocs in the calibration mode."
840    PRINT
850    PRINT "Input variables: Hard and Floppy drive for data storage"
860    PRINT "                 Sample frequency per port (1-50,000 Hz)"
870    PRINT "                 Samples per Port (1-1021)"
880    PRINT "                 Number of Zocs and their capacity"
890    PRINT
900    ! Note: HFS Files limited to 14 characters, LIF Files limited to 10 char.
910    !        Output files have a length of 10 characters to support LIF files.
920    !        Hard drive format is HFS Files.
930    !        Floppy drive format is LIF Files.
940    PRINT "Output files!     Raw data =>      ZW(Zoc#)(Date YMMDD)(Run#)"
950    PRINT "                  Calibration =>   ZC(Zoc#)(Date YMMDD)(Run#)"
960    PRINT "                  Reduced data => ZR(Zoc#)(Date YMMDD)(Run#)"
970    DISP "Select F2 key for Key Menu, F3 for system inputs, or F6 for data red
uction."
980 Hold: !
990    GOTO Hold
1000 !
1010 Key_menu:!----- KEY MENU ----------------------------------------------
1020 !
1030   CLEAR SCREEN
1040   PRINT "ZOC-14 Operating Menu."
1050   PRINT
1060   PRINT "Function                                        Function Key"
1070   PRINT
1080   PRINT "  Introduction                                      F1"
1090   PRINT "  Operating Menu                                    F2"
1100   PRINT "  System Set-up                                     F3"
1110   PRINT "  Final checklist and P2/P1 Cascade                 F4"
1120   PRINT "  Data Collection                                   F5"
1130   PRINT "  Data Reduction                                    F6"
1140   PRINT "  List Files (Copy files to Floppy)                 F7"
```

Figure C1. (cont) Program "SCAN_ZOC_06"

```
1150  PRINT
1160  PRINT "   Exit                                              F8"
1170  !
1180  GOTO Hold
1190  !
1200 Input:!----- INPUT VARIABLES ---------
1210        !
1220  ! Some array initialization and TIMEDATE value
1230  !
1240  MAT Zoc_cal1= (0)
1250  MAT Zoc_cal2= (0)
1260  MAT Zoc_cal3= (0)
1270  MAT File$= ("-")
1280  Date$=FNDate$(TIMEDATE)
1290  !
1300  !*******************************************************************************
1310  !  The following provides inputs for current run.
1320  !*******************************************************************************
1330  !
1340  CLEAR SCREEN
1350  PRINT "System Set-up."
1360  PRINT
1370  INPUT "Input the Atmospheric Pressure in PSIA:",P_atm
1380  !
1390  !  Hard drive or LIF floppy slection
1400  !
1410  INPUT "Select Hard drive for storing data (0=:,700 1=:,700,1)",Drv
1420  IF Drv=0 THEN
1430    Data_drive$=":,700,0"
1440  ELSE
1450    Data_drive$=":,700,1"
1460  END IF
1470  !
1480  !    Further inputs
1490  !
1500  INPUT "Enter data sampling rate (1-50Hz):",Hz
1510  PRINT "Data acquisition rate:";TAB(50);Hz;" Hz"
1520  !
1530  !    Input the type of scan made
1540  !
1550 Type_scan:  !
1560  PRINT
1570  PRINT
1580  PRINT "Enter the type of scan desired."
1590  PRINT
1600  PRINT "0 for a single scan."
1610  PRINT "1 for a multiple scans."
1620  PRINT "2 for LOWER BLADE survey."
1630  PRINT "3 for MIDDLE BLADE survey."
1640  PRINT
1650  INPUT "The desired scan type is:",Scan_type
1660  PRINT "The scan type is:";TAB(50);Scan_type
1670  !
1680  !    Selection of scan type routine
1690  !
1700  SELECT Scan_type
1710  CASE 0
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
1720      Itrav=1
1730      INPUT "Number of samples per port (1-1021): ",Sample_number
1740      PRINT "Number of samples per port:";TAB(50);Sample_number
1750   CASE 1
1760      PRINT "You have chosen the multiple scans option."
1770      PRINT "The number of scans chosen will determine the maximum"
1780      PRINT "number of samples per port as 1021/#scans."
1790      PRINT
1800      INPUT "Number of scans desired:",Itrav
1810      PRINT
1820      PRINT "The scans desired is:";TAB(50);Itrav
1830      PRINT "The max number of samples per port:";TAB(50);1023/Itrav
1840      PRINT
1850      INPUT "Number of samples per port: ",Sample_number
1860      PRINT "Number of samples per port:";TAB(50);Sample_number
1870      PRINT
1880   CASE 2
1890      Itrav=33
1900      Sample_number=10
1910      Increment=1000
1920   CASE 3
1930      Itrav=33
1940      Sample_number=10
1950      Increment=1000
1960   CASE ELSE
1970      BEEP
1980      PRINT "YOU DONE SCREWED UP PARD!  TRY AGAIN!!"
1990      GOTO Type_scan
2000   END SELECT
2010   !
2020   !****************************************************************
2030   !    ZOCS AND CALMOD COMBINATION UTILIZED
2040   !****************************************************************
2050   !
2060   INPUT "Number of Zoc's connected to Multi-programer",Zoc_number
2070   PRINT "Number of Zocs to be scanned:";TAB(50);Zoc_number
2080   Cal_mod_id(0)=Zoc_number
2090   FOR Zoc_case=1 TO Zoc_number
2100     SELECT Zoc_case
2110     CASE 1
2120       Run=1
2130       CALL File(1)
2140       INPUT "Enter Calibration Module number set for Zoc #1 (Enter 1 or 2):"
,Cal_mod_id(1)
2150     CASE 2
2160       Run=1
2170       CALL File(2)
2180       INPUT "Enter Calibration Module number set for Zoc #2 (Enter 1 or 2):"
,Cal_mod_id(2)
2190     CASE 3
2200       Run=1
2210       CALL File(3)
2220       INPUT "Enter Calibration Module number set for Zoc #3 (Enter 1 or 2):"
,Cal_mod_id(3)
2230     END SELECT
2240   NEXT Zoc_case
2250   !
2260   Period=1/Hz
2270   Pulse=Period/2                          !Pulse length of HP6973GA trigger signal
2280   !
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
2290  PRINT "Total raw data acquisition time: ";TAB(50);Itrav*Period*Sample_numbe
r*31;" sec."
2300  PRINT "Total calibration data acquisition time:";TAB(50);Period*5*31+(7*Pa
use_for);" sec."
2310  PRINT
2320  PRINT "Data storage disc - ";Data_dri$
2330  PRINT "Data will be stored in the following files beginning with Run #";Ru
n
2340  PRINT
2350  FOR I=1 TO Zoc_number
2360    J=(I-1)*3
2370    PRINT "Raw data file:              ";File$(Run,J+1)
2380    PRINT "Calibration data file:      ";File$(Run,J+2)
2390    PRINT "Reduced data file:          ";File$(Run,J+3)
2400    PRINT
2410  NEXT I
2420  !
2430  DISP "Select F4 key to begin data aquisition"
2440  GOTO Hold
2450  !
2460 Data_prep: !----- PREPARE FOR DATA COLLECTION                          -----
2470  CLEAR SCREEN
2480  PRINT "Data Collection Preparation."
2490  PRINT
2500  !
2510  !************************************************************************
2520  !   ERROR TRAP IF NO INITIAL PROGRAM SETTINGS COMPLETED
2530  !************************************************************************
2540  !
2550  IF Run=0 THEN
2560    PRINT "Program not initialized for data collection."
2570    DISP "Select F3 to initialize Set-up"
2580    GOTO Hold
2590  END IF
2600  !
2610  !**************************************************************************
2620  !   FINAL CHECKLIST PRIOR TO STARTING DATA RUN
2630  !**************************************************************************
2640  !
2650  PRINT "Check list:"
2660  PRINT "   - HiScan CALSYS2000 on-line"
2670  PRINT "   - CALMOD supply line valve is OPEN (on back of CALSYS2000)"
2680  PRINT "   - CALSYS2000 (Nitrogen) pressure source at 90 psi"
2690  !
2700  !****************************************************************************
2710  !  PLACING TRAVERSE IN INITIAL LOCATION HERE
2720  !****************************************************************************
2730  !
2740  IF Scan_type<2 THEN Skip_traverse
2750  PRINT
2760  PRINT "   - The Probe traverse is now moving to its initial position."
2770  PRINT
2780  !
2790  DIM Travcmd$[1]
2800  Sc2=10                          !Select code for 2nd serial card
2810  ASSIGN @Traverse TO Sc2         !Assign a path to the serial card
2820  CONTROL Sc2,14;30
2830  OUTPUT @Traverse;"EN"           !Place stepping motor on line
2840  !
2850  IF Scan_type=2 THEN
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
2860  OUTPUT @Traverse;"C,S1M1200,I1M35500,R"  !LOWER BLADE Traverse
2870  ELSE
2880  OUTPUT @Traverse;"C,S1M1200,I1M53000,R"  !MIDDLE BLADE Traverse
2890  END IF
2900  !
2910 Pre_posit: !
2920  ENTER @Traverse USING "#,-K";Travcmd$      !Receive acknowledge from stepper
2930  IF Travcmd$<>"^" THEN Pre_posit            !If no receipt, try again.
2940  !OUTPUT @Traverse;"X"
2950  !ENTER @Traverse USING "#,80";Pre_pos
2960  !
2970  !
2980 Skip_traverse:  !
2990  !
3000  !**************************************************************************
3010  !   INITIALIZE CALMOD HERE
3020  !**************************************************************************
3030  !
3040  PRINT
3050  PRINT "     You will here the CALMOD(s) cycle while it initiates.
3060  PRINT
3070  !
3080  CONTROL 9,5;3                           ! Set DIP & PIS to Active for CALSYS2000
3090  OUTPUT 9;VAL$(1);"IC";CHR$(13);END! Initialize Calibrator module #1
3100  OUTPUT 9;VAL$(2);"IC";CHR$(13);END! Initialize Calibrator module #2
3110  WAIT Pause_for                          ! Allow CALSYS2000 to set Zocs
3120  !
3130  !**************************************************************************
3140  !STEADY STATE P2/P1 ROUTINE HERE
3150  !**************************************************************************
3160  !
3170  DISP "Monitor Pratio and select F5 to start data acquisition."
3180  !
3190  !
3200 P2p1:!
3210  !
3220  ! Initialize devices
3230  Dacu=709
3240  Dvm=720
3250  ASSIGN @Dacu TO Dacu
3260  ASSIGN @Dvm TO Dvm
3270  ASSIGN @Instruments TO Dvm,Dacu
3280  CLEAR @Instruments
3290  OUTPUT @Dvm;"F1R7M3A0H0T3"      !DCV,Autorange,MathOff,AutocalOff
3300                                  !HiresOff,TriggerManual
3310 Ratio_loop: !
3320              FOR Id=0 TO 4 STEP 4
3330              GOSUB Read_stdy
3340              SELECT Id
3350                 CASE 0
3360                   P1=P_stdy*1000+P_atm
3370                 CASE 4
3380                   P2=P_stdy*1000+P_atm
3390              END SELECT
3400              NEXT Id
3410              Pratio=P2/P1
3420              PRINT "  P2   ","   P1   ","Pratio"
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
3430                PRINT P2,P1,Pratio
3440 GOTO Ratio_loop
3450 !
3460 Read_stdy:   !
3470                CLEAR @Dacu
3480                Ac$="AC"
3490                Id$=VAL$(Id)
3500                OUTPUT @Dacu;Ac$&Id$
3510                Total=0
3520                FOR I=1 TO 5
3530                  TRIGGER @Dvm
3540                  ENTER @Dvm;P_stdy
3550                  Total=Total+P_stdy
3560                NEXT I
3570                CLEAR @Dacu
3580                P_stdy=Total/5
3590                P_stdy=2*P_stdy          !Scaled for 100 psid transducer
3600                RETURN
3610  CLEAR @Instruments
3620  ASSIGN @Dacu TO *
3630  ASSIGN @Dvm TO *
3640  ASSIGN @Instruments TO *
3650  GOTO Hold
3660 !
3670 !**************************************************************************
3680 Collect_data:!------ COLLECT DATA -----------------------------------------
3690 !**************************************************************************
3700 !
3710 CLEAR @Instruments
3720 ASSIGN @Dacu TO *          !Deallocate paths used in stdy state read sys
3730 ASSIGN @Dvm TO *
3740 ASSIGN @Instruments TO *
3750  !
3760  !***********************************************************************
3770  !  ERROR TRAP IF NOT INITIALIZED
3780  !***********************************************************************
3790  IF Run=0 THEN
3800    PRINT "Program not initialized for data collection."
3810    DISP "Select F3 to initialize Set-up"
3820    GOTO Hold
3830  END IF
3840  !
3850  !
3860  !**********************************************************************
3870  !  DATA COLLECTION (CALLS Scan_zocs AND Traverse)
3880  !**********************************************************************
3890  !
3900  CLEAR SCREEN
3910  PRINT
3920  PRINT "Collecting raw pressure data."
3930  Count=Sample_number*32             ! Set Count as function of sample number
3940                                     ! and number of port readings (32) on
3950                                     ! Zoc for raw data collection.
3960  !
3970  ! The scan loop for all scan types is here
3980  !
3990  FOR Iscan=1 TO Itrav
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
4000  CALL Scan_zocs(Count,Pulse,Iscan) ! Collect raw data into Memory System
4010  IF Scan_type>1 AND Iscan<Itrav THEN GOSUB Traverse
4020  NEXT Iscan
4030  !
4040  !
4050  IF Scan_type<2 THEN Else
4060  PRINT "Zeroing traverse and taking stepping motor off line
4070  OUTPUT @Traverse;"C,S1M1000,I1M0,R"
4080  OUTPUT @Traverse;"Q"
4090  ASSIGN @Traverse TO *
4100 Else:  !
4110  !
4120  PRINT
4130  PRINT "Raw data collection complete.
4140  BEEP
4150 !
4160  GOTO Raw_data_xfer
4170 !*************************************************************************
4180 ! TRAVERSE OPERATIONS FOR VELMEX NF90 STEPPING MOTOR CONTROLLER
4190 !*************************************************************************
4200 Traverse: !
4210           SELECT Scan_type
4220           CASE 2
4230           OUTPUT @Traverse;"C,S1M1000,I1M-1000,R"
4240           CASE 3
4250           OUTPUT @Traverse;"C,S1M1000,I1M-1000,R"
4260           END SELECT
4270           !
4280 Posit:    !
4290           ENTER @Traverse USING "#,-K";Travcmd$
4300           IF Travcmd$<>"^" THEN Posit
4310           WAIT 0
4320           !OUTPUT @Traverse;"X"
4330           !ENTER @Traverse USING "#,80";Pos
4340           RETURN
4350           !
4360           !
4370 Raw_data_xfer:!------ TRANSFER RAW DATA FM MEMORY SYSTEM TO HARD DISC -----
4380  PRINT
4390 !
4400  FOR Zoc_case=1 TO Zoc_number      ! Collect raw data, reduce data and
4410    SELECT Zoc_case                 ! and store reduce data on hard drive
4420    CASE 1
4430      CALL Raw_dat(Buffer1,1)
4440    CASE 2
4450      IF Run>1 THEN
4460        Run=Run-1
4470      END IF
4480      CALL Raw_dat(Buffer2,2)
4490    CASE 3
4500      IF Run>1 THEN
4510        Run=Run-1
4520      END IF
4530      CALL Raw_dat(Buffer3,3)
4540    END SELECT
4550  NEXT Zoc_case
4560 !
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
4570 Initial_cal:!--------- CALIBRATION SET-UP
4580 ! Calibration data array for each Zoc: Zoc_cal(32,11)
4590 ! Format:
4600 !   For ports I=1 to 32
4610 !       Row 0, column 0: Period
4620 !       Row 0, column 1: Sample number
4630 !       Row 0, column 2: Zoc #
4640 !       Row 0, column 3: Calibrator module ID (1:50 psi 2:15 psi)
4650 !       Row 0: __ __ __ __ NH NM NL ZO PL PM PH (pressure Hg.)
4660 !       Row 0-3, column 11: Scan type,Itrav,Increment,P_atm
4670 !       Row 1: A0 A1 A2 A3 NH NM NL ZO PL PM PH (LS coef,press volts)
4680 !   LS coef are Least Squares curve fit coef for third order polynomial.
4690 !
4700  PRINT
4710  PRINT "Collecting calibration data."
4720  REAL Cal1(1120),Cal2(1120),Cal3(1120)! Calibration data array
4730  Iscan=1.0
4740  Count=32*5                      ! Set count to collect calibration data
4750  !
4760  MAT Zoc_cal1= (0)
4770  MAT Zoc_cal2= (0)
4780  MAT Zoc_cal3= (0)
4790  Zoc_cal1(0,0)=Period
4800  Zoc_cal1(0,1)=Sample_number
4810  Zoc_cal1(0,2)=1
4820  Zoc_cal1(0,3)=Cal_mod_id(1)
4830  Zoc_cal1(0,11)=Scan_type
4840  Zoc_cal1(1,11)=Itrav
4850  Zoc_cal1(2,11)=Increment
4860  Zoc_cal1(3,11)=P_atm
4870  Zoc_cal2(0,0)=Period
4880  Zoc_cal2(0,1)=Sample_number
4890  Zoc_cal2(0,2)=2
4900  Zoc_cal2(0,3)=Cal_mod_id(2)
4910  Zoc_cal2(0,11)=Scan_type
4920  Zoc_cal2(1,11)=Itrav
4930  Zoc_cal2(2,11)=Increment
4940  Zoc_cal2(3,11)=P_atm
4950  Zoc_cal3(0,0)=Period
4960  Zoc_cal3(0,1)=Sample_number
4970  Zoc_cal3(0,2)=3
4980  Zoc_cal3(0,3)=Cal_mod_id(3)
4990  Zoc_cal3(0,11)=Scan_type
5000  Zoc_cal3(1,11)=Itrav
5010  Zoc_cal3(2,11)=Increment
5020  Zoc_cal3(3,11)=P_atm
5030  !
5040 Collect_cal_dat:!---- COLLECT RAW CALIBRATION DATA ----
5050 !
5060 ! Collect raw calibration data for each CALSYS2000 setting
5070  FOR Index=1 TO 7
5080    CALL Cal2000(Command_mode$(Index),Index)
5090    CALL Scan_zocs(Count,Pulse,Iscan)
5100    FOR Zoc_case=1 TO Zoc_number
5110      SELECT Zoc_case
5120      CASE 1
5130        Input_rblock(Buffer1,Cal1(*),160,(Index-1)*160+1)
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
5140      CASE 2
5150        Input_rblock(Buffer2,Cal2(*),160,(Index-1)*160+1)
5160      CASE 3
5170        Input_rblock(Buffer3,Cal3(*),160,(Index-1)*160+1)
5180      END SELECT
5190    NEXT Zoc_case
5200  NEXT Index
5210  !
5220  ! Store collected calibration data
5230  FOR Zoc_case=1 TO Zoc_number
5240    SELECT Zoc_case
5250    CASE 1
5260      CALL Cal_dat(Cal1(*),Zoc_cal1(*))
5270    CASE 2
5280      CALL Cal_dat(Cal2(*),Zoc_cal2(*))
5290    CASE 3
5300      CALL Cal_dat(Cal3(*),Zoc_cal3(*))
5310    END SELECT
5320  NEXT Zoc_case
5330  !
5340  PRINT
5350  PRINT "Calibration data collection complete."
5360  BEEP
5370  WAIT .25
5380  BEEP
5390  OUTPUT 9;VAL$(1);"IC";CHR$(13);END! Initialize Calibrator module #1
5400  OUTPUT 9;VAL$(2);"IC";CHR$(13);END! Initialize Calibrator module #2
5410  PRINT
5420  PRINT "*** Secure Calibrator pressure valve to conserve Nitrogen ***"
5430  PRINT
5440  PRINT "CALSYS2000 Calibration modes and pressures (in Hg):"
5450 Fmt1:IMAGE /,5X,K,10X,K,10X,K,10X,K
5460  PRINT USING Fmt1;"Mode","Zoc #1","Zoc #2","Zoc #3"
5470 Fmt2:IMAGE 6X,K,10X,3D.4D,8X,3D.4D,8X,3D.4D
5480  FOR I=4 TO 10
5490    PRINT USING Fmt2;Command_mode$(I-3),Zoc_cal1(0,I),Zoc_cal2(0,I),Zoc_cal3
(0,I)
5500  NEXT I
5510  DISP "Select F4 for another data run, or F6 to reduce data"
5520  GOTO Hold
5530  !
5540 Reduce_data:!----- REDUCE DATA AND STORE ON HARD DRIVE --------------------
5550 ! Routine loads raw and calibration data from storage drive, reduces the
5560 ! data, and stores the data to the storage drive.
5570 !
5580  CLEAR SCREEN
5590  PRINT "Calibration and Raw data reduction and storage."
5600  PRINT
5610  IF Run=0 THEN
5620    INPUT "Enter the date of data for reduction (YMMDD):",Date$
5630    INPUT "Number of Zoc's connected to Multi-programer",Zoc_number
5640    INPUT "Select data storage drive (0=:,700 1=:,700,1)",Drv_case
5650    SELECT Drv_case
5660    CASE 0
5670      Data_drive$=":,700,0"
5680    CASE 1
5690      Data_drive$=":,700,1"
5700    END SELECT
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
5710  END IF
5720 !
5730  MAT File$= ("-")
5740  FOR Zoc_case=1 TO Zoc_number    !Assign files from storage to File$(*)
5750    SELECT Zoc_case
5760    CASE 1
5770      CALL File_scan(1)
5780    CASE 2
5790      CALL File_scan(2)
5800    CASE 3
5810      CALL File_scan(3)
5820    END SELECT
5830  NEXT Zoc_case
5840 !
5850  PRINT "Current files on storage disc ";Data_drive$;" for date ";Date$
5860  PRINT
5870  FOR Rn=1 TO Run
5880    FOR Zn=1 TO Zoc_number
5890      FOR I=1 TO 3
5900        PRINT USING "3X,K,#";File$(Rn,(Zn-1)*3+I)
5910      NEXT I
5920      PRINT USING "+,L"
5930    NEXT Zn
5940  NEXT Rn
5950  PRINT
5960 !
5970  FOR Run_red=1 TO Run                   ! Reduce data routine.
5980    FOR Zoc_case=1 TO Zoc_number
5990      SELECT Zoc_case
6000      CASE 1
6010        CALL Raw_red_dat(1,Run_red)
6020      CASE 2
6030        CALL Raw_red_dat(2,Run_red)
6040      CASE 3
6050        CALL Raw_red_dat(3,Run_red)
6060      END SELECT
6070    NEXT Zoc_case
6080  NEXT Run_red
6090  Run=0
6100  Data_reduced=1
6110  BEEP
6120  DISP "Select F3 reinitialize set-up for data collection, or F8 to Exit"
6130  GOTO Hold
6140  !
6150 View_files: !----- VIEW FILES ON STORAGE DRIVE -----------------------------
6160 ! Routine loads files from storage drive and displays file names.
6170 !
6180  CLEAR SCREEN
6190  PRINT "List Raw, Calibration and Reduced data files."
6200  PRINT
6210  IF Data_reduced=1 THEN Print_files
6220  IF Run=0 THEN
6230    INPUT "Enter the date of data for for reduction (YMMDD):",Date$
6240    INPUT "Number of Zoc's connected to Multi-programer",Zoc_number
6250    INPUT "Select data storage drive (0=:,700 1=:,700,1)",Drv_case
6260    SELECT Drv_case
6270    CASE 0
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
6280      Data_drive$=":,700,0"
6290    CASE 1
6300      Data_drive$=":,700,1"
6310    END SELECT
6320  END IF
6330 Print_files: !
6340  PRINT "Data storage drive name =    ";Data_drive$
6350 !
6360  MAT File$= ("-")
6370  FOR Zoc_case=1 TO Zoc_number    !Assign files from storage to File$(*)
6380    SELECT Zoc_case
6390    CASE 1
6400      CALL File_scan(1)
6410    CASE 2
6420      CALL File_scan(2)
6430    CASE 3
6440      CALL File_scan(3)
6450    END SELECT
6460  NEXT Zoc_case
6470 !
6480  PRINT
6490  PRINT "Current files on storage disc for date ";Date$
6500  PRINT
6510  FOR Rn=1 TO Run                         !Print the files listing on the
6520    FOR Zn=1 TO Zoc_number                !designated storage drive.
6530      FOR I=1 TO 3
6540        PRINT USING "3X,K,#";File$(Rn,(Zn-1)*3+I)
6550      NEXT I
6560      PRINT USING "/"
6570    NEXT Zn
6580  NEXT Rn
6590  !
6600  IF Drv_case<2 THEN
6610    INPUT "Do you want to copy files from the Hard drive to Floppy? (0=No 1=
Yes)",Copy_h_to_f
6620    IF Copy_h_to_f=0 THEN End_view
6630    ON ERROR GOSUB View_error
6640    PRINT
6650    PRINT "WARNING: Any duplicate existing files on the Floppy will be copie
d over!"
6660    PRINT                                 !Copy the files from the designated
6670    FOR Rn=1 TO Run                       !hard drive to the floppy drive.
6680      FOR Zn=1 TO Zoc_number
6690        FOR I=1 TO 3
6700          Fi$=File$(Rn,(Zn-1)*3+I)
6710          COPY Fi$&Data_drive$ TO Fi$&":,700,1"
6720          IF Fi$<>"-" THEN
6730            PRINT "File ";Fi$;" copied to Floppy"
6740          END IF
6750        NEXT I
6760      NEXT Zn
6770    NEXT Rn
6780    PRINT
6790    PRINT "Files have been copied from ";Data_drive$;" to Floppy :,700,1"
6800  END IF
6810  GOTO End_view
6820 View_error:   !
6830  SELECT ERRN
6840  CASE 56                                  !File does not exist, then continue.
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
6850     CLEAR ERROR
6860     ERROR RETURN                              !Return to line following COPY
6870   CASE 54                                     !Duplicate file exist on the floppy,
6880     PURGE F1$&":,700,1"                       !then purge the dup file, retrun to
6890     CLEAR ERROR
6900     RETURN                                    !the line COPY and copy the file.
6910   CASE ELSE
6920     DISP ERRM$
6930     PAUSE
6940   END SELECT
6950   !
6960   !
6970 End_view: !
6980   Run=0
6990   DISP "Select F2 to return to menu, or F8 to Exit"
7000   GOTO Hold
7010   !
7020 Finish:!
7030   LOAD "ZOC_MENU",10
7040 !
7050   END
7060 End:!==========================================================================
7070 ! Function to return todays date for input into file names
7080   DEF FNDate$(Seconds)
7090     Julian=Seconds DIV 86400-1721119
7100     Year=(4*Julian-1) DIV 146097
7110     Julian=(4*Julian-1) MOD 146097
7120     Day=Julian DIV 4
7130     Julian=(4*Day+3) DIV 1461
7140     Day=(4*Day+3) MOD 1461
7150     Day=(Day+4) DIV 4
7160     Month=(5*Day-3) DIV 153   ! Month
7170     Day=(5*Day-3) MOD 153
7180     Day=(Day+5) DIV 5         ! Day
7190     Year=100*Year+Julian
7200     IF Month<10 THEN
7210       Month=Month+3
7220     ELSE
7230       Month=Month+3
7240       Year=Year+1
7250     END IF
7260     Year$=VAL$(Year)
7270     IF Month<10 THEN
7280       Month$="0"&VAL$(Month)
7290     ELSE
7300       Month$=VAL$(Month)
7310     END IF
7320     IF Day<10 THEN
7330       Day$="0"&VAL$(Day)
7340     ELSE
7350       Day$=VAL$(Day)
7360     END IF
7370     D$=Year$[4]&Month$&Day$
7380     RETURN D$
7390   FNEND
7400   !--------------------------------------------------------------------------
7410   ! Subroutine to build file names as required by Run number for a specified
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
7420  ! Zoc, and assign existing files to the File$ matrix.
7430  SUB File(Zn)
7440    COM /Stats/ REAL Pulse,Sample_number,Pause_for,INTEGER Cal_mod_id(3),Dat
e$,Run,Itray
7450    COM /Files/ File$(*),Data_drive$
7460    DIM Data_disc1$[23],Data_disc2$[23],Data_disc3$[23]
7470    ON ERROR GOTO Error
7480    J=(Zn-1)*3
7490 Assign_file:   !
7500    File1=0
7510    Data_file1$="ZW"&VAL$(Zn)&Date$&VAL$(Run)
7520    Data_disc1$=Data_file1$&Data_drive$
7530    ASSIGN @Check_path1 TO Data_disc1$    !Check for existance of ZW_.
7540    File$(Run,J+1)=Data_file1$            !Assign ZW_ to matrix.
7550    File1=1                               !Flag to ID file exists.
7560    !
7570    File2=0
7580    Data_file2$="ZC"&VAL$(Zn)&Date$&VAL$(Run)
7590    Data_disc2$=Data_file2$&Data_drive$
7600    ASSIGN @Check_path2 TO Data_disc2$    !Check for existance of ZC_.
7610    File$(Run,J+2)=Data_file2$            !Assign ZC_ to matrix.
7620    File2=1                               !Flag to ID file exists.
7630    !
7640    Data_file3$="ZR"&VAL$(Zn)&Date$&VAL$(Run)
7650    Data_disc3$=Data_file3$&Data_drive$
7660    ASSIGN @Check_path3 TO Data_disc3$    !Check for existance of ZR_.
7670    File$(Run,J+3)=Data_file3$            !Assign ZR_ to matrix.
7680    !
7690    Run=Run+1                             !If ZW_ exist, reassign Run #
7700    ASSIGN @Check_path1 TO *
7710    ASSIGN @Check_path2 TO *
7720    ASSIGN @Check_path3 TO *
7730    GOTO Assign_file                      !Check storage disc again.
7740 Error:  ! Subroutine if ERROR=56, files donot exist for Run and Zoc
7750    IF ERRN<>56 THEN
7760      PRINT ERRM$
7770      PAUSE
7780    END IF
7790    IF File1=0 THEN Fin                   !File ZW_ doesnot exist, exit
7800    IF File1=1 THEN                       !File ZW_ exists
7810      IF File2=0 THEN                     !File ZC_ doesnot exists, therefore
7820        ASSIGN @Check_path1 TO *
7830        PURGE Data_disc1$                 !delete ZW_.
7840      ELSE
7850        Run=Run+1                         !File ZW_ & ZC_ exist, step Run
7860      END IF                              !and continue.
7870    END IF
7880    ASSIGN @Check_path1 TO *
7890    ASSIGN @Check_path2 TO *
7900    ASSIGN @Check_path3 TO *
7910    GOTO Assign_file
7920 Fin:   !
7930    ASSIGN @Check_path1 TO *
7940    ASSIGN @Check_path2 TO *
7950    ASSIGN @Check_path3 TO *
7960    Data_file2$="ZC"&VAL$(Zn)&Date$&VAL$(Run)
7970    Data_file3$="ZR"&VAL$(Zn)&Date$&VAL$(Run)
7980    File$(Run,J+1)=Data_file1$            !Create ZW_ to matrix.
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
7990     File$(Run,J+2)=Data_file2$              !Create ZC   to matrix.
8000     File$(Run,J+3)=Data_file3$              !Assign ZP_  to matrix.
8010   SUBEND
8020   !----------------------------------------------------------------------
8030   ! Subroutine to operate the HP69440 Multi-programmer for scanning Zocs.
8040   SUB Scan_zocs(Count,Pulse,Iscan)
8050     COM /Names/ Buffer1,Adc1,Buffer2,Adc2,Buffer3,Adc3,Timer
8060     Wait_time=Count*2*Pulse+10.0        ! Set Timer wait time to +10 secs.
8070     Init(Timer)                         ! Initialize Timer system
8080     Set_timeout(Timer,Wait_time)        ! Set Pause_for period of xx secs.
8090     Set_count(Timer,Count)              ! Set Count number into Timer
8100     Set_period(Timer,Pulse)             ! Set Timer pulse length in secs.
8110     IF Iscan>1 THEN Maintain_point      ! If scanning>1 then don't reset pointer
8120     Init(Buffer1)                       ! Initialize Buffer for data storage
8130     Init(Buffer2)
8140     Init(Buffer3)
8150 Maintain_point:    !
8160     Start(Timer)                        ! Start data sample collection
8170     Wait_for(Timer)                     ! Data samples stored in Memory System
8180   SUBEND
8190   !
8200   !----------------------------------------------------------------------
8210   ! Subroutine to collect raw pressure data from Memory System and store
8220   ! onto the hard drive for future data reduction.
8230   SUB Raw_dat(Buff,Zn)
8240     COM /Stats/ REAL Pulse,Sample_number,Pause_for,INTEGER Cal_mod_id(3),Dat
e$,Run,Itrav
8250     COM /Files/ File$(*),Data_drive$ ! Data file listing for 99 runs.
8260     ON ERROR GOTO Error
8270     INTEGER Raw_data(32672) BUFFER  ! Integer raw data buffer for 32*1021
8280                                     ! data samples.  Integer format for
8290                                     ! mininum transfer time to storage.
8300     DIM Data_disc$[25]
8310     It=Itrav
8320     Sn=Sample_number
8330 Assign_file:   !
8340     Data_file$=File$(Run,(Zn-1)*3+1) ! Raw data file
8350     Data_disc$=Data_file$&Data_drive$
8360     CREATE BDAT Data_disc$,32*It*Sn+1*It,2 ! Create BDAT file w/2 byte recor
ds.
8370     ASSIGN @Data_path TO Data_disc$ ! Assign path to hard drive
8380     ASSIGN @Buffer_path TO BUFFER Raw_data(*);FORMAT OFF
8390     Input_iblock(Buff,Raw_data(*),It*Sn*32+1*It,1)      ! Load data samples
8400     !
8410     !PRINTER IS 702
8420     !PRINT Raw_data(*)            ! Block print raw data for test
8430     !PRINTER IS CRT
8440     !
8450     CONTROL @Buffer_path,4;32*2*It*Sn+2*It     ! Close buffer when full
8460     TRANSFER @Buffer_path TO @Data_path     ! Transfer data Data_disc
8470     ASSIGN @Buffer_path TO *
8480     ASSIGN @Data_path TO *
8490     PRINT "Raw pressure data: Run#";Run;", Zoc#";Zn;", storage drive file ";
Data_file$&Data_drive$
8500     GOTO Fin
8510 Error: !
8520     IF ERRN<>54 THEN
8530       PRINT ERRM$
8540       PAUSE
8550     END IF
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
8560     IF ERRN=54 THEN                          ! Run stop routine when compiling
8570       Run=Run+1                              ! multiple data runs without data
8580       CALL File(Zn)                          ! reduction.
8590     END IF
8600     GOTO Assign_file
8610 Fin:      !
8620  SUBEND
8630 !---------------------------------------------------------------------------
8640 ! Subroutine controls calibration mode and reads pressure from Pressure
8650 ! Standard into Zoc_cal(*) array.
8660  SUB Cal2000(Command$,I)
8670     COM /Zoc_dat/ REAL Zoc_cal1(*) BUFFER,Zoc_cal2(*) BUFFER,Zoc_cal3(*) BUF
FER
8680     COM /Stats/ REAL Pulse,Sample_number,Pause_for,INTEGER Cal_mod_id(3),Dat
e$,Run,Itrav
8690     DIM Pressure$[5]                          ! Required to read data stream
8700     OUTPUT 9;VAL$(1);Command$;CHR$(13);END    ! Sets calibrator #1 mode
8710     OUTPUT 9;VAL$(2);Command$;CHR$(13);END    ! Sets calibrator #2 mode
8720     WAIT Pause_for                            ! Allow CALSYS2000 to stabilize
8730     FOR K=1 TO Cal_mod_id(0)                  ! Read CALSYS2000 cal press
8740       SELECT K
8750       CASE 1
8760         OUTPUT 9;VAL$(Cal_mod_id(1));"RP";CHR$(13);END
8770         ENTER 9 USING "#,SD.5DESZZ,K";Zoc_cal1(0,I+3),Pressure$
8780       CASE 2
8790         OUTPUT 9;VAL$(Cal_mod_id(2));"RP";CHR$(13);END
8800         ENTER 9 USING "#,SD.5DESZZ,K";Zoc_cal2(0,I+3),Pressure$
8810       CASE 3
8820         OUTPUT 9;VAL$(Cal_mod_id(3));"RP";CHR$(13);END
8830         ENTER 9 USING "#,SD.5DESZZ,K";Zoc_cal3(0,I+3),Pressure$
8840       END SELECT
8850     NEXT K
8860     IF I<=3 THEN                          ! Account for positive pressures used
8870       Zoc_cal1(0,I+3)=-Zoc_cal1(0,I+3)    ! by CALSYS2000 in the NH,NM, & NL mo
de.
8880       Zoc_cal2(0,I+3)=-Zoc_cal2(0,I+3)
8890       Zoc_cal3(0,I+3)=-Zoc_cal3(0,I+3)
8900     END IF
8910  SUBEND
8920 !---------------------------------------------------------------------------
8930 ! Subroutine stores calibration data collected from Memory System and
8940 ! CALSYS2000 calibration pressure data onto the hard drive.
8950 ! Zoc_cal_ is then stored onto the hard drive.
8960  SUB Cal_dat(REAL Cal(*),Zoc_cal(*) BUFFER)
8970     COM /Stats/ REAL Pulse,Sample_number,Pause_for,INTEGER Cal_mod_id(3),Dat
e$,Run,Itrav
8980     COM /Files/ File$(*),Data_drive$ ! Data file listing for 99 runs.
8990 !
9000 ! Converting Cal(*) to Zoc_cal(*)
9010     FOR J=4 TO 10                    ! Cal runs: NH,NM,NL,ZO,PL,PM,PH
9020       FOR I=1 TO 32                  ! Zoc ports per calibration run
9030         FOR K=0 TO 4                 ! Number of samples per run
9040           Zoc_cal(I,J)=Zoc_cal(I,J)+Cal(I+K*32+(J-4)*160)
9050         NEXT K
9060         Zoc_cal(I,J)=Zoc_cal(I,J)/5 ! Average of 5 samples per port I
9070       NEXT I
9080     NEXT J
9090 !
9100 ! Transfer calibration data to hard drive.
9110     ON ERROR GOSUB Purge_file
9120     DIM Data_disc$[23]               ! Define string for data file name
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
9130     Zn=Zoc_cal(0,2)                    ! Define Zoc number
9140     Data_file$=File$(Run,(Zn-1)*3+2) ! Calibration data file
9150     Data_disc$=Data_file$&Data_drive$
9160     CREATE BDAT Data_disc$,33,8*12  ! Create BDAT file of 12*8 byte
9170     ASSIGN @Data_path TO Data_disc$ ! Assign path to hard drive
9180     ASSIGN @Buffer_path TO BUFFER Zoc_cal(*);FORMAT OFF
9190     CONTROL @Buffer_path,4;8*12*33  !Set data file length
9200     TRANSFER @Buffer_path TO @Data_path!Store cal data on hard drive
9210     ASSIGN @Buffer_path TO *          ! Close path
9220     ASSIGN @Data_path TO *            ! Close path
9230     PRINT "Calibration data: Run#";Run;", Zoc#";Zn;", storage drive file ";D
ata_disc$
9240     GOTO Fin
9250 Purge_file:   !
9260     IF ERRN=54 THEN
9270       PRINT "Error occured in SUB Cal_dat.  Error:";ERRN
9280       PAUSE
9290     END IF
9300     RETURN
9310 Fin:                    !
9320  SUBEND
9330  !-----------------------------------------------------------------------------
9340  ! Subroutine loads raw and calibration data from the storage drive,
9350  ! reduces the data, and stores the data onto the storage drive.
9360  ! Calibration data is reduced using the Least Squares Curve fit to obtain
9370  ! coefficients for a third-order polynomial.  The raw pressure data is
9380  ! reduced using these coefficients.
9390  ! Buffer arrays are replaced with standard arrays for data manipulation.
9400  ! Utilization of Buffers and the TRANSFER routine results in lost of the
9410  ! first several data bytes when data is transferred from floppy media to
9420  ! the buffer;  Utilization of OUTPUT, ENTER, and arrays results in no
9430  ! data lost with floppy media.  Hard disc media works well with either
9440  ! data manipulation technique using buffers or standard arrays.
9450  SUB Raw_red_dat(Zn,Rn)
9460    COM /Names/ Buffer1,Adc1,Buffer2,Adc2,Buffer3,Adc3,Timer
9470    COM /Stats/ REAL Pulse,Sample_number,Pause_for,INTEGER Cal_mod_id(3),Dat
e$[6],Run,Itrav
9480    COM /Files/ File$(*),Data_drive$   !Data file listing for 99 runs.
9490    Data_file1$=File$(Rn,(Zn-1)*3+2)   ! Calibration data file
9500    Data_file2$=File$(Rn,(Zn-1)*3+1)   ! Raw data file name
9510    Data_file3$=File$(Rn,(Zn-1)*3+3)   ! Reduced data file name
9520    !
9530    IF Data_file3$<>"-" THEN           ! Continue if Reduce data file
9540      GOTO Fin                         ! doesnot exist.
9550    END IF
9560    !
9570    IF Data_file1$="-" THEN
9580      PRINT "Calibration file doesnot exist for Run#";Rn;", Zoc#";Zn
9590      GOTO Fin
9600    END IF
9610    !
9620    ON ERROR GOSUB Error
9630    DIM Data_disc1$[23]
9640    DIM Data_disc2$[23]
9650    DIM Data_disc3$[23]
9660    Data_disc1$=Data_file1$&Data_drive$
9670    REAL Zoc_cal(32,11)                 !Array to handle calibration data
9680    !
9690 Data_reduction:   !
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
9700    PRINT "Data reduction: Run#";Rn;", Zoc#";Zn
9710    !
9720    ASSIGN @Data_path1 TO Data_disc1$;FORMAT OFF
9730    ENTER @Data_path1;Zoc_cal(*)        !Load raw calibration data into array
9740    ASSIGN @Data_path1 TO *
9750    !
9760 ! Calibration data reduction using Least Squares Polynominal fitting.
9770    REAL A(3,3),B(3),C(3),Sum_x(6),A_inv(3,3)! Least Square reduction arrays
9780    FOR K=1 TO 32                     ! Loop for each port
9790 !
9800      MAT C= (0)
9810      MAT Sum_x= (0)
9820 !
9830      FOR J=1 TO 6                    ! Routine to reduce individual port cal
9840        FOR I=4 TO 10                 ! data into elements to a power - J
9850          Sum_x(J)=Sum_x(J)+Zoc_cal(K,I)^J
9860        NEXT I
9870      NEXT J
9880 !
9890      FOR I=0 TO 3                    ! Derive A array
9900        FOR J=0 TO 3
9910          A(I,J)=Sum_x(I+J)
9920        NEXT J
9930      NEXT I
9940      A(0,0)=7
9950 !
9960      FOR J=0 TO 3                    ! Derive C array
9970        FOR I=4 TO 10
9980          C(J)=C(J)+Zoc_cal(K,I)^J*Zoc_cal(0,I)
9990        NEXT I
10000     NEXT J
10010!
10020     MAT A_inv= INV(A)
10030     MAT B= A_inv*C                 ! B array is matrix of Least Square
10040!                                     coefficients a0,a1,a2,& a3 for polynomial
10050!                                     equation fitting calibration data for a
10060!                                     specified port
10070!
10080! Collect Least Square coefficients
10090     Zoc_cal(K,0)=B(0)              !Coefficient a0
10100     Zoc_cal(K,1)=B(1)              !Coefficient a1
10110     Zoc_cal(K,2)=B(2)              !Coefficient a2
10120     Zoc_cal(K,3)=B(3)              !Coefficient a3
10130!
10140   NEXT K
10150   !
10160   ASSIGN @Data_path1 TO Data_disc1$;FORMAT OFF
10170   OUTPUT @Data_path1;Zoc_cal(*)       !Store reduced calibration data
10180   ASSIGN @Data_path1 TO *
10190   !
10200   PRINT "Calibration data reduced and transferred to ";Data_file1$
10210   !
10220   ! Recover raw data, convert to real, reduce then store in blocks
10230   ! of samples (32*ports scanned per block)*Itrav
10240   !
10250   Itrav=Zoc_cal(1,11)
10260   Sn=Zoc_cal(0,1)                        !Sample number.
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
10270   ALLOCATE INTEGER Data_integer(1:32) !Array to handle raw integer data.
10280   ALLOCATE REAL Data_real(1:32),Data(32) !Arrays to handle raw and reduced
.
10290   Data_disc2$=Data_file2$&Data_drive$ !real data.
10300   Data_file3$="ZR"&VAL$(Zn)&Date$&VAL$(Rn)  !Reduced data file name.
10310   Data_disc3$=Data_file3$&Data_drive$
10320   CREATE BDAT Data_disc3$,Sn*Itrav,8*33 !BDAT file of 33*8 byte records.
10330   ASSIGN @Data_path2 TO Data_disc2$;FORMAT OFF
10340   ASSIGN @Data_path3 TO Data_disc3$;FORMAT OFF
10350   !
10360   Step_point=2
10370   Step_increment=32*Sn+1
10380   FOR Group=1 TO Itrav
10390   !
10400   CONTROL @Data_path2,5;Step_point  !Set read pointer to 2nd record
10410   !                                 !in raw integer data file.
10420   Step_point=Step_point+Step_increment  !Increment pointer start point.
10430   !
10440   FOR Block=1 TO Sn
10450     ENTER @Data_path2;Data_integer(*) !Load raw data into array.
10460     SELECT Zoc_cal(0,2)               !Translating raw interger data into
10470     CASE 1                            !raw real data.
10480       Translate(Adc1,Data_integer(*),Data_real(*))
10490     CASE 2
10500       Translate(Adc2,Data_integer(*),Data_real(*))
10510     CASE 3
10520       Translate(Adc3,Data_integer(*),Data_real(*))
10530     END SELECT
10540  !
10550  !  Data check steps commented out.
10560  !
10570     !PRINTER IS 702
10580     !PRINT "Integer data"
10590     !PRINT Data_integer(*)
10600     !PRINT "Real data"
10610     !PRINT Data_real(*)
10620     !PRINTER IS CRT
10630   !
10640! Routine to reduce raw real data:
10650!
10660!       Data = a0 + a1*x + a2*x^2 + a3*x^3
10670!
10680! where a0,a1,a2, & a3 are Least Square coefficients, and x is
10690! the individual port raw data value.
10700!
10710     Data(0)=Block                    ! Store reduce data sample number.
10720         FOR K=1 TO 32
10730             Data(K)=Zoc_cal(K,0)+Zoc_cal(K,1)*Data_real(K)+Zoc_cal(K,2)*Da
ta_real(K)^2+Zoc_cal(K,3)*Data_real(K)^3
10740         NEXT K
10750!
10760     !
10770     !PRINTER IS 702
10780     !PRINT Data(*)                   ! Print bloack for test commented out.
10790     !PRINTER IS CRT
10800     !
10810     OUTPUT @Data_path3;Data(*)       !Store block of reduced data into
10820    NEXT Block                        !into the file on the designated drive.
10830    NEXT Group
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

```
10840    !
10850    ASSIGN @Data_path3 TO *
10860    ASSIGN @Data_path2 TO *
10870    PRINT "Raw data reduced and transferred to ";Data_file3$
10880    PRINT
10890    GOTO Fin
10900 Error:                                !Routine to trap error in program.
10910    PRINT ERRM$
10920    PAUSE
10930    RETURN
10940 Fin:  !
10950 SUBEND
10960!------------------------------------------------------------------------
10970 ! Subroutine to load existing files required by Run number for a specified
10980 ! Zoc, and assign existing files to the File$ matrix for Data reduction
10990 ! and List files routines.
11000 SUB File_scan(Zn)
11010    COM /Stats/ REAL Pulse,Sample_number,Pause_for,INTEGER Cat_mod_id(3),Dat
e$,Run,Itrav
11020    COM /Files/ File$(*),Data_drive$
11030    DIM Data_disc1$[23],Data_disc2$[23],Data_disc3$[23]
11040    Rn=1
11050    Loop=1
11060    File_in_storage=0
11070    ON ERROR GOTO Error
11080    J=(Zn-1)*3
11090    WHILE Loop=1
11100      File1=0
11110      Data_file1$="ZW"&VAL$(Zn)&Date$&VAL$(Rn)
11120      Data_disc1$=Data_file1$&Data_drive$
11130      ASSIGN @Check_path1 TO Data_disc1$ !Check for existance of ZW_.
11140      File$(Rn,J+1)=Data_file1$          !Assign ZW_ to matrix.
11150      File1=1
11160    !
11170      Data_file2$="ZC"&VAL$(Zn)&Date$&VAL$(Rn)
11180      Data_disc2$=Data_file2$&Data_drive$
11190      ASSIGN @Check_path2 TO Data_disc2$ !Check for existance of ZC_.
11200      File$(Rn,J+2)=Data_file2$          !Assign ZC_ to matrix.
11210    !
11220      Data_file3$="ZR"&VAL$(Zn)&Date$&VAL$(Rn)
11230      Data_disc3$=Data_file3$&Data_drive$
11240      ASSIGN @Check_path3 TO Data_disc3$ !Check for existance of ZR_.
11250      File$(Rn,J+3)=Data_file3$          !Assign ZR_ to matrix.
11260    !
11270      GOTO Assign_file                   !Check storage disc again.
11280 Error: ! Subroutine if ERROR=56, files donot exist for Rn and Zoc
11290      IF ERRN<>56 THEN
11300        PRINT ERRM$
11310        PAUSE
11320      END IF
11330 Assign_file:!
11340      IF File1=1 THEN                    !Switch to exit program
11350        File_in_storage=1
11360      END IF
11370      IF File1=0 THEN
11380        IF File_in_storage=1 THEN
11390          Loop=0
11400        END IF
```

Figure C1. (cont) Program "SCAN_ZOC_06"

```
11410      END IF
11420      ASSIGN @Check_path1 TO *
11430      ASSIGN @Check_path2 TO *
11440      ASSIGN @Check_path3 TO *
11450      IF Rn=100 THEN
11460        Loop=0
11470      END IF
11480      Rn=Rn+1
11490    END WHILE
11500 Fin:  !
11510    Run=Rn-2
11520 SUBEND
11530 !-----------------------------------------------------------
```

**Figure C1.** (cont) Program "SCAN_ZOC_06"

# APPENDIX D. DATA ANALYSIS PROGRAM "READ_ZOC2"

```
10    ! Program: READ_ZOC2
20    ! Description: Reads specified data compiled from program SCAN_ZOC_05.
30    ! by Rick Wendland
40    ! modified by David Myre
50    ! modified 5 Nov 1992
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$[60],X_label$[60],Y_label$[
601
110    INTEGER Disk_drive,Zoc,Run,View,Sample_min,Sample_max,Port_min
120    INTEGER Port_max,Scan_max,Avg
130    REAL N1,N2
140    !Variable initialization
150    P_atm=14.696           !Standard day atmospheric pressure
160    Conv=.491154           !Conversion from In-Hg to psi
170    Gamma=1.4              !Ratio of specific heats
180    Sc=.0025               !Sub Square sizing
190    Allocated=0
200    !Dimension string variable for data location:
210    DIM Data_disc1$[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
290    ON KEY 2 LABEL "SAVE AS ASCII     " GOTO Save
300    ON KEY 3 LABEL "PRINT    DATA     " GOTO Print
310    ON KEY 4 LABEL "Cp       PLOT     " GOTO Cp
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"
480     PRINT "       Save reduced data to an ASCII file               F2"
490     PRINT "       Print data to CRT or PRINTER                     F3"
500     PRINT "       Plot and Print P/Pt                              F4"
510     PRINT "       Plot Pt data/Print Losses                        F5"
520     PRINT
530     PRINT
540     PRINT "       Exit Program                                     F8"
550     PRINT
560     !
570 Hold:    !
```

**Figure D1.** Program "READ_ZOC2"

```
580          GOTO Hold
590          !
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 # (1,2,3), date (YMMDD), and run #:",Zoc,Date$,Run
700    PRINT
710    PRINT
720    PRINT
730    PRINT "Enter the disk drive where data is stored as below.
740    PRINT "       0 is HFS format or 700,0"
750    PRINT "       1 is LIF floppy or 700,1"
760    PRINT
770    INPUT "Enter Disc where data is located:",Disk_drive
780    PRINT
790    !
800    !*********************************************************************
810    !FILE/DISK PATH ASSIGNED
820    !*********************************************************************
830    !
840    Data_file1$="ZC"&VAL$(Zoc)&Date$&VAL$(Run)
850    Data_file2$="ZR"&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   Hz=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 inches.
1120   P_atm=Cal(3,11)
1130   !
1140   ALLOCATE REAL Data(1:N2,0:32)      !Allocate real data array
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
1150  ENTER @Data_path2;Data(*)
1160  IF Scan_max<8 THEN
1170  ALLOCATE REAL Pa(1:32,1:7)
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
1260  !*****************************************************************
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          Pg_sum=0
1380          FOR Sample=Sample_min TO Sample_max
1390              Pg=Data(Sample,Port_number)    ! Data read from reduced dåta.
1400              Pg_sum=Pg_sum+Pg
1410          NEXT Sample
1420          !
1430          Pa_avg=(Pg_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  !
1550  !***********************************************************************
1560  !ROUTINE STORES DATA TO AN ASCII FILE
1570  !***********************************************************************
1580  !
1590 Save:   !
1600         !
1610         CLEAR SCREEN
1620  INPUT "Store on hard or floppy drive (0=:,700, 1=:,700,1):",Drv
1630  PRINT "Storing data please wait"
1640  IF Drv=0 THEN
1650  Drv$=":,700"
1660  ELSE
1670  Drv$=":,700,1"
1680  END IF
1690  Asc$="A"
1700  Filename$=Data_file2$&Asc$&Drv$
1710  CREATE ASCII Filename$,10
1720  ASSIGN @Path_1 TO Filename$
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
1730  OUTPUT @Path_1;Pa(*)
1740  ASSIGN @Path_1 TO *
1750  PRINT
1760  PRINT "Data stored to ASCII file called";Filename$
1770  WAIT 2
1780  GOTO Reset
1790  !
1800  !*****************************************************************
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_file2$
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(28,1)
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,6X,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
2080  PRINT "Scan","         Port Number"
2090  PRINT " "," 1"," 2"," 3"," 4"," 5"," 6"," 7"
2100  PRINT
2110  FOR I=1 TO Scan_max
2120       PRINT USING Format1;I,Pa(1,I),Pa(2,I),Pa(3,I),Pa(4,I),Pa(5,I),Pa(6,I),
Pa(7,I)
2130  NEXT I
2140  FOR J=1 TO 3
2150  PRINT
2160  NEXT J
2170  PRINT "Scan","         Port Number"
2180  PRINT " "," 8"," 9","10","11","12","13","14"
2190  PRINT
2200  FOR I=1 TO Scan_max
2210       PRINT USING Format1;I,Pa(8,I),Pa(9,I),Pa(10,I),Pa(11,I),Pa(12,I),Pa(13
,I),Pa(14,I)
2220  NEXT I
2230  FOR J=1 TO 3
2240  PRINT
2250  NEXT J
2260  PRINT "Scan","         Port Number"
2270  PRINT " ","15","16","17","18","19","20","21"
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
2280  PRINT
2290  FOR I=1 TO Scan_max
2300       PRINT USING Format1;I,Pa(15,I),Pa(16,I),Pa(17,I),Pa(18,I),Pa(19,I),Pa(
20,I),Pa(21,I)
2310  NEXT I
2320  FOR J=1 TO 3
2330  PRINT
2340  NEXT J
2350  PRINT "Scan","          Port Number"
2360  PRINT " ","22","23","24","25","26","27","28"
2370  PRINT
2380  FOR I=1 TO Scan_max
2390       PRINT USING Format1;I,Pa(22,I),Pa(23,I),Pa(24,I),Pa(25,I),Pa(26,I),Pa(
27,I),Pa(28,I)
2400  NEXT I
2410  FOR J=1 TO 3
2420  PRINT
2430  NEXT J
2440  PRINT "Scan","          Port Number"
2450  PRINT " ","29","30","31","32"
2460  PRINT
2470  FOR I=1 TO Scan_max
2480       PRINT USING Format1;I,Pa(29,I),Pa(30,I),Pa(31,I),Pa(32,I)
2490  NEXT I
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 Format2;I,Pa(I,1),Pa(I,2),Pa(I,3),Pa(I,4),Pa(I,5),Pa(I,
6),Pa(I,7)
2580     NEXT I
2590  END IF
2600  PRINTER IS CRT
2610  GOTO Reset
2620  !
2630  !
2640 !************************************************************************
2650 !PLOT AND PRINT Cp DATA AND SAVE TO ASCII FILE
2660 !************************************************************************
2670 !
2680 Cp: !
2690 !
2700 ALLOCATE INTEGER Pen(1:25)
2710 ALLOCATE REAL X(1:25)
2720 ALLOCATE REAL P_local(1:25,1:Scan_max)
2730 ALLOCATE REAL P_inf(1:Scan_max)
2740 ALLOCATE REAL P_ref(1:Scan_max)
2750 ALLOCATE REAL M_inf(1:Scan_max)
2760 !
2770 !IF Scan_max<7 THEN
2780 !   ALLOCATE REAL B(1:25,1:7)
2790 !   ALLOCATE REAL Cp(1:25,1:7)
2800 !   ALLOCATE REAL M_local(1:25,1:7)
2810 !   ALLOCATE REAL P_normal(1:25,1:7)
2820 !ELSE
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
2830     ALLOCATE REAL B(1:25,1:Scan_max)
2840     ALLOCATE REAL Cp(1:25,1:Scan_max)
2850     ALLOCATE REAL M_local(1:25,1:Scan_max)
2860     ALLOCATE REAL P_normal(1:25,1:Scan_max)
2870 !END IF
2880 !
2890 RESTORE
2900 !
2910 DATA 0.1667,0.25,0.3333,0.3467,0.36,0.3733,0.3867,0.4,0.4133,0.4267,0.4400,
0.4533,0.4667,0.4800,0.4933,0.5067,0.52,0.5333,0.56,0.5867,0.6133,0.6400,0.75
2920 DATA 0.8333,0.9167
2930 !
2940 READ X(*)                              !Read in axial location of ports
2950 !
2960 ! Calculate reference parameters.
2970 !
2980 FOR I=1 TO Scan_max
2990      P_inf(I)=Pa(29,I)                 !Get P_inf for all scans.
3000      P_ref(I)=Pa(31,I)                 !Get P_ref for all scans.
3010      M_inf(I)=SQRT(2/(Gamma-1)*((P_ref(I)/P_inf(I))^((Gamma-1)/Gamma)-1))
3020 NEXT I
3030 !
3040 ! Calculate local flow parameters.
3050 !
3060 FOR I=1 TO 25
3070      FOR J=1 TO Scan_max
3080           P_local(I,J)=Pa(I,J)       !Get P_local for all scans.
3090           P_normal(I,J)=P_local(I,J)/P_ref(J)  !Normalized pressure
3100           Cp(I,J)=(2/(Gamma*M_inf(J)^2))*((P_local(I,J)/P_inf(J))-1)
3110           M_local(I,J)=SQRT(2/(Gamma-1)*((P_ref(J)/P_local(I,J))^((Gamma-1)/G
amma)-1))
3120      NEXT J
3130 NEXT I
3140 !
3150 !Plot Cp or M_local vs x/c below:
3160 !
3170 Plot_cpmach:!
3180 !
3190 CLEAR SCREEN
3200 !
3210 PRINT "      POST PROCESSING OF Static Pressure Data"
3220 PRINT
3230 PRINT
3240 !
3250 PRINT "      The following routine will plot and print P/Pt or Mach Number"
3260 PRINT "      for a single scan desired or a set of seven scans."
3270 PRINT
3280 PRINT "      The selections are as follows.."
3290 PRINT "      1.  Plot Cp (then provide scan or scans desired)"
3300 PRINT "      2.  Plot Mach Number (provide scans as above)"
3310 PRINT
3320 INPUT "      Input the parameter to plot(0=P/Pt,1=Mach)",Plot_case
3330 INPUT "      Input the first scan to be plotted",First_scan
3340 INPUT "      Input the last scan to be plotted",Last_scan
3350 INPUT "      Dump plots to Laser or Thinkjet (TJ=0,LJ=1)",Dump
3360 !
3370 IF Dump=1 THEN
3380    DUMP DEVICE IS 9
3390 ELSE
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
3400     DUMP DEVICE IS 702
3410 END IF
3420 !
3430 !Initialize graphics environment parameters
3440 !
3450 Xo=0
3460 Xf=1
3470 Dx=10
3480 Dy=10
3490 MAT Pen= (-1)      !Pen control parameter "Pen down before moving".
3500 Pen(1)=-2
3510 Pen(25)=-2         !Pen control parameter "Pen up before moving".
3520 !
3530 SELECT Plot_case
3540         CASE 0
3550             Title$="Normalized Pressure vs. Percent Chord"
3560             X_label$="x/c"
3570             Y_label$="P/Pt"
3580             Yo=0
3590             Yf=1
3600         CASE 1
3610             Title$="Mach number vs. Percent Chord"
3620             X_label$="x/c"
3630             Y_label$="Mach Number"
3640             Yo=0
3650             Yf=2
3660  END SELECT
3670  !
3680 LINE TYPE 1    !First line type
3690 N=3            !Second line type
3700 !
3710 CALL Plot                          !Sets up graphics background
3720 FOR J=First_scan TO Last_scan
3730 FOR I=1 TO 25
3740      SELECT Plot_case
3750              CASE 0
3760              PLOT X(I),P_normal(I,J),Pen(I)
3770              CASE 1
3780              PLOT X(I),M_local(I,J),Pen(I)
3790      END SELECT
3800 NEXT I
3810      LINE TYPE N
3820      N=N+1
3830 NEXT J
3840 !
3850 PAUSE
3860 !
3870 CLEAR SCREEN
3880 !
3890 INPUT "Would you like to make another plot (Y=yes,N=no)?",Go$
3900 IF Go$="Y" THEN Plot_cpmach
3910 !
3920 !The following routine will print P/Pt or Mach number for the scans selecte
d
3930 !
3940 FOR P=1 TO 5
3950 PRINT
3960 NEXT P
3970 PRINT "The following will print P/Pt or Mach Number data for scans selected
."
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
3980 PRINT "Select 7 scans to bracket data plotted above or any others."
3990 PRINT
4000 PRINT "The scans selected for printing must be available in the data"
4010 PRINT "ie starting at scan 5 when only scans 1-7 available will results"
4020 PRINT "in ERROR 17."
4030 PRINT
4040 INPUT "Would you like to print the P/Pt or Mach Number Data (Y=yes,N=no)?",
Go1$
4050 IF Go1$="N" THEN Skip_print
4060 !
4070 INPUT "Would you like to print P/Pt or Mach Number (0=P/Pt,1=Mach)?",Cp_m
4080 INPUT "Input the first of seven scans to be printed.",Fs
4090 INPUT "Print to CRT or printer(0=CRT,1=Printer)?",View
4100 !
4110 IF Cp_m=0 THEN
4120    MAT B= P_normal
4130 ELSE
4140    MAT B= M_local
4150 END IF
4160 !
4170 IF View=1 THEN PRINTER IS 702
4180 !
4190 PRINT "Port","            Scan Number"
4200 PRINT
4210 PRINT " ",Fs,Fs+1,Fs+2,Fs+3,Fs+4,Fs+5,Fs+6
4220 PRINT
4230 FOR I=1 TO 25
4240     PRINT USING Format2;I,B(I,Fs),B(I,Fs+1),B(I,Fs+2),B(I,Fs+3),B(I,Fs+4),B
(I,Fs+5),B(I,Fs+6)
4250 NEXT I
4260 !
4270 PAUSE
4280 Skip_print:!
4290 PRINTER IS CRT
4300 DEALLOCATE Cp(*)
4310 DEALLOCATE B(*)
4320 DEALLOCATE P_local(*)
4330 DEALLOCATE P_normal(*)
4340 DEALLOCATE P_inf(*)
4350 DEALLOCATE P_ref(*)
4360 DEALLOCATE M_inf(*)
4370 DEALLOCATE M_local(*)
4380 DEALLOCATE X(*)
4390 DEALLOCATE Pen(*)
4400 KEY LABELS ON
4410 !
4420 GOTO Reset
4430 !
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
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
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."
4580 PRINT
4590 PRINT
4600 INPUT "      Dump plots to Laser or ThinkJet (0-LJ,1-TJ).",Dump
4610 INPUT "      Maximum Recorded Plenum Temperature in deg F.",Ttmax
4620 INPUT "      Mininmum Recorded Plenum Temperature in deg F.",Ttmin
4630 PRINT "      Type F2 to continue(no other inputs necessary (yet)!"
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)
4870 !
4880 Plot_pt:!
4890         !
4900 !Initialize plot parameters
4910 LINE TYPE 1
4920 Title$="Verticle Distance Traversed vs. Pt"
4930 X_label$="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 Gc=32.2
5100 Rgas=53.3
5110 Ttmax=Ttmax+460
5120 Ttmin=Ttmin+460
5130 Tt=(Ttmax+Ttmin)/2
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
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      !
5210      Rhot1=144*P_ref(I)/(Rgas*Tt)
5220      Rhot2=144*Pt(I)/(Rgas*Tt)
5230      !
5240      M_inf(I)=SQRT((2/(Gamma-1))*((P_ref(I)/P_inf(I))^((Gamma-1)/Gamma)-1))
5250      M_exit(I)=SQRT((2/(Gamma-1))*((Pt(I)/P_exit(I))^((Gamma-1)/Gamma)-1))
5260      !
5270      T1=Tt/(1+((Gamma-1)/2)*(M_inf(I))^2)
5280      T2=Tt/(1+((Gamma-1)/2)*(M_exit(I))^2)
5290      !
5300      A1=SQRT(Gamma*Rgas*T1*Gc)
5310      A2=SQRT(Gamma*Rgas*T2*Gc)
5320      !
5330      V1=A1*M_inf(I)
5340      V2=A2*M_exit(I)
5350      !
5360      Rho1=Rhot1*(1+((Gamma-1)/2)*M_inf(I))^(-(1/(Gamma-1)))
5370      Rho2=Rhot2*(1+((Gamma-1)/2)*M_exit(I))^(-(1/(Gamma-1)))
5380      !
5390      Ma1(I)=Rho1*V1
5400      Ma2(I)=Rho2*V2
5410      Ma3(I)=Rho1*V1*P_ref(I)*144
5420      Ma4(I)=Rho2*V2*Pt(I)*144
5430      !
5440      Q(I)=P_ref(I)-P_inf(I)
5450      !
5460      Y(I)=(I-1)*Increment
5470      PLOT Pt(I),Y(I),Pen2(I)
5480 NEXT I
5490 !
5500 FOR I=1 TO Scan_max
5510 PLOT P_ref(I),Y(I),Pen2(I)
5520 NEXT I
5530 !
5540 FOR I=1 TO Scan_max
5550 PLOT P_exit(I),Y(I),Pen2(I)
5560 NEXT I
5570 !
5580 PAUSE
5590 !
5600 INPUT "Would you like to make another plot (Y=yes,N=no)?",Go$
5610 IF Go$="Y" THEN Plot_pt
5620 !
5630 CLEAR SCREEN
5640 !
5650 PRINT
5660 PRINT
5670 DISP "Now calculating cascade loss coefficient"
5680 !
5690 Rhov1=0                          !Initialize totaling variables
5700 Rhov2=0
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
5710 Rhovpt1=0
5720 Rhovpt2=0
5730 Qin=0
5740 !
5750 FOR I=1 TO Scan_max              !Total mass averaging quantities
5760      Rhov1=Rhov1+Ma1(I)
5770      Rhov2=Rhov2+Ma2(I)
5780      Rhovpt1=Rhovpt1+Ma3(I)
5790      Rhovpt2=Rhovpt2+Ma4(I)
5800      Qin=Qin+Q(I)
5810 NEXT I
5820 !
5830 Avg1=Rhov1/Scan_max
5840 Avg2=Rhov2/Scan_max
5850 Avg3=Rhovpt1/Scan_max
5860 Avg4=Rhovpt2/Scan_max
5870 Avg5=Qin/Scan_max
5880 !
5890 Ptma1=Avg3/(Avg1*144)
5900 Ptma2=Avg4/(Avg2*144)
5910 Qavg=Avg5
5920 W_bar=(Ptma1-Ptma2)/Qavg
5930 !
5940 INPUT "Print Losses to CRT or Printer (0=CRT,1=PRINTER)",Lossp
5950 IF Lossp=1 THEN PRINTER IS 702
5960 !
5970 FOR I=1 TO 5
5980 PRINT
5990 NEXT I
6000 !
6010 PRINT "      The cascade loss coefficient based on inlet "
6020 PRINT "      dynamic pressure as calculated using        "
6030 PRINT "      mass averaged quantities as shown below."
6040 PRINT
6050 PRINT
6060 PRINT
6070 PRINT "      Ptma1 = ";Ptma1;" PSIA"
6080 PRINT "      Ptma2 = ";Ptma2;" PSIA"
6090 PRINT
6100 PRINT "      Pt1-P1 = ";Qavg;" PSIA"
6110 PRINT "      Ttavg = ";Tt;" deg R"
6120 PRINT
6130 PRINT "      W_bar = ";W_bar
6140 PRINT
6150 DISP "      Type F2 to return to main menu"
6160 PAUSE
6170 !Deallocate all real variables
6180 !
6190 DEALLOCATE Pen2(*)
6200 DEALLOCATE P_inf(*)
6210 DEALLOCATE P_exit(*)
6220 DEALLOCATE P_ref(*)
6230 DEALLOCATE M_inf(*)
6240 DEALLOCATE M_exit(*)
6250 DEALLOCATE Ma1(*)
6260 DEALLOCATE Ma2(*)
6270 DEALLOCATE Ma3(*)
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
6280 DEALLOCATE Da4(*)
6290 DEALLOCATE Q(*)
6300 DEALLOCATE Pt(*)
6310 DEALLOCATE Y(*)
6320 KEY LABELS ON
6330 PRINTER IS CRT
6340 !
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 bottom center screen
6750  LORG 4                         !Character ref pt:bottom center
6760  LABEL X_label$                 !X-axis label
6770  DEG                            !Desig degrees for LDIR
6780  LDIR 90                        !Sets Y-axis label on end
6790  LORG 6
6800  MOVE 0,50
6810  LABEL Y_label$                 !Y-axis label
6820  LDIR 0                         !Reset label to horizontal orientation
6830  LORG 2                         !Chr ref pt:left center
6840  VIEWPORT 10,90*RATIO,10,90     !Sets graph screen size
```

**Figure D1.** (cont) Program "READ_ZOC2"

```
6850  FRAME                                   !Box around viewport
6860  WINDOW Xo,Xf,Yo,Yf          !Set axis lengths in VIEWPORT
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 VIEWPORT
6910  CSIZE 3.0,.4                            !Axes 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,Sc)
7080  !Subroutine to plot squares around the local origin designated
7090  !by the PLOT statement.
7100  Xd=Sc*(Xf-Xo)
7110  Yd=Sc*(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 "READ_ZOC2"

# APPENDIX E. SELECTED DATA

Data Print Out for Zoc # 1 , Run # 3 , FileZR1211163

Period between samples (sec): .00333333333333

Sample collection rate (Hz): 300

Number of samples per port: 10

Length of data run (sec): 34.1

The scan type is: 2

Number of scans/traverses: 33

Increment of traverse: .0625 Inches

Atmospheric pressure is: 14.71 psia

Tunnel Pressure Ratio is: 2.03894334573

| Scan | Port Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 17.386 | 16.838 | 17.049 | 17.616 | 19.135 | 21.167 | 23.343 |
| 2 | 17.335 | 16.784 | 17.137 | 17.687 | 19.714 | 22.121 | 24.331 |
| 3 | 17.365 | 16.730 | 17.093 | 17.738 | 19.564 | 22.414 | 24.279 |
| 4 | 17.447 | 16.849 | 17.104 | 17.596 | 19.225 | 21.701 | 23.497 |
| 5 | 17.335 | 16.741 | 17.071 | 17.667 | 19.614 | 21.764 | 23.487 |
| 6 | 17.365 | 16.827 | 16.927 | 17.281 | 18.696 | 20.569 | 23.219 |
| 7 | 17.417 | 16.784 | 17.026 | 17.281 | 19.155 | 21.921 | 23.229 |
| 8 | 17.233 | 16.676 | 16.960 | 17.372 | 18.536 | 20.473 | 22.601 |
| 9 | 17.335 | 16.784 | 16.993 | 17.433 | 18.856 | 21.607 | 23.466 |
| 10 | 17.345 | 16.687 | 16.905 | 17.251 | 18.496 | 20.087 | 22.303 |
| 11 | 17.345 | 16.773 | 16.971 | 17.525 | 19.175 | 21.576 | 23.137 |
| 12 | 17.345 | 16.773 | 17.004 | 17.423 | 18.866 | 21.083 | 23.065 |
| 13 | 17.294 | 16.752 | 16.882 | 17.454 | 19.065 | 21.796 | 23.898 |
| 14 | 17.314 | 16.719 | 16.938 | 17.332 | 19.045 | 20.936 | 22.828 |
| 15 | 17.273 | 16.687 | 16.905 | 17.393 | 19.065 | 20.517 | 21.912 |
| 16 | 17.314 | 16.665 | 16.882 | 17.342 | 19.025 | 21.030 | 22.848 |
| 17 | 17.253 | 16.687 | 16.960 | 17.433 | 19.025 | 21.219 | 23.497 |
| 18 | 17.243 | 16.698 | 16.938 | 17.484 | 18.826 | 20.810 | 22.818 |
| 19 | 17.314 | 16.676 | 16.893 | 17.240 | 18.397 | 20.863 | 21.870 |
| 20 | 17.171 | 16.665 | 16.893 | 17.504 | 19.205 | 21.083 | 22.210 |
| 21 | 17.222 | 16.655 | 16.871 | 17.230 | 18.656 | 21.041 | 23.209 |
| 22 | 17.243 | 16.709 | 16.860 | 17.281 | 18.616 | 20.454 | 22.159 |
| 23 | 17.263 | 16.622 | 16.871 | 17.383 | 18.736 | 21.293 | 23.023 |
| 24 | 17.089 | 16.525 | 16.916 | 17.444 | 18.636 | 20.265 | 21.973 |
| 25 | 17.130 | 16.633 | 16.794 | 17.118 | 18.526 | 20.485 | 21.901 |
| 26 | 17.273 | 16.644 | 16.794 | 17.220 | 18.616 | 20.590 | 21.912 |
| 27 | 17.345 | 16.752 | 16.794 | 17.139 | 18.496 | 20.328 | 21.603 |
| 28 | 17.294 | 16.730 | 16.882 | 17.342 | 19.936 | 20.685 | 22.251 |
| 29 | 17.284 | 16.676 | 16.860 | 17.352 | 18.706 | 20.318 | 22.416 |
| 30 | 17.192 | 16.601 | 16.849 | 17.342 | 18.496 | 20.538 | 22.591 |
| 31 | 17.202 | 16.687 | 16.805 | 17.159 | 18.247 | 20.569 | 22.334 |
| 32 | 17.212 | 16.644 | 16.905 | 17.342 | 19.015 | 20.873 | 23.044 |
| 33 | 17.130 | 16.568 | 16.827 | 17.525 | 19.514 | 21.345 | 23.641 |

**Figure E1.** Run 3, 16 Nov 1992 (Raw Data)

| Scan | Port Number 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| 1 | 25.048 | 26.629 | 27.054 | 27.503 | 27.917 | 28.289 | 28.424 |
| 2 | 24.934 | 25.459 | 26.479 | 27.234 | 27.792 | 28.071 | 28.281 |
| 3 | 25.670 | 26.247 | 27.128 | 27.340 | 27.754 | 28.147 | 28.585 |
| 4 | 25.483 | 26.383 | 26.804 | 27.282 | 27.965 | 28.176 | 28.452 |
| 5 | 24.571 | 25.505 | 26.609 | 27.089 | 27.869 | 28.157 | 28.538 |
| 6 | 24.809 | 26.066 | 26.962 | 27.465 | 27.591 | 27.939 | 28.481 |
| 7 | 24.519 | 25.188 | 25.868 | 26.743 | 27.360 | 27.834 | 28.034 |
| 8 | 24.001 | 25.804 | 26.192 | 26.955 | 27.466 | 27.958 | 28.395 |
| 9 | 24.706 | 24.907 | 26.025 | 26.772 | 27.744 | 28.308 | 28.348 |
| 10 | 24.115 | 25.351 | 26.090 | 27.003 | 27.562 | 27.853 | 28.024 |
| 11 | 24.498 | 24.961 | 26.294 | 27.291 | 27.859 | 28.081 | 28.319 |
| 12 | 24.343 | 25.296 | 26.322 | 27.128 | 27.533 | 28.005 | 28.281 |
| 13 | 24.913 | 25.496 | 26.072 | 26.839 | 27.619 | 28.005 | 28.414 |
| 14 | 24.540 | 26.166 | 26.637 | 27.128 | 27.821 | 27.787 | 27.967 |
| 15 | 23.762 | 24.925 | 26.229 | 26.897 | 27.591 | 27.806 | 28.129 |
| 16 | 24.343 | 25.496 | 26.730 | 27.465 | 27.783 | 28.128 | 28.224 |
| 17 | 24.374 | 25.668 | 26.294 | 26.916 | 27.475 | 27.920 | 28.376 |
| 18 | 24.042 | 25.405 | 26.137 | 26.541 | 27.303 | 27.929 | 28.243 |
| 19 | 23.026 | 23.667 | 25.181 | 26.435 | 27.303 | 27.967 | 28.357 |
| 20 | 23.856 | 25.794 | 26.201 | 26.859 | 27.216 | 27.560 | 27.948 |
| 21 | 25.069 | 26.302 | 26.480 | 27.176 | 27.629 | 27.986 | 28.186 |
| 22 | 24.208 | 26.220 | 26.693 | 27.051 | 27.619 | 28.043 | 28.443 |
| 23 | 24.364 | 25.405 | 26.007 | 26.474 | 27.312 | 27.863 | 28.471 |
| 24 | 23.493 | 24.961 | 25.534 | 26.301 | 26.957 | 27.304 | 27.910 |
| 25 | 23.368 | 24.907 | 25.914 | 26.849 | 27.293 | 27.550 | 27.986 |
| 26 | 24.156 | 25.831 | 26.674 | 27.070 | 27.485 | 27.806 | 28.148 |
| 27 | 22.736 | 24.499 | 26.174 | 27.349 | 27.581 | 27.787 | 28.395 |
| 28 | 23.203 | 24.835 | 25.775 | 26.685 | 27.139 | 27.304 | 27.540 |
| 29 | 24.260 | 25.514 | 26.489 | 27.109 | 27.427 | 27.654 | 27.901 |
| 30 | 23.887 | 24.690 | 25.775 | 26.753 | 27.312 | 27.474 | 27.568 |
| 31 | 24.073 | 25.677 | 26.433 | 27.147 | 27.677 | 27.977 | 28.129 |
| 32 | 24.612 | 25.858 | 26.544 | 26.916 | 27.447 | 27.683 | 27.910 |
| 33 | 24.239 | 24.961 | 25.942 | 26.840 | 27.255 | 27.853 | 27.996 |

**Figure E1.** (cont) Run 3, 16 Nov 1992 (Raw Data)

| Scan | Port Number 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|
| 1 | 28.732 | 28.870 | 29.052 | 29.180 | 29.820 | 30.267 | 30.563 |
| 2 | 28.553 | 28.905 | 29.104 | 29.345 | 30.049 | 30.295 | 30.504 |
| 3 | 28.722 | 28.922 | 29.061 | 29.337 | 29.961 | 30.139 | 30.413 |
| 4 | 28.722 | 29.054 | 29.312 | 29.475 | 29.996 | 30.368 | 30.579 |
| 5 | 28.862 | 28.861 | 28.905 | 29.189 | 29.917 | 30.194 | 30.413 |
| 6 | 28.623 | 28.975 | 29.104 | 29.267 | 30.058 | 30.184 | 30.496 |
| 7 | 28.712 | 29.054 | 29.269 | 29.206 | 29.811 | 30.386 | 30.563 |
| 8 | 28.613 | 28.922 | 29.382 | 29.285 | 29.758 | 30.267 | 30.771 |
| 9 | 28.752 | 29.019 | 29.156 | 29.250 | 29.846 | 30.065 | 30.488 |
| 10 | 28.244 | 28.528 | 28.775 | 29.206 | 29.873 | 30.194 | 30.363 |
| 11 | 28.702 | 28.878 | 29.026 | 29.016 | 29.599 | 29.955 | 30.313 |
| 12 | 28.483 | 28.826 | 28.957 | 29.232 | 29.820 | 30.038 | 30.338 |
| 13 | 28.643 | 28.791 | 28.983 | 29.189 | 29.767 | 30.111 | 30.446 |
| 14 | 28.174 | 28.659 | 29.061 | 29.163 | 29.476 | 29.790 | 30.213 |
| 15 | 28.293 | 28.545 | 28.957 | 29.180 | 29.590 | 30.166 | 30.496 |
| 16 | 28.513 | 28.686 | 28.957 | 29.215 | 29.732 | 30.026 | 30.246 |
| 17 | 28.493 | 28.686 | 29.009 | 29.033 | 29.820 | 30.074 | 30.254 |
| 18 | 28.662 | 28.826 | 28.983 | 29.154 | 29.705 | 30.038 | 30.388 |
| 19 | 28.573 | 28.624 | 28.870 | 29.128 | 29.643 | 30.285 | 30.346 |
| 20 | 28.423 | 28.554 | 28.983 | 29.163 | 29.626 | 30.276 | 30.288 |
| 21 | 28.473 | 28.598 | 29.052 | 29.120 | 29.687 | 29.982 | 30.396 |
| 22 | 28.333 | 28.642 | 28.705 | 28.816 | 29.590 | 29.982 | 30.196 |
| 23 | 28.214 | 28.466 | 28.671 | 29.120 | 29.679 | 29.973 | 30.246 |
| 24 | 28.293 | 28.388 | 28.723 | 29.059 | 29.476 | 29.680 | 30.213 |
| 25 | 28.383 | 28.878 | 29.165 | 28.894 | 29.493 | 30.028 | 30.354 |
| 26 | 28.353 | 28.449 | 28.723 | 28.990 | 29.785 | 30.010 | 30.113 |
| 27 | 28.772 | 28.808 | 28.827 | 29.224 | 29.807 | 30.001 | 30.321 |
| 28 | 28.293 | 28.554 | 28.827 | 29.085 | 29.732 | 30.138 | 30.379 |
| 29 | 28.124 | 28.528 | 28.766 | 28.808 | 29.802 | 30.010 | 30.396 |
| 30 | 27.824 | 28.379 | 28.870 | 28.990 | 29.617 | 30.065 | 30.338 |
| 31 | 28.463 | 28.466 | 28.792 | 29.076 | 29.537 | 29.918 | 30.246 |
| 32 | 28.204 | 28.493 | 28.766 | 29.120 | 29.590 | 30.010 | 30.313 |
| 33 | 28.313 | 28.624 | 28.861 | 28.825 | 29.617 | 29.845 | 30.163 |

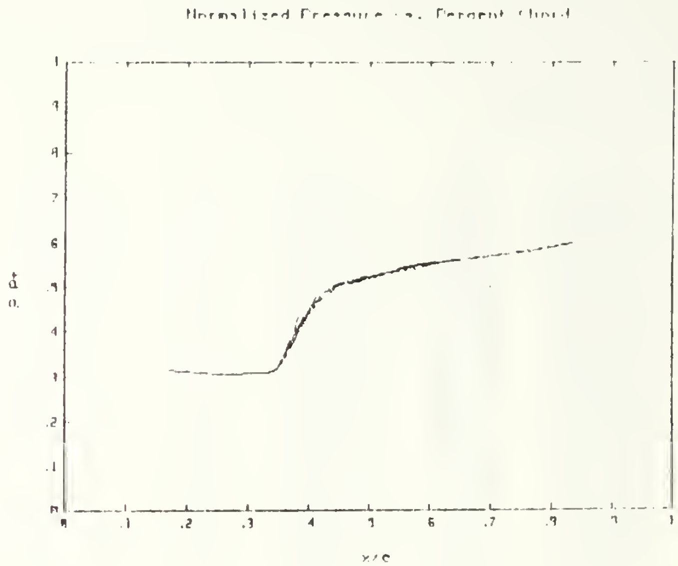
**Figure E1.** (cont) Run 3, 16 Nov 1992 (Raw Data)

| Scan | Port Number 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|
| 1 | 30.820 | 31.615 | 32.730 | 34.161 | 24.430 | 27.585 | 23.366 |
| 2 | 30.988 | 31.735 | 32.815 | 34.352 | 25.078 | 27.8[illegible]4 | 23.719 |
| 3 | 30.887 | 31.777 | 32.858 | 34.352 | 24.711 | 27.664 | 23.299 |
| 4 | 31.038 | 31.752 | 32.807 | 34.334 | 24.135 | 27.462 | 23.215 |
| 5 | 30.871 | 31.667 | 32.764 | 34.280 | 23.963 | 27.401 | 22.929 |
| 6 | 30.745 | 31.667 | 32.738 | 34.298 | 23.993 | 27.559 | 23.324 |
| 7 | 30.837 | 31.718 | 32.730 | 34.180 | 23.729 | 27.295 | 23.181 |
| 8 | 30.963 | 31.658 | 32.747 | 34.216 | 23.750 | 27.234 | 22.803 |
| 9 | 30.770 | 31.581 | 32.687 | 34.216 | 23.242 | 27.015 | 22.560 |
| 10 | 30.787 | 31.615 | 32.764 | 34.152 | 24.592 | 27.506 | 23.072 |
| 11 | 30.610 | 31.505 | 32.678 | 34.152 | 23.679 | 27.173 | 22.308 |
| 12 | 30.762 | 31.573 | 32.627 | 34.170 | 23.811 | 27.664 | 23.072 |
| 13 | 30.594 | 31.752 | 32.670 | 34.152 | 23.638 | 26.681 | 22.299 |
| 14 | 30.778 | 31.564 | 32.713 | 34.134 | 23.577 | 27.085 | 22.551 |
| 15 | 30.678 | 31.581 | 32.695 | 34.180 | 23.851 | 27.120 | 22.484 |
| 16 | 30.761 | 31.650 | 32.661 | 34.052 | 24.135 | 27.295 | 22.719 |
| 17 | 30.669 | 31.471 | 32.670 | 34.043 | 24.186 | 27.146 | 22.845 |
| 18 | 30.644 | 31.479 | 32.670 | 33.988 | 23.587 | 26.532 | 22.224 |
| 19 | 30.543 | 31.752 | 32.653 | 34.189 | 23.293 | 26.936 | 22.224 |
| 20 | 30.627 | 31.479 | 32.584 | 34.098 | 23.669 | 27.067 | 22.501 |
| 21 | 30.845 | 31.624 | 32.601 | 34.125 | 23.618 | 27.146 | 22.518 |
| 22 | 30.585 | 31.692 | 32.524 | 33.943 | 23.466 | 27.304 | 22.686 |
| 23 | 30.711 | 31.650 | 32.507 | 34.079 | 23.719 | 27.024 | 22.375 |
| 24 | 30.669 | 31.650 | 32.413 | 33.988 | 22.847 | 27.120 | 21.980 |
| 25 | 30.602 | 31.684 | 32.541 | 34.034 | 22.634 | 26.637 | 21.955 |
| 26 | 30.661 | 31.547 | 32.567 | 33.943 | 23.080 | 26.953 | 22.366 |
| 27 | 30.627 | 31.650 | 32.721 | 34.107 | 23.557 | 26.980 | 22.560 |
| 28 | 30.585 | 31.530 | 32.601 | 34.180 | 22.603 | 26.752 | 22.039 |
| 29 | 30.636 | 31.598 | 32.661 | 34.189 | 24.044 | 27.304 | 22.677 |
| 30 | 30.585 | 31.505 | 32.644 | 34.125 | 23.851 | 27.164 | 22.686 |
| 31 | 30.736 | 31.539 | 32.653 | 34.189 | 23.100 | 26.945 | 22.257 |
| 32 | 30.694 | 31.505 | 32.576 | 34.098 | 23.760 | 27.331 | 22.803 |
| 33 | 30.585 | 31.513 | 32.464 | 34.043 | 24.328 | 27.374 | 22.963 |

**Figure E1.** (cont) Run 3, 16 Nov 1992 (Raw Data)

| Scan | Port Number | | | |
|---|---|---|---|---|
| | 29 | 30 | 31 | 32 |
| 1 | 17.552 | 35.788 | 54.550 | 51.851 |
| 2 | 17.614 | 35.845 | 54.645 | 51.950 |
| 3 | 17.623 | 35.854 | 54.523 | 52.210 |
| 4 | 17.614 | 35.863 | 54.690 | 52.561 |
| 5 | 17.561 | 35.807 | 54.671 | 52.598 |
| 6 | 17.561 | 35.798 | 54.584 | 52.776 |
| 7 | 17.561 | 35.882 | 54.636 | 52.875 |
| 8 | 17.472 | 36.024 | 54.576 | 52.776 |
| 9 | 17.561 | 35.769 | 54.593 | 52.679 |
| 10 | 17.499 | 35.722 | 54.497 | 52.201 |
| 11 | 17.543 | 35.693 | 54.576 | 51.419 |
| 12 | 17.534 | 35.778 | 54.515 | 48.982 |
| 13 | 17.525 | 35.684 | 54.549 | 46.850 |
| 14 | 17.534 | 35.722 | 54.575 | 44.132 |
| 15 | 17.561 | 35.684 | 54.515 | 40.756 |
| 16 | 17.517 | 35.599 | 54.480 | 38.864 |
| 17 | 17.481 | 35.618 | 54.428 | 37.396 |
| 18 | 17.561 | 35.712 | 54.445 | 36.567 |
| 19 | 17.543 | 35.655 | 54.480 | 35.963 |
| 20 | 17.508 | 35.608 | 54.375 | 35.675 |
| 21 | 17.534 | 35.551 | 54.462 | 35.585 |
| 22 | 17.428 | 35.561 | 54.436 | 35.576 |
| 23 | 17.366 | 35.693 | 54.793 | 35.649 |
| 24 | 17.357 | 35.608 | 54.793 | 35.558 |
| 25 | 17.419 | 35.514 | 54.636 | 35.549 |
| 26 | 17.445 | 35.570 | 54.584 | 35.594 |
| 27 | 17.588 | 35.504 | 54.619 | 35.594 |
| 28 | 17.677 | 35.684 | 54.549 | 35.648 |
| 29 | 17.632 | 35.551 | 54.471 | 35.558 |
| 30 | 17.597 | 35.665 | 54.410 | 35.549 |
| 31 | 17.543 | 35.627 | 54.488 | 35.558 |
| 32 | 17.543 | 35.636 | 54.567 | 35.513 |
| 33 | 17.481 | 35.580 | 54.340 | 35.486 |

**Figure E1.** (cont) Run 3, 16 Nov 1992 (Raw Data)



| Port | Scan Number 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|
| 1 | .318 | .318 | .318 | .317 | .317 | .317 | .318 |
| 2 | .306 | .307 | .308 | .307 | .306 | .306 | .306 |
| 3 | .310 | .311 | .312 | .309 | .310 | .310 | .310 |
| 4 | .317 | .321 | .320 | .320 | .318 | .319 | .318 |
| 5 | .339 | .351 | .346 | .350 | .349 | .350 | .349 |
| 6 | .369 | .395 | .387 | .400 | .384 | .376 | .386 |
| 7 | .409 | .424 | .423 | .438 | .418 | .402 | .419 |
| 8 | .442 | .449 | .447 | .457 | .450 | .436 | .447 |
| 9 | .465 | .457 | .464 | .467 | .479 | .457 | .468 |
| 10 | .479 | .482 | .483 | .478 | .488 | .481 | .491 |
| 11 | .495 | .500 | .498 | .492 | .497 | .493 | .504 |
| 12 | .506 | .510 | .505 | .506 | .510 | .506 | .510 |
| 13 | .511 | .515 | .514 | .513 | .509 | .510 | .516 |
| 14 | .514 | .519 | .519 | .521 | .512 | .516 | .519 |
| 15 | .518 | .526 | .522 | .525 | .516 | .519 | .523 |
| 16 | .523 | .529 | .529 | .528 | .525 | .521 | .527 |
| 17 | .528 | .532 | .531 | .531 | .532 | .531 | .532 |
| 18 | .536 | .532 | .536 | .535 | .534 | .535 | .536 |
| 19 | .548 | .542 | .547 | .546 | .540 | .543 | .546 |
| 20 | .554 | .549 | .551 | .552 | .546 | .553 | .551 |
| 21 | .557 | .555 | .557 | .558 | .554 | .559 | .555 |
| 22 | .565 | .561 | .564 | .561 | .561 | .563 | .565 |
| 23 | .580 | .577 | .579 | .582 | .578 | .579 | .581 |
| 24 | .601 | .599 | .598 | .599 | .599 | .600 | .600 |
| 25 | .627 | .626 | .627 | .626 | .625 | .627 | .625 |

**Figure E1.** (cont) Run 3, 16 Nov 1992 (P/Pt Distribution)

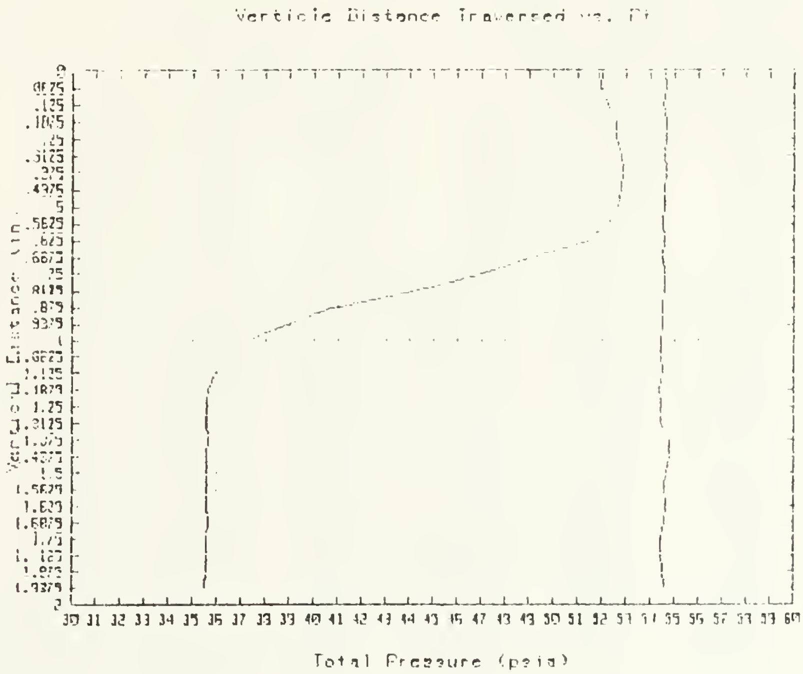



**Figure E1.** (cont) Run 3, 16 Nov 1992 (Loss Distribution)

Data Print Out for Zoc # 1 , Run # 4 , FileZR1211194

Period between samples (sec): .0033333333333333
Sample collection rate (Hz): 300
Number of samples per port: 10
Length of data run (sec): 34.1
The scan type is: 3
Number of scans/traverses: 33
Increment of traverse: .0625 Inches
Atmospheric pressure is: 14.75 psia
Tunnel Pressure Ratio is: 2.1400325978

| Scan | Port Number 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 17.201 | 16.711 | 25.960 | 26.681 | 27.411 | 28.041 | 28.310 |
| 2 | 17.222 | 16.647 | 25.882 | 26.549 | 27.452 | 27.779 | 28.114 |
| 3 | 17.191 | 16.647 | 25.860 | 26.620 | 27.341 | 27.695 | 28.073 |
| 4 | 17.232 | 16.679 | 25.971 | 26.722 | 27.361 | 27.926 | 28.248 |
| 5 | 17.242 | 16.668 | 25.860 | 26.569 | 27.391 | 27.789 | 28.207 |
| 6 | 17.048 | 16.625 | 25.794 | 26.569 | 27.331 | 27.726 | 28.145 |
| 7 | 17.099 | 16.722 | 25.993 | 26.823 | 27.492 | 27.810 | 28.073 |
| 8 | 17.181 | 16.701 | 26.048 | 26.671 | 27.351 | 27.947 | 28.434 |
| 9 | 17.303 | 16.754 | 26.026 | 26.813 | 27.522 | 27.968 | 28.269 |
| 10 | 17.140 | 16.787 | 25.993 | 26.701 | 27.270 | 27.758 | 28.269 |
| 11 | 17.171 | 16.668 | 26.070 | 26.742 | 27.361 | 27.737 | 28.238 |
| 12 | 17.120 | 16.765 | 26.015 | 26.793 | 27.502 | 27.873 | 28.279 |
| 13 | 17.130 | 16.711 | 26.015 | 26.803 | 27.613 | 27.852 | 28.155 |
| 14 | 17.150 | 16.711 | 25.971 | 26.661 | 27.281 | 27.768 | 28.207 |
| 15 | 17.130 | 16.701 | 25.882 | 26.518 | 27.170 | 27.684 | 28.269 |
| 16 | 17.089 | 16.679 | 25.915 | 26.793 | 27.502 | 27.926 | 28.372 |
| 17 | 17.130 | 16.776 | 26.170 | 26.803 | 27.442 | 27.810 | 28.124 |
| 18 | 17.120 | 16.668 | 25.760 | 26.732 | 27.361 | 27.852 | 28.310 |
| 19 | 17.201 | 16.733 | 26.181 | 26.742 | 27.341 | 27.663 | 28.176 |
| 20 | 17.130 | 16.797 | 25.926 | 26.701 | 27.401 | 27.779 | 28.166 |
| 21 | 17.069 | 16.733 | 26.269 | 26.884 | 27.361 | 27.789 | 28.104 |
| 22 | 17.120 | 16.679 | 25.949 | 26.752 | 27.361 | 27.789 | 28.207 |
| 23 | 17.059 | 16.625 | 25.860 | 26.712 | 27.361 | 27.800 | 28.424 |
| 24 | 17.099 | 16.744 | 26.037 | 26.773 | 27.462 | 27.894 | 28.289 |
| 25 | 17.181 | 16.744 | 25.926 | 26.600 | 27.361 | 27.999 | 28.186 |
| 26 | 17.079 | 16.528 | 26.148 | 26.742 | 27.361 | 27.842 | 28.114 |
| 27 | 16.987 | 16.776 | 25.993 | 26.569 | 27.220 | 27.590 | 28.114 |
| 28 | 17.120 | 16.690 | 25.849 | 26.691 | 27.381 | 27.779 | 28.228 |
| 29 | 17.008 | 16.754 | 25.860 | 26.651 | 27.462 | 27.789 | 28.145 |
| 30 | 17.008 | 16.765 | 26.070 | 26.630 | 27.311 | 27.800 | 28.114 |
| 31 | 17.150 | 16.916 | 26.203 | 26.945 | 27.562 | 27.852 | 28.331 |
| 32 | 17.038 | 16.776 | 26.070 | 26.630 | 27.351 | 27.653 | 28.073 |
| 33 | 17.059 | 16.701 | 26.026 | 26.651 | 27.371 | 27.789 | 28.104 |

**Figure E2.** Run 4, 19 Nov 1992 (Raw Data)

| Scan | Port Number 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| 1 | 28.408 | 28.656 | 28.970 | 29.279 | 29.764 | 29.95[illegible] | 30.215 |
| 2 | 28.419 | 28.792 | 29.063 | 29.394 | 29.810 | 30.071 | 30.283 |
| 3 | 28.419 | 28.692 | 29.072 | 29.318 | 29.879 | 30.138 | 30.388 |
| 4 | 28.429 | 28.819 | 29.081 | 29.356 | 29.869 | 30.033 | 30.283 |
| 5 | 28.471 | 28.828 | 29.146 | 29.337 | 29.802 | 30.119 | 30.378 |
| 6 | 28.356 | 28.674 | 29.026 | 29.279 | 29.840 | 30.005 | 30.273 |
| 7 | 28.336 | 28.538 | 29.026 | 29.414 | 29.860 | 30.214 | 30.426 |
| 8 | 28.585 | 28.819 | 28.942 | 29.097 | 29.831 | 30.147 | 30.321 |
| 9 | 28.481 | 28.810 | 28.942 | 29.385 | 29.898 | 30.033 | 30.369 |
| 10 | 28.564 | 28.910 | 29.127 | 29.298 | 29.677 | 29.900 | 30.283 |
| 11 | 28.481 | 28.873 | 29.127 | 29.241 | 29.696 | 29.881 | 30.064 |
| 12 | 28.471 | 28.846 | 28.961 | 29.231 | 29.860 | 29.805 | 30.150 |
| 13 | 28.408 | 28.638 | 29.035 | 29.308 | 29.812 | 30.128 | 30.159 |
| 14 | 28.491 | 28.828 | 29.137 | 29.212 | 29.648 | 29.976 | 30.235 |
| 15 | 28.429 | 28.855 | 28.998 | 29.250 | 29.725 | 29.672 | 30.254 |
| 16 | 28.502 | 28.728 | 28.979 | 29.222 | 29.648 | 29.814 | 30.150 |
| 17 | 28.419 | 28.674 | 28.933 | 29.327 | 29.620 | 29.900 | 30.159 |
| 18 | 28.439 | 28.647 | 29.137 | 29.385 | 29.975 | 30.014 | 30.311 |
| 19 | 28.512 | 28.719 | 29.109 | 29.366 | 29.773 | 29.967 | 30.150 |
| 20 | 28.315 | 28.665 | 29.118 | 29.318 | 29.773 | 30.005 | 30.273 |
| 21 | 28.263 | 28.629 | 28.942 | 29.183 | 29.773 | 29.976 | 30.016 |
| 22 | 28.419 | 28.647 | 28.970 | 29.126 | 29.716 | 29.919 | 30.216 |
| 23 | 28.429 | 28.710 | 28.933 | 29.250 | 29.850 | 29.814 | 30.159 |
| 24 | 28.419 | 28.783 | 28.914 | 29.270 | 29.725 | 29.795 | 30.073 |
| 25 | 28.356 | 28.620 | 28.886 | 29.241 | 29.581 | 29.643 | 29.949 |
| 26 | 28.408 | 28.601 | 29.090 | 29.318 | 29.620 | 29.891 | 29.969 |
| 27 | 28.419 | 28.765 | 28.961 | 29.231 | 29.600 | 29.795 | 30.188 |
| 28 | 28.491 | 28.828 | 29.090 | 29.116 | 29.524 | 29.862 | 30.235 |
| 29 | 28.253 | 28.592 | 28.979 | 29.356 | 29.773 | 29.979 | 30.150 |
| 30 | 28.471 | 28.701 | 28.970 | 29.250 | 29.764 | 30.062 | 30.264 |
| 31 | 28.377 | 28.837 | 29.081 | 29.087 | 29.543 | 29.767 | 30.111 |
| 32 | 28.419 | 28.728 | 29.072 | 29.154 | 29.620 | 29.833 | 30.102 |
| 33 | 28.377 | 28.574 | 29.063 | 29.366 | 29.677 | 29.976 | 30.140 |

**Figure E2.** (cont) Run 4, 19 Nov 1992 (Raw Data)

| Scan | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|
| | | Port Number | | | | | |
| 1 | 30.333 | 30.593 | 30.706 | 31.016 | 31.636 | 32.129 | 32.302 |
| 2 | 30.523 | 30.584 | 30.879 | 31.008 | 31.495 | 31.913 | 32.369 |
| 3 | 30.453 | 30.760 | 31.044 | 31.008 | 31.433 | 32.005 | 32.444 |
| 4 | 30.343 | 30.900 | 30.965 | 30.938 | 31.676 | 32.051 | 32.260 |
| 5 | 30.513 | 30.576 | 30.792 | 31.016 | 31.477 | 31.931 | 32.444 |
| 6 | 30.583 | 30.654 | 30.879 | 31.034 | 31.451 | 31.885 | 32.461 |
| 7 | 30.623 | 30.803 | 30.879 | 30.999 | 31.654 | 32.216 | 32.544 |
| 8 | 30.363 | 30.514 | 30.671 | 30.999 | 31.530 | 32.088 | 32.595 |
| 9 | 30.423 | 30.725 | 31.079 | 31.190 | 31.689 | 32.069 | 32.377 |
| 10 | 30.543 | 30.681 | 31.035 | 31.129 | 31.459 | 31.876 | 32.318 |
| 11 | 30.393 | 30.584 | 30.879 | 31.025 | 31.583 | 32.005 | 32.394 |
| 12 | 30.393 | 30.505 | 30.801 | 30.869 | 31.583 | 31.894 | 32.327 |
| 13 | 30.403 | 30.584 | 30.853 | 31.051 | 31.565 | 32.051 | 32.427 |
| 14 | 30.603 | 30.725 | 30.905 | 30.790 | 31.433 | 32.134 | 32.427 |
| 15 | 30.583 | 30.733 | 30.957 | 31.042 | 31.495 | 31.720 | 32.168 |
| 16 | 30.383 | 30.523 | 30.706 | 30.929 | 31.530 | 31.950 | 32.394 |
| 17 | 30.363 | 30.514 | 30.714 | 30.947 | 31.451 | 31.958 | 32.268 |
| 18 | 30.523 | 30.444 | 30.714 | 30.999 | 31.433 | 31.830 | 32.352 |
| 19 | 30.293 | 30.479 | 31.018 | 30.921 | 31.474 | 31.950 | 32.335 |
| 20 | 30.273 | 30.593 | 30.896 | 30.938 | 31.565 | 31.859 | 32.226 |
| 21 | 30.373 | 30.663 | 30.740 | 30.903 | 31.548 | 32.014 | 32.344 |
| 22 | 30.373 | 30.567 | 30.740 | 30.808 | 31.539 | 31.775 | 32.218 |
| 23 | 30.383 | 30.523 | 30.749 | 30.764 | 31.504 | 31.913 | 32.377 |
| 24 | 30.353 | 30.584 | 30.801 | 30.860 | 31.592 | 31.959 | 32.377 |
| 25 | 30.204 | 30.418 | 30.706 | 30.877 | 31.380 | 31.922 | 32.151 |
| 26 | 30.263 | 30.383 | 30.402 | 30.955 | 31.256 | 31.830 | 32.143 |
| 27 | 30.323 | 30.444 | 30.558 | 30.877 | 31.247 | 31.793 | 32.335 |
| 28 | 30.443 | 30.628 | 30.775 | 30.843 | 31.548 | 31.858 | 32.302 |
| 29 | 30.393 | 30.523 | 30.836 | 30.912 | 31.504 | 31.931 | 32.159 |
| 30 | 30.493 | 30.479 | 30.723 | 30.877 | 31.203 | 31.793 | 32.134 |
| 31 | 30.393 | 30.654 | 30.957 | 31.016 | 31.415 | 31.894 | 32.318 |
| 32 | 30.353 | 30.453 | 30.792 | 31.060 | 31.336 | 31.931 | 32.235 |
| 33 | 30.643 | 30.453 | 30.853 | 31.051 | 31.283 | 32.014 | 32.226 |

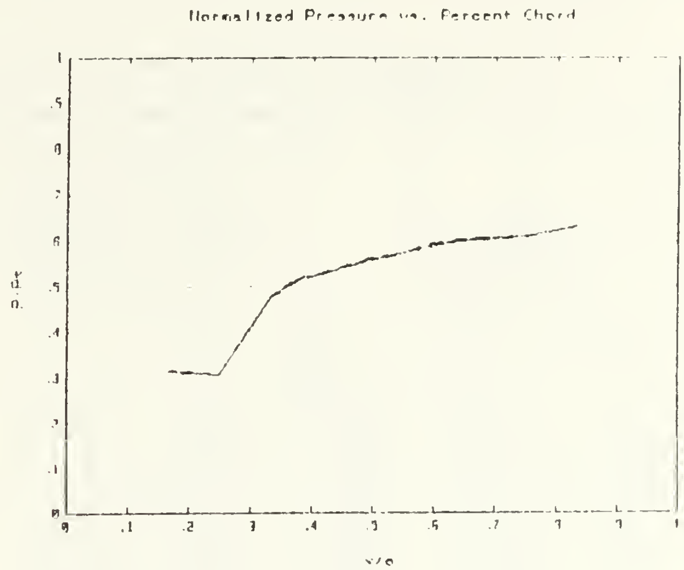
**Figure E2.** (cont) Run 4, 19 Nov 1992 (Raw Data)

| Scan | Port Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| 1 | 32.775 | 33.109 | 34.261 | 35.543 | 28.090 | 30.333 | 25.886 |
| 2 | 32.581 | 33.219 | 34.295 | 35.607 | 28.373 | 30.350 | 26.071 |
| 3 | 32.707 | 33.194 | 34.338 | 35.716 | 28.231 | 30.368 | 25.878 |
| 4 | 32.632 | 33.160 | 34.372 | 35.589 | 28.120 | 30.210 | 25.827 |
| 5 | 32.657 | 33.177 | 34.218 | 35.589 | 28.231 | 30.289 | 25.945 |
| 6 | 32.783 | 33.160 | 34.269 | 35.443 | 28.231 | 30.368 | 25.978 |
| 7 | 32.909 | 33.271 | 34.449 | 35.680 | 28.414 | 30.614 | 26.071 |
| 8 | 32.808 | 33.202 | 34.338 | 35.598 | 28.211 | 30.403 | 26.155 |
| 9 | 32.758 | 33.211 | 34.398 | 35.707 | 28.444 | 30.342 | 25.752 |
| 10 | 32.640 | 33.134 | 34.295 | 35.561 | 28.566 | 30.465 | 25.911 |
| 11 | 32.682 | 33.211 | 34.338 | 35.607 | 28.353 | 30.280 | 26.071 |
| 12 | 32.699 | 33.134 | 34.235 | 35.625 | 28.424 | 30.307 | 25.962 |
| 13 | 32.615 | 33.143 | 34.381 | 35.580 | 28.323 | 30.306 | 25.852 |
| 14 | 32.766 | 33.151 | 34.355 | 35.443 | 28.383 | 30.350 | 25.894 |
| 15 | 32.564 | 33.228 | 34.278 | 35.680 | 28.323 | 30.280 | 25.903 |
| 16 | 32.758 | 33.168 | 34.364 | 35.589 | 28.242 | 30.227 | 25.920 |
| 17 | 32.615 | 33.185 | 34.355 | 35.607 | 28.424 | 30.456 | 25.760 |
| 18 | 32.699 | 33.219 | 34.286 | 35.470 | 28.191 | 30.254 | 25.953 |
| 19 | 32.598 | 33.262 | 34.321 | 35.652 | 28.312 | 30.377 | 26.012 |
| 20 | 32.716 | 33.049 | 34.364 | 35.525 | 28.282 | 30.430 | 25.878 |
| 21 | 32.724 | 33.075 | 34.312 | 35.543 | 28.302 | 30.315 | 25.903 |
| 22 | 32.707 | 33.168 | 34.295 | 35.589 | 28.383 | 30.342 | 25.920 |
| 23 | 32.657 | 33.092 | 34.304 | 35.416 | 28.353 | 30.236 | 25.651 |
| 24 | 32.615 | 33.109 | 34.286 | 35.470 | 28.292 | 30.500 | 25.861 |
| 25 | 32.573 | 33.109 | 34.381 | 35.680 | 28.373 | 30.377 | 25.970 |
| 26 | 32.472 | 33.143 | 34.149 | 35.489 | 28.130 | 30.025 | 25.785 |
| 27 | 32.463 | 33.066 | 34.201 | 35.407 | 28.302 | 30.307 | 25.869 |
| 28 | 32.564 | 33.117 | 34.209 | 35.388 | 28.333 | 30.254 | 25.668 |
| 29 | 32.480 | 33.049 | 34.338 | 35.534 | 28.515 | 30.227 | 25.945 |
| 30 | 32.623 | 33.126 | 34.312 | 35.479 | 28.211 | 30.421 | 26.037 |
| 31 | 32.606 | 33.219 | 34.346 | 35.398 | 28.434 | 30.315 | 25.617 |
| 32 | 32.724 | 33.109 | 34.235 | 35.552 | 28.292 | 30.430 | 25.777 |
| 33 | 32.581 | 33.134 | 34.209 | 35.716 | 28.535 | 30.456 | 25.928 |

**Figure E2.** (cont) Run 4, 19 Nov 1992 (Raw Data)

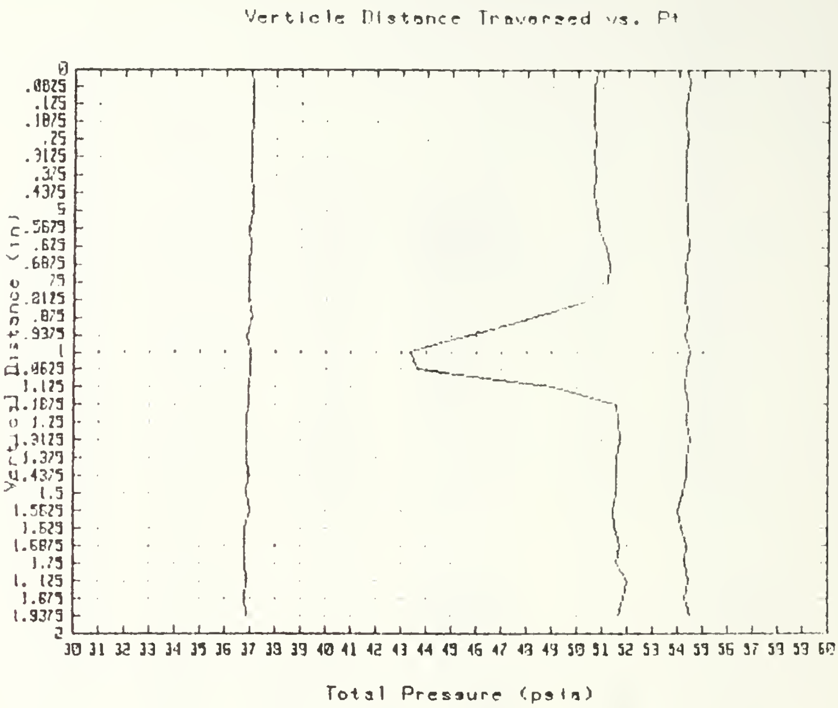
| Scan | Port Number 29 | 30 | 31 | 32 |
|---|---|---|---|---|
| 1 | 17.289 | 36.999 | 54.332 | 50.809 |
| 2 | 17.316 | 37.066 | 54.430 | 50.619 |
| 3 | 17.253 | 37.056 | 54.279 | 50.637 |
| 4 | 17.280 | 37.113 | 54.279 | 50.619 |
| 5 | 17.351 | 36.999 | 54.341 | 50.755 |
| 6 | 17.405 | 36.980 | 54.323 | 50.646 |
| 7 | 17.485 | 36.999 | 54.323 | 50.691 |
| 8 | 17.342 | 37.046 | 54.270 | 50.682 |
| 9 | 17.333 | 37.075 | 54.385 | 50.791 |
| 10 | 17.298 | 36.951 | 54.359 | 50.854 |
| 11 | 17.369 | 37.018 | 54.421 | 51.181 |
| 12 | 17.298 | 36.941 | 54.323 | 51.325 |
| 13 | 17.351 | 36.951 | 54.359 | 51.199 |
| 14 | 17.369 | 36.913 | 54.296 | 50.429 |
| 15 | 17.218 | 37.056 | 54.430 | 48.165 |
| 16 | 17.431 | 36.884 | 54.305 | 45.594 |
| 17 | 17.307 | 37.037 | 54.510 | 43.377 |
| 18 | 17.396 | 37.018 | 54.359 | 43.640 |
| 19 | 17.333 | 36.970 | 54.323 | 49.052 |
| 20 | 17.467 | 36.941 | 54.456 | 51.588 |
| 21 | 17.351 | 36.855 | 54.350 | 51.679 |
| 22 | 17.405 | 36.884 | 54.474 | 51.733 |
| 23 | 17.324 | 36.846 | 54.332 | 51.543 |
| 24 | 17.476 | 36.941 | 54.341 | 51.570 |
| 25 | 17.307 | 36.874 | 54.243 | 51.561 |
| 26 | 17.235 | 36.989 | 54.003 | 51.461 |
| 27 | 17.333 | 36.760 | 54.181 | 51.516 |
| 28 | 17.431 | 36.817 | 54.376 | 51.733 |
| 29 | 17.360 | 36.827 | 54.314 | 51.606 |
| 30 | 17.449 | 36.865 | 54.456 | 52.014 |
| 31 | 17.387 | 36.769 | 54.323 | 51.878 |
| 32 | 17.405 | 36.865 | 54.483 | 51.670 |
| 33 | 17.253 | 37.094 | 54.056 | 50.972 |

**Figure E2.** (cont) Run 4, 19 Nov 1992 (Raw Data)




| Port | Scan Number 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|
| 1 | .316 | .315 | .315 | .316 | .315 | .315 | .314 |
| 2 | .306 | .309 | .307 | .308 | .307 | .307 | .308 |
| 3 | .479 | .479 | .479 | .478 | .476 | .477 | .480 |
| 4 | .491 | .493 | .493 | .491 | .487 | .493 | .492 |
| 5 | .503 | .506 | .508 | .502 | .499 | .506 | .503 |
| 6 | .510 | .513 | .512 | .511 | .509 | .514 | .510 |
| 7 | .519 | .521 | .518 | .519 | .519 | .522 | .516 |
| 8 | .523 | .524 | .523 | .525 | .522 | .525 | .521 |
| 9 | .531 | .531 | .527 | .531 | .530 | .529 | .526 |
| 10 | .535 | .533 | .534 | .537 | .533 | .534 | .531 |
| 11 | .537 | .538 | .539 | .538 | .537 | .538 | .538 |
| 12 | .546 | .550 | .548 | .546 | .546 | .546 | .543 |
| 13 | .549 | .549 | .554 | .552 | .545 | .549 | .549 |
| 14 | .552 | .555 | .555 | .557 | .556 | .555 | .553 |
| 15 | .558 | .559 | .559 | .564 | .567 | .559 | .557 |
| 16 | .562 | .562 | .563 | .566 | .565 | .562 | .560 |
| 17 | .567 | .567 | .568 | .569 | .569 | .565 | .563 |
| 18 | .570 | .568 | .571 | .567 | .570 | .570 | .568 |
| 19 | .580 | .581 | .581 | .579 | .579 | .581 | .577 |
| 20 | .588 | .587 | .590 | .592 | .583 | .589 | .584 |
| 21 | .595 | .595 | .597 | .597 | .591 | .597 | .592 |
| 22 | .601 | .602 | .600 | .603 | .598 | .603 | .598 |
| 23 | .610 | .610 | .610 | .611 | .610 | .611 | .609 |
| 24 | .631 | .630 | .632 | .633 | .630 | .633 | .630 |
| 25 | .654 | .656 | .655 | .653 | .656 | .655 | .653 |

**Figure E2.** (cont) Run 4, 19 Nov 1992 (P/Pt Distribution)




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

Ptma1 = 54.3345292679 PSIA
Ptma2 = 50.6123122685 PSIA

Pt1-P1 = 36.9826244479 PSIA
Ttavg = 511 deg R

W_bar = .100647724572

**Figure E2.** (cont) Run 4, 19 Nov 1992 (Loss Distribution)

Data Print Out for Zoc # 1 , Run # 2 , FileZB1212012

Period between samples (sec): .00333333333333
Sample collection rate (Hz): 300
Number of samples per port: 10
Length of data run (sec): 34.1
The scan type is: 3
Number of scans/traverses: 33
Increment of traverse: .0625 Inches
Atmospheric pressure is: 14.725 psia
Tunnel Pressure Ratio is: 2.09968174398

| Scan | Port Number | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 18.311 | 18.602 | 18.663 | 20.062 | 23.040 | 25.376 | 27.196 |
| 2 | 18.321 | 18.591 | 18.697 | 19.757 | 22.820 | 25.114 | 26.168 |
| 3 | 18.372 | 18.655 | 18.619 | 19.828 | 22.181 | 24.643 | 26.373 |
| 4 | 18.331 | 18.666 | 18.619 | 19.747 | 22.361 | 25.124 | 26.435 |
| 5 | 18.311 | 18.591 | 18.486 | 19.076 | 21.652 | 24.643 | 26.785 |
| 6 | 18.331 | 18.613 | 18.541 | 19.330 | 22.231 | 24.674 | 26.795 |
| 7 | 18.362 | 18.613 | 18.686 | 19.696 | 22.331 | 24.464 | 25.931 |
| 8 | 18.331 | 18.591 | 18.486 | 18.853 | 21.703 | 23.543 | 25.818 |
| 9 | 18.300 | 18.602 | 18.541 | 19.219 | 21.672 | 24.381 | 25.900 |
| 10 | 18.300 | 18.570 | 18.486 | 19.279 | 22.002 | 24.433 | 26.209 |
| 11 | 18.280 | 18.602 | 18.430 | 19.076 | 21.293 | 24.339 | 26.332 |
| 12 | 18.259 | 18.462 | 18.563 | 19.584 | 22.102 | 24.391 | 26.127 |
| 13 | 18.219 | 18.516 | 18.552 | 19.371 | 22.231 | 24.779 | 26.229 |
| 14 | 18.270 | 18.580 | 18.508 | 19.493 | 22.251 | 24.234 | 26.137 |
| 15 | 18.259 | 18.559 | 18.552 | 19.137 | 21.872 | 24.224 | 26.137 |
| 16 | 18.311 | 18.623 | 18.586 | 19.005 | 21.074 | 23.270 | 25.623 |
| 17 | 18.229 | 18.570 | 18.508 | 19.239 | 21.293 | 23.826 | 25.756 |
| 18 | 18.208 | 18.495 | 18.441 | 19.229 | 21.732 | 24.527 | 26.301 |
| 19 | 18.290 | 18.537 | 18.452 | 18.995 | 21.263 | 23.815 | 25.839 |
| 20 | 18.259 | 18.473 | 18.519 | 19.422 | 21.922 | 24.412 | 26.127 |
| 21 | 18.188 | 18.548 | 18.630 | 19.269 | 21.642 | 24.758 | 26.322 |
| 22 | 18.219 | 18.441 | 18.530 | 19.290 | 22.421 | 24.737 | 26.096 |
| 23 | 18.188 | 18.409 | 18.419 | 19.117 | 21.503 | 23.794 | 25.767 |
| 24 | 18.147 | 18.484 | 18.475 | 19.188 | 21.682 | 23.920 | 25.643 |
| 25 | 18.126 | 18.441 | 18.419 | 18.914 | 21.293 | 24.349 | 26.075 |
| 26 | 18.147 | 18.559 | 18.386 | 19.158 | 21.523 | 24.014 | 25.900 |
| 27 | 18.188 | 18.323 | 18.408 | 19.117 | 21.602 | 23.951 | 25.859 |
| 28 | 18.106 | 18.462 | 18.430 | 19.005 | 21.902 | 24.192 | 25.777 |
| 29 | 18.085 | 18.301 | 18.475 | 19.747 | 22.421 | 24.307 | 25.664 |
| 30 | 18.147 | 18.323 | 18.464 | 19.290 | 21.552 | 24.108 | 26.353 |
| 31 | 18.075 | 18.452 | 18.552 | 19.615 | 22.351 | 25.020 | 26.404 |
| 32 | 18.004 | 18.312 | 18.408 | 19.310 | 21.483 | 24.035 | 25.674 |
| 33 | 18.075 | 18.430 | 18.297 | 19.676 | 22.231 | 24.758 | 26.332 |

**Figure E3.** Run 2, 1 Dec 1992 (Raw Data)

| Scan | Port Number 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| 1 | 27.965 | 28.331 | 28.827 | 29.653 | 29.807 | 30.196 | 30.473 |
| 2 | 27.903 | 28.638 | 29.031 | 29.489 | 29.836 | 30.101 | 30.188 |
| 3 | 27.768 | 28.376 | 28.836 | 29.307 | 29.616 | 30.139 | 30.369 |
| 4 | 27.550 | 28.349 | 28.883 | 29.432 | 29.855 | 30.215 | 30.416 |
| 5 | 27.768 | 28.313 | 29.040 | 29.432 | 29.740 | 30.034 | 30.330 |
| 6 | 27.747 | 28.267 | 28.660 | 29.125 | 29.817 | 29.987 | 30.140 |
| 7 | 27.311 | 28.385 | 28.725 | 29.144 | 29.702 | 30.129 | 30.235 |
| 8 | 27.456 | 28.159 | 28.799 | 29.441 | 29.740 | 30.044 | 30.235 |
| 9 | 27.083 | 27.842 | 28.697 | 29.345 | 29.759 | 29.977 | 30.168 |
| 10 | 27.373 | 28.041 | 28.697 | 29.297 | 29.530 | 29.982 | 30.130 |
| 11 | 27.363 | 27.896 | 28.660 | 29.297 | 29.606 | 29.844 | 29.940 |
| 12 | 27.415 | 28.267 | 28.920 | 29.336 | 29.740 | 30.053 | 30.292 |
| 13 | 27.311 | 28.096 | 28.577 | 29.230 | 29.779 | 30.006 | 30.168 |
| 14 | 27.166 | 27.887 | 28.651 | 29.230 | 29.510 | 29.844 | 30.188 |
| 15 | 27.249 | 28.285 | 28.957 | 29.211 | 29.597 | 29.958 | 30.226 |
| 16 | 26.917 | 27.797 | 28.651 | 29.297 | 29.558 | 29.949 | 30.083 |
| 17 | 27.207 | 28.077 | 28.354 | 28.971 | 29.453 | 29.797 | 30.111 |
| 18 | 27.332 | 28.132 | 28.818 | 29.211 | 29.463 | 29.806 | 29.940 |
| 19 | 27.145 | 28.059 | 28.632 | 29.317 | 29.530 | 29.673 | 30.035 |
| 20 | 27.073 | 27.697 | 28.493 | 28.942 | 29.415 | 29.740 | 29.959 |
| 21 | 27.508 | 28.258 | 28.781 | 29.067 | 29.300 | 29.835 | 30.064 |
| 22 | 26.969 | 27.851 | 28.744 | 29.067 | 29.625 | 29.711 | 30.064 |
| 23 | 27.176 | 27.887 | 28.595 | 29.115 | 29.577 | 29.683 | 30.083 |
| 24 | 26.875 | 27.670 | 28.521 | 29.077 | 29.491 | 29.730 | 29.911 |
| 25 | 27.093 | 27.824 | 28.679 | 29.134 | 29.472 | 29.740 | 30.111 |
| 26 | 27.052 | 27.716 | 28.363 | 28.952 | 29.549 | 29.806 | 30.016 |
| 27 | 27.104 | 27.860 | 28.372 | 29.009 | 29.309 | 29.730 | 30.006 |
| 28 | 27.000 | 28.077 | 28.706 | 29.048 | 29.290 | 29.607 | 30.178 |
| 29 | 26.574 | 27.942 | 28.632 | 29.067 | 29.463 | 29.683 | 30.083 |
| 30 | 27.581 | 27.915 | 28.632 | 29.144 | 29.443 | 29.806 | 30.064 |
| 31 | 27.259 | 28.050 | 28.679 | 29.019 | 29.434 | 29.901 | 30.054 |
| 32 | 26.813 | 27.562 | 28.512 | 29.153 | 29.204 | 29.797 | 30.197 |
| 33 | 27.581 | 28.105 | 28.456 | 29.000 | 29.510 | 29.749 | 29.673 |

**Figure E3.** (cont) Run 2, 1 Dec 1992 (Raw Data)

| Scan | Port Number 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|
| 1 | 30.470 | 30.664 | 30.618 | 30.808 | 30.914 | 31.090 | 30.988 |
| 2 | 30.470 | 30.542 | 30.514 | 30.678 | 30.958 | 30.998 | 31.180 |
| 3 | 30.550 | 30.656 | 30.705 | 30.765 | 30.905 | 31.090 | 31.205 |
| 4 | 30.530 | 30.585 | 30.627 | 30.652 | 30.914 | 30.989 | 31.071 |
| 5 | 30.421 | 30.533 | 30.644 | 30.634 | 30.852 | 30.861 | 30.938 |
| 6 | 30.421 | 30.340 | 30.523 | 30.582 | 30.888 | 31.017 | 31.029 |
| 7 | 30.351 | 30.533 | 30.505 | 30.695 | 30.755 | 31.008 | 30.988 |
| 8 | 30.371 | 30.384 | 30.505 | 30.634 | 30.755 | 30.800 | 30.988 |
| 9 | 30.431 | 30.340 | 30.497 | 30.634 | 30.667 | 30.909 | 30.887 |
| 10 | 30.321 | 30.375 | 30.366 | 30.652 | 30.641 | 30.851 | 30.913 |
| 11 | 30.091 | 30.340 | 30.340 | 30.521 | 30.623 | 30.741 | 30.946 |
| 12 | 30.351 | 30.358 | 30.419 | 30.556 | 30.667 | 30.824 | 30.913 |
| 13 | 30.291 | 30.279 | 30.314 | 30.513 | 30.729 | 30.833 | 30.879 |
| 14 | 30.271 | 30.349 | 30.288 | 30.443 | 30.703 | 30.704 | 30.745 |
| 15 | 30.261 | 30.445 | 30.332 | 30.591 | 30.667 | 30.787 | 30.954 |
| 16 | 30.281 | 30.419 | 30.462 | 30.565 | 30.676 | 30.851 | 30.779 |
| 17 | 30.361 | 30.366 | 30.358 | 30.695 | 30.782 | 30.870 | 30.862 |
| 18 | 30.131 | 30.270 | 30.271 | 30.435 | 30.447 | 30.576 | 30.712 |
| 19 | 30.221 | 30.323 | 30.375 | 30.365 | 30.676 | 30.796 | 30.938 |
| 20 | 30.171 | 30.349 | 30.445 | 30.400 | 30.650 | 30.677 | 30.846 |
| 21 | 30.181 | 30.270 | 30.358 | 30.400 | 30.685 | 30.741 | 30.737 |
| 22 | 30.331 | 30.445 | 30.375 | 30.435 | 30.782 | 30.760 | 30.963 |
| 23 | 30.221 | 30.436 | 30.497 | 30.530 | 30.773 | 30.787 | 30.996 |
| 24 | 30.111 | 30.375 | 30.236 | 30.608 | 30.606 | 30.796 | 30.821 |
| 25 | 29.992 | 30.121 | 30.297 | 30.339 | 30.641 | 30.714 | 30.587 |
| 26 | 30.251 | 30.200 | 30.253 | 30.339 | 30.667 | 30.677 | 30.896 |
| 27 | 30.351 | 30.252 | 30.080 | 30.452 | 30.676 | 30.548 | 30.704 |
| 28 | 30.151 | 30.103 | 30.410 | 30.348 | 30.491 | 30.796 | 30.796 |
| 29 | 30.121 | 30.165 | 30.236 | 30.374 | 30.526 | 30.530 | 30.762 |
| 30 | 30.211 | 30.147 | 30.184 | 30.617 | 30.509 | 30.695 | 30.796 |
| 31 | 29.992 | 30.130 | 30.210 | 30.374 | 30.412 | 30.741 | 30.670 |
| 32 | 30.091 | 30.191 | 30.219 | 30.408 | 30.332 | 30.576 | 30.720 |
| 33 | 30.101 | 30.270 | 30.071 | 30.322 | 30.606 | 30.668 | 30.553 |

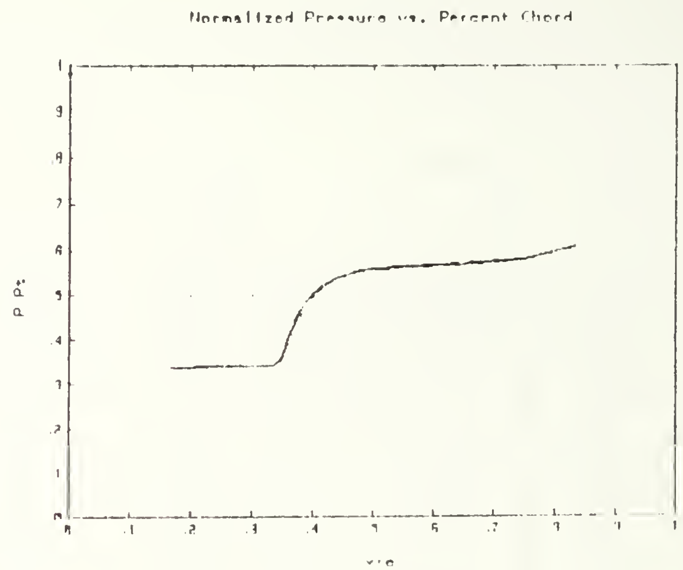
**Figure E3.** (cont) Run 2, 1 Dec 1992 (Raw Data)

| Scan | Port Number 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|
| 1 | 31.347 | 31.630 | 33.022 | 35.091 | 27.018 | 29.064 | 26.704 |
| 2 | 31.178 | 31.622 | 33.099 | 35.109 | 26.370 | 29.081 | 26.637 |
| 3 | 31.162 | 31.605 | 33.201 | 35.008 | 26.613 | 29.151 | 26.738 |
| 4 | 31.204 | 31.647 | 33.141 | 34.981 | 26.421 | 29.046 | 26.780 |
| 5 | 31.120 | 31.664 | 33.141 | 35.063 | 26.410 | 29.090 | 26.569 |
| 6 | 31.120 | 31.579 | 33.107 | 34.963 | 26.431 | 28.846 | 26.477 |
| 7 | 31.036 | 31.528 | 33.099 | 34.944 | 26.441 | 29.099 | 26.653 |
| 8 | 31.061 | 31.460 | 32.953 | 34.862 | 26.025 | 28.881 | 26.118 |
| 9 | 31.162 | 31.537 | 32.842 | 34.890 | 26.269 | 28.899 | 26.536 |
| 10 | 30.985 | 31.418 | 33.064 | 35.036 | 26.421 | 28.994 | 26.485 |
| 11 | 30.884 | 31.520 | 33.056 | 34.844 | 26.279 | 28.793 | 26.418 |
| 12 | 30.960 | 31.375 | 33.073 | 34.963 | 26.329 | 28.785 | 26.190 |
| 13 | 31.111 | 31.596 | 33.133 | 34.963 | 26.340 | 28.627 | 26.477 |
| 14 | 30.884 | 31.622 | 33.022 | 34.935 | 26.188 | 28.819 | 26.392 |
| 15 | 31.002 | 31.613 | 33.082 | 34.954 | 26.279 | 28.915 | 26.451 |
| 16 | 30.867 | 31.435 | 32.945 | 34.881 | 26.350 | 28.872 | 26.460 |
| 17 | 30.926 | 31.418 | 32.987 | 34.835 | 26.167 | 28.828 | 26.460 |
| 18 | 30.910 | 31.248 | 32.910 | 34.871 | 26.117 | 28.645 | 26.207 |
| 19 | 31.002 | 31.486 | 33.064 | 34.908 | 26.238 | 28.715 | 26.266 |
| 20 | 30.943 | 31.469 | 33.047 | 34.780 | 26.188 | 28.662 | 26.233 |
| 21 | 30.977 | 31.562 | 32.833 | 34.835 | 26.238 | 28.706 | 26.477 |
| 22 | 30.952 | 31.392 | 33.013 | 34.771 | 26.228 | 28.592 | 26.392 |
| 23 | 31.010 | 31.528 | 32.987 | 34.963 | 26.309 | 28.654 | 26.350 |
| 24 | 30.985 | 31.571 | 32.928 | 34.890 | 26.289 | 28.846 | 26.350 |
| 25 | 30.775 | 31.256 | 32.970 | 34.771 | 26.096 | 28.785 | 26.342 |
| 26 | 31.027 | 31.537 | 32.945 | 34.698 | 26.147 | 28.697 | 26.367 |
| 27 | 30.792 | 31.503 | 32.808 | 34.826 | 26.036 | 28.514 | 26.123 |
| 28 | 30.851 | 31.180 | 32.868 | 34.716 | 25.884 | 28.654 | 26.334 |
| 29 | 30.867 | 31.239 | 32.782 | 34.835 | 26.157 | 28.645 | 26.308 |
| 30 | 30.985 | 31.324 | 32.851 | 34.899 | 26.218 | 28.523 | 26.233 |
| 31 | 30.809 | 31.392 | 32.936 | 34.680 | 25.975 | 28.558 | 26.106 |
| 32 | 30.691 | 31.239 | 32.756 | 34.707 | 26.177 | 28.697 | 26.275 |
| 33 | 30.800 | 31.477 | 32.859 | 34.634 | 26.198 | 28.793 | 26.207 |

**Figure E3.** (cont) Run 2, 1 Dec 1992 (Raw Data)

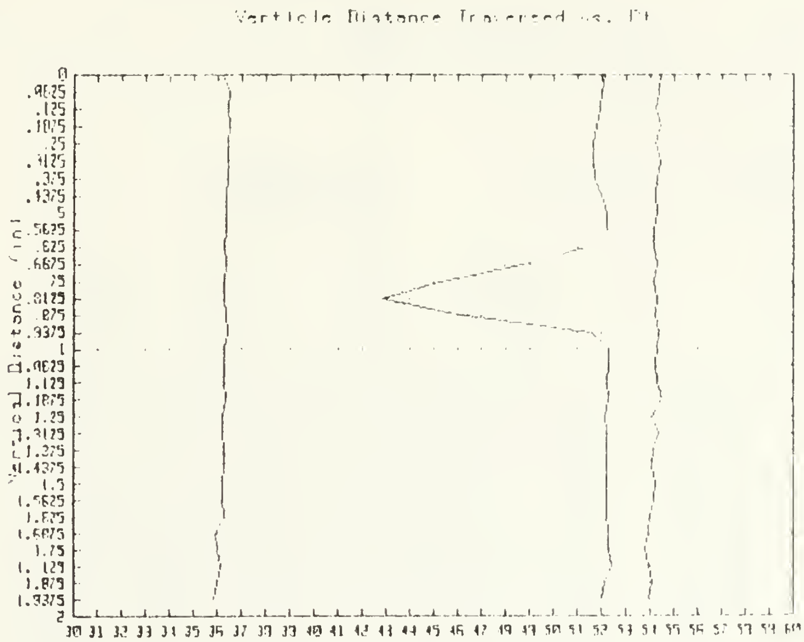
| Scan | Port Number 29 | 30 | 31 | 32 |
|---|---|---|---|---|
| 1 | 17.266 | 36.252 | 54.454 | 52.194 |
| 2 | 17.337 | 36.528 | 54.340 | 52.003 |
| 3 | 17.372 | 36.471 | 54.243 | 51.940 |
| 4 | 17.354 | 36.518 | 54.428 | 51.795 |
| 5 | 17.319 | 36.423 | 54.199 | 51.669 |
| 6 | 17.363 | 36.471 | 54.428 | 51.674 |
| 7 | 17.372 | 36.461 | 54.287 | 51.732 |
| 8 | 17.345 | 36.366 | 54.252 | 52.031 |
| 9 | 17.363 | 36.357 | 54.287 | 52.202 |
| 10 | 17.292 | 36.366 | 54.173 | 52.239 |
| 11 | 17.328 | 36.290 | 54.147 | 51.361 |
| 12 | 17.363 | 36.347 | 54.322 | 48.695 |
| 13 | 17.301 | 36.281 | 54.182 | 45.189 |
| 14 | 17.337 | 36.328 | 54.278 | 42.759 |
| 15 | 17.345 | 36.395 | 54.252 | 46.273 |
| 16 | 17.408 | 36.414 | 54.331 | 51.587 |
| 17 | 17.363 | 36.328 | 54.270 | 52.293 |
| 18 | 17.345 | 36.290 | 54.217 | 52.266 |
| 19 | 17.345 | 36.290 | 54.305 | 52.248 |
| 20 | 17.319 | 36.338 | 54.472 | 52.320 |
| 21 | 17.425 | 36.243 | 54.103 | 52.194 |
| 22 | 17.399 | 36.205 | 54.357 | 52.248 |
| 23 | 17.292 | 36.309 | 54.155 | 52.257 |
| 24 | 17.328 | 36.271 | 54.103 | 52.211 |
| 25 | 17.328 | 36.224 | 54.190 | 52.229 |
| 26 | 17.337 | 36.186 | 54.120 | 52.193 |
| 27 | 17.390 | 36.309 | 54.041 | 52.220 |
| 28 | 17.301 | 35.939 | 53.936 | 52.302 |
| 29 | 17.417 | 36.024 | 53.821 | 52.275 |
| 30 | 17.452 | 36.129 | 53.927 | 52.428 |
| 31 | 17.212 | 35.986 | 54.059 | 52.184 |
| 32 | 17.230 | 35.882 | 53.901 | 52.031 |
| 33 | 17.221 | 36.214 | 54.138 | 51.081 |

**Figure E3.** (cont) Run 2, 1 Dec 1992 (Raw Data)




| Port | Scan Number 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|
| 1 | .338 | .338 | .336 | .336 | .337 | .337 | .337 |
| 2 | .343 | .344 | .340 | .342 | .342 | .342 | .343 |
| 3 | .341 | .340 | .342 | .342 | .341 | .342 | .342 |
| 4 | .356 | .352 | .361 | .358 | .359 | .353 | .350 |
| 5 | .406 | .393 | .407 | .410 | .410 | .403 | .388 |
| 6 | .451 | .449 | .449 | .457 | .446 | .447 | .428 |
| 7 | .484 | .486 | .481 | .484 | .482 | .482 | .472 |
| 8 | .505 | .605 | .505 | .504 | .500 | .502 | .495 |
| 9 | .518 | .515 | .520 | .519 | .514 | .521 | .512 |
| 10 | .530 | .529 | .532 | .527 | .528 | .534 | .527 |
| 11 | .541 | .541 | .540 | .539 | .539 | .538 | .539 |
| 12 | .545 | .547 | .547 | .550 | .544 | .546 | .544 |
| 13 | .552 | .551 | .553 | .554 | .550 | .552 | .551 |
| 14 | .556 | .553 | .558 | .557 | .556 | .557 | .554 |
| 15 | .560 | .556 | .559 | .559 | .558 | .558 | .557 |
| 16 | .561 | .560 | .559 | .559 | .559 | .561 | .560 |
| 17 | .561 | .560 | .560 | .559 | .558 | .559 | .561 |
| 18 | .566 | .584 | .562 | .563 | .561 | .564 | .563 |
| 19 | .566 | .566 | .565 | .567 | .566 | .565 | .565 |
| 20 | .569 | .568 | .567 | .569 | .566 | .567 | .568 |
| 21 | .571 | .572 | .569 | .570 | .566 | .571 | .567 |
| 22 | .572 | .570 | .570 | .574 | .569 | .571 | .568 |
| 23 | .580 | .582 | .578 | .583 | .583 | .583 | .579 |
| 24 | .610 | .610 | .609 | .612 | .608 | .610 | .606 |
| 25 | .647 | .644 | .644 | .645 | .644 | .644 | .642 |

**Figure E3.** (cont) Run 2, 1 Dec 1992 (P/Pt Distribution)




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

Ptma1 = 54.2040569826 PSIA
Ptma2 = 51.4784813851 PSIA

Pt1-P1 = 36.8650770313 PSIA
Ttavg = 507.5 deg R

W_bar = .0739338099084

**Figure E3.** (cont) Run 2, 1 Dec 1992 (Loss Distribution)

Data Print Out for Zoc # 1 , Run # 1 , FileZP1212071

Period between samples (sec): .00333333333333

Sample collection rate (Hz): 300

Number of samples per port: 10

Length of data run (sec): 34.1

The scan type is: 3

Number of scans/traverses: 33

Increment of traverse: .0625 Inches

Atmospheric pressure is: 14.725 psia

Tunnel Pressure Ratio is: 1.93212824279

| Scan | Port Number 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 18.654 | 18.899 | 19.720 | 22.161 | 25.184 | 26.894 | 28.134 |
| 2 | 18.613 | 18.824 | 19.787 | 22.669 | 25.095 | 26.926 | 28.144 |
| 3 | 18.654 | 18.856 | 19.798 | 22.151 | 24.345 | 26.204 | 27.959 |
| 4 | 18.613 | 18.845 | 19.610 | 21.765 | 24.805 | 26.769 | 28.031 |
| 5 | 18.593 | 18.835 | 19.676 | 22.212 | 24.535 | 26.654 | 27.959 |
| 6 | 18.623 | 18.813 | 19.643 | 21.846 | 24.755 | 26.643 | 28.113 |
| 7 | 18.644 | 18.813 | 19.367 | 21.927 | 24.685 | 26.496 | 27.558 |
| 8 | 18.542 | 18.792 | 19.500 | 22.110 | 25.005 | 26.905 | 27.815 |
| 9 | 18.623 | 18.813 | 19.820 | 22.262 | 24.755 | 26.570 | 27.743 |
| 10 | 18.552 | 18.781 | 19.489 | 21.643 | 24.625 | 26.601 | 27.815 |
| 11 | 18.522 | 18.835 | 19.544 | 21.622 | 24.545 | 26.382 | 27.794 |
| 12 | 18.603 | 18.802 | 19.522 | 21.460 | 23.735 | 26.193 | 28.000 |
| 13 | 18.511 | 18.706 | 19.334 | 21.277 | 24.335 | 26.528 | 27.969 |
| 14 | 18.542 | 18.684 | 19.389 | 21.582 | 23.905 | 26.057 | 27.732 |
| 15 | 18.481 | 18.759 | 19.544 | 21.571 | 24.115 | 26.026 | 27.547 |
| 16 | 18.491 | 18.749 | 19.312 | 21.328 | 23.965 | 26.465 | 27.650 |
| 17 | 18.379 | 18.544 | 19.378 | 21.571 | 24.655 | 26.905 | 27.712 |
| 18 | 18.522 | 18.759 | 19.411 | 21.561 | 24.195 | 26.256 | 27.743 |
| 19 | 18.491 | 18.706 | 19.356 | 21.886 | 24.215 | 26.287 | 27.537 |
| 20 | 18.461 | 18.587 | 19.345 | 21.378 | 23.825 | 26.308 | 27.671 |
| 21 | 18.501 | 18.770 | 19.400 | 21.307 | 24.625 | 26.277 | 27.712 |
| 22 | 18.522 | 18.706 | 19.544 | 21.866 | 24.245 | 26.214 | 27.702 |
| 23 | 18.450 | 18.620 | 19.500 | 21.714 | 24.055 | 26.507 | 27.599 |
| 24 | 18.369 | 18.706 | 19.632 | 21.815 | 24.145 | 26.057 | 27.558 |
| 25 | 18.440 | 18.609 | 19.422 | 21.338 | 24.195 | 26.319 | 27.558 |
| 26 | 18.491 | 18.673 | 19.334 | 21.582 | 24.425 | 26.695 | 27.990 |
| 27 | 18.389 | 18.630 | 19.334 | 21.338 | 24.185 | 26.277 | 27.763 |
| 28 | 18.440 | 18.663 | 19.224 | 21.043 | 23.905 | 26.036 | 27.516 |
| 29 | 18.318 | 18.523 | 19.378 | 21.439 | 23.495 | 25.733 | 27.290 |
| 30 | 18.430 | 18.523 | 19.213 | 21.409 | 24.065 | 26.476 | 27.527 |
| 31 | 18.399 | 18.566 | 19.202 | 21.673 | 24.075 | 25.806 | 27.084 |
| 32 | 18.287 | 18.555 | 19.312 | 21.256 | 23.665 | 25.771 | 27.527 |
| 33 | 18.318 | 18.502 | 19.213 | 21.124 | 24.325 | 26.685 | 27.619 |

**Figure E4.** Run 1, 7 Dec 1992 (Raw Data)

| Scan | Port Number 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| 1 | 28.798 | 29.491 | 29.835 | 30.438 | 30.609 | 30.719 | 31.029 |
| 2 | 29.026 | 29.617 | 29.974 | 30.380 | 30.657 | 30.900 | 31.191 |
| 3 | 29.223 | 29.644 | 30.103 | 30.670 | 30.906 | 30.976 | 31.077 |
| 4 | 28.767 | 29.292 | 30.020 | 30.438 | 30.713 | 31.014 | 31.096 |
| 5 | 28.684 | 29.427 | 29.890 | 30.246 | 30.714 | 31.052 | 31.096 |
| 6 | 28.642 | 29.436 | 30.094 | 30.351 | 30.638 | 30.972 | 30.982 |
| 7 | 28.777 | 29.744 | 30.048 | 30.524 | 30.777 | 31.014 | 31.077 |
| 8 | 28.819 | 29.509 | 29.974 | 30.274 | 30.618 | 30.862 | 30.972 |
| 9 | 28.684 | 29.491 | 29.872 | 30.380 | 30.858 | 30.966 | 30.925 |
| 10 | 28.705 | 29.301 | 29.770 | 30.361 | 30.781 | 30.938 | 31.153 |
| 11 | 29.005 | 29.536 | 29.964 | 30.534 | 30.676 | 30.919 | 30.991 |
| 12 | 28.798 | 29.382 | 29.844 | 30.399 | 30.647 | 30.796 | 31.039 |
| 13 | 28.870 | 29.274 | 29.696 | 30.236 | 30.599 | 30.995 | 31.210 |
| 14 | 28.777 | 29.328 | 29.742 | 30.217 | 30.494 | 30.758 | 30.934 |
| 15 | 28.456 | 29.328 | 29.853 | 30.265 | 30.570 | 30.919 | 31.010 |
| 16 | 28.456 | 29.048 | 29.779 | 30.226 | 30.590 | 30.777 | 30.887 |
| 17 | 28.601 | 29.346 | 29.779 | 30.246 | 30.599 | 30.673 | 30.725 |
| 18 | 28.839 | 29.084 | 29.668 | 30.274 | 30.542 | 30.815 | 30.953 |
| 19 | 28.829 | 29.554 | 29.742 | 30.159 | 30.628 | 30.929 | 30.849 |
| 20 | 28.777 | 29.455 | 29.779 | 30.217 | 30.580 | 30.702 | 30.896 |
| 21 | 28.622 | 29.192 | 29.742 | 30.159 | 30.494 | 30.853 | 31.058 |
| 22 | 28.694 | 29.220 | 29.714 | 30.207 | 30.494 | 30.654 | 30.963 |
| 23 | 28.300 | 29.192 | 29.751 | 30.188 | 30.417 | 30.607 | 30.773 |
| 24 | 28.694 | 29.427 | 29.547 | 29.957 | 30.398 | 30.541 | 30.896 |
| 25 | 28.393 | 28.705 | 29.529 | 30.217 | 30.532 | 30.673 | 30.858 |
| 26 | 28.725 | 29.346 | 29.807 | 30.217 | 30.494 | 30.597 | 30.887 |
| 27 | 28.487 | 29.256 | 29.733 | 30.217 | 30.436 | 30.692 | 31.039 |
| 28 | 28.300 | 29.183 | 29.584 | 30.044 | 30.436 | 30.626 | 30.763 |
| 29 | 28.383 | 28.903 | 29.464 | 29.890 | 30.408 | 30.607 | 30.725 |
| 30 | 28.331 | 29.220 | 29.547 | 30.111 | 30.551 | 30.512 | 30.678 |
| 31 | 28.394 | 29.057 | 29.473 | 30.284 | 30.523 | 30.531 | 30.716 |
| 32 | 28.819 | 29.129 | 29.510 | 29.919 | 30.436 | 30.777 | 30.782 |
| 33 | 28.580 | 28.994 | 29.557 | 29.890 | 30.235 | 30.399 | 30.640 |

**Figure E4.** (cont) Run 1, 7 Dec 1992 (Raw Data)

| Scan | Port Number 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|
| 1 | 31.008 | 31.106 | 31.198 | 31.219 | 31.137 | 31.251 | 22.350 |
| 2 | 31.187 | 31.202 | 31.337 | 31.419 | 31.295 | 31.454 | 22.731 |
| 3 | 31.337 | 31.220 | 31.111 | 31.298 | 31.163 | 31.307 | 21.729 |
| 4 | 31.277 | 31.220 | 31.181 | 31.428 | 31.330 | 31.242 | 22.193 |
| 5 | 31.247 | 31.185 | 31.103 | 31.237 | 31.049 | 31.297 | 21.605 |
| 6 | 31.088 | 31.132 | 31.051 | 31.185 | 31.163 | 31.325 | 21.183 |
| 7 | 31.158 | 31.150 | 31.155 | 31.237 | 31.274 | 31.195 | 21.713 |
| 8 | 31.178 | 31.158 | 31.120 | 31.245 | 31.181 | 31.270 | 21.572 |
| 9 | 31.018 | 31.071 | 30.964 | 31.280 | 31.216 | 31.408 | 21.323 |
| 10 | 31.237 | 31.193 | 31.051 | 31.115 | 31.137 | 31.233 | 21.290 |
| 11 | 30.938 | 31.079 | 30.998 | 31.159 | 31.198 | 31.334 | 21.025 |
| 12 | 31.128 | 31.106 | 31.051 | 31.159 | 30.987 | 31.150 | 20.918 |
| 13 | 31.098 | 31.044 | 30.981 | 31.272 | 31.128 | 31.104 | 21.257 |
| 14 | 31.028 | 31.193 | 30.955 | 31.107 | 31.181 | 31.068 | 20.479 |
| 15 | 31.068 | 31.185 | 31.111 | 30.985 | 30.996 | 31.159 | 20.992 |
| 16 | 31.088 | 30.957 | 30.842 | 30.985 | 30.881 | 31.095 | 20.239 |
| 17 | 30.868 | 30.992 | 30.860 | 31.211 | 31.198 | 31.086 | 21.117 |
| 18 | 31.038 | 30.974 | 31.051 | 31.167 | 31.101 | 30.994 | 21.108 |
| 19 | 30.958 | 30.878 | 30.964 | 31.211 | 31.093 | 31.058 | 20.876 |
| 20 | 30.898 | 31.088 | 30.929 | 31.072 | 30.978 | 30.976 | 20.777 |
| 21 | 31.108 | 31.009 | 30.998 | 31.080 | 30.996 | 31.068 | 20.595 |
| 22 | 30.928 | 31.001 | 31.094 | 31.072 | 31.075 | 31.077 | 20.852 |
| 23 | 30.938 | 31.036 | 30.860 | 30.968 | 30.881 | 31.003 | 21.282 |
| 24 | 30.938 | 30.869 | 30.868 | 31.072 | 30.864 | 30.875 | 20.868 |
| 25 | 31.018 | 30.790 | 30.851 | 31.115 | 30.899 | 30.893 | 20.587 |
| 26 | 30.829 | 30.834 | 30.834 | 30.985 | 30.837 | 30.875 | 20.934 |
| 27 | 31.098 | 30.904 | 30.929 | 30.994 | 30.943 | 31.049 | 21.166 |
| 28 | 30.898 | 30.904 | 30.704 | 30.907 | 31.031 | 30.930 | 21.199 |
| 29 | 30.848 | 30.694 | 30.721 | 30.881 | 30.899 | 30.902 | 20.222 |
| 30 | 30.779 | 30.790 | 30.825 | 31.063 | 30.908 | 31.022 | 21.539 |
| 31 | 30.779 | 30.764 | 30.851 | 30.811 | 30.802 | 30.755 | 21.448 |
| 32 | 30.809 | 30.939 | 30.730 | 31.089 | 30.934 | 30.829 | 21.199 |
| 33 | 30.749 | 30.878 | 30.652 | 30.863 | 30.776 | 30.847 | 21.497 |

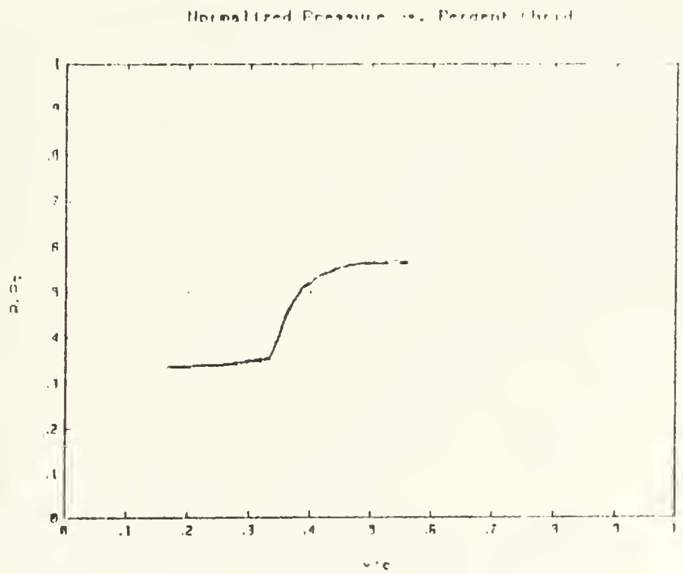
**Figure E4.** (cont) Run 1, 7 Dec 1992 (Raw Data)

| Scan | Port Number 22 | 23 | 24 | 25 | 26 | 27 | 28 |
|---|---|---|---|---|---|---|---|
| 1 | 27.184 | 29.624 | 30.967 | 31.219 | [illegible] | [illegible] | 31.003 |
| 2 | 27.512 | 29.437 | 30.864 | 31.055 | 31.370 | [illegible] | 31.020 |
| 3 | 27.218 | 29.565 | 30.864 | 31.055 | 31.388 | 31.135 | 30.970 |
| 4 | 27.478 | 29.539 | 30.787 | 31.073 | 31.410 | 31.231 | 30.936 |
| 5 | 27.159 | 29.497 | 30.958 | 31.201 | 31.501 | 31.231 | 30.970 |
| 6 | 27.058 | 29.531 | 30.864 | 31.091 | 31.451 | 31.205 | 31.020 |
| 7 | 26.849 | 29.318 | 30.735 | 31.128 | 31.360 | 31.118 | 30.936 |
| 8 | 26.949 | 29.182 | 30.615 | 30.991 | 31.360 | 31.126 | 30.810 |
| 9 | 27.025 | 29.225 | 30.795 | 31.119 | 31.131 | 31.257 | 30.987 |
| 10 | 26.622 | 28.928 | 30.392 | 30.772 | 31.157 | 31.100 | 31.020 |
| 11 | 26.647 | 28.919 | 30.409 | 30.790 | 31.309 | 31.214 | 30.902 |
| 12 | 26.748 | 29.131 | 30.658 | 31.027 | 31.269 | 31.039 | 30.944 |
| 13 | 26.874 | 29.327 | 30.701 | 30.954 | 31.279 | 31.153 | 30.944 |
| 14 | 26.160 | 28.775 | 30.444 | 30.854 | 31.248 | 31.100 | 30.793 |
| 15 | 26.605 | 29.106 | 30.658 | 30.936 | 31.259 | 31.030 | 30.793 |
| 16 | 26.504 | 29.106 | 30.547 | 30.772 | 31.198 | 31.091 | 30.869 |
| 17 | 26.874 | 29.098 | 30.581 | 30.964 | 31.188 | 30.908 | 30.751 |
| 18 | 26.614 | 28.953 | 30.401 | 30.845 | 31.168 | 31.048 | 30.793 |
| 19 | 26.311 | 28.860 | 30.452 | 30.909 | 31.289 | 30.969 | 30.827 |
| 20 | 26.135 | 28.741 | 30.358 | 30.790 | 31.157 | 30.890 | 30.810 |
| 21 | 26.060 | 28.766 | 30.341 | 30.809 | 31.218 | 31.030 | 30.818 |
| 22 | 26.261 | 28.775 | 30.349 | 30.827 | 31.157 | 30.925 | 30.818 |
| 23 | 26.823 | 29.225 | 30.547 | 30.863 | 31.168 | 30.952 | 30.810 |
| 24 | 26.244 | 28.817 | 30.324 | 30.745 | 31.016 | 30.873 | 30.760 |
| 25 | 26.546 | 28.826 | 30.118 | 30.654 | 31.066 | 30.960 | 30.642 |
| 26 | 26.244 | 28.707 | 30.478 | 30.827 | 31.157 | 30.934 | 30.709 |
| 27 | 26.412 | 28.715 | 30.349 | 30.708 | 31.026 | 30.890 | 30.718 |
| 28 | 26.681 | 28.996 | 30.504 | 30.763 | 31.168 | 30.873 | 30.650 |
| 29 | 26.001 | 28.605 | 30.298 | 30.763 | 31.056 | 30.724 | 30.718 |
| 30 | 26.958 | 29.208 | 30.607 | 30.790 | 31.117 | 30.917 | 30.701 |
| 31 | 26.706 | 28.919 | 30.444 | 30.617 | 31.127 | 31.065 | 30.559 |
| 32 | 26.597 | 29.030 | 30.281 | 30.553 | 30.925 | 30.938 | 30.726 |
| 33 | 26.907 | 28.698 | 30.143 | 30.626 | 30.975 | 30.807 | 30.659 |

**Figure E4.** (cont) Run 1, 7 Dec 1992 (Raw Data)

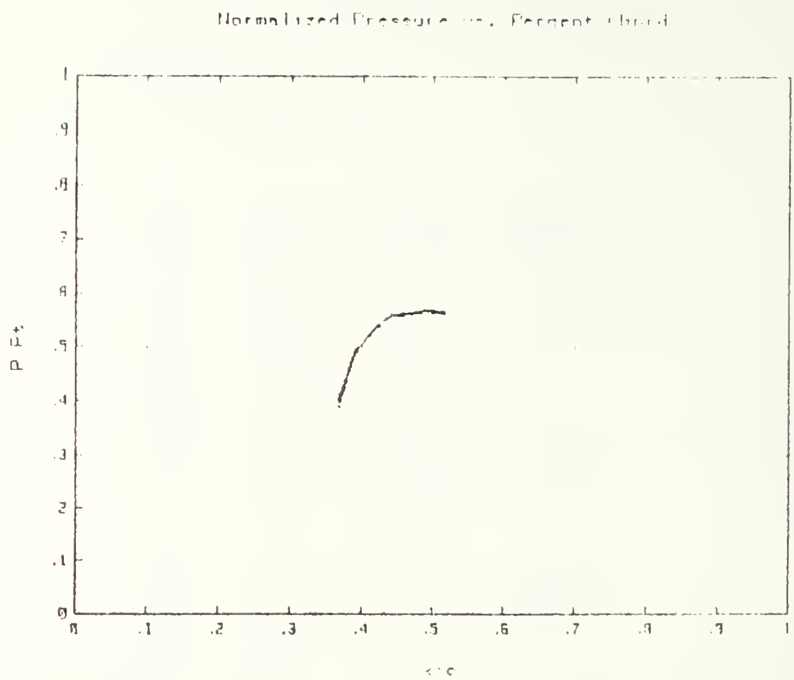
| Scan | Port Number | | | |
|---|---|---|---|---|
| | 29 | 30 | 31 | 32 |
| 1 | 18.945 | 36.604 | 55.220 | 52.948 |
| 2 | 19.025 | 36.708 | 55.094 | 52.804 |
| 3 | 18.980 | 36.651 | 55.346 | 52.921 |
| 4 | 18.954 | 36.604 | 55.238 | 52.921 |
| 5 | 18.972 | 36.594 | 55.328 | 52.930 |
| 6 | 18.989 | 36.661 | 55.337 | 52.921 |
| 7 | 18.954 | 36.585 | 55.346 | 52.948 |
| 8 | 18.883 | 36.471 | 55.256 | 52.939 |
| 9 | 18.989 | 36.594 | 55.382 | 53.192 |
| 10 | 19.176 | 36.604 | 55.031 | 52.894 |
| 11 | 18.998 | 36.423 | 55.229 | 51.179 |
| 12 | 18.954 | 36.547 | 55.319 | 47.399 |
| 13 | 19.060 | 36.547 | 55.229 | 43.675 |
| 14 | 18.936 | 36.499 | 55.319 | 44.027 |
| 15 | 18.972 | 36.528 | 55.292 | 50.359 |
| 16 | 19.016 | 36.395 | 55.238 | 53.075 |
| 17 | 18.945 | 36.585 | 55.283 | 53.138 |
| 18 | 18.972 | 36.385 | 55.283 | 53.183 |
| 19 | 18.954 | 36.556 | 55.364 | 53.174 |
| 20 | 19.025 | 36.556 | 55.220 | 52.984 |
| 21 | 18.954 | 36.471 | 55.220 | 53.102 |
| 22 | 18.998 | 36.395 | 55.103 | 53.111 |
| 23 | 18.980 | 36.328 | 55.094 | 53.021 |
| 24 | 19.069 | 36.414 | 54.896 | 53.057 |
| 25 | 18.865 | 36.271 | 55.166 | 53.084 |
| 26 | 18.954 | 36.376 | 55.067 | 53.156 |
| 27 | 18.954 | 36.347 | 55.094 | 53.219 |
| 28 | 18.900 | 36.290 | 55.040 | 53.174 |
| 29 | 18.989 | 36.357 | 54.887 | 53.084 |
| 30 | 18.874 | 36.252 | 54.914 | 53.255 |
| 31 | 18.785 | 36.139 | 54.941 | 53.201 |
| 32 | 18.972 | 36.091 | 54.941 | 53.057 |
| 33 | 18.891 | 36.177 | 54.716 | 52.154 |

**Figure E4.** (cont) Run 1, 7 Dec 1992 (Raw Data)



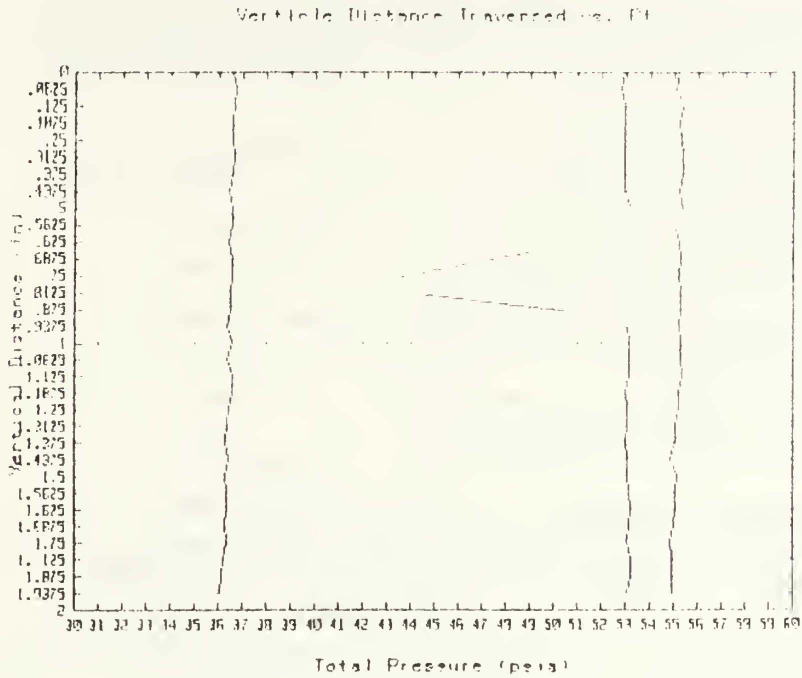
| Port | Scan Number 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | .338 | .338 | .337 | .337 | .336 | .337 | .337 |
| 2 | .342 | .342 | .341 | .341 | .340 | .340 | .340 |
| 3 | .357 | .359 | .358 | .355 | .356 | .355 | .350 |
| 4 | .401 | .411 | .400 | .394 | .401 | .395 | .396 |
| 5 | .456 | .455 | .440 | .449 | .443 | .447 | .446 |
| 6 | .487 | .489 | .473 | .485 | .482 | .481 | .479 |
| 7 | .509 | .511 | .505 | .507 | .505 | .508 | .498 |
| 8 | .522 | .527 | .528 | .521 | .518 | .518 | .520 |
| 9 | .534 | .538 | .536 | .530 | .532 | .532 | .537 |
| 10 | .540 | .544 | .544 | .543 | .540 | .544 | .543 |
| 11 | .551 | .551 | .553 | .551 | .547 | .548 | .552 |
| 12 | .554 | .556 | .558 | .557 | .555 | .554 | .556 |
| 13 | .557 | .561 | .560 | .561 | .561 | .558 | .560 |
| 14 | .562 | .566 | .561 | .563 | .562 | .560 | .561 |
| 15 | .562 | .566 | .566 | .566 | .565 | .562 | .563 |
| 16 | .563 | .566 | .564 | .565 | .564 | .563 | .563 |
| 17 | .565 | .569 | .562 | .564 | .562 | .561 | .563 |
| 18 | .565 | .570 | .565 | .569 | .565 | .564 | .564 |
| 19 | .564 | .568 | .563 | .567 | .561 | .563 | .564 |
| 20 | .568 | .571 | .566 | .566 | .566 | .566 | .564 |

**Figure E4.** (cont) Run 1, 7 Dec 1992 (Lower Passage P/Pt Distribution)




| Port | Scan Number 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 21 | .405 | .413 | .393 | .402 | .390 | [illegible] | .392 |
| 22 | .492 | .499 | .492 | .497 | .491 | .489 | .485 |
| 23 | .536 | .534 | .534 | .535 | .533 | .531 | .530 |
| 24 | .561 | .560 | .558 | .557 | .560 | .558 | .555 |
| 25 | .565 | .564 | .561 | .563 | .564 | .562 | .562 |
| 26 | .571 | .569 | .567 | .569 | .569 | .568 | .567 |
| 27 | .566 | .568 | .563 | .565 | .564 | .564 | .562 |
| 28 | .561 | .563 | .560 | .560 | .560 | .561 | .559 |

**Figure E4.** (cont) Run 1, 7 Dec 1992 (Upper Passage P/Pt Distribution)




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

Ptma1 = 55.1654793409 PSIA
Ptma2 = 52.3818787735 PSIA

Pt1-P1 = 36.1988140382 PSIA
Ttavg = 513 deg R

W_bar = .0768975625679

**Figure E4.** (cont) Run 1, 7 Dec 1992 (Loss Distribution)

## APPENDIX F. SAMPLE RVCQ3D INPUT AND SUMMARY OF RESTARTS

1. Sample RVCQ3D Input File:

```
     'GAS DYNAMICS LAB TRANSONIC FAN CASCADE'

&nl1 m=250,n=49,mtl=50,mil=112 &end

&nl2 nstg=4,ivdt=1,irs=1,epi=0.3,epj=0.4,
     cfl=4.5,av2=1.00,av4=1.0 &end

&nl3 ibcin=1,ibcex=1,itmax=2000,iresti=1,iresto=1,
     ires= 10,icrnt=10,ixrm=0 &end

&nl4 amle=1.40,alle=56.49,bete=53.0,prat=0.704,g=1.4,
     p0in=1.00000,t0in=1.00000 &end

&nl5 ilt=2,jedge=30,renr=17.83e6,prnr=0.71,prtr=0.90,
     tw=0.0,vispwr=0.83500,cmutm=14.0 &end

&nl6 omega= 0.000000,nblade= 1,nmn=0 &end
```

2. Summary of RVCQ3D restart inputs:

**TABLE XII.** SUMMARY OF RVCQ3D RESTART INPUTS

| **Iterations** | **P2/Pt1** | **Residual Smoothing (i-direction)** | **Residual Smoothing (j-direction)** |
|---|---|---|---|
| 0-500 | 0.76 | 0.55 | 0.65 |
| 510-1000 | 0.74 | 0.55 | 0.65 |
| 1010-1500 | 0.72 | 0.55 | 0.65 |
| 1510-2000 | 0.71 | 0.45 | 0.55 |
| 2010-2500 | 0.71 | 0.45 | 0.55 |
| 2510-3000 | 0.71 | 0.35 | 0.45 |
| 3010-4000 | 0.71 | 0.35 | 0.45 |
| 4010-5000 | 0.71 | 0.3 | 0.4 |
| 5010-7000 | 0.704 | 0.3 | 0.4 |

# APPENDIX G. SAMPLE CALCULATION USING KOCH AND SMITH

The following is a loss estimate based on the Koch and Smith model [Ref. 25]. Experimental results will be used as inputs where possible and estimates of other quantities will be input elsewhere. Blade anf passage geometry is determined. The deviation angle is estimated using NASA SP-36 [Ref. 27] and AGARD-R-745 [Ref. 26]. The loss estimate is obtained using relations, figures and tables from reference 33 and 34.

A. The cascade and passage geometry for the a suction surface incidence of 1.15 degrees is presented.

Variable geometry: $\Delta i_{ss} := 0 \cdot deg$

Blade Camber: $\phi := 6.66773 \cdot deg$

Maximum Thickness: $t_{max} := 0.22866 \cdot in$

Chord: $c := 6 \cdot in$ $\qquad tcmax := \frac{t_{max}}{c}$

Thickness (LE) $t_{LE} := 0.015 \cdot in$

t/cmax: $tcmax = 0.03811$

Blade Spacing: $s := 3 \cdot in$ $\qquad \sigma := \frac{c}{s}$

Solidity: $\sigma = 2$

Stagger Angle: $\xi := 51.84 \cdot deg$

Wedge Angle: $wedge := 3.5 \cdot deg$

Metal angles: $K_{1m} := \frac{1}{2} \cdot wedge + \xi$ $\qquad K_{1m} = 53.59 \cdot deg$

$K_{2m} := K_{1m} - \phi$ $\qquad K_{2m} = 46.92227 \cdot deg$

Suction Surface Incidence:

$$i_{ss} := 1.15 \cdot deg + \Delta i_{ss}$$

Suction Surface Metal Angle:

$$K_{1s} := K_{1m} + \frac{1}{2} \cdot wedge$$

$$K_{1s} = 55.34 \cdot deg$$

Blade Incidence Angle:

$$i_m := i_{ss} + (K_{1s} - K_{1m})$$

$$i_m = 2.9 \cdot deg$$

Inlet Flow Angle:

$$\beta_1 := i_m + K_{1m}$$

$$\beta_1 = 56.49 \cdot deg$$

**Figure G1.** Loss Estimation by Koch and Smith Method

B. Deviation angle is estimated using three methods. The first two are from NASA SP-36 and the third is a modified Carter rule taken from AGRARD-R-745.

Using NASA SP-36 two "methods" can be used to find deviation angle which yield similar results:

Method 1 (EQN 268)

1. Zero camber deviation for 10% thick 65 series airfoils as a function of inlet flow angle in Figure 161

$\delta_{o\_10\%} = 2.5 \cdot deg$

2. Slope function as taken from Figure 168 as a function of inlet flow and solidity.

$m = 0.185$

3. Corrections to zero camber deviation for C-series airfoils and thickness. The thickness correction is from Figure 172 as a function of t/c.

$K_{\delta sh\_C\_series} := 1.1$

$K_{\delta t} = 0.32$

4. Corrected zero camber deviation from equation 271.

$\delta_o = K_{\delta sh\_C\_series} \cdot K_{\delta t} \cdot \delta_{o\_10\%}$

5. Estimated deviation angle from equation 268.

$\delta_1 = \delta_o + m \cdot \phi$

$\delta_1 = 2.11353 \cdot deg$

Method 2 (EQN 269)

1. Slope function for solidity of 1 taken from Figure 166

$m_{\sigma\_1} = 0.305$

2. Solidity exponent taken form Figure 164.

$b = 0.72$

3. Using equation 269 and the zero camber deviation from method 1, the deviation can be estimated.

$$\delta_2 = \delta_o + \phi \cdot \left( \frac{m_{\sigma\_1}}{\sigma^b} \right)$$

$\delta_2 = 2.11463 \cdot deg$

**Fgure G1.** (cont) Loss Estimation by Koch and Smith Method

Method 3 (Modified Carter's Rule)

1. Carter's rule slope function as taken form Figure 160 in NASA SP-36: $\xi = 51.84 \cdot deg$

$m_{c\_ca} := 0.33$

$m_{c\_pa} = 0.275$

2. Carter's rule: (EQN 270 In SP-36)

$$\delta_{car\_ca} = \frac{m_{c\_ca}\,\phi}{\sqrt{\sigma}} \qquad \delta_{car\_pa} = \frac{m_{c\_pa}\,\phi}{\sqrt{\sigma}}$$

$$\delta_{car\_ca} = 1.55588 \cdot deg \qquad \delta_{car\_pa} = 1.29657 \cdot deg$$

3. Modified Carter's rule relation from AGARD-R-745 (EQN 3.5)

$$\delta_3 = -1.099379 + 3.0186 \cdot \delta_{car\_pa} - 0.1988 \cdot \delta_{car\_pa}^{\;2}$$

$$\delta_3 = 2.48024 \cdot deg$$

$$\delta = \delta_3$$

Now, outlet flow angle can be estimated using the deviation angle(s) found above.

$$\beta_2 := \delta + K_{2m}$$

Total flow turning is..

$$\varepsilon = \beta_1 - \beta_2$$

$$\beta_2 = 49.40251 \cdot deg \qquad \varepsilon = 7.08749 \cdot deg$$

C. Cascade losses are calculated using the Koch and Smith model outlined in AGARD-R-745 and described in "Loss Sources and Magnitudes in Axial-Flow Compressors" by C. C. Koch and L.H. Smith, Jr.

1. Profile Losses:

a. The first step is to calculate the following parameters:

Velocities and Mach numbers will be taken as the average value and it should be noted that for the actual machine these would be relative velocities:

$$V_{1avg} = 1306.60877 \cdot \frac{ft}{sec} \qquad V_{2avg} = 717.18277 \cdot \frac{ft}{sec}$$

$$M_{1avg} = 1.38862$$

**Figure G1.** (cont) Loss Estimation by Koch and Smith Method

Radius values must be determined to completely utilize the model, but there effect cancels out for the 2-D case so the radius shown is arbitrary

$r_1 = 10\cdot in$ $\qquad r_2 = 10\cdot in$

$r_{mean} = \dfrac{r_1 + r_2}{2}$ $\qquad r_{mean} = 10\cdot in$

Other constants defined for use in this model are as shown:

$K_1 = 0.2445$ $\qquad K_2 = 0.4458$

$K_3 := 0.7688$ $\qquad K_4 := 0.6024$

Velocity diagram parameters:

$$\beta_{mean} := \frac{\beta_1 + \beta_2}{2} \qquad \beta_{mean} = 52.94626\cdot deg$$

$$M_{z1} = M_{1avg}\cdot\cos(\beta_1) \qquad M_{z1} = 0.76663$$

$$V_{\theta 1} = V_{1avg}\cdot\sin(\beta_1) \qquad V_{\theta 1} = 1089.43665\cdot\frac{ft}{sec}$$

$$V_{\theta 2} := V_{2avg}\cdot\sin(\beta_2) \qquad V_{\theta 2} = 544.55674\cdot\frac{ft}{sec}$$

Annulus parameters of questionable value:

$$A_{a1} := s\cdot\sin(\xi)\cdot(r_2 - r_1) \qquad A_{a1} = 0\cdot in^2$$

$$A_{a2} := A_{a1}$$

$$A_p = \left(1 - \frac{K_2\cdot\sigma\cdot\frac{t_{max}}{c}}{\cos(\beta_{mean})}\right)\cdot\left(1 - \frac{A_{a1} - A_{a2}}{3\cdot A_{a1}}\right)$$ < this term = 1.0

$$A_p = 0.94361$$

Density and circulation paramters:

$$\Gamma_{star} = \frac{r_1\cdot V_{\theta 1} - r_2\cdot V_{\theta 2}}{r_{mean}\cdot\sigma\cdot V_{1avg}} \qquad \Gamma_{star} = 0.20851$$

$$\rho_{star} := 1 - \left(\frac{M_{z1}^2}{1 - M_{z1}^2}\right)\cdot\left(1 - A_p - K_1\cdot\frac{\tan(\beta_1)}{\cos(\beta_1)}\cdot\sigma\cdot\Gamma_{star}\right)$$

$$\rho_{star} = 1.31723$$

**Figure G1.** (cont) Loss Estimation by Koch and Smith Method

Equivalent diffusion factor:

$$D_{eq} := \frac{V_{1avg}}{V_{2avg}} \cdot \left[ \left( \sin(\beta_1) - K_1 \cdot \sigma \cdot \Gamma_{star} \right)^2 + \left( \frac{\cos(\beta_1)}{A_p \rho_{star}} \right)^2 \right]^{\frac{1}{2}} \cdot \left( 1 + K_3 \cdot \frac{t_{max}}{c} + K_4 \cdot \Gamma_{star} \right)$$

$D_{eq} = 1.80124$

b. The next step is to use the quantities above as well as flow quantities in the figures contained in the Koch and Smith paper. The quantities obtained will be used in equation 2 of AGARD-R-745. (which is equation 264 of SP-36)

With Deq and inlet Re, figures 2a and b can be used to find Momentum thickness to chord and Trailing edge boundary layer form factor.

$Re_{1avg} := mean(R_{e1})$ $\quad$ $Re_{1avg} = 9.10881 \cdot 10^5$

$D_{eq} = 1.80124$

$\theta_{c1} := 0.0075$ $\quad$ $H_{TE} := 1.57$

A correction for inlet Mach Number is provided by Figure 3 as a function Deq and M1.

$M_{1avg} = 1.38862$

$\theta_{M1} := 0.7$ $\quad$ $H_{M1} = 1.23$

A correction for stream tube correction based on h1/h2 is given, but is impossible to estimate in the current experimental configuration.

A Re/roughness Momentum Thickness correction is provided using ks from Appendix 2 and Figure 5 both of the Koch and Smith paper.

Assuming a surface roughness of ASTM Paper number 180

$k_{CLA} := 7.0866 \cdot 10^{-4} \cdot in$ $\quad$ $k_s := 6.2 \cdot k_{CLA}$

$k_{sc} := \frac{k_s}{c_{Re}}$ $\quad$ $k_{sc} = 0.00073$

Then Figure 5 provides corrections as a function of Re

$\theta_{ks} := 1.25$ $\quad$ and for a roughness Reynolds number as shown, the Hte is corrected in the same manner. (ie power variation of -0.06 is not applied.)

$H_{ks} := 1.25$

$R_{er} := \frac{k_s \cdot mean(\rho_1) \cdot V_{1avg}}{mean(\mu_1)}$

$R_{er} = 6670.23772$

**Figure G1.** (cont) Loss Estimation by Koch and Smith Method

The corrected momentum thickness per chord and wake form factor are

$\theta_c := \theta_{M1} \cdot \theta_{ks} \cdot \theta_{c1}$ $\qquad \theta_c = 0.00656$

$H := H_{M1} \cdot H_{ks} \cdot H_{TE}$ $\qquad H = 2.41388$

Now, using equation 2, the profile losses can be determined

$$\omega_{bar\_profile} := 2 \cdot (\theta_c) \cdot \frac{\sigma}{\cos(\beta_2)} \cdot \left(\frac{\cos(\beta_1)}{\cos(\beta_2)}\right)^2 \cdot \frac{\frac{2 \cdot H}{3 \cdot H - 1}}{\left(1 - \theta_c \cdot \frac{\sigma \cdot H}{\cos(\beta_2)}\right)^3}$$

$\omega_{bar\_profile} = 0.02608$

2. Shock losses and leading edge bluntness losses can be calculated as follows:

a. Shock losses obtained from Figure 7 of Koch and Smith

$\omega_{bar\_shock} := 0.065$

b. Leading edge bluntness losses obtained as shown:

$$\Delta s := R \cdot \left[ -\ln\left[ 1 - \frac{t_{LE}}{(s \cdot \cos(\beta_1))} \cdot \left[ 1.28 \cdot (M_{1avg} - 1) + 0.96 \cdot (M_{1avg} - 1)^2 \right] \right] \right]$$

$$P_{t\_ratio} := e^{\frac{-\Delta s}{R}}$$

$$\Delta P_t := P_{t1ma} \cdot (1 - P_{t\_ratio})$$

$\omega_{bar\_LE} := \dfrac{\Delta P_t}{q_{1avg}}$ $\qquad \omega_{bar\_LE} = 0.00855$

3. Finally, the total cascade losses estimated by the model are. .

$\omega_{bar} := \omega_{bar\_profile} + \omega_{bar\_shock} + \omega_{bar\_LE}$

$\omega_{bar} = 0.09963$

**Figure G1.** (cont) Loss Estimation by Koch and Smith Method

4. Compare experimental, emperical and numerical values... $\varpi_{num} = 0.11231$

$$\Delta\varpi_{exp\_emp\%} = \frac{\varpi - \varpi_{bar}}{\varpi} \cdot 100 \qquad \Delta\varpi_{exp\_num\%} = \frac{\varpi_{num} - \varpi}{\varpi_{num}} \cdot 100$$

$$\Delta\varpi_{exp\_emp\%} = 1.31097 \qquad \Delta\varpi_{exp\_num\%} = 10.1098$$

**Figure G1.** (cont) Loss Estimation by Koch and Smith Method

## LIST OF REFERENCES


1. Hill P. G., and Peterson C. R., Mechanics and Thermodynamics of Propulsion, 2nd ed., p. 346, Addison-Wesley, 1992.

2. Linn, J. C., Selby, G. V., and Howard, F. G., "Exploratory Study of Vortex Generating Devices for Turbulent Flow Separation Control", AIAA Paper 91-0042, January 1992.

3. McCormick, D. C., "Shock-Boundary Layer Interaction Control with Low-Profile Vortex Generators and Passive Cavity", AIAA Paper 92-0064, January 1992.

4. Wheeler, G. O., Means for Maintaining Attached Flow of a Flowing Medium, United States Patent 4,455,045, June 1984.

5. Johnston, J. P., and Nishi, M., "Vortex Generator Jets-Means for Flow Separation Control", AIAA Journal, v. 28, pp. 989-994, June 1990.

6. Compton, D. A., and Johnston, J. P. "Streamwise Vortex Production by Pitched and Skewed Jets in a Turbulent Boundary Layer", AIAA Paper 91-0638, January 1991.

7. United Technologies Research Center Report R90-957946, Transonic Fan Shock-Boundary Layer Separation Control, April 1990.

8. Golden, W. L., Static Pressure Measurements of the Shock-Boundary Layer Interaction in a Simulated Fan Passage, M.S.A.E. Thesis, Naval Postgraduate School, Monterey, California, March 1992.

9. Collins, C. C., Preliminary Investigation of the Shock-Boundary Layer Interaction in a Simulated Fan Passage, M.S.A.E. Thesis, Naval Postgraduate School, Monterey, California, March 1991.

10. Demo, Jr., W. J., Cascade Wind Tunnel for Transonic Compressor Blading Studies, M.S.A.E. Thesis, Naval Postgraduate School, Monterey, California, June 1978.

11. Hegland, M. G., Investigation of a Mach 1.4 Compressor Cascade with Variable Back Pressure Using Flow Visualization, M.S.A.E. Thesis, Naval Postgraduate School, Monterey, California, 1986.

12. Wendland, R. A., Upgrade and Extension of the Data acquisition System for Propulsion and Gas Dynamic Laboratories, M.S.A.E. Thesis, Naval Postgraduate School, Monterey, California, June 1992.

13. UNISLIDE Motor Driven Assemblies, Installation and Maintenance Instructions, VELMEX Incorporated, August 1990.

14. Operating Manual, HP3455A Digital Voltmeter, Hewlett Packard Company, 1984.

15. HP 3497A Data Acquisition and Control Unit, Operating, Programming and Configuration Manual, Hewlett Packard Company, 1982.

16. NF90 Stepping Motor Controller, NF90 Series User's Guide One, Two and Three Axis Stepping Motor Controller/Drivers, VELMEX Incorporated, March 1991.

17. HP98644A Asynchronous Serial Interface, Reference Manual, Hewlett Packard Company, 1985.

18. NASA TM-81198, A Computer Program to Generate Two-Dimensional Grids About Airfoils and Other Shapes by use of Poisson's Equation., Sorensen, R. L., 1980.

19. Steger, J. L., and Sorensen, R. L., "Automatic Mesh Point Clustering Near a Boundary in Grid Generation with Elliptic Partial Differential Equations", Journal of Computational Physics, v. 33, no. 3, pp. 405-410, December 1979.

20. Chima, R. V. "Revised GRAPE Code Input for Cascades", NASA Lewis Research Center, June 1990.

21. Chima, R. V., "RVCQ3D (Rotor Viscous Code Quasi-3-D) Documentation", NASA Lewis Research Center, August 1990.

22. Phone Conversations between Dan Tweedt, NASA Lewis Research Center, and David D. Myre, Naval Postgraduate School.

23. Chima, R. V., "Explicit Multigrid Algorithm for Quasi-Three Dimensional Viscous Flows in Turbomachinery", Journal of Propulsion and Power, v. 3, no. 5, pp. 397-405, September-October 1987.

24. NASA TM-88878, Comparison of Three Explicit Multigrid Methods for Euler and Navier-Stokes Equations, by Chima, R. V., Turkel, E., and Schaffer, S., January 1987.

25. Koch, C. C., and Smith, L. H., "Loss Sources and Magnitudes in Axial-Flow Compressors", Transactions of the ASME, Journal of Engineering for Power, pp. 411-424.

26. AGARD-R-745, Application of Modified Loss and Deviation Correlations to Transonic Axial Compressors, by Cetin, M., Ucer, A. S., Hirsch, Ch., Serovy, G. K., 1987.

27. NASA SP-36, Aerodynamic Design of Axial-Flow Compressor, 1965.

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