Development of a Data Reduction Method

for a High Frequency Angle Probe

by

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(ABSTRACT)

A data reduction method has been developed and tested for a high frequency angle probe. The angle probe is designed for unsteady aerodynamic measurements in transonic cryogenic wind tunnels. The probe measures time-resolved total pressure, static pressure, angle of attack, and yaw angle from readings of four pressure transducers. The unique feature of this probe, as compared to a conventional multi-hole directional probe, is that the four high frequency response silicon pressure transducers are mounted flush on the probe tip. The data reduction method is basically an interpolation routine of calibration curves. The calibration curves consist of experimentally determined non-dimensional flow coefficients.

Two experiments were conducted to test the probe and the data reduction method. The first experiment tested the angle probe in a Karman vortex street shed from a cylinder. In the second experiment, the angle probe was placed in an open air jet with an exit Mach number of 0.42. Plots of the time-resolved measurements and the Fast Fourier Transform analysis were made for each test.

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I would like to thank my many friends at Virginia Tech who made this time very special. The comradery of , , , and provided for many hilarious and unforgettable moments.

Primarily, I would like to thank my family and my sweetheart, , for their support and encouragement. To my parents, I dedicate this thesis as I try to convey my appreciation for everything they have done for me.

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Nomenclature

CP_1	Total pressure calibration coefficient
CP_4	Angle of attack calibration coefficient
f	Shedding frequency (Hertz)
F_{23}	Yaw angle calibration coefficient
H_{23}	Dynamic pressure calibration coefficient
KP_n	Static pressure calibration coefficient
M	Mach number
P_n	Local pressure transducer reading
P_s	Static pressure
P_t	Total (stagnation) pressure
Re_d	Reynolds number based on diameter
St	Strouhal number
U	Velocity
α	Angle of attack
β	Yaw angle
γ	Ratio of specific heats

1.0 Introduction

1.1 Background-Transonic Cryogenic Wind Tunnels

A high priority of the aircraft industry today is to produce fuel efficient aircraft while using cost effective analysis techniques. Currently, there are two popular methods of testing new aircraft designs. The first method uses numerical analysis of complex fluid flow equations. This method requires developing sophisticated computer codes to obtain solutions. The second method is to construct scaled down models of prototypes and test them in wind tunnels that simulate the in-flight environment. Currently, the computer codes are unable to solve many of the necessary flow fields required to yield accurate results and, therefore, wind tunnel model testing must be used. However, as the size of current aircraft continue to grow larger, the wind tunnel capability to provide the necessary in-flight characteristics is decreasing. This problem is especially apparent in the transonic regime for high Reynolds numbers. In this regime, sub-scale models can no longer produce the necessary full scale Reynolds numbers in conventional wind tunnels without greatly increasing the tunnel size and fan power requirements. The most effective solution to this problem has been to increase the sub-scale model Reynolds number by decreasing the temperature of the test gas into the cryogenic region (less than 150 K). This is the idea used by transonic cryogenic wind tunnels. The cryogenic technique has proven effective and provides several important advantages. The most important advantage is that cryogenic wind tunnels of moderate size and reasonable operating pressures can produce the necessary full scale values of Reynolds numbers. Cryogenic tunnels also provide the ability to independently vary fluid temperature, pressure, and velocity, thus, allowing researchers to separate the effects of Reynolds number, aeroelasticity, and Mach number.

Approximately one dozen of these cryogenic tunnels exist in the world today. Two of them, the 0.3 meter Transonic Cryogenic Tunnel (TCT) and the National Transonic Facility (NTF), are located at NASA-Langely Research Center. The 0.3 meter TCT facility is currently used for high Reynolds number airfoil research, and development of technology required for efficient use of cryogenic tunnels [1]. The NTF tunnel, which began operations in 1984, is rated for test pressures that range from 1 to 9 atmospheres with gas temperatures from 78 K to 340 K [2]. Many of the other tunnels are found in Europe and Japan. In Europe, an alliance of four countries have developed the European Transonic Windtunnel (ETW) to meet their agencies needs for high Reynolds number testing. A small (0.1 m x 0.1 m test section) cryogenic tunnel has been built for the Japanese National Aerospace Laboratory (NAL) with the intent of constructing another larger tunnel [3]. As the number of these tunnels grow, more research and instrumentation techniques will be developed to meet the growing needs of aerodynamic researchers.

1.2 Reasons for Instrumentation Research

The environment created within transonic cryogenic tunnels produce complex problems. Experiments have shown that freestream turbulence and noise in these tunnels may influence boundary layer transition and the character of the onset of buffet [4]. Thus, it is important to characterize the freestream turbulence and noise levels in cryogenic wind tunnels. Of particular interest are the detailed time-resolved measurements of velocity, both magnitude and direction, and turbulence level as a function of location. Although hot-wire anemometers have been used to make these flow quality measurements for atmospheric transonic wind tunnels, the combination of low temperature, high dynamic pressure, and high flow velocity in cryogenic tunnels can cause premature failure of the hot-wire sensor. The need to measure fluctuating flow quantities has provided incentive and support for the development of a high frequency angle probe.

A high frequency angle probe has been developed at Virginia Polytechnic Institute and State University for time-resolved measurements of compressible unsteady flows. The high frequency angle probe consists of four miniature surface mounted pressure transducers arranged in a pyramid fashion and is capable of measuring total pressure, static pressure, and two orthogonal flow angles. Multi-sensor pressure probes for making steady-state measurements have been used in fluid flow research for many years and their effectiveness is well documented. For two-dimensional flows, a three hole pitot-static probe can be rotated until the readings from the two peripheral static pressure holes are balanced to show the direction of the flow. Meanwhile, for three-dimensional flows, the two orthogonal flow angles must be determined and this requires more sensors. Four and five sensor probes in shapes of cones, hemispheres, and pyramids have been developed to measure the air speed and the two flow angles [5].

Two basic modes of operation exist for three-dimensional sensing probes. The first mode is the null method. In this method, the probe is aligned in the flow field until the peripheral pairs of transducers produce equal readings. At this point, the flow direction can be found from measurement of the probe orientation. The second mode is the pressure difference method. This method requires the probe to be held in a fixed position. Differences in readings from the pressure transducers are correlated with previous calibration data to determine the desired flow quantities. For the high frequency angle probe, the probe is calibrated and operated during experiments by the pressure difference method.

This thesis describes the development of the data reduction method and the data acquisition system used with the high frequency angle probe. First, the angle probe is described, followed by a brief description of the aerodynamic calibration of the probe. The calibration was performed by Rosson and is documented in detail in [6] and will not be repeated here. Next, the data reduction routine developed, which reduces the four pressure transducer readings from the angle probe into the flow quantities of interest, is presented in detail. The data acquisition system with high sampling rates and accurate channel-to-channel time synchronization is described next. Finally, two experiments to test the effectiveness of the angle probe and the data reduction routine are described. The first experiment consisted of placing the angle probe behind a 2.54 cm (1.0 inch) diameter cylinder in a Karman vortex street. The Karman vortex street had a shedding frequency of 310 Hz with a Mach number of 0.1 upstream of the cylinder. The second test placed the angle probe in a 7.3 cm (2.9 inch) diameter air jet with a Mach number of 0.42. Plots of the time-resolved measurements and the Fast Fourier Transform analysis were made for each test. The purpose of this work is to check the effectiveness of the angle probe and the data reduction routine, therefore, no effort has been made to interpret the flow fields from the reduced data.

This thesis is part of an overall effort of developing advanced instrumentation for detailed time-resolved measurements of dynamic flow quality in the National Transonic Facility. Future work in the development of the angle probe includes cryogenic calibration of the transducers and cryogenic wind tunnel testing of the probe.

2.0 Angle Probe System Development

2.1 Angle Probe Development

A combination probe consisting of a high frequency aspirating probe mounted with a high frequency angle probe was designed to make time-resolved flow measurements in the National Transonic Facility (NTF) at NASA-Langley. The combination probe is shown in Figure 1. The top probe is the dual hot-wire aspirating probe for measuring fluctuating total temperature and pressure. Details of the dual wire aspirating probe's construction, calibration, and performance are documented by Rosson [6] and will not be discussed here. The bottom probe in Figure 1 is the high frequency angle probe. The high frequency angle probe is used to determine time-resolved values of total pressure, static pressure, and two orthogonal flow angles. The original application for the angle probe was to make measurements in transonic compressors found in aircraft gas turbine engines. A similarly constructed high frequency angle probe was tested at the Massachusetts Institute of Technology (MIT) [7].

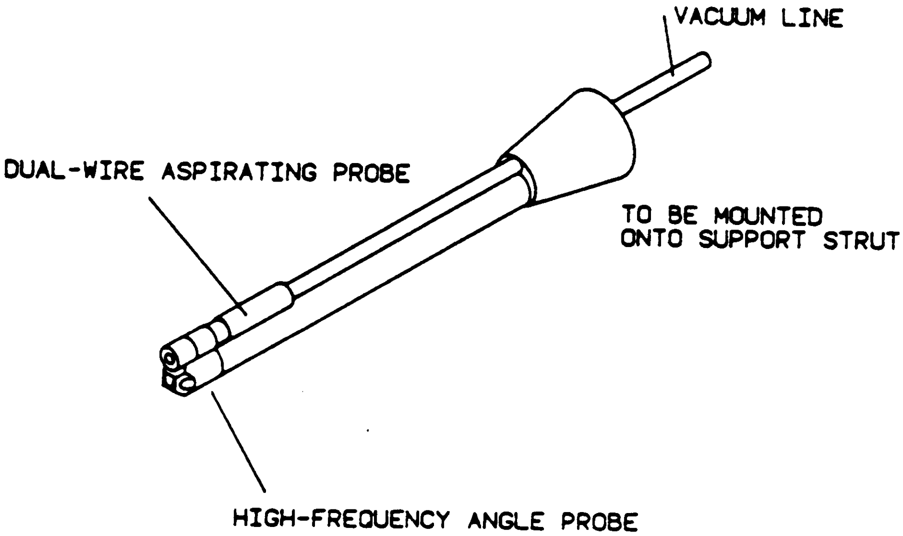

Figure 1. Combination Probe Containing Aspirating Probe and Angle Probe

The angle probe consists of four miniature pressure transducers mounted on the pyramid-shaped head of the probe. A diagram showing the tip of the angle probe with transducer locations and flow angle definitions is found in Figure 2. The transducers are silicon pressure transducer diaphragms with semiconductor integral strain gage bridges produced by Kulite Semiconductor Products, Inc. Each transducer has a frequency response of up to 200 kHz. With effective diameters of a millimeter or less, the sensors can be mounted onto small probes so the aerodynamic characteristic frequency is of the same order. Thus, the concept of multi-hole sphere and wedge shaped probes can be extended to transonic cryogenic wind tunnels without losing the desired high frequency response of the transducers.

The angle probe was designed for cryogenic wind tunnel operation. The probe head containing the four Kulite pressure transducers is 5.2 mm (0.203 inch) in diameter and is machined from 42% Nickel Invar. This material was chosen because it has a thermal coefficient of expansion (4.76×10^{-6} /°C) to match the silicon pressure transducers. A close match was required to reduce thermal sensitivity problems with the semiconducting bridges mounted on the back of the silicon diaphragms. The Kulite pressure transducers were chosen because they are thermally compensated for a temperature range of -196°C (-320°F) to 39°C (100°F) to give a zero sensitivity shift of less than 2 percent full scale per 56°C (100°F). The transducers are operated with 7.5 VDC excitation and have a maximum pressure rating of 172 kPa (25 psi). The signal output at full scale is 150 mV. Each diaphragm is mounted onto the probe head with cryogenic epoxy and placed in a milled slot. The backs of the diaphragms are mounted over a 0.53 mm (0.021 inch) diameter hole that passes through the probe interior to a pressure reference tube. All sixteen lead wires (four per transducer) are brought into the probe interior through 0.63 mm (0.025 inch) diameter lead wire holes. Each transducer is protected from particle impingement by a small screen placed over the transducer and mounted flush with the

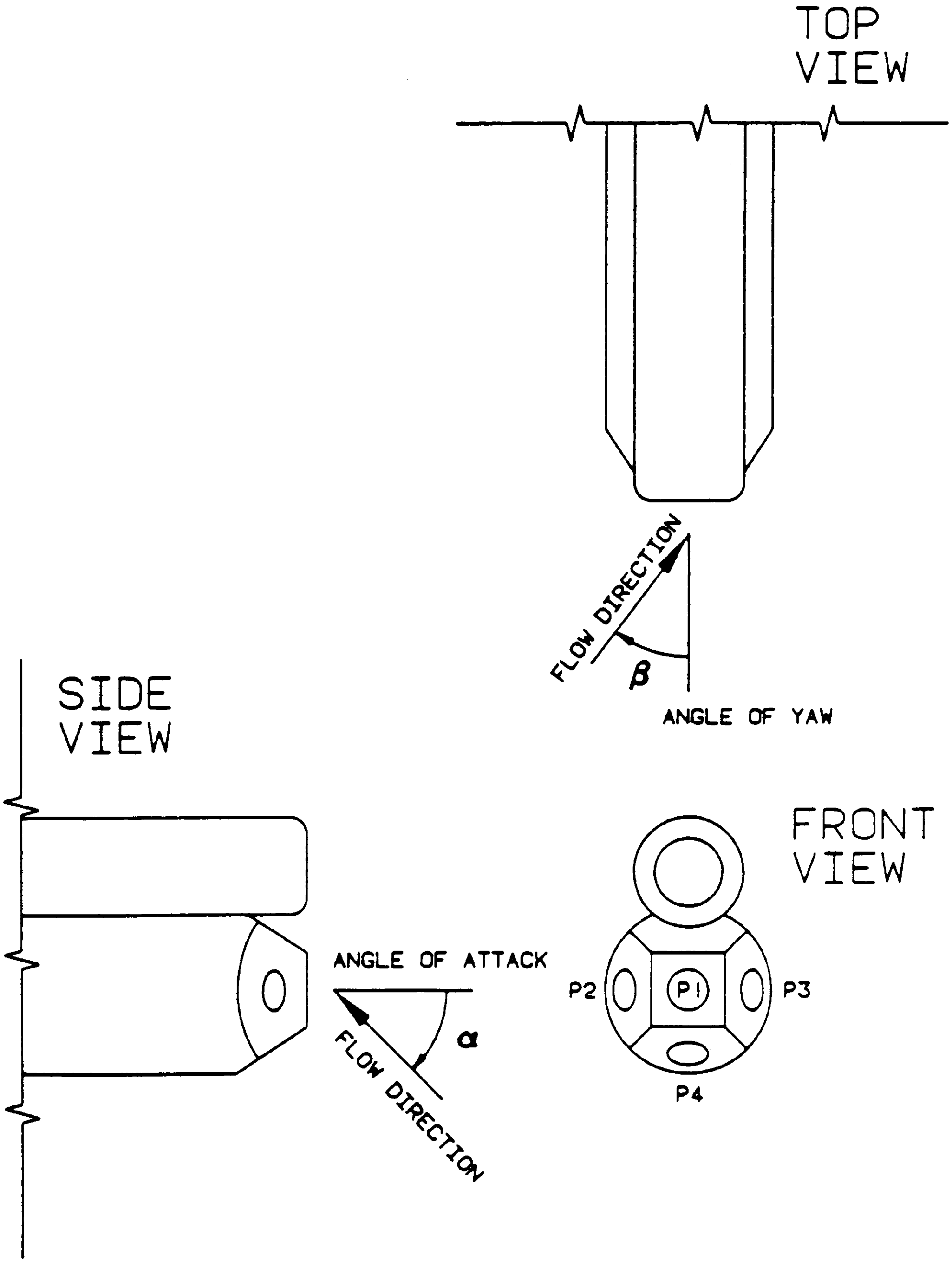

Figure 2. Angle Probe Transducer and Flow Angle Definitions

probe surface. This screen has a peripheral array of apertures to allow for pressure sensing.

2.2 Angle Probe Calibration

The aerodynamic behavior of the high frequency angle probe mounted with the aspirating probe was established by steady-state testing of a full size model in an air jet. This model used pressure taps at the center of the flats representing the four diaphragms to obtain the calibration data. A vacuum pump was connected to the aspirating probe to determine the effect of suction on the calibration. The calibrations were carried out in a 2.54 cm (1.0 inch) open air jet of known conditions at Mach numbers of 0.10, 0.24, 0.50, and 0.75. Before performing steady-state calibration of the angle probe, the jet uniformity at the test plane was confirmed. Calibration for the angle of attack α covered a range of -24° to +24°. Because of probe symmetry, the calibration for the yaw angle β covered only a range of 0° to +24°. All calibration data were recorded with the probe position changed in increments of six degrees. Further detail on the calibration can be found in Rosson [6].

2.3 Data Reduction Method

With calibration data for a wide range of subsonic Mach numbers and flow angles, a data reduction routine was developed to convert the four instantaneous pressure measurements of the angle probe into values for total pressure, static pressure, and two orthogonal flow angles. From the ratio of static to total pressure, the Mach number can be calculated. A similar, but more restrictive method, was used previously by Ng [8]. Several non-dimensional coefficients, originally described by Figueiredo [9], were used in setting up the calibration data for data reduction. The following non-dimensional coefficients were used.

$$F_{23} = \frac{P_2 - P_1}{[(P_2 - P_1) + (P_3 - P_1)]} \tag{2.4}$$

$$CP_4 = \frac{P_4 - P_s}{P_t - P_s} \tag{2.5}$$

$$KP_n = \frac{P_n - P_s}{[(P_2 - P_1) + (P_3 - P_1)]} \qquad (n = 2 \text{ or } 3) \tag{2.6}$$

$$H_{23} = \frac{P_t - P_s}{[(P_2 - P_1) + (P_3 - P_1)]} \tag{2.7}$$

$$CP_1 = \frac{P_1 - P_s}{P_t - P_s} \tag{2.8}$$

Here, P_t and P_s are the total and static pressures, respectively.

Plots of the calibration data, in the form of the above non-dimensional coefficients, were presented and discussed by Rosson [6] for the high frequency angle probe. Several observations can be made from the complete set of calibration data plots regarding the use of these coefficients in retrieving the desired flow quantities. A sample of these plots is shown in Figure 3 for a Mach number of 0.5. From Figure 3.a, it can be seen that although the value of F_{23} depends primarily on the yaw angle β , F_{23} is influenced weakly by the angle of attack α from -18° α to + 18° α. At larger α angles, β directional retrieval becomes more difficult as the F_{23} dependence on α increases. Figure 3.b shows that the angle of attack α is found primarily from the coefficient CP_4 . However, the effect on

CP_4 by β is large enough to affect the retrieval of α. The KP_n coefficient, shown in Figure 3.c, depends strongly on α and β and can be used to calculate the static pressure. In Figures 3.d and 3.e, the total pressure coefficients H_{23} and CP_1 show that they are functions of α and β. The coefficients H_{23} and CP_1 are combined in the following equation to determine the total pressure.

$$P_t = P_1 + \frac{H_{23}(1 - CP_1)}{[(P_2 - P_1) + (P_3 - P_1)]} \tag{2.9}$$

Although not shown in Figure 3, the coefficients CP_4 , KP_n , H_{23} , and CP_1 show some Mach number dependence. Due to the above mentioned observations, the data reduction routine was required to account for all these effects (α, β, and Mach number) in the determination of the flow quantities.

The data reduction routine uses the four simultaneous pressure measurements and double interpolation with the calibration data, in the form of non-dimensional coefficients, to determine the flow quantities of interest. A flowchart of the data reduction routine is shown in Figure 4. The data reduction routine begins with the entering of the four pressures P_1, P_2, P_3, and P_4. The F_{23} coefficient is calculated using Equation (2.4) since it involves only the four instantaneous pressures. The data reduction routine begins the first iteration by guessing values for the total and static pressures. The total pressure, P_t, is assumed to be equal to P_1 . This is a good assumption for small deflection angles. The value of the static pressure, P_s, is assigned the lower of the two pressures, P_2 or P_3. The next step is the calculation of a Mach number, M, based on the assumed P_t and P_s, using the isentropic flow equation with the appropriate ratio of specific heats, γ.

$$M^2 = \frac{2}{\gamma - 1}\left[\left(\frac{P_t}{P_s}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right] \tag{2.10}$$

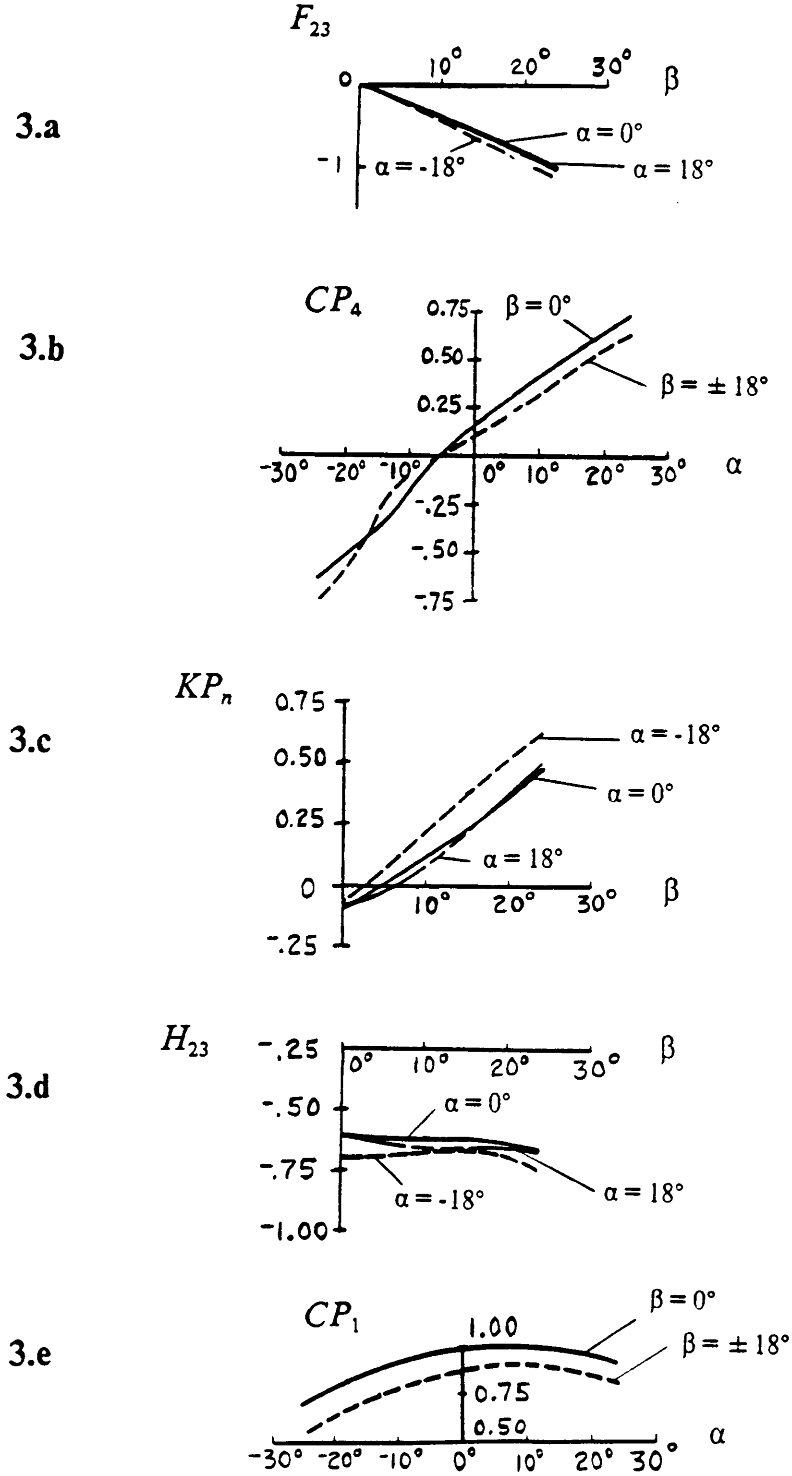

Figure 3. Typical Angle Probe Calibration Curves for a Mach Number of 0.5

The angle of attack coefficient, CP_4, is calculated from Equation (2.5). For the initial pass only, the angle of attack α is set equal to 0°. In all future iterations, α will be assigned the α' value from the previous iteration. Using F_{23}, M, and α, the yaw angle β is determined through interpolation of the calibration data. The new value for the angle of attack, α', is similarly found from the values of CP_4, M, and β. With β, α', and M now known, the KP_n coefficient is interpolated from the calibration data. Manipulating Equation (2.6) and using KP_n , the new value for the static pressure, $P_s\,'$, is found. Also, interpolation with β, α', and M gives the coefficients H_{23} and CP_1. Applying Equation (2.9) to H_{23} and CP_1, yields the new total pressure, P_t'. A new Mach number, M', is found by using $P_s\,'$ and P_t' in Equation (2.10). Convergence is checked by comparing the new values with the previous values of the static and total pressures. The convergence criteria is met when the change in both pressures are less than 0.1% of their value in psia. The reduction routine was written into the FORTRAN program named ANGLE4 (see Appendix A for program listing). The program uses the non-dimensional coefficients from every calibration point. Neither simplification nor approximation is involved with the calibration data. Linear interpolation is used between calibration data points to determine the intermediate values for the flow quantities. The consistency of the data reduction program was checked by inputting the known calibration pressures and comparing the output with the known flow quantities.

Before using the angle probe in a high Reynolds number wind tunnel, such as the National Transonic Facility, the effect of Reynolds number on the steady-state aerodynamic calibration must be investigated. The NTF tunnel can achieve a maximum Reynolds number of 150 million per foot at a Mach number of 1.0. The present aerodynamic calibration of the angle probe in an open air jet is only at a Reynolds number of 5 million per foot. Previous calibration of a similar flow-angularity probe was performed at the 0.3 meter Transonic Cryogenic Tunnel. The results from this test show

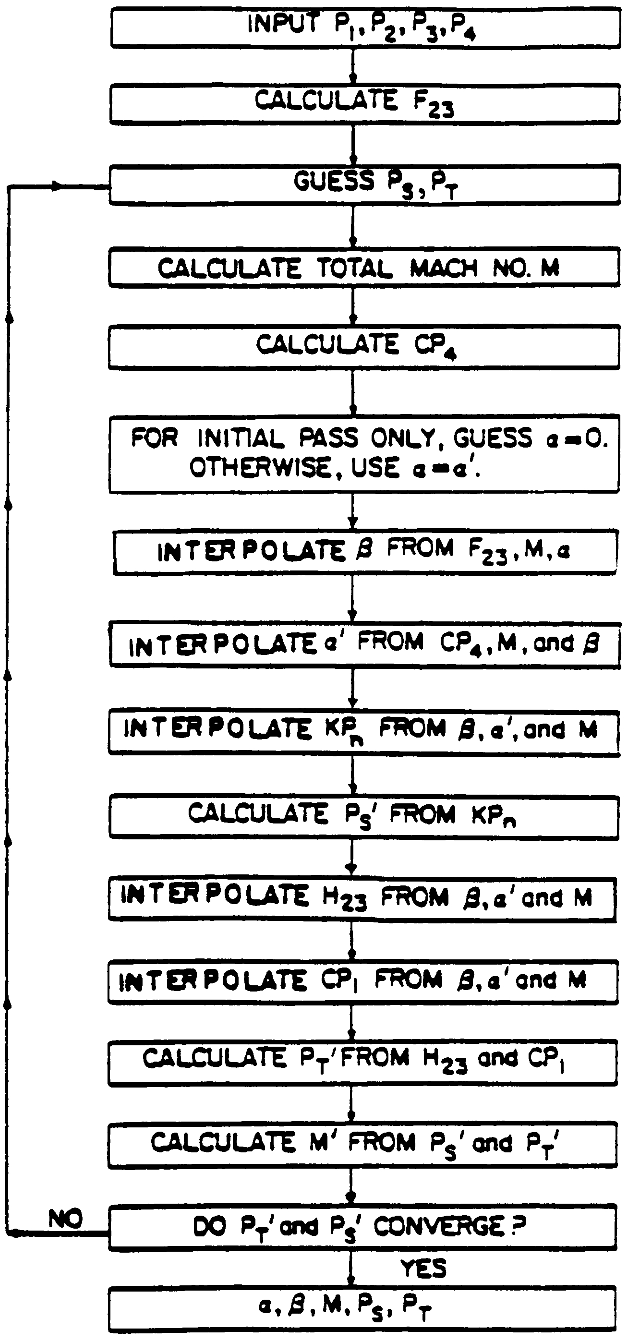

Figure 4. Flowchart of Angle Probe Data Reduction Method

that a non-dimensional pressure coefficient increases by 7 percent when the Reynolds number increases from 5 million per foot to 20 million per foot. Beyond a Reynolds number of 20 million per foot, the probe sensitivity was independent of the Reynolds number. This suggests that it is necessary to calibrate the angle probe for the effects of Reynolds number and Mach number [10].

2.4 Data Acquisition System

The data acquisition system used in the experiments coupled accurate channel-to-channel time synchronization with low system noise. A block diagram of the data acquisition system is found in Figure 5. The electrical noise of the system is small since most of the transducers have low impedances. Four analog signals, one from each pressure transducer, were passed through a small cryogenic-rated cable to a junction box. The junction box provided a transition point from the cryogenic cable to standard BNC coaxial cable. From the junction box, the signals passed through a variable setting amplifier. After amplification, the signals passed through 4-pole low pass Bessel filters obtained from Frequency Devices, Inc.. The corner frequencies of the low pass filters were set manually by 8-position dip switches at frequencies less than half the signal sampling rate to prevent signal aliasing. A LeCroy 8210 10-bit digitizer sampled the data at a rate set by a seven speed clock. The maximum sampling rate is 1 MHz for each of the four channels with the resolution of the digitizer being 10 mV/count. From the digitizer, the signals passed through a LeCroy 8901A CAMAC to GPIB interface and were stored in LeCroy 8800 Memory modules. Directed by LeCroy's CATALYST software, the data were written from the memory modules, through the CAMAC to GPIB interface, and onto the memory boards of an IBM PC. Once in the IBM PC, the data were written onto standard flexible disks. On the flexible disks, the signals were encoded in unformatted binary code in a serial fashion.

To put the data in a usable format, the LECROYRD program was written in FORTRAN for use on the IBM PC (see Appendix A for program listing). LECROYRD uses information stored in the header (the first section) of the unformatted data file to process the binary code into an equivalent voltage produced by the transducer. A program that is interactive from the screen, LECROYRD allows the user to input values for transducer sensitivities, zero voltage shifts, reference pressures, and file names. The output of the program is a file containing the relative time (in seconds) that the data were taken and the pressure readings (in psia) of each of the four pressure transducers for the first 1024 points. This file is immediately written to a blank flexible disk for storage. Only 1024 points are processed because of space limitations of the flexible disk. The 1024 points are approximately 1/16 of the total stored data on the unformatted data disk.

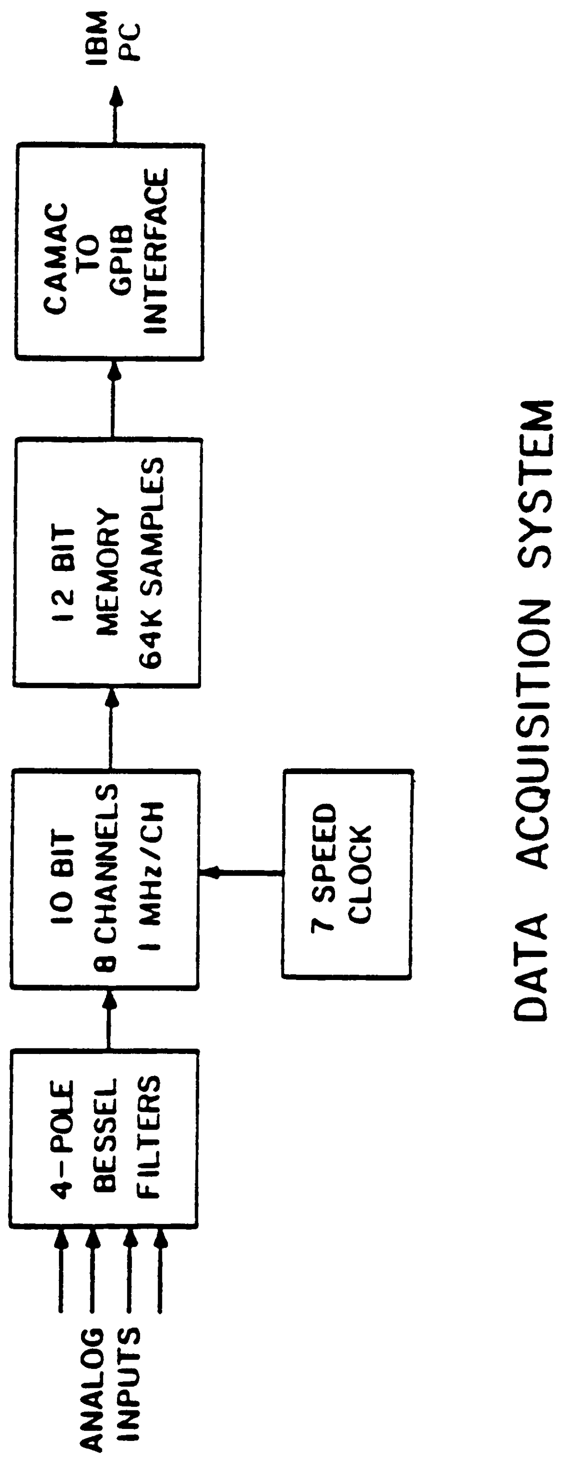

Figure 5. Schematic Diagram of Data Acquisition System

3.0 Karman Vortex Shedding Experiment

3.1 Experiment Set-up

The objective of this experiment is to determine if the angle probe can measure the pressure fluctuations characteristic of the shedding produced in a Karman vortex street. The data were processed using the LECROYRD and ANGLE4 data reduction programs. Plots of the data from the four transducers and the reduced flow quantities are presented in the time and frequency domains.

Over a certain range of Reynolds numbers, flow over a cylinder causes a non-stationary separation point. As the separation point moves along the cylinder toward the stagnation point, a vortex is created near the cylinder. When the vortex is shed, the separation point moves back away from the stagnation point and the process is repeated. This process occurs at a distinct frequency called the shedding frequency. In the wake downstream of the cylinder, the vortex remains intact and is known as the Karman vortex street [11]. A useful relationship exists in determining the shedding frequency. The Strouhal number (St) is defined as follows,

$$St = \frac{fd}{U} \tag{3.1}$$

where, f = shedding frequency
d = diameter of cylinder
U = freestream velocity

The combination probe was placed in the Karman vortex shed from a cylinder to test the effectiveness of the probe. A sketch of the experimental set-up is given in Figure 6. A 2.54 cm (1.0 inch) diameter (d) circular cylinder was placed in the crossflow at the exit of an atmospheric low-speed wind tunnel. The test section of the tunnel measured 35 cm x 25 cm (14 in. x 10 in.). The static pressure was assumed to be atmospheric. The total pressure upstream of the cylinder was measured with a Kiel probe connected to an open-ended water manometer board and recorded as 3.4 inches of water. Using Equation (2.10), a freestream Mach number of 0.1 was calculated. The corresponding freestream velocity was determined to be 39 m/s (128 fps). The Reynolds number (Re_d) based on the diameter of the cylinder was 66,000. Using Equation (3.1) above and a characteristic Strouhal number of 0.2, the expected shedding frequency was calculated as 310 Hz.

Using the coordinate system shown in Figure 6, the tip of the probe was located at x/d = 6, y/d = -1.25, and z/d = 0 with the probe tip pointing upstream parallel to the x-axis. This position was chosen because it produced the strongest signal fluctuations from the four pressure transducers during a survey of the flow field. The amplifier gain was set at a value of 1000 to make the fluctuating signals strong enough to be digitalized by the data acquisition system. However, because of the small temperature fluctuations, the output signals from the aspirating probe were too small to be recorded and were

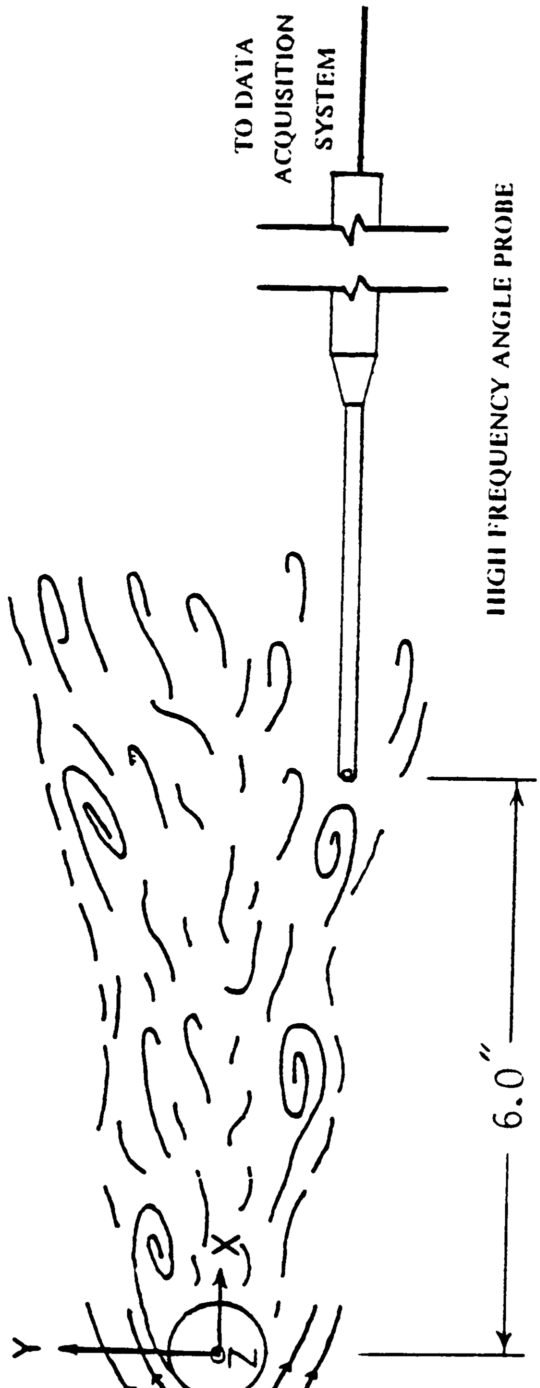

Figure 6. Karman Vortex Shedding Experimental Set-up

discarded. The LeCroy digitizer was set at a sampling rate of 10 kHz and the anti-aliasing filters at corner frequencies of 3.2 kHz.

3.2 Presentation of Results

A total of 1024 data points from this experiment were processed. This sample was large enough to provide several cycles of the vortex shedding. A temperature dependent zero shift in the Kulite transducers occurred during the test to void the steady-state signal component. Based on previous experience with the Kulite transducers and the data reduction process, this is not a significant problem in computing the oscillating component. In Figure 7, traces of the pressure signals from the angle probe show the vortex shedding recorded by each transducer. All pressure fluctuations are of the order of 0.1 psi. The Fast Fourier Transform (FFT) spectral analysis of the four pressure signals are shown in Figure 8.

This sample of data points was reduced using the ANGLE4 data reduction program. The corresponding values for the total pressure, static pressure, and the transverse and spanwise flow angles are shown in Figure 9 on an equivalent time scale as the individual transducer pressure signals. Changes in the total pressure were of the order of 0.1 psi while those of the static pressure were only half as strong. The transverse flow angle, β, located in the x-y plane, shows fluctuations of up to ten degrees. This fluctuation is expected because of the moving vortex street. Meanwhile, the spanwise flow angle, α, found in the y-z plane, exhibits fluctuations of similar magnitude to suggest that the flow field is not two-dimensional. The results of the FFT analysis performed on the reduced data are found in Figure 10. These Fourier spectrums show the Karman vortex shedding

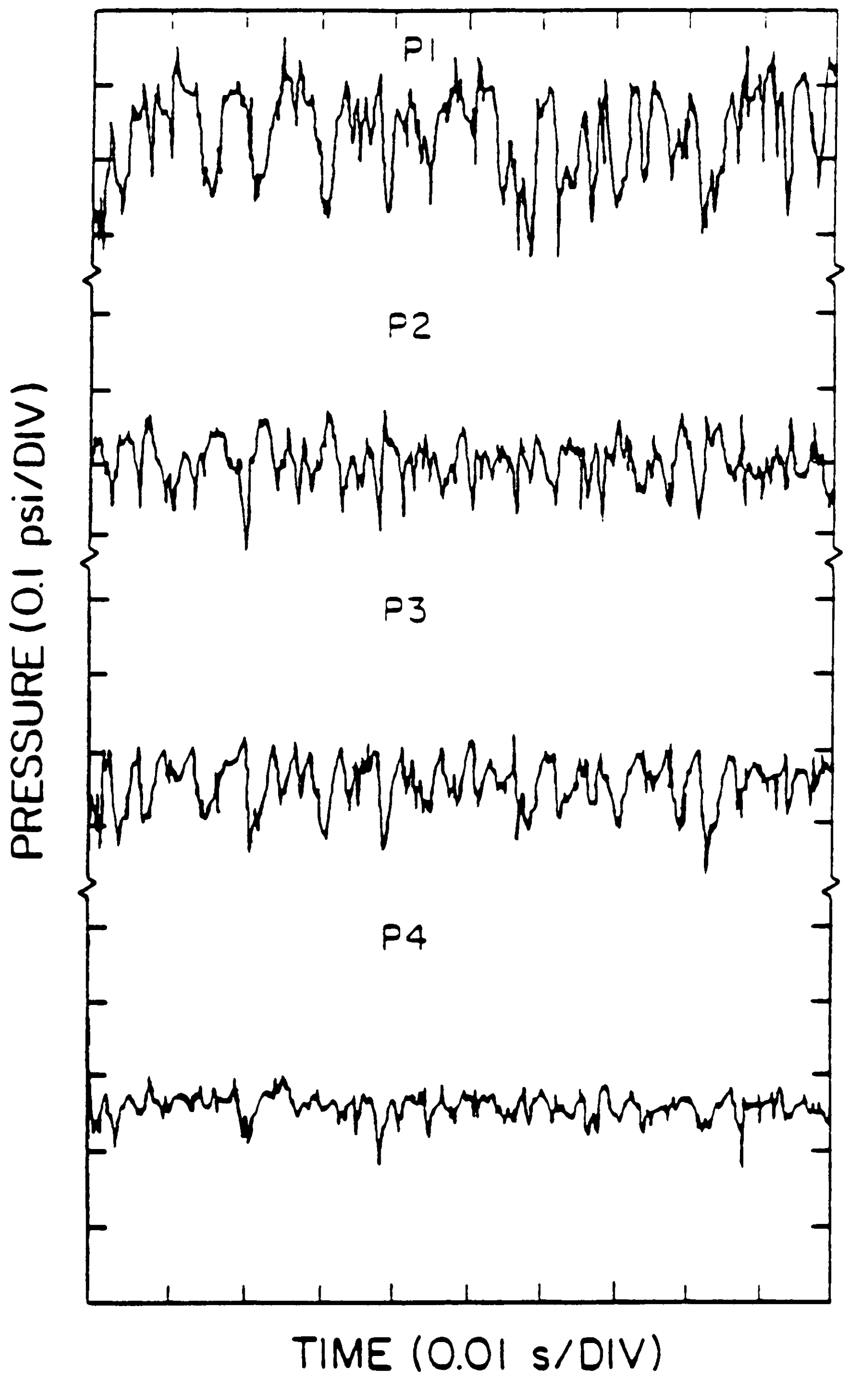

Figure 7. Time Traces of the Four Transducer Pressure Signals (Vortex Shedding)

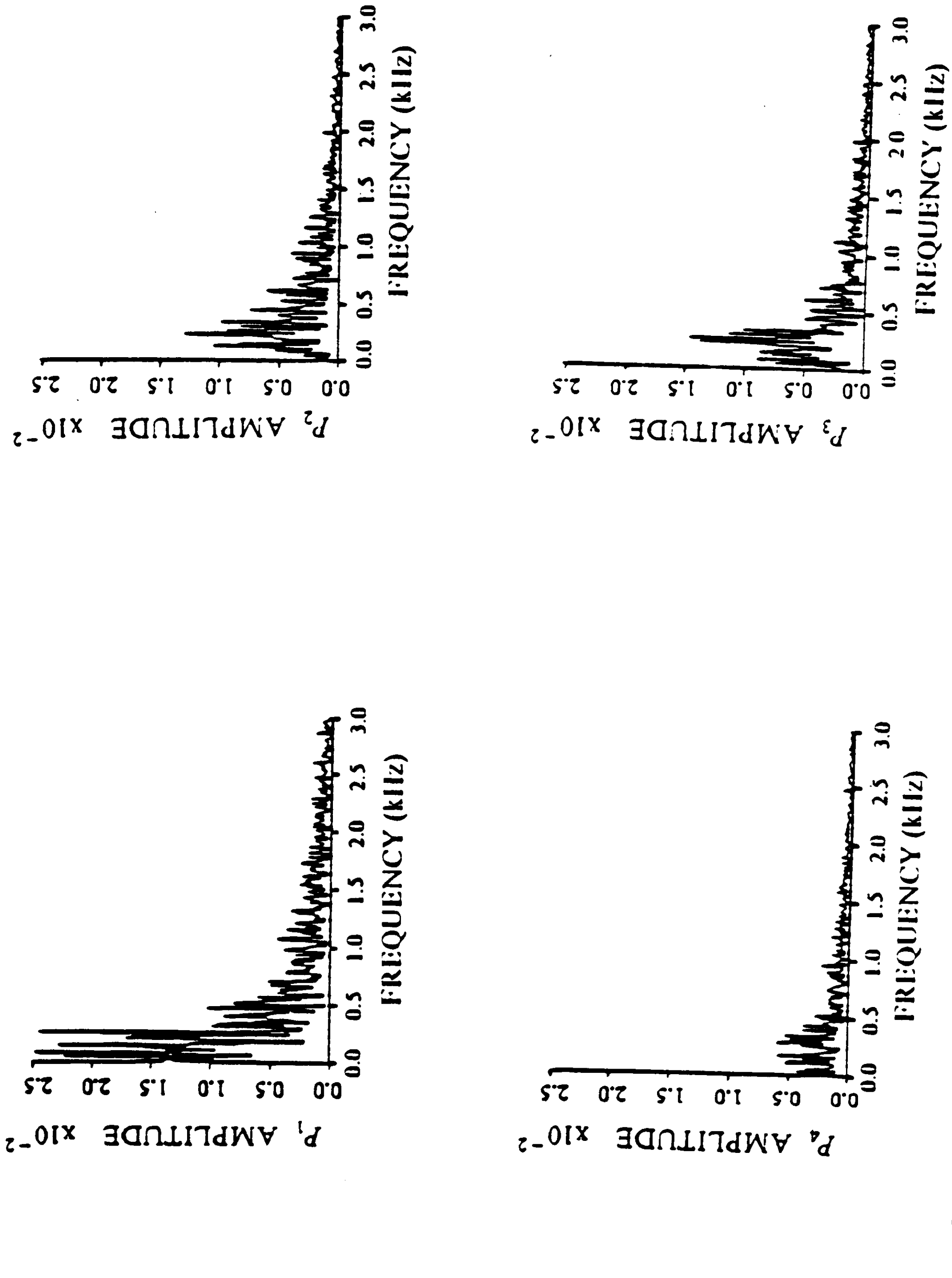

Figure 8. Fourier Spectrums of Transducer Pressure Signals (Vortex Shedding)

to be near 280 Hz. This value is in close agreement with the expected shedding frequency of 310 Hz.

The results of this experiment show that the angle probe system can be used to measure the Karman vortex shed from a 2.54 cm (1.0 inch) diameter cylinder. Information obtained from the fluctuations in the total pressure, static pressure, and two flow angles can be used to describe the flow field behind the cylinder.

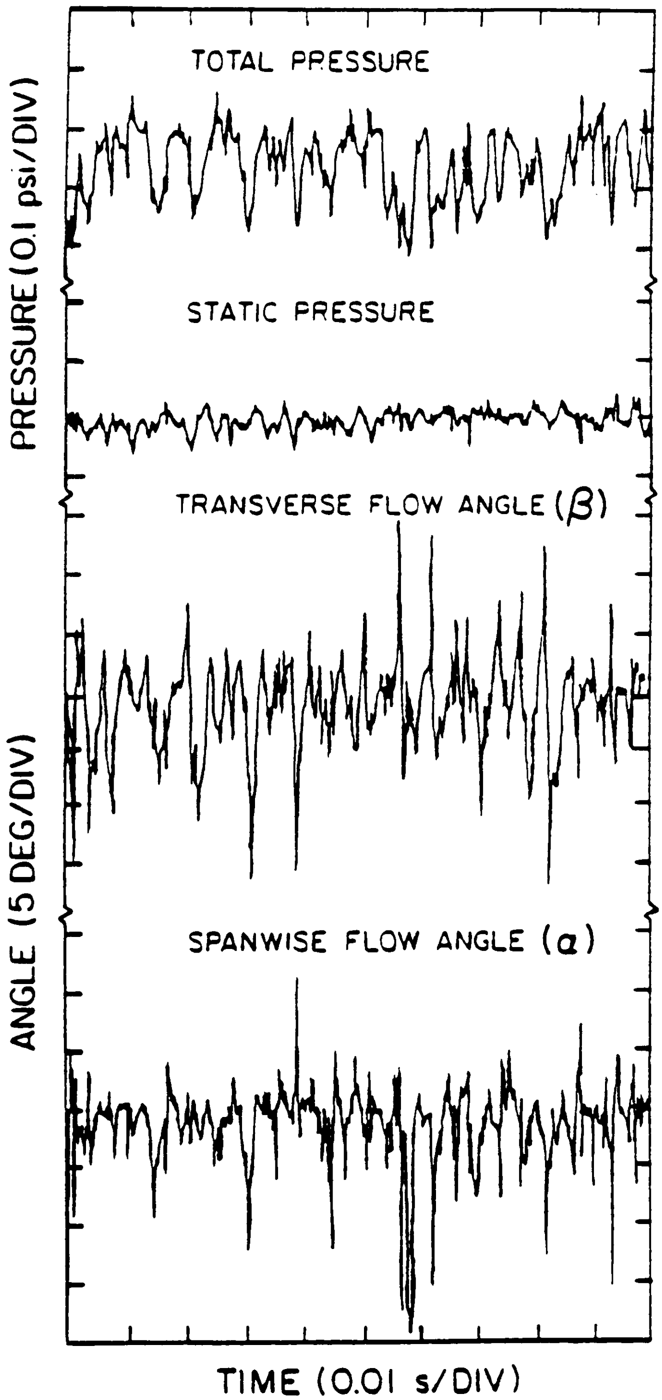

Figure 9. Time Traces of Reduced Total Pressure, Static Pressure, and Flow Angles (Vortex Shedding)

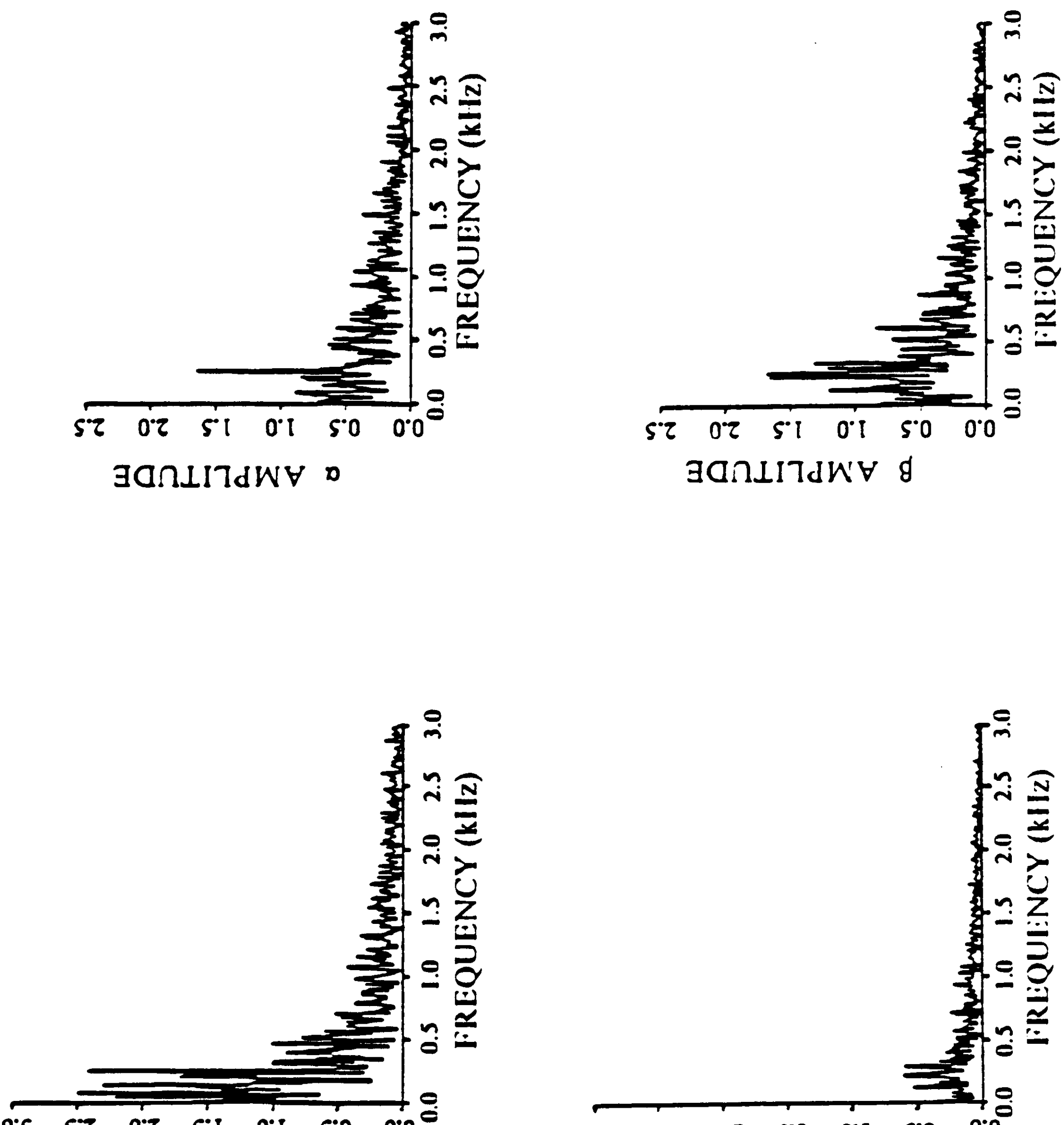

Figure 10. Fourier Spectrums of Reduced Pressures and Flow Angles (Vortex Shedding)

4.0 Air Jet Turbulence Experiment

4.1 Experiment Set-up

A second test of the angle probe was performed by placing the probe in an open air jet. The purpose of the test was to show that the angle probe could be used to measure the levels of freestream turbulence. The existing 2.54 cm (1.0 inch) diameter open air jet used in the calibration of the angle probe was modified to provide for a 7.3 cm (2.9 inch) diameter exit jet. A sketch of the test set-up is shown in Figure 11. The maximum air supply pressure of 120 psi was used to give an exit Mach number of 0.42 based on the ratio of total to static pressures.

Using the center of the nozzle exit as a reference, a right-handed coordinate system was established with the x-axis pointing downstream, y-axis directly upward, and the z-axis pointing to the left when facing upstream. Based on the exit nozzle diameter (d), the probe tip was located at $x/d = 1$, $y/d = 0$, and $z/d = 0$ and oriented upstream along the x-axis. The angle of attack α is defined lying in the x-y plane and the yaw angle β is located in the x-z plane. The amplification of the Kulite transducers were set at a gain

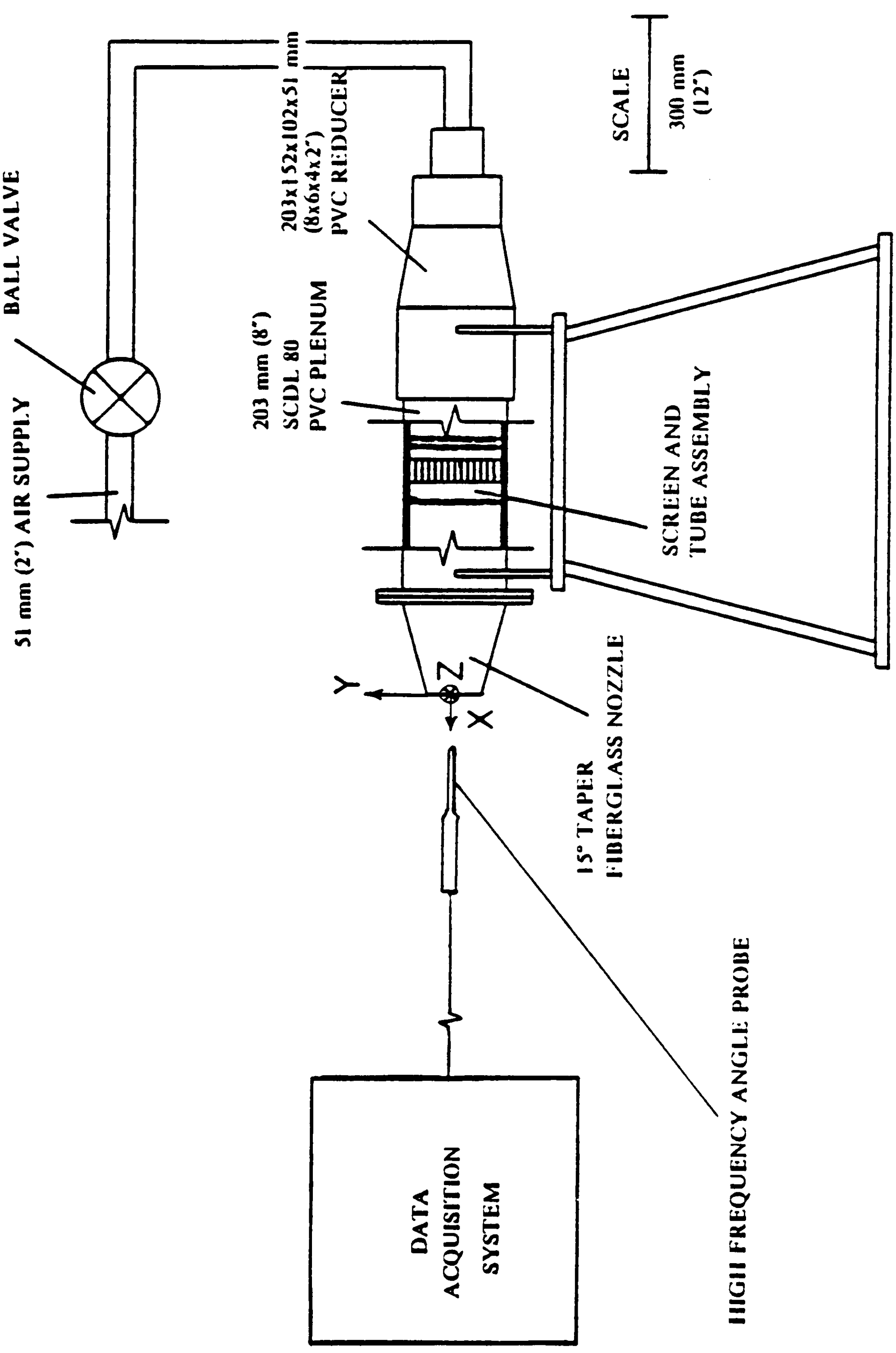

Figure 11. Air Jet Turbulence Experimental Set-up

of 100. The sampling rate of the digitizer was set at 25 kHz and the corner frequency of the four anti-aliasing filters at 9.6 kHz.

The zero shifts of the Kulite transducers were recorded and found to be temperature dependent. The zero setting of each transducer was recorded before and after the experiment. The zero shift was compensated for by incorporating the zero reading from immediately after the test into the data reduction program to determine the transducer output pressure values.

4.2 Presentation of Results

The experiment was conducted at room temperature, therefore, output signals from the aspirating probe were too small to be recorded and were discarded. Only data from the high frequency angle probe were analyzed. Freestream turbulence pressure fluctuations of nearly 0.5 psi are shown in Figure 12 for a sample of 1024 points. Plots of the FFT analysis of P_1, P_2, P_3, and P_4 are found in Figure 13. A disturbance at a frequency near 1 kHz appears in the Fourier spectrum plots of each of the four transducers. In an attempt to locate the source of the disturbance, a hot wire was placed in the flow and the output displayed on a spectrum analyzer. A similar 1 kHz signal was found leading to the conclusion that the disturbance was created within the air jet assembly and not associated with the use of the angle probe.

The instantaneous pressures P_1, P_2, P_3, and P_4 were reduced using the ANGLE4 program to yield the desired flow quantities. Corresponding time-resolved plots of the total pressure, static pressure, angle of attack, and yaw angle are given in Figure 14. Both the static and total pressure changes can be readily distinguished and are of the order of 0.5 psi. Variations with time in the flow angles of ten degrees can be observed

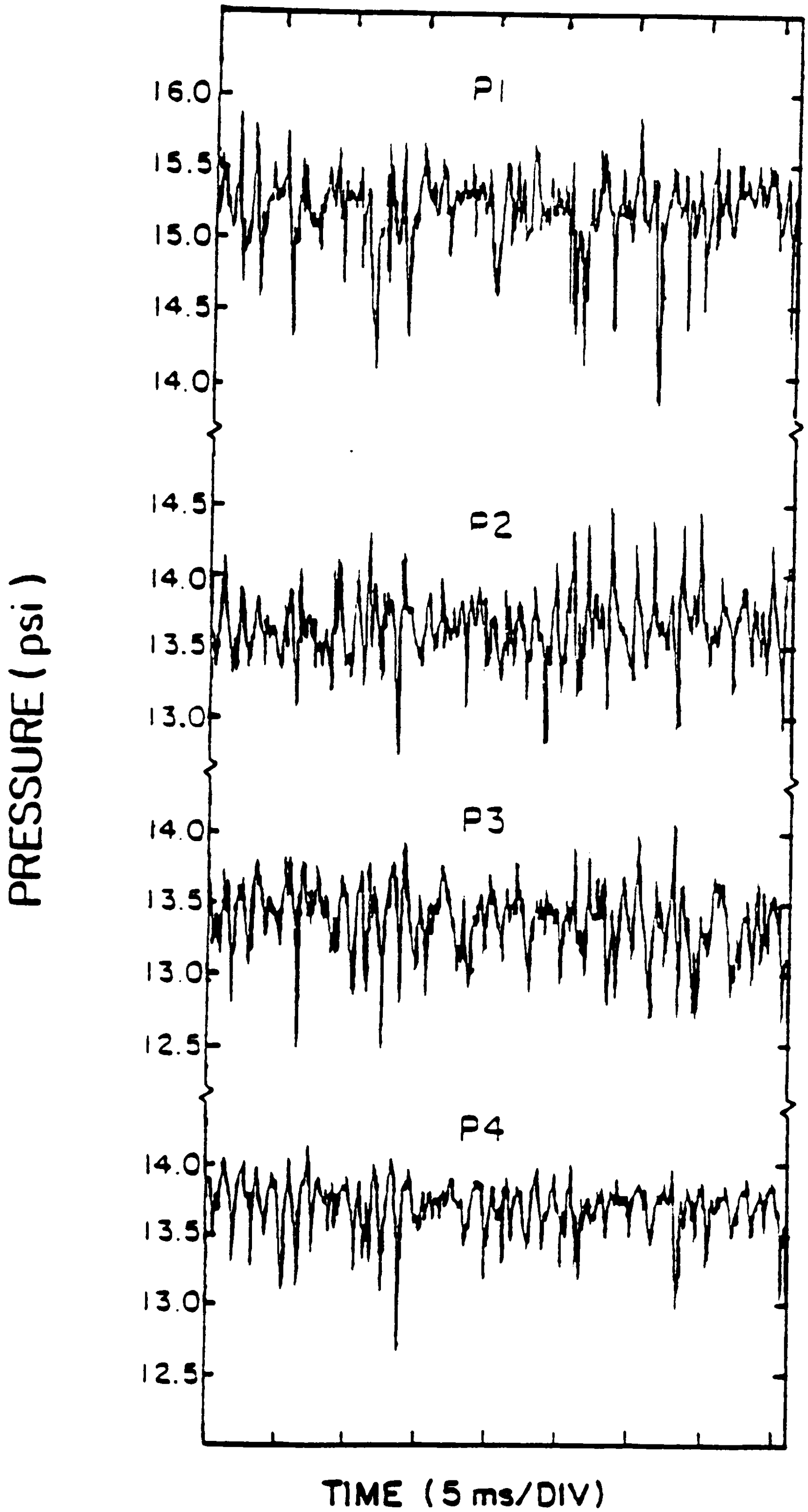

Figure 12. Time Traces of the Four Transducer Pressure Signals (Air Jet)

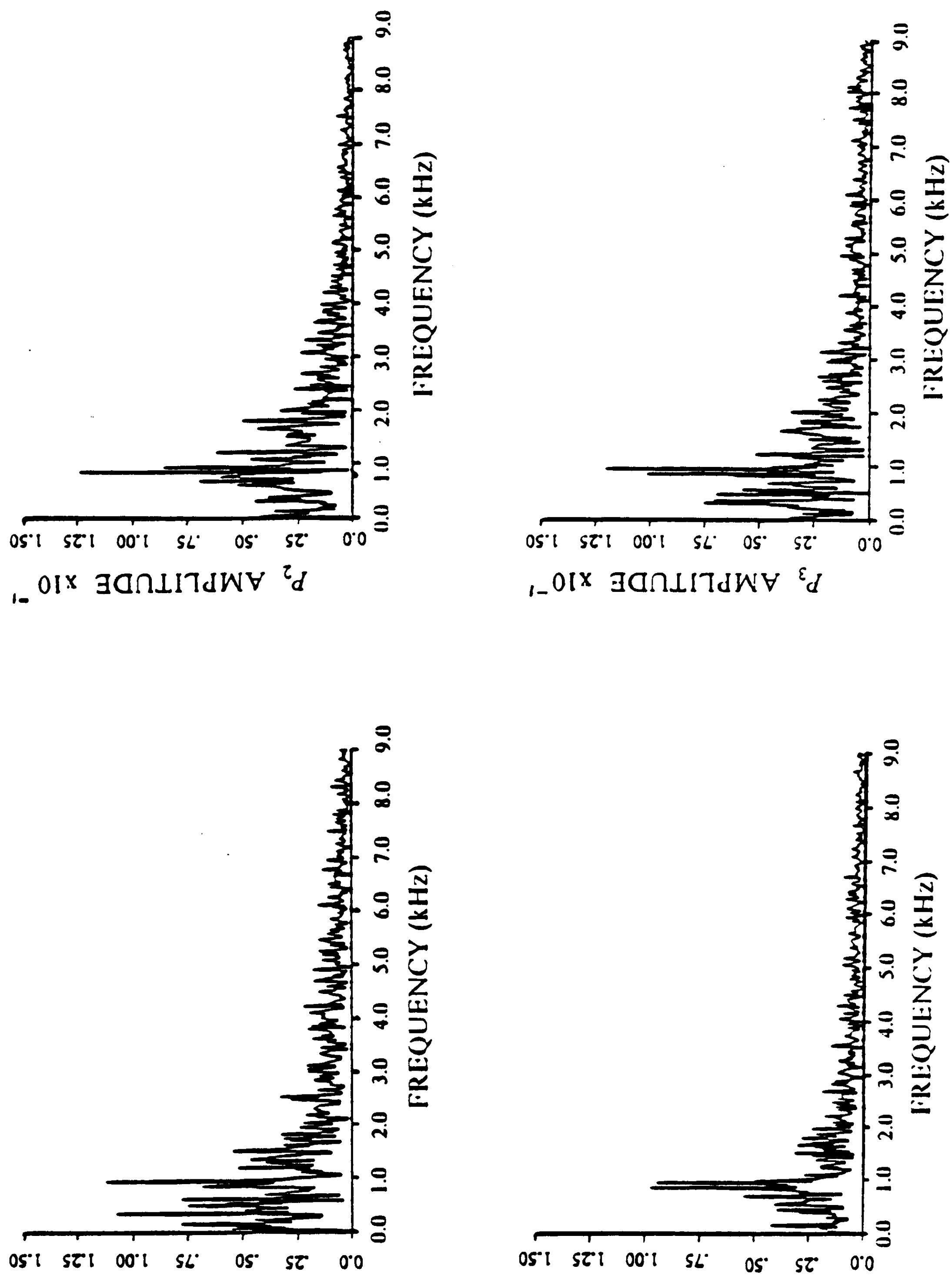

Figure 13. Fourier Spectrums of Transducer Pressure Signals (Air Jet)

indicating a three-dimensional flow field. The Mach number and its components in the x-, α-, and β-directions are shown in Figure 15 for the same interval of data. Fast Fourier Transform analysis of the reduced flow data were performed and the 1 kHz peak, as expected, was found in the Fourier spectrum for each flow quantity. The results of this analysis are shown in Figures 16 for the total pressure, static pressure, and two flow angles. The FFT results for the Mach number and its components are found in Figure 17.

Unlike the Karman vortex shedding experiment, no description of the flow field was available to compare with the results of the angle probe. A 1 kHz disturbance was detected from the air jet assembly. The angle probe measured total and static pressure fluctuations of 0.5 psi while in the Mach 0.42 open air jet.

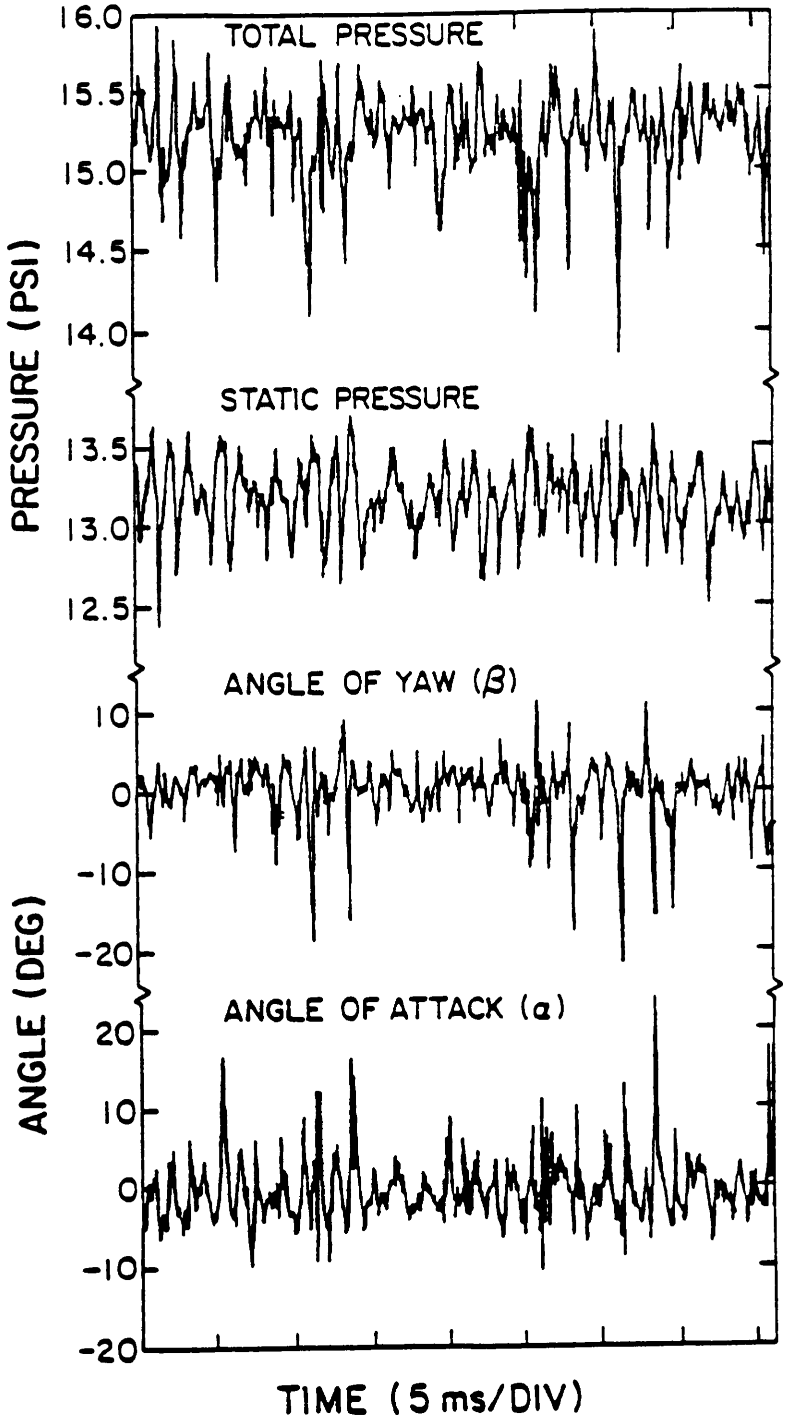

Figure 14. Time Traces of Reduced Total Pressure, Static Pressure, and Flow Angles (Air Jet)

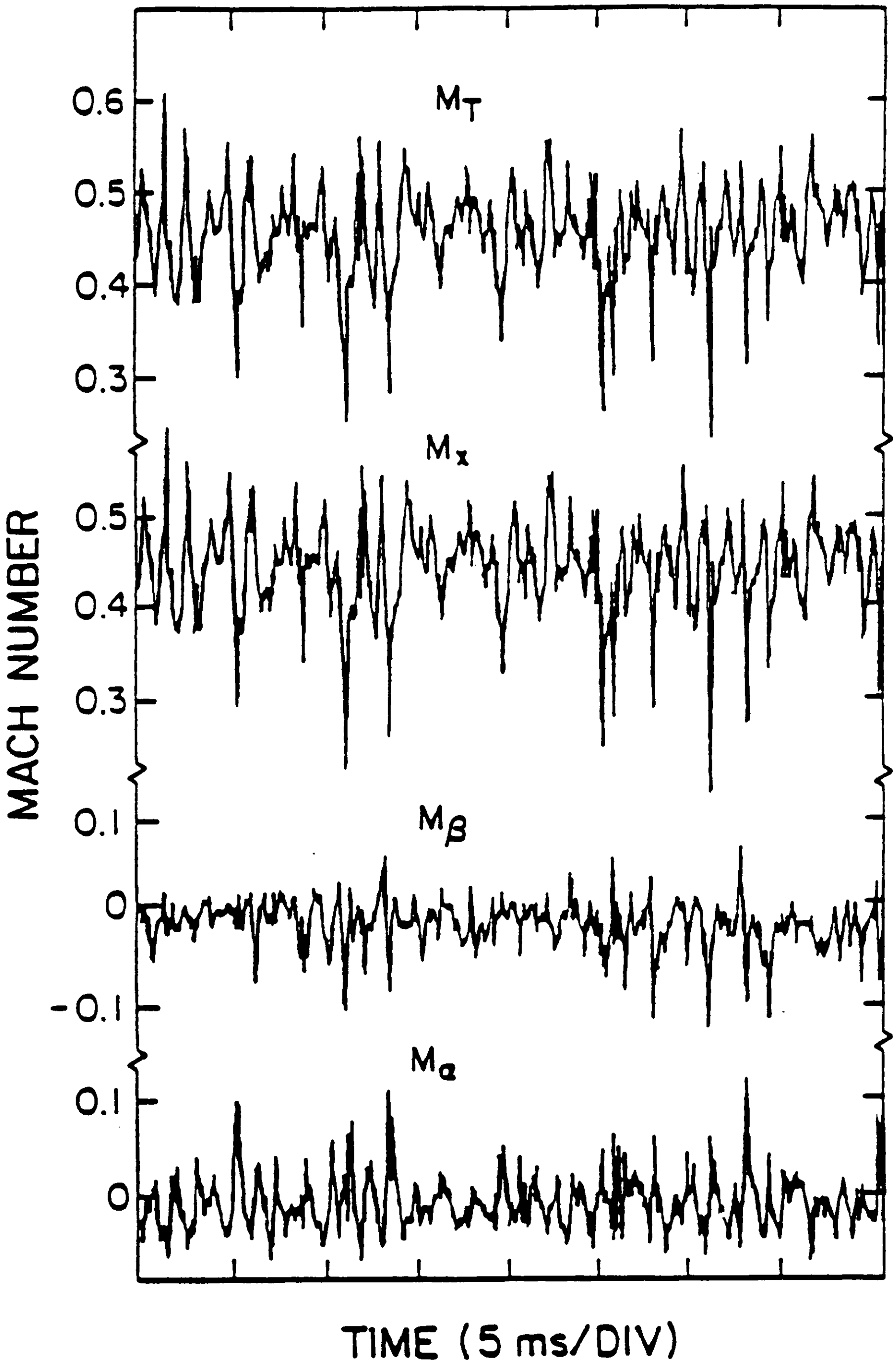

Figure 15. Time Traces of Mach Number and Three Components (Air Jet)

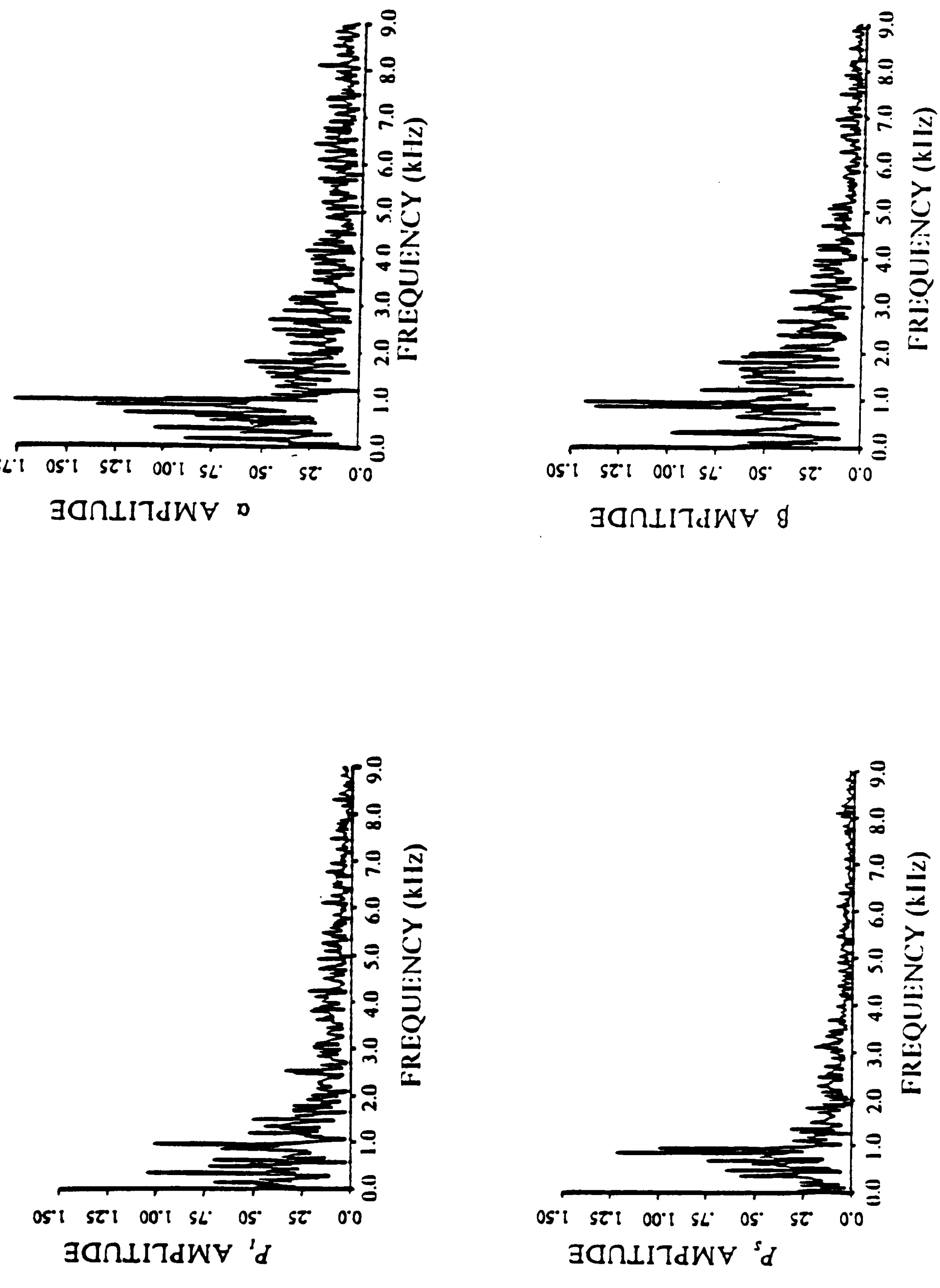

Figure 16. Fourier Spectrums of Reduced Pressures and Flow Angles (Air Jet)

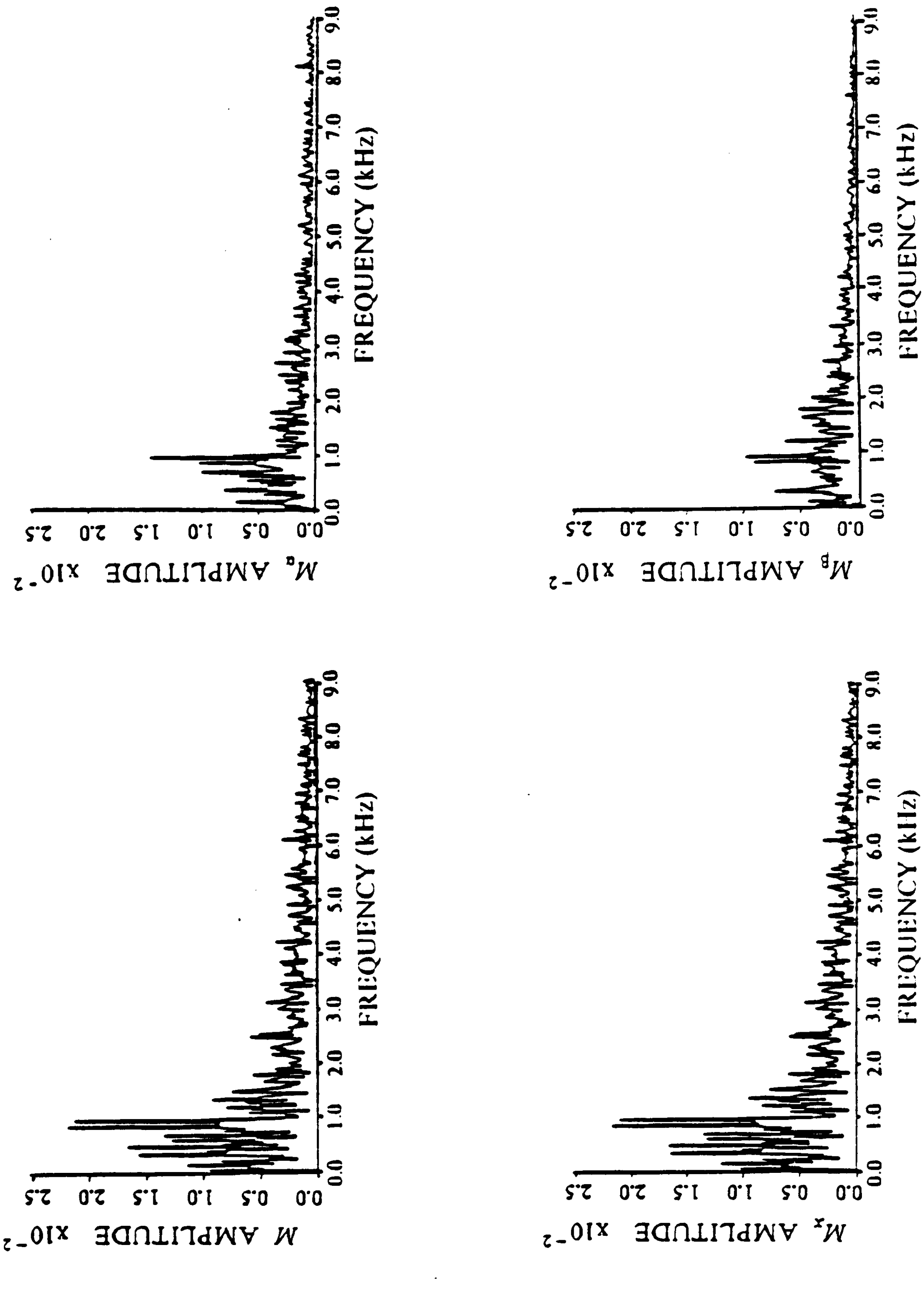

Figure 17. Fourier Spectrums of Mach Number and Three Components (Air Jet)

5.0 Conclusions and Recommendations

A high frequency angle probe was developed and successfully tested for time-resolved measurements of total pressure, static pressure, and two orthogonal flow angles. This probe was designed to make unsteady aerodynamic measurements in transonic cryogenic tunnels such as the National Transonic Facility at NASA-Langley Research Center. A data reduction method was developed to reduce the four probe pressure measurements to the desired flow quantities. The method is an interpolation routine which relates the four measured pressures with calibration data. Non-dimensional flow coefficients were calculated from the measured pressures and compared with the calibration coefficients to determine the total pressure, static pressure, Mach number, and two flow angles. The angle probe demonstrated its effectiveness in measuring the unsteady Karman vortex street shed from a cylinder placed in a low speed atmospheric wind tunnel. The testing of the angle probe in a Mach 0.42 open air jet further established the probe as an useful instrument for high frequency flow research.

The following recommendations are made for the future development of the high frequency angle probe.

1. A more effective solution to the zero drift of the Kulite transducers must be found. A technique to monitor the zero drift during the test should be explored until this problem is solved.

2. Angle probe calibration should be made Reynolds number independent. This could be accomplished by calibrating the angle probe in a cryogenic tunnel or a high pressure facility capable of producing similar results. Information obtained from this type of calibration can be easily incorporated into the data reduction method.

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Appendix A. Data Acquisition and Reduction Methods

This appendix contains a discussion of the data transfer from the analog angle probe signals to the reduced flow quantities. The necessary program listings and samples of input and output files are given.

The four channels of analog outputs from the high frequency angle probe were sampled by a LeCroy 8210 Quad 10-bit Transient Digitizer directed by a LeCroy 8901A CAMAC to GPIB interface. Program instructions via the GPIB (General Purpose Interface Bus, IEEE Standard 488-1978) pass into the registers of the Model 8901A and select the desired instrument module within the CAMAC (Computer Automated Measurement And Control, IEEE Standard 583-1975) mainframe to communicate the necessary read/write commands. From the digitizer, the signals passed through the LeCroy 8901A module and were stored in LeCroy 8800A memory modules. Directed by LeCroy's CATALYST software, a block transfer of the data was initiated from the memory modules, through the CAMAC to GPIB interface, and finally through the

GPIB Listener of an IBM PC. Once in the IBM PC memory, the data were written in unformatted binary code onto standard flexible disks.

To put the data in a usable format, the LECROYRD program was written in FORTRAN for use on the IBM PC. LECROYRD uses information stored in the header (the first section) of the data file to process the binary code into a corresponding voltage produced by the transducer. A program that is interactive with the screen, LECROYRD allows the user to input values for transducer sensitivities, zero voltage shifts, reference pressures, and file names. The output of the program is a file containing the relative time that the data were taken (seconds) and the pressure readings (psia) of each of the four pressure transducers for the first 1024 points. This file is immediately written to a blank formatted flexible disk for storage. Only 1024 points are processed because of space limitations of the flexible disk. The 1024 points are approximately 1/16 of the total stored data on the unformatted data disk.

The next step in the data transfer was to upload the information stored on the formatted data disks to the Virginia Tech mainframe computer system. The formatted data were transferred from an IBM PC via a localnet line to the mainframe computer using the PCTRANS command. The Virginia Tech computer system has an IBM 3090 processor complex with 64 megabytes of memory. Two processors run the VM1 interactive system with a capacity of 28 million instructions per second. The increase in speed and storage capacity of the mainframe computer over the IBM PC improved the efficiency of the data reduction.

With the data file on the mainframe computer, the ANGLE4 data reduction program was used to reduce the instantanteous pressure readings to total and static pressures, two flow angles, and directional Mach numbers. ANGLE4 is written in FORTRAN code and contains detailed documentation on the techniques used for data reduction. Output files containing reduced flow values and time averaged flow quantities are created and stored in files of the mainframe computer. For 1024 data points, the ANGLE4 data reduction program used approximately 0.2 seconds of CPU time.

A.1 Program LECROYRD

```
C     LECROYRD.FOR   ANGLE PROBE LECROY DATA REDUCTION
C
C      THIS PROGRAM REDUCES ANGLE PROBE DATA FROM VOLTAGES TO PSIA.
C      THIS PROGRAM IS TAYLORED FOR USE WITH TWO LECROY 8210'S SENDING
C      DATA TO TWO SEPARATELY NAMED FILES.
C
C      THIS PROGRAM TRANSFERS AN UNFORMATTED 4-CHANNEL LECROY DATA
C      FILE DISK TO A FORMATTED FILE ON A ANOTHER DISK. ONLY THE
C      FIRST 1024 DATA POINTS OF EACH CHANNEL ARE USED.  THIS IS
C      WRITTEN FOR A LECROY CRATE WITH 2 MEMORIES.  A TWO-DISK
C      DRIVE IBM-PC IS REQUIRED.
C
C      THIS PROGRAM WAS WRITTEN BY TOM POPERNACK 7/86 WITH ASSISTANCE
C      FROM MR. FRANK CALDWELL.  HEADER INFORMATION WAS FOUND IN THE
C      LECROY WAVEFORM CATALYST MANUAL, APPENDIX A.
C
C      DECLARE VARIABLE TYPES AND SIZE
        INTEGER*2 SDFILE, HEADER(17),LENGTH,TYPE,START,BLKCNT
        INTEGER*2 LEN,BLOCK,DATBUF(4100),WFILE
        INTEGER*2 BLKCHN, CHNLST,PTR,OFFSET,WIDTH
         REAL      B1DAT(1024) ,B2DAT(1024) ,B3DAT(1024)
         REAL      B4DAT(1024)
        INTEGER*4    TRIG, PERIOD, AMPL, TOTAL , DUM
         REAL TIME(1024)
        CHARACTER*1 TEXT(161)
        CHARACTER*14 FNAME,WRNAME
         DATA WFILE/2/
        DATA SDFILE/1/
C
         WRITE(*,*)' INSERT LECROY DATA DISK IN B DRIVE '
         WRITE(*,*)
C      INPUT FILE SPECIFICATION  OF DATA FILE
        WRITE(*,*)' ENTER DRIVE: FILENAME.TYPE OF DATA FILE '
        READ(*,'(A)')FNAME
         WRITE(*,*)
C      OPEN DISK DATA FILE
        OPEN(SDFILE, FILE=FNAME, STATUS='OLD', FORM='UNFORMATTED')
C
C      READ FIRST SEVENTEEN BYTES OF HEADER (DATA PARAMETERS)
        READ(SDFILE)(HEADER(I),I = 1, 17)
C      READ NEXT 161 BYTES OF HEADER (TEXT REMARKS ON DATA)
        READ(SDFILE)(TEXT(I), I = 1, 161)
C      PRINT NUMBER OF DATA WORDS PER BLOCK
        LENGTH=HEADER(1)
        WRITE(*,*) 'NO. OF DATA WORDS/BLOCK =.......... ',LENGTH
C      PRINT NUMBER OF BITS PER DATA WORD
        WIDTH=HEADER(2)
        WRITE(*,*)'NO. OF BITS/WORD =.................. ',WIDTH
C      CONVERT NEXT FOUR BYTES AND PRINT PERIOD OF SAMPLE
        PERIOD=HEADER(3)
         IF(PERIOD.LT.0)PERIOD=PERIOD+65536
         DUM=HEADER(4)*65536
         PERIOD=PERIOD+DUM
        WRITE(*,*)'THE SAMPLE PERIOD IS (0.1nSEC)=..... ',PERIOD
C      PRINT OFFSET DATA
        OFFSET=HEADER(5)
        WRITE(*,*)'ZERO VOLT OFFSET =.................. ',OFFSET
C      CONVERT AND PRINT TRIGGER DATA
        TRIG=HEADER(6)
         IF(TRIG.LT.0)TRIG=TRIG+65536
         DUM=HEADER(7)*65536
         TRIG=TRIG+DUM
        WRITE(*,*)'TRIGGER OCCURRED AT................. ',TRIG
C      CONVERT AND PRINT AMPLITUDE DATA
        AMPL=HEADER(8)
         IF(AMPL.LT.0)AMPL=AMPL+65536
         DUM=HEADER(9)*65536
         AMPL=AMPL+DUM
        WRITE(*,*)'AMPLITUDE =......................... ',AMPL
C      PRINT START BYTE INFORMATION
        START=HEADER(10)
        WRITE(*,*)'START BYTE =........................ ',START
C      PRINT NUMBER OF DATA BLOCKS
        BLKCNT=HEADER(11)
        WRITE(*,*)'NUMBER OF BLOCKS =.................. ',BLKCNT
C      PRINT TYPE OF DATA
        TYPE=HEADER(12)
        WRITE(*,*)'TYPE OF DATA =...................... ',TYPE
C      PRINT NUMBER OF BLOCKS PER CHANNEL
        BLKCHN=HEADER(13)
```

```
      WRITE(*,*)'BLOCKS PER CHANNEL =................ ',BLKCHN
C     PRINT STARTING CHANNEL
      CHNLST=HEADER(14)
      WRITE(*,*)'STARTING CHANNEL =.................. ',CHNLST
C     PRINT REMARKS TEXT
       WRITE(*,*)(TEXT(I),I = 1, 161)
C
C     ASK FOR KULITE SENSITIVITIES
C
       WRITE(*,*)' ENTER SENSITIVITY OF KULITE #1,#2,#3,#4 (V/psi)'
       READ(*,*)SEN1,SEN2,SEN3,SEN4
       WRITE(*,*)
       WRITE(*,*)' ENTER REF. PRESSURE OF KULITE (psia)'
       READ(*,*)PATM
      WRITE(*,*)' ENTER KULITE ZERO #1,#2,#3,#4 (VOLTS)'
      READ(*,*)ZV1,ZV2,ZV3,ZV4
       WRITE(*,*)
C
C
C     START TO READ THE DATA FROM THE LECROY DISK
C      THE FIRST DATA BLOCK OF EACH CHANNEL IS READ
C        CH 1-BLOCK 1            CH 3-BLOCK  9
C        CH 2-BLOCK 5            CH 4-BLOCK 13
C
C     COMPUTE NUMBER OF BYTES PER BLOCK
       BLOCK=0
       LEN=(WIDTH+7)/8
       LEN=(LEN*LENGTH+1)/2
C     LEN IS THE LENGTH OF ONE BLOCK OF DATA
   10  BLOCK=BLOCK+1
       IF(BLOCK.GT.13)GO TO 21
       READ(SDFILE)(DATBUF(I),I=1,LEN)
       IF(BLOCK.EQ.1)GO TO 101
       IF(BLOCK.EQ.5)GO TO 102
       IF(BLOCK.EQ. 9)GO TO 103
       IF(BLOCK.EQ.13)GO TO 104
       GO TO 10
C
C     ONLY THE FIRST 1024 DATA POINTS OF EACH BLOCK ARE PROCESSED
C
  101  DO 111 I=1,1024
       B1DAT(I)=((((1.0E-6)*(FLOAT(AMPL))*(FLOAT(DATBUF(I)-
     $OFFSET)))-ZV1)/SEN1)+PATM
  111  CONTINUE
       GO TO 10
  102  DO 112 I=1,1024
       B2DAT(I)=((((1.0E-6)*(FLOAT(AMPL))*(FLOAT(DATBUF(I)-
     $OFFSET)))-ZV2)/SEN2)+PATM
  112  CONTINUE
       GO TO 10
  103  DO 113 I=1,1024
       B3DAT(I)=((((1.0E-6)*(FLOAT(AMPL))*(FLOAT(DATBUF(I)-
     $OFFSET)))-ZV3)/SEN3)+PATM
  113  CONTINUE
       GO TO 10
  104  DO 114 I=1,1024
       B4DAT(I)=((((1.0E-6)*(FLOAT(AMPL))*(FLOAT(DATBUF(I)-
     $OFFSET)))-ZV4)/SEN4)+PATM
  114  CONTINUE
       GO TO 10
C
C     COMPUTE THE TIME ARRAY
C
   21  TIME(1)=0.0
       DO 22 JJ=2,1024
        TIME(JJ)=TIME(JJ-1)+(FLOAT(PERIOD)*(1.0E-10))
   22  CONTINUE
C     NOW ALL TIME AND DATA ARRAYS ARE FILLED
C
C     ASK FOR FILE TO WRITE DATA TO
C
       WRITE(*,*)' INSERT BLANK DISK IN B DRIVE '
       WRITE(*,*)
       WRITE(*,*)' ENTER DRIVE: FILENAME.TYPE TO WRITE DATA TO '
       READ(*,'(A\)')WRNAME
       OPEN(WFILE, FILE=WRNAME, STATUS='NEW', FORM='FORMATTED')

C     WRITE ABSOLUTE PRESSURES(psia) FROM KULITE TO DISK FILE
C
       WRITE(WFILE,50)
   50  FORMAT(5X,'TIME(SEC)',8X,' P1',10X,' P2',10X,' P3',10X,' P4')
       DO 65 L=1,1024
       WRITE(WFILE,70)TIME(L),B1DAT(L),B2DAT(L),B3DAT(L),B4DAT(L)
   70  FORMAT(1X,5(3X,F10.6))
```

```
65    CONTINUE
      CLOSE(WFILE)
       CLOSE(SDFILE)
      STOP
     END
```

A.2 Data File LECOUT

This is a sample file of the output of LECROYRD which can be used as an input file for ANGLE4.

TIME(SEC)	P1	P2	P3	P4
0.000000	13.941740	13.817280	13.804740	13.918490
0.000100	13.930250	13.808660	13.815740	13.892910
0.000200	13.922590	13.797170	13.823990	13.890770
0.000300	13.934080	13.802920	13.840500	13.884380
0.000400	13.937910	13.825900	13.832250	13.854530
0.000500	13.918760	13.840260	13.823990	13.839600
0.000600	13.899610	13.834510	13.821240	13.826810
0.000700	13.895780	13.823020	13.804740	13.822550
0.000800	13.922590	13.823020	13.790990	13.822550
0.000900	13.957050	13.828770	13.807490	13.828940

A.3 Program ANGLE4

```
C       ANGLE4.FORTRAN
C
C       MODIFIED BY THOMAS G. POPERNACK JR.-VIRGINIA TECH, 1986
C       FOR USE WITH HIGH FREQUENCY ANGLE PROBE DEVELOPED BY DR. W.F. NG
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C
C       OUTLINE FOR DATA REDUCTION ROUTINE- ANGLE4.FORTRAN
C
C       THE FOLLOWING ARE THE NON-DIMENSIONAL COEFFICIENTS USED IN THE
C       DATA REDUCTION ROUTINE.
C
C        F23=(P2-P3)/((P2-P1)+(P3-P1))
C
C        CP4=(P4-PS)/(PT-PS)
C
C        KP2=(P2-PS)/((P2-P1)+(P3-P1))
C
C        H23=(PT-PS)/((P2-P1)+(P3-P1))
C
C        CP1=(P1-PS)/(PT-PS)
C
C
C       THE FOLLOWING IS A STEP-BY-STEP APPROACH TO THE DATA REDUCTION
C       ROUTINE.  INPUTS ARE TIME,P1, P2, P3, AND P4 WHILE THE OUTPUTS ARE
C       YAW ANGLE, ANGLE OF ATTACK, TOTAL PRESSURE, STATIC PRESSURE,
C       TOTAL MACH NUMBER, X-, THETA-, AND PHI-DIRECTIONAL MACH NUMBERS.
C
C        STEP  1. INPUT ABSOLUTE VALUES (PSIA) FOR P1,P2,P3, AND P4.
C
C        STEP  2. CALCULATE THE VALUE FOR F23 FROM THE INPUT PRESSURES.
C
C        STEP  3. FOR THE FIRST PASS, GUESS THE VALUE FOR PS TO BE THE
C                 SMALLER OF P2 AND P3.
C
C        STEP  4. FOR THE FIRST PASS, GUESS THE VALUE FOR PT TO BE EQUAL
C                 TO P1.
C
C        STEP  5. WITH THE VALUES FOR PS AND PT, CALCULATE A TOTAL MACH
C                 NUMBER, M, AND ITS DIRECTIONAL COMPONENTS (X-, THETA-,
C                 PHI-DIRECTION).
C
C        STEP  6. CALCULATE THE VALUE FOR CP4 FROM THE INPUT PRESSURES
C                 AND THE GUESSED VALUES.
C
C        STEP  7. FOR THE INITIAL PASS ONLY, GUESS THE PHI ANGLE=0 DEGREES
C                 OTHERWISE, SET PHI ANGLE= PHI PRIME.
C
C        STEP  8. FIND THETA FROM THE VALUES OF F23, M, AND PHI BY
C                 COMPARING THE THREE VALUES TO THE CALIBRATION DATA.
C
C        STEP  9. FIND PHI PRIME FROM THE VALUES OF CP4, M, AND THETA BY
C                 COMPARING THE THREE VALUES TO CALIBRATION DATA.
C
C        STEP 10. FIND THE CORRESPONDING COEFFICIENT VALUES FOR KP3, H23,
C                 AND CP1 FROM THE VALUES OF THETA, PHI PRIME, AND TOTAL
C                 MACH NUMBER (M).
C
C        STEP 11. CALCULATE A VALUE FOR PS PRIME FROM KP3.
C
C        STEP 12. CALCULATE A VALUE FOR PT PRIME FROM H23 AND CP1.
C
C        STEP 13. CALCULATE A VALUE FOR M PRIME (TOTAL MACH NUMBER PRIME)
C                 FROM PS PRIME AND PT PRIME.
C
C        STEP 14. CHECK CONVERGENCE ON STATIC AND TOTAL PRESSURE.
C                 IF THE CONVERGENCE CRITERIA OF A CHANGE IN PRESSURE
C                 OF 0.001 PSI IS NOT MET, RETURN TO STEP 3.
C                 WHEN THE CONVERGENCE CRITERIA IS MET,
C                 DISCONTINUE THE LOOP AND RETURN TO STEP 1 FOR
C                 THE NEXT POINT.  THE MAXIMUM NUMBER OF ITERATIONS
C                 IS 25.
C
C        STEP 15. AFTER ALL DATA POINTS ARE USED, TIME AVERAGED VALUES
C                 ARE CALCULATED FOR ALL FLOW QUANTITIES.
C
C ======================================================================
C
C                         SUBROUTINE DESCRIPTIONS
C
C
C        ANGLE4.FORTRAN
```

```
C           THIS IS THE MAIN DATA REDUCTION ROUTINE.
C              -DATA (TIME,P1,P2,P3,P4) ARE READ IN FROM A SEPERATE FILE
C               (FILE DEFINITION IS #15)
C              -DATA ARE WRITTEN BACK OUT TO ANOTHER FILE AS A CHECK TO
C               MAKE SURE THE DATA IS READ IN ACCURATELY (FILE
C               DEFINITION IS #16)
C              -INITIAL GUESSES FOR PS, PT, AND MACH NUMBER ARE MADE
C              -ALL SUBROUTINES FOR DATA REDUCTION ARE CALLED
C              -CONVERGENCE CRITERIA ARE SET FOR NUMBER OF ITERATIONS
C               AND CONVERGENCE LIMITS ON PS (MOST SENSITIVE)
C              -AVERAGING OF ALL REDUCED DATA VALUES ARE DONE AND STORED
C               IN A FILE (FILE DEFINITION IS #3)
C              -ALL REDUCED DATA IS STORED IN A FILE (FILE DEFINITION
C               IS #2)
C
C     BLOCK DATA ANGLE
C           THIS DATA FILE CONTAINS ALL THE CALCULATED CALIBRATION
C           COEFFICIENTS FOR MACH NUMBERS OF 0.1, 0.24, 0.50, AND 0.75.
C           THESE COEFFICIENTS ARE F23, CP4, H23, KP2, AND CP1.
C           SYMMETRY OF THE PROBE REDUCES THE NUMBER OF CALIBRATION
C           POINTS FOR SOME OF THESE VALUES.
C
C     SUBROUTINE MACH
C           THIS SUBROUTINE CALCULATES THE TOTAL MACH NUMBER AND ITS
C           DIRECTIONAL COMPONENTS (X-, THETA-, PHI- ) BASED ON STATIC
C           AND TOTAL PRESSURES.
C
C     SUBROUTINE WORK
C           THIS SUBROUTINE CALCULATES FLOW ANGLES, STATIC PRESSURE, AND
C           TOTAL PRESSURE FROM THE CALIBRATION CURVES.
C           THE SUBROUTINE ALSO CALLS FOR MACH NUMBER CALCULATIONS.
C
C     SUBROUTINE INP
C           THIS SUBROUTINE CALCULATES AN INTERPOLATED CALIBRATION
C           CURVE FOR ANY GIVEN MACH NUMBER FROM THE ORIGINAL
C           CALIBRATION CURVES.
C
C     SUBROUTINE INTPOL
C           THIS SUBROUTINE DOES SIMPLE LINEAR INTERPOLATION.
C
C     SUBROUTINE CHEC
C           THIS SUBROUTINE SET NUMBERS LESS THAN E-8 TO E-8. THIS IS
C           USED TO KEEP DENOMENATORS FROM GOING TO ZERO.  A PROBLEM
C           LIKE THIS WOULD OCCUR IF P2=P3.
C
C     SUBROUTINE RENAME
C           THIS SUBROUTINE RENAMES ARRAYS INTO GENERIC ARRAYS FOR
C           EASIER PROGRAMMING.
C
C=====================================================================
C
C                       UNIT (FILE) DEFINITIONS
C
C     UNIT 2 - REDCED OUTPUT A
C              ALL REDUCED DATA IS STORED IN THIS FILE
C
C     UNIT 3 - AVERGD OUTPUT A
C              AVERAGED VALUES OF REDUCED DATA IS STORED IN THIS FILE
C
C     UNIT 4 - UNCONV DATA A
C              TIME VALUE OF UNCONVERGED DATA IS STORED IN THIS FILE
C
C     UNIT 15- INPUT DATA A
C              DATA FILE CONTAINING TIME, P1, P2, P3, AND P4
C
C     UNIT 16- ECHO INPUT A
C              ECHO DUMMY FILE OF DATA FILE IN UNIT 15
C
C
C=====================================================================
C    THIS IS THE MAIN DATA REDUCTION ROUTINE-ANGLE4.FORTRAN
C
      INTEGER ITER(1250)
        COMMON /BTET2/TET(10),NTET,NMACH
        COMMON /BPHI2/NPHI,PHI(10)
        COMMON /DAT/F(9),PL,SIGN
        REAL DATA(1250,6),FINE(1250,9),P(4)
C
C    FOR NASA PAPERS:
C       THE ANGLE OF ATTACK (ALPHA) IS THE NEGATIVE OF THE PHI ANGLE AND
C       THE ANGLE OF YAW (BETA) IS THE NEGATIVE OF THE THETA ANGLE.
C
C------- STEP 1-------
C
```

```
C    READ IN PROBE DATA INTO AN ARRAY 'DATA'
C    DATA ARE READ IN THE FOLLOWING FORMAT:TIME(SEC),P1,P2,P3,P4(PSIA)
C
C    'NDATA' IS THE NUMBER OF DATA POINTS TO BE EXAMINED.
C    FOR THE ABOVE ARRAY SIZES,THE MAXIMUM NUMBER OF POINTS TO BE
C    EXAMINED IS 1250.
C    FOR THIS TEST, THE NUMBER OF POINTS IS 1024.
C
C    FOR THIS VERSION, THE ECHO FILE WRITE STATEMENTS FOR UNIT #16
C    HAVE BEEN CHANGED BY PLACING A 'C' IN COLUMN 1 OF THESE TWO
C    STATEMENTS. NOW, THE ECHO FILE IS NOT CREATED.
C
C      WRITE(16,77)
 77    FORMAT(8X,'TIME',9X,'P1',11X,'P2',11X,'P3',11X,'P4',/)
        NDATA=1024
        DO 500 J=1,NDATA
        READ(15,78)(DATA(J,I),I=1,5)
 78     FORMAT(1X,5(3X,F10.6))
        NN=J
C       WRITE(16,79)(DATA(J,I),I=1,5)
 79     FORMAT(1X,5(3X,F10.6))
 500   CONTINUE
C
C    THE NEXT TWO LINES ARE FOR WRITING COLUMN TITLES FOR FILES.
C
       WRITE(3,160)
       WRITE(3,170)
C
C    'NN' IS THE NUMBER OF DATA POINTS EXAMINED.
C
 47     DO 90 I=1,NN
C
C    F(1) IS THE TIME ASSOCIATED WITH THE DATA POINT.
C
        F(1)=DATA(I,1)
        NO=1
          DO 30 JJ=2,5
C
C    THIS STEP LOADS THE P ARRAY WITH THE 4 PRESSURES FROM
C    THE 'DATA' ARRAY.
C
 30       P(JJ-1)=DATA(I,JJ)
C
C*** CALCULATION OF F23 BEGINS ***
C
C    'P2P3' IS A COMMON DENOMINATOR IN MANY OF THE COEFFICIENTS USED.
C
        P2P3=P(2)-P(1)+P(3)-P(1)
        CALL CHEC(P2P3)
C
C------- STEP 2 -------
C
        FF23=(P(2)-P(3))/P2P3
C
C------- STEP 3 -------
C
C    FOR THE FIRST GUESS, ASSUME PS(STATIC) TO BE THE SMALLER OF P2 AND
C    P3.  ALSO, ASSUME PT(TOTAL) TO BE P(1).  'PL' IS AN INTERMEDIATE
C    VARIABLE USED TO DENOTE THE GUESSED VALUE OF THE STATIC PRESSURE.
C
        IF(P(2).GT.P(3))GOTO 35
        PL=P(2)
        GOTO 36
 35     PL=P(3)
C     FIRST GUESS FOR MACH NUMBER,PT,PS
C
C------- STEP 4 -------
C
 36     PT=P(1)
        PS=PL
C
C------- STEP 5 -------
C
C
C    CALCULATE AN INITIAL MACH NUMBER BASED ON PS AND PT.
C
       CALL MACH(PT,PS,45.,0.,XMT,D1,D2,D3)
C
C*********************************************************************
C
C    THESE NEXT STEPS ARE SIMILAR TO A 'DO LOOP'.  THEY CHECK ON THE
C    CONVERGENCE OF PS AND PT AND ALLOW FOR 25 ITERATIONS.
C
C    FIRST, CP4 IS CALCULATED AND THEN THE 'WORK' SUBROUTINE IS USED TO
```

```
C    FIND NEW VALUES FOR PT, PS, XMT(MACH NO.), AND XFEE(PHI ANGLE.)
C    IF THE CONVERGENCE CRITERIA OF CHANGES IN PS AND PT< 0.1% ARE
C    NOT MET, NEW PS AND PT  ARE CALCULATED (PS=PS+0.5*(PSN-PS)).
C    IF THE ITERATION LIMIT IS MET, AN UNCONVERGED DATA
C    WARNING IS ISSUED.
C
C    THE LOOP THEN RETURNS TO LINE 40 WHERE A NEW 'PTPS' IS FOUND.  NEXT,
C    A NEW CP4 IS CALCULATED AND THE 'WORK' SUBROUTINE IS CALLED AGAIN.
C
C*********************************************************************
C
 40    PTPS=PT-PS
C
C    THE SUBROUTINE 'CHECK' IS CALLED TO SET THE MINIMUM VALUE OF 'PTPS'
C    TO E-6.  THIS IS DONE SO THAT THE DENOMINATOR IN CP4 WILL NOT
C    CAUSE THE COEFFICENT TO GO TO INFINITY.
C
       CALL CHEC(PTPS)
C
C
C------- STEP 6 -------
C
C    CALCULATE AN INITIAL VALUE FOR CP4
C
       CP4=(P(4)-PS)/PTPS
C
C------- STEP 7 -------
C
C*** CALCULATE FLOW PARAMETERS ***
C
         CALL WORK(CP4,FF23,P2P3,PT,XMT,PS,PSN,P,XFEE,PTN)
C
C------- STEP 14 -------
C
C*********************************************************************
C
C    CHECK CONVERGENCE ON PS (MOST SENSITIVE) AND ALLOW FOR 25
C    ITERATIONS.
C
C    A CONVERGENCE LIMIT OF 0.1% IS RECOMMENDED
C         IN. OF WATER = 0.40
C         IN. OF HG    = 0.03
C                 PSIA = 0.001
C
C*********************************************************************
C
        LFLAG=0
        IF(ABS(PS-PSN).LT..001)LFLAG=1
        IF(ABS(PT-PTN).LT..001)LFLAG=LFLAG+1
        IF (LFLAG.EQ.2)GO TO 70
        IF(NO.GE.25)GOTO 60
 50     NO=NO+1
        URF=0.5
        PS=PS+URF*(PSN-PS)
        PT=PT+URF*(PTN-PT)
        GOTO 40
 60     WRITE(4,*)' UNCONVERGED DATA ACCEPTED AT T=',F(1)
C
C    DO LOOP STORES CONVERGED DATA FROM 'F' ARRAY INTO 'FINE' ARRAY.
C
 70       DO 80 IF=1,9
          FINE(I,IF)=F(IF)
 80       CONTINUE
        ITER(I)=NO
C
C    FOR ONE DATA POINT, THE ITERATION PROCESS IS NOW COMPLETE.
C    GO BACK TO LINE 47 AND GET THE NEXT DATA POINT.
C
 90     CONTINUE
C
C*************** AVERAGING ********************************************
C    THIS IS A SIMPLE AVERAGING TECHNIQUE.
C       AVERAGE=SUM OF ALL VALUES / NO. OF DATA POINTS
C*********************************************************************
C
        DO 110 IAV=1,9
        F(IAV)=0
          DO 100 IBV=1,NN-1
          F(IAV)=F(IAV)+FINE(IBV,IAV)
 100      CONTINUE
        F(IAV)=F(IAV)/(FLOAT(NN-1))
 110    CONTINUE
C
C************ REDUCED DATA BEING STORED ******************************
```

```
C
C    STORE REDUCED DATA IN AN OUTPUT FILE
C
      WRITE(2,*)'NUMBER OF DATA POINTS= ',NN
      WRITE(2,99)
 99   FORMAT(2X,'TIME',5X,'THETA',6X,'PHI',6X,'PT',6X,'PS',6X,'MT',
     $6X,'MX',6X,'MTH',4X,'MPHI',2X,'ITER',/)
      DO 151 I=1,NN
        WRITE(2,150)(FINE(I,J),J=1,9),ITER(I)
 150    FORMAT(1X,F6.4,1X,2(F9.3,1X),6(F7.3,1X),1X,I2)
 151  CONTINUE
 160  FORMAT(/,15X,'*** SPHERE PROBE AVERAGED REDUCED DATA ***')
 170    FORMAT(2X,'TIME',4X,'THETA',2X,'PHI',4X,'PT',6X,'PS',
     1  6X,'MT',7X,'MX',5X,'MTH',4X,'MPHI',/)
C
C
C------- STEP 15 -------
C
C     STORE AVERAGED REDUCED DATA IN AN OUTPUT FILE
C
      WRITE(3,190)F
 190  FORMAT(1X,F6.4,2X,2(F5.1,1X),6(F7.3,1X))
C
        STOP
        END
C
C***********************************************************************
C***********************************************************************
C      BLOCK DATA ANGLE
C
C///////////////////////////////////////////////////////////////////////
C
      BLOCK DATA ANGLE
C
        COMMON /BTET2/TET(10),NTET,NMACH
        COMMON /BPHI2/NPHI,PHI(10)
        COMMON /BTET3/COCP4(10,4),C6CP4(10,4),C12CP4(10,4)
        COMMON /BTET4/HOH23(10,4),H6H23(10,4),H12H23(10,4)
        COMMON /BTET5/XOKP2(10,4),X6KP2(10,4),X12KP2(10,4)
        COMMON /BTET6/ZOCP1(10,4),Z6CP1(10,4),Z12CP1(10,4)
        COMMON /BTET7/Z18CP1(10,4),Z24CP1(10,4),X18KP2(10,4)
        COMMON /BTET8/X24KP2(10,4),H18H23(10,4),H24H23(10,4)
        COMMON /BTET9/C18CP4(10,4),C24CP4(10,4)
        COMMON /BPHI4/FN24(10,4),FN18(10,4),FN12(10,4)
        COMMON /BPHI5/FN6(10,4),F0(10,4),F6(10,4)
        COMMON /BPHI6/F12(10,4),F18(10,4),F24(10,4)
C
C    *******************************************************************
C    IN THIS VERSION THERE ARE  : 5 THETA ANGLES
C                                     0,6,12,18,24 DEG.
C                                 9 PHI ANGLES
C                                     -24,-18,-12,-6,0,6,12,18,24 DEG.
C                                 4 MACH NUMBERS
C                                     0.1,0.24,0.5,0.75
C    *******************************************************************
C
C
C
C    CALIBRATION DATA WERE TAKEN AT VPI&SU USING THE ANGLE PROBE AND THE
C    AIR JET DEVELOPED BY J. ROSSON.  DATA FOR MACH NO.'S 0.243, 0.5,
C    AND 0.75 WAS TAKEN BY J. ROSSON AND M. WATTS FROM JULY 29-31,1985.
C    DATA FOR MACH NO. 0.1 WAS TAKEN BY M. FLETCHER FROM JAN. 27-31,1986.
C
C    NOMENCLATURE:
C       FN24 =F23 VALUES FOR ALL CALIBRATION THETA ANGLES SET AT A PHI
C             ANGLE OF -24 DEG. (N=NEGATIVE)
C      COCP4=CP4 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 0
C             DEG.
C               C=CP4
C               0=THETA ANGLE SPECIFIED (0 DEG.)
C      H6H23=H23 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 6
C             DEG.
C               H=H23
C               6=THETA ANGLE SPECIFIED (6 DEG.)
C     X12KP2=KP2 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 12
C             DEG.
C               X=KP2
C              12=THETA ANGLE SPECIFIED (12 DEG.)
C     Z18CP1=CP1 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 18
C             DEG.
C               Z=CP1
C              18=THETA ANGLE SPECIFIED (18 DEG.)
C
C    *******************************************************************
C
```

```
      DATA NMACH/4/
      DATA NTET/5/
      DATA NPHI/9/
C
      DATA TET/0.,6.,12.,18.,24.,24.,24.,24.,24.,24./
C
      DATA PHI/-24.,-18.,-12.,-6.,0.,6.,12.,18.,24.,24./
C
C     DATA FOR F23 IS BROKEN INTO 9 ARRAYS (ONE FOR EACH PHI ANGLE.)
C     EACH ONE OF THESE ARRAYS HAS THE CORRESPONDING MACH NUMBER AS THE
C     FIRST ENTRY.  THE NEXT 9 ENTRIES MATCH THE THETA ANGLES.  THE LAST
C     VALUE IS REPEATED TO MAKE THE ARRAY MANIPULATION EASIER.
C
C     N=NEGATIVE, I.E., N24=-24 DEG. PHI ANGLE
C
C
        DATA FN24/
     1  0.1,.0115,.2048,.4210,.7838,1.139,1.139,1.139,1.139,1.139,
     2  0.243,.0,.2144,.4367,.7367,1.0688,1.0688,1.0688,1.0688,1.0688,
     3  0.5,.0,.2208,.4865,.7600,1.0833,1.0833,1.0833,1.0833,1.0833,
     4  0.75,.0,.2471,.5000,.7627,1.0112,1.0112,1.0012,1.0112,1.0112/
C
        DATA FN18/
     1  0.1,.0115,.2195,.4615,.7867,1.149,1.149,1.149,1.149,1.149,
     2  0.243,.0,.1713,.4286,.7243,1.0302,1.0302,1.0302,1.0302,1.0302,
     3  0.5,.0,.2099,.4750,.7531,1.0256,1.0256,1.0256,1.0256,1.0256,
     4  0.75,.0,.2291,.4919,.7354,.9780,.9780,.9780,.9780,.9780/
C
        DATA FN12/
     1  0.1,.0115,.1954,.4353,.7500,1.055,1.055,1.055,1.055,1.055,
     2  0.243,.0,.1792,.4286,.7199,1.0126,1.0126,1.0126,1.0126,1.0126,
     3  0.5,.0,.2289,.4699,.7317,1.0253,1.0253,1.0253,1.0253,1.0253,
     4  0.75,.0,.2366,.4845,.7273,.9526,.9526,.9526,.9526,.9526/
C
        DATA FN6/
     1  0.1,.0,.2093,.4824,.7561,1.083,1.083,1.083,1.083,1.083,
     2  0.243,.0,.1917,.4569,.7333,1.0123,1.0123,1.0123,1.0123,1.0123,
     3  0.5,.0,.2471,.4651,.7349,1.0253,1.0253,1.0253,1.0253,1.0253,
     4  0.75,.0,.2526,.4900,.7214,.9572,.9572,.9572,.9572,.9572/
C
        DATA F0/
     1  0.1,.0042,.1879,.4349,.7188,1.035,1.035,1.035,1.035,1.035,
     2  0.243,.0,.2045,.4823,.7538,1.0504,1.0504,1.0504,1.0504,1.0504,
     3  0.5,.0,.2381,.4762,.7143,1.0000,1.0000,1.0000,1.0000,1.0000,
     4  0.75,.0,.2764,.5050,.7413,.9783,.9783,.9783,.9783,.9783/
C
        DATA F6/
     1  0.1,-.0112,.2045,.4419,.7590,1.1096,1.1096,1.1096,1.1096,1.1096,
     2  0.243,.0,.2231,.5028,.7712,1.0998,1.0998,1.0998,1.0998,1.0998,
     3  0.5,.0,.2326,.4943,.7412,1.0533,1.0533,1.0533,1.0533,1.0533,
     4  0.75,.0,.2764,.5271,.7551,1.0114,1.0114,1.0114,1.0114,1.0114/
C
        DATA F12/
     1  0.1,.0115,.2143,.4937,.7882,1.1351,1.1351,1.1351,1.1351,1.1351,
     2  0.243,.0,.2137,.5198,.8152,1.1222,1.1222,1.1222,1.1222,1.1222,
     3  0.5,.0,.2439,.5238,.8000,1.0833,1.0833,1.0833,1.0833,1.0833,
     4  0.75,.0,.2990,.5600,.8041,1.0592,1.0592,1.0592,1.0592,1.0592/
C
        DATA F18/
     1  0.1,.0,.2368,.5128,.8684,1.2687,1.2687,1.2687,1.2687,1.2687,
     2  0.243,.0,.2138,.5378,.8511,1.2014,1.2014,1.2014,1.2014,1.2014,
     3  0.5,.0,.2632,.5641,.8462,1.1429,1.1429,1.1429,1.1429,1.1429,
     4  0.75,.0,.3039,.6082,.8503,1.1307,1.1307,1.1307,1.1307,1.1307/
C
        DATA F24/
     1  0.1,.0,.2222,.5454,.9385,.9118,.9118,.9118,.9118,.9118,
     2  0.243,.0,.2155,.5794,.9299,1.2990,1.2990,1.2990,1.2990,1.2990,
     3  0.5,.0,.2537,.6000,.9143,1.2388,1.2388,1.2388,1.2388,1.2388,
     4  0.75,.0,.3165,.6649,.9205,1.2121,1.2121,1.2121,1.2121,1.2121/
C
C     DATA FOR ALL OTHER NUMBERS (CP4,H23,KP2, AND CP1) ARE ENTERED INTO 5
C     ARRAYS (ONE FOR EACH THETA ANGLE.)  EACH OF THESE ARRAYS HAS THE
C     CORRESPONDING MACH NUMBER AS THE FIRST ENTRY.  THE NEXT 9 ENTRIES
C     MATCH THE PHI ANGLES.
C
C     AN EXAMPLE, C6CP4 CORRESPONDS TO THETA=6 DEG.
C
        DATA C0CP4/
     1  0.1,.7407,.6038,.4615,.3019,.1607,.0000,-.1887,-.4444,-.6654,
     2  0.243,.7410,.6024,.4575,.2915,.1254,-.0345,-.3197,-.4734,-.6928,
     3  0.5,.7294,.5950,.4607,.3071,.1536,-.0192,-.2688,-.4608,-.6336,
     4  0.75,.7347,.6162,.4898,.3555,.2212,.0000,-.2449,-.4661,-.6399/
C
        DATA C6CP4/
```

```
     1 .1,.7222,.5849,.4340,.2830,.1250,.0000,-.1887,-.4528,-.6654,
     2 .243,.7216,.5960,.4446,.2790,.1411,-.0376,-.3135,-.4828,-.6834,
     3 .5,.7102,.5950,.4415,.2879,.1344,-.0384,-.2496,-.4800,-.6912,
     4 .75,.7189,.6083,.4740,.3476,.2054,.0000,-.2528,-.4977,-.6794/
C
      DATA C12CP4/
     1 0.1,.6981,.5472,.4074,.2592,.1273,-.0183,-.1887,-.4821,
     2    -.6717,
     3 0.243,.6927,.5606,.4156,.2539,.0972,-.0376,-.3166,-.5361,
     4    -.7774,
     5 0.5,.6910,.5566,.4223,.2687,.1152,-.0192,-.2496,-.4992,
     6    -.7296,
     7 0.75,.6952,.5762,.4582,.3318,.1975,-.0316,-.2528,-.5451,
     8    -.7110/
C
      DATA C18CP4/
     1 0.1,.6038,.4906,.3518,.2453,.0909,-.0185,-.1786,-.4545,
     2    -.6906,
     3 0.243,.6282,.4961,.3608,.2132,.0690,-.0627,-.2978,-.5611,
     4    -.7962,
     5 0.5,.6334,.5182,.3647,.2303,.0960,-.0192,-.1536,-.4992,
     6    -.7489,
     7 0.75,.6478,.5372,.4187,.2923,.1659,-.0474,-.1738,-.5530,
     8    -.7189/
C
      DATA C24CP4/
     1 0.1,.5185,.3962,.3019,.1509,.0364,-.0370,-.2000,-.4364,
     2    -.6963,
     3 0.243,.5380,.4188,.2899,.1567,.0251,-.1003,-.2320,-.4702,
     4    -.7994,
     5 0.5,.5566,.4415,.3263,.1919,.0576,-.0384,-.1152,-.4032,
     6    -.7873,
     7 0.75,.5846,.4740,.3634,.2528,.1185,-.0158,-.1264,-.5372,
     8    -.7110/
C
      DATA H0H23/
     1 0.1,-.6207,-.6092,-.5977,-.6023,-.5858,-.5955,-.6092,-.6750,
     2    -.7432,
     3 0.243,-.6159,-.5879,-.5777,-.5886,-.5821,-.5951,-.6182,-.6646,
     4    -.7453,
     5 0.5,-.6354,-.6058,-.5920,-.5920,-.6056,-.6200,-.6351,-.7038,
     6    -.7659,
     7 0.75,-.7275,-.6880,-.6734,-.6663,-.6593,-.6593,-.6734,-.7193,
     8    -.7719/
C
      DATA H6H23/
     1 0.1,-.6506,-.6463,-.6092,-.6163,-.6048,-.6250,-.6309,-.6974,
     2    -.7639,
     3 0.243,-.6309,-.6183,-.5981,-.5996,-.5958,-.6135,-.6431,-.6890,
     4    -.7724,
     5 0.5,-.6766,-.6432,-.6277,-.6129,-.6200,-.6056,-.6351,-.6853,
     6    -.7773,
     7 0.75,-.7446,-.7072,-.6806,-.6628,-.6361,-.6361,-.6525,-.6994,
     8    -.8012/
C
      DATA H12H23/
     1 0.1,-.6974,-.6795,-.6353,-.6353,-.6071,-.6395,-.6709,-.7179,
     2    -.8030,
     3 0.243,-.6777,-.6335,-.6074,-.5974,-.5940,-.6053,-.6329,-.6702,
     4    -.7453,
     5 0.5,-.7041,-.6513,-.6277,-.6058,-.6200,-.5986,-.6200,-.6677,
     6    -.7440,
     7 0.75,-.7360,-.6843,-.6525,-.6267,-.6330,-.6236,-.6330,-.6525,
     8    -.6843/
C
      DATA H18H23/
     1 0.1,-.7162,-.7067,-.6750,-.6463,-.6138,-.6506,-.6588,-.7237,
     2    -.8154,
     3 0.243,-.6792,-.6387,-.6122,-.6076,-.6135,-.6292,-.6550,-.6787,
     4    -.7453,
     5 0.5,-.6947,-.6432,-.6354,-.6277,-.6200,-.6127,-.6510,-.6677,
     6    -.7440,
     7 0.75,-.7152,-.6698,-.6393,-.6298,-.6298,-.6459,-.6525,-.6770,
     8    -.7193/
C
      DATA H24H23/
     1 0.1,-.7500,-.7910,-.7260,-.7361,-.6824,-.7397,-.7432,-.8209,
     2    -.7941,
     3 0.243,-.7119,-.6690,-.6507,-.6564,-.6702,-.6920,-.7217,-.7650,
     4    -.7819,
     5 0.5,-.7236,-.6679,-.6595,-.6595,-.6592,-.6944,-.7233,-.7440,
     6    -.7773,
     7 0.75,-.7072,-.6955,-.6000,-.6770,-.6880,-.7234,-.7491,-.8274,
```

```
     8    -.9590/
C
      DATA X0KP2/
     1 0.1,-.0460,-.0575,-.0805,-.0909,-.0941,-.0899,-.0690,-.0750,
     2    -.0540,
     3 0.243,-.0595,-.0644,-.0743,-.0867,-.0730,-.0672,-.0523,-.0438,
     4    -.0280,
     5 0.5,-.0732,-.0814,-.0795,-.0909,-.0930,-.0833,-.0732,-.0676,
     6    -.0441,
     7 0.75,-.1724,-.1739,-.1702,-.1579,-.1458,-.1250,-.1064,-.0909,
     8    -.0610/
C
      DATA X6KP2/
     1 0.1,.0361,.0244,.0000,.0116,-.0108,.0114,.0357,.0395,.0556,
     2 0.243,.0407,-.0080,-.0019,.0000,.0150,.0346,.0444,.0562,.0726,
     3 0.5,.0000,-.0123,.0000,.0235,.0238,.0465,.0732,.0921,.0896,
     4 0.75,-.0529,-.0670,-.0484,-.0209,.0151,.0402,.0722,.0884,
     5    .0886/
C
      DATA X12KP2/
     1 0.1,.1316,.1410,.1176,.1529,.1214,.1395,.1772,.2051,.2273,
     2 0.243,.1332,.1286,.1311,.1536,.1806,.2068,.2341,.2647,.3131,
     3 0.5,.1351,.1375,.1446,.1512,.1667,.2069,.2381,.2821,.3143,
     4 0.75,.0988,.1081,.1134,.1350,.1584,.1970,.2450,.3041,.3730/
C
      DATA X18KP2/
     1 0.1,.3514,.3333,.3000,.3171,.3013,.3253,.3765,.4342,.4923,
     2 0.243,.3260,.3148,.3116,.3200,.3423,.3669,.4148,.4681,.5514,
     3 0.5,.3200,.3210,.3049,.3133,.3095,.3529,.4000,.4615,.5286,
     4 0.75,.2881,.2751,.2828,.2836,.3085,.3316,.3814,.4439,.5170/
C
      DATA X24KP2/
     1 0.1,.5833,.5373,.4658,.4861,.4839,.5205,.5676,.6716,.4853,
     2 0.243,.5390,.5086,.4927,.4815,.5168,.5597,.5950,.6667,.7990,
     3 0.5,.5278,.5000,.4937,.4937,.4810,.5200,.5556,.6286,.7463,
     4 0.75,.4693,.4286,.4692,.4118,.4293,.4514,.4970,.5425,.5758/
C
C
      DATA Z0CP1/
     1 0.1,.8889,.9254,.9808,.9811,1.0178,.9811,.9434,.8518,.7454,
     2 0.243,.9085,.9601,.9955,.9969,.9843,.9530,.8934,.8182,.7085,
     3 0.5,.9021,.9597,.9789,.9981,.9793,.9409,.9025,.8065,.7104,
     4 0.75,.9242,.9795,.9953,.9874,.9795,.9479,.9005,.8215,.7268/
C
      DATA Z6CP1/
     1 0.1,.8704,.9057,.9811,.9623,1.0000,.9454,.9057,.8302,.7273,
     2 0.243,.8956,.9601,.9890,.9937,.9812,.9404,.8746,.7994,.6928,
     3 0.5,.9021,.9597,.9789,.9789,.9601,.9409,.8641,.7872,.6912,
     4 0.75,.9084,.9367,.9795,.9795,.9795,.9400,.8847,.8058,.7110/
C
C
      DATA Z12CP1/
     1 0.1,.8301,.8679,.9444,.9259,.9818,.9091,.8490,.7678,.6792,
     2 0.243,.8634,.9246,.9601,.9624,.9436,.8997,.8307,.7524,.6395,
     3 0.5,.8637,.9213,.9405,.9597,.9217,.9025,.8449,.7488,.6528,
     4 0.75,.8847,.9321,.9637,.9637,.9479,.9084,.8452,.7663,.6715/
C
      DATA Z18CP1/
     1 0.1,.7547,.7924,.8518,.8679,.9091,.8519,.7857,.6909,.5849,
     2 0.243,.7990,.8570,.8956,.8997,.8715,.8245,.7524,.6740,.5549,
     3 0.5,.8061,.8637,.8829,.8829,.8833,.8449,.7681,.6912,.5760,
     4 0.75,.8249,.8847,.9084,.9163,.8926,.8452,.7979,.7110,.6162/
C
      DATA Z24CP1/
     1 0.1,.6481,.6792,.7736,.7547,.7818,.7222,.6727,.5636,.5926,
     2 0.243,.6959,.7571,.7893,.7994,.7586,.7085,.6458,.5674,.4483,
     3 0.5,.7102,.7678,.7869,.7869,.7873,.7296,.6720,.5952,.4800,
     4 0.75,.7584,.8058,.8452,.8373,.8137,.7663,.7110,.6320,.5530/
C
      END
C
C/////////////////////////////////////////////////////////////////////
C\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
C     SUBROUTINE MACH
C
C*********************************************************************
      SUBROUTINE MACH(PT,PS,BETA,FEE,XMT,XMX,XMTH,XMFE)
C
C   THIS SUBROUTINE CALCULATES A NEW TOTAL MACH NUMBER AND
C   ITS COMPONENTS BASED ON CALCULATED ANGLES AND
C   TOTAL AND STATIC PRESSURES.
C
C   PT  =TOTAL PRESSURE
C   PS  =STATIC PRESSURE
```

```
C     BETA=THETA FLOW ANGLE
C     FEE =PHI FLOW ANGLE
C     XMT =MACH NO. (TOTAL)
C     XMX =MACH NO. (AXIAL)
C     XMTH=MACH NO. (IN THETA DIRECTION)
C     XMFE=MACH NO. (IN PHI DIRECTION)
C
      AZ=PT/PS
      IF(AZ.LE.1.0)GO TO 20
      XMT=((((PT/PS)**.286)-1.)/.2)**.5
      GO TO 10
C     ********************************************
C     CHANGE XMT=1 TO XMT=0   NG   7/24/81
C     **********************************************
 20     XMT=0.
 10     CONTINUE
        BETAR=BETA*.01745
      FEER=FEE*.01745
      BB=((TAN(FEER))**2)
      AA=((TAN(BETAR))**2)
      XMX=XMT/((1+AA+BB)**.5)
      XMTH=XMX*TAN(BETAR)
      XMFE=XMX*TAN(FEER)
      GO TO 101
 30   XMX=.5
 40   XMTH=TAN(BETAR)*XMX
      XMFE=TAN(FEER)*XMX
      XMT1=((XMTH*XMTH)+(XMFE*XMFE)+(XMX*XMX))**.5
      IF(ABS(XMT-XMT1).LE..0001) GO TO 101
      XMX1=((XMT*XMT)-(XMTH*XMTH)-(XMFE*XMFE))**.5
      XMX=XMX-((XMX-XMX1)/2.)
      GO TO 40
 101  RETURN
      END
C///////////////////////////////////////////////////////////////////////
C\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
C     SUBROUTINE WORK
C
C**********************************************************************
C
C
        SUBROUTINE WORK(CP4,FF23,P2P3,PT,XMT,PS,PSN,P,XFEE,PTN)
C
C    THIS SUBROUTINE CALCULATES FLOW ANGLES, STATIC PRESSURE,
C    AND TOTAL PRESSURE AND CALLS FOR MACH NUMBER CALCULATION.
C    THE INTERPOLATIONS ARE ON MACH NUMBER.
C
C    CP4 =CP4
C    FF23=F23
C    P2P3=(P2-P1)+(P3-P1)
C    PT  =TOTAL PRESSURE
C    XMT =TOTAL MACH NUMBER
C    PS  =STATIC PRESSURE
C    PSN =STATIC PRESSURE (NEW)
C    P   =ARRAY OF P1, P2, P3, AND P4
C    XFEE=CALCULATED PHI ANGLE
C    PTN =TOTAL PRESSURE (NEW)
C
        COMMON /BTET2/TET(10),NTET,NMACH
        COMMON /BPHI2/NPHI,PHI(10)
        COMMON /DAT/F(9),PL,SIGN
        COMMON /BTET3/C0CP4(10,4),C6CP4(10,4),C12CP4(10,4)
        COMMON /BTET4/H0H23(10,4),H6H23(10,4),H12H23(10,4)
        COMMON /BTET5/X0KP2(10,4),X6KP2(10,4),X12KP2(10,4)
        COMMON /BTET6/Z0CP1(10,4),Z6CP1(10,4),Z12CP1(10,4)
        COMMON /BTET7/Z18CP1(10,4),Z24CP1(10,4),X18KP2(10,4)
        COMMON /BTET8/X24KP2(10,4),H18H23(10,4),H24H23(10,4)
        COMMON /BTET9/C18CP4(10,4),C24CP4(10,4)
        COMMON /BPHI4/FN24(10,4),FN18(10,4),FN12(10,4)
        COMMON /BPHI5/FN6(10,4),F0(10,4),F6(10,4)
        COMMON /BPHI6/F12(10,4),F18(10,4),F24(10,4)
C
C
        REAL P(4)
        REAL CLOW(10,4),CHIGH(10,4),YMPL(10),YMPU(10)
        REAL HLOW(10,4),HHIGH(10,4),HYPL(10),HYPU(10)
        REAL XLOW(10,4),XHIGH(10,4),XYPL(10),XYPU(10)
        REAL ZLOW(10,4),ZHIGH(10,4),ZYPL(10),ZYPU(10)
        REAL YPRIME(10),XY(10,2)
        REAL YHPRIM(10),HY(10,2)
        REAL YKPRIM(10),XKY(10,2)
        REAL YCPRIM(10),XCY(10,2)
        REAL YFPRIM(10),FY(10,2)
```

```
      REAL FLOW(10,4),FHIGH(10,4),FMPL(10),FMPU(10)
C
C
C------ STEP 8 -------
C
C*********************************************************************
C
C    THIS NEW METHOD BY TOM POPERNACK 2/17/86
C
C    FIND THETA CORRESPONDING TO F23(ABSOLUTE VALUE) AND THE GUESSED
C    MACH NUMBER.  INITIALLY, SET PHI ANGLE TO ZERO AND USE THE
C    GUESSED MACH NUMBER.
C
C*********************************************************************
C
C*** THETA ANGLE DETERMINATION ***
C
      F23=FF23
      IF(F23.LE.0.)GO TO 10
      SIGN=1.0
      GO TO 20
 10   F23=F23*(-1.0)
      SIGN=-1.0
 20   CONTINUE
C
C    FIND THE CALIBRATION PHI ANGLES (FEEH AND FEEL) THAT BOUND THE
C    CALCULATED PHI ANGLE.
C
      IF(XFEE.LE.-18.)GO TO 101
C
      IF(XFEE.LE.-12.)GO TO 102
C
      IF(XFEE.LE.-6.)GO TO 103
C
      IF(XFEE.LE.0.)GO TO 104
C
      IF(XFEE.LE.6.)GO TO 105
C
      IF(XFEE.LE.12.)GO TO 106
C
      IF(XFEE.LE.18.)GO TO 107
C
      GO TO 108
C
C    THE CALIBRATION DATA IS RENAMED INTO GENERIC ARRAYS FOR
C    PROGRAMMING SIMPLIFICATION.
C
 101  CALL RENAME(FN24,FN18,FLOW,FHIGH)
      FEEL=-24.0
      FEEH=-18.0
      GOTO 150
C
 102  CALL RENAME(FN18,FN12,FLOW,FHIGH)
      FEEL=-18.0
      FEEH=-12.0
      GOTO 150
C
 103  CALL RENAME(FN12,FN6,FLOW,FHIGH)
      FEEL=-12.0
      FEEH=-6.0
      GOTO 150
C
 104  CALL RENAME(FN6,F0,FLOW,FHIGH)
      FEEL=-6.0
      FEEH=0.0
      GOTO 150
C
 105  CALL RENAME(F0,F6,FLOW,FHIGH)
      FEEL=0.0
      FEEH=6.0
      GOTO 150
C
 106  CALL RENAME(F6,F12,FLOW,FHIGH)
      FEEL=6.0
      FEEH=12.0
      GOTO 150
C
 107  CALL RENAME(F12,F18,FLOW,FHIGH)
      FEEL=12.0
      FEEH=18.0
      GOTO 150
C
 108  CALL RENAME(F18,F24,FLOW,FHIGH)
      FEEL=18.0
```

```
      FEEH=24.0
      GOTO 150
C
C   USE 'INP' SUBROUTINE TO CALCULATE AN INTERMEDIATE CALIBRATION
C   CURVE (FMPL) AT THE LOWER PHI ANGLE BOUND AT THE GUESSED MACH NUMBER
C
 150  CALL INP(FLOW,NTET,NMACH,FMPL,XMT)
C
C   USE 'INP' SUBROUTINE TO CALCULATE AN INTERMEDIATE CALIBRATION
C   CURVE (FMPU) AT THE UPPER PHI ANGLE BOUND AT THE GUESSED MACH NUMBER
C
      CALL INP(FHIGH,NTET,NMACH,FMPU,XMT)
C
C   LOAD THE INTERMEDIATE CALIBRATION CURVES AND THE PHI ANGLE BOUNDS
C   INTO AN ARRAY (FY) TO FIT THE 'INP' SUBROUTINE FORMAT.
C
      DO 44 I=1,10
           N=I+1
          FY(N,1)=FMPL(I)
          FY(N,2)=FMPU(I)
 44   CONTINUE
          FY(1,1)=FEEL
          FY(1,2)=FEEH
C
C   CALCULATE ANOTHER CALIBRATION CURVE (YFPRIM) USING THE TWO CURVES
C   DETERMINED ABOVE AT THE PHI ANGLE.
C
      CALL INP(FY,NTET,2,YFPRIM,XFEE)
C
C   USE THE 'INTPOL' SUBROUTINE TO LINEARLY INTERPOLATE ON THETA FROM
C   THE 'TET' ARRAY.  THE VALUE OF F23 IS USED TO BACK OUT TETA (THE
C   ABSOLUTE VALUE OF THETA.)
C
      CALL INTPOL(F23,NTET,YFPRIM,TET,TETA)
C
      THETA=TETA*SIGN
C
C------ STEP 9 -------
C
C*** PHI ANGLE DETERMINATION ***
C
C   CALIBRATION CURVES FOR CP4, H23, KP2, AND CP1 ARE CALCULATED
C   CONCURRENTLY.
C
C   NOW CALCULATE PHI FROM CP4 FOR GUESSED MACH NO. AND THETA.  FIND
C   THE UPPER AND LOWER BOUNDS OF TETA BASED ON CALIBRATION TET VALUES.
C
      IF(TETA.LE.6.0)GOTO 201
C
      IF(TETA.LE.12.0)GOTO 202
C
      IF(TETA.LE.18.0)GOTO 203
      GOTO 204
C
C   CALIBRATION DATA IS RENAMED TO GENERIC ARRAYS TO FIT 'INP'
C   SUBROUTINE.
C
 201  CALL RENAME(COCP4,C6CP4,CLOW,CHIGH)
      CALL RENAME(HOH23,H6H23,HLOW,HHIGH)
      CALL RENAME(XOKP2,X6KP2,XLOW,XHIGH)
      CALL RENAME(ZOCP1,Z6CP1,ZLOW,ZHIGH)
      TETL=0.0
      TETH=6.0
      GOTO 250
 202  CALL RENAME(C6CP4,C12CP4,CLOW,CHIGH)
      CALL RENAME(H6H23,H12H23,HLOW,HHIGH)
      CALL RENAME(X6KP2,X12KP2,XLOW,XHIGH)
      CALL RENAME(Z6CP1,Z12CP1,ZLOW,ZHIGH)
      TETL=6.0
      TETH=12.0
      GOTO 250
 203  CALL RENAME(C12CP4,C18CP4,CLOW,CHIGH)
      CALL RENAME(H12H23,H18H23,HLOW,HHIGH)
      CALL RENAME(X12KP2,X18KP2,XLOW,XHIGH)
      CALL RENAME(Z12CP1,Z18CP1,ZLOW,ZHIGH)
      TETL=12.0
      TETH=18.0
      GOTO 250
 204  CALL RENAME(C18CP4,C24CP4,CLOW,CHIGH)
      CALL RENAME(H18H23,H24H23,HLOW,HHIGH)
      CALL RENAME(X18KP2,X24KP2,XLOW,XHIGH)
      CALL RENAME(Z18CP1,Z24CP1,ZLOW,ZHIGH)
      TETL=18.0
      TETH=24.0
```

```
      GOTO 250
C
C   USE 'INP' SUBROUTINE TO CALCULATE AN INTERMEDIATE CALIBRATION
C   CURVES AT THE LOWER TETA ANGLE BOUND AT THE GUESSED MACH NUMBER.
C
 250  CALL INP(CLOW,NPHI,NMACH,YMPL,XMT)
      CALL INP(HLOW,NPHI,NMACH,HYPL,XMT)
      CALL INP(XLOW,NPHI,NMACH,XYPL,XMT)
      CALL INP(ZLOW,NPHI,NMACH,ZYPL,XMT)
C
C
C   USE 'INP' SUBROUTINE TO CALCULATE AN INTERMEDIATE CALIBRATION
C   CURVES AT THE UPPER TETA ANGLE BOUND AT THE GUESSED MACH NUMBER.
C
      CALL INP(CHIGH,NPHI,NMACH,YMPU,XMT)
      CALL INP(HHIGH,NPHI,NMACH,HYPU,XMT)
      CALL INP(XHIGH,NPHI,NMACH,XYPU,XMT)
      CALL INP(ZHIGH,NPHI,NMACH,ZYPU,XMT)
C
C
C   LOAD THE INTERMEDIATE CALIBRATION CURVES AND THE TETA ANGLE BOUNDS
C   INTO AN ARRAY TO FIT THE 'INP' SUBROUTINE FORMAT.
C
C
      DO 33 I=1,10
          N=I+1
          XY(N,1)=YMPL(I)
          XY(N,2)=YMPU(I)
          HY(N,1)=HYPL(I)
          HY(N,2)=HYPU(I)
         XKY(N,1)=XYPL(I)
         XKY(N,2)=XYPU(I)
         XCY(N,1)=ZYPL(I)
         XCY(N,2)=ZYPL(I)
 33   CONTINUE
          XY(1,1)=TETL
          XY(1,2)=TETH
          HY(1,1)=TETL
          HY(1,2)=TETH
         XKY(1,1)=TETL
         XKY(1,2)=TETH
         XCY(1,1)=TETL
         XCY(1,2)=TETH
C
C   CALCULATE OTHER CALIBRATION CURVES USING THE TWO CURVES
C   DETERMINED ABOVE AT THE TETA ANGLE.
C
      CALL INP(XY,NPHI,2,YPRIME,TETA)
      CALL INP(HY,NPHI,2,YHPRIM,TETA)
      CALL INP(XKY,NPHI,2,YKPRIM,TETA)
      CALL INP(XCY,NPHI,2,YCPRIM,TETA)
C
C------- STEP 10 -------
C
C   USE THE 'INTPOL' SUBROUTINE TO LINEARLY INTERPOLATE ON PHI FROM
C   THE 'PHI' ARRAY.  THE VALUE OF CP4 IS USED TO BACK OUT PHI.
C   VALUES FOR H23, KP2, AND CP1 ARE CALCULATED USING THE NEW
C   VALUE FOR THE PHI ANGLE.
C
      CALL INTPOL(CP4,NPHI,YPRIME,PHI,FEE)
      CALL INTPOL(FEE,NPHI,PHI,YHPRIM,H)
      CALL INTPOL(FEE,NPHI,PHI,YKPRIM,XP2)
      CALL INTPOL(FEE,NPHI,PHI,YCPRIM,CP1)
C
C   RESET XFEE TO THE NEW PHI ANGLE
C
      XFEE=FEE
C
C------- STEP 11 -------
C
C  PSN CALCULATION (NEW STATIC PRESSURE)
C
      PSN=PL-XP2*P2P3
C
C------- STEP 12 -------
C
C  PTN CALCULATION (NEW TOTAL PRESSURE)
C
      PTN=P(1)+H*(1.-CP1)*P2P3
C
C  LOAD 'F' ARRAY WITH VALUES
C
      F(2)=THETA
      F(3)=FEE
```

```
      F(4)=PTN
      F(5)=PSN
C
C------- STEP 13 -------
C
C     CALCULATION OF MACH NUMBERS
C
      CALL MACH(PTN,PSN,F(2),FEE,XMTN,XMX,XMTH,XMFI)
C
C    RESET XMT TO NEWLY DETERMINED MACH NUMBER.
C    COMPLETE LOADING 'F' ARRAY WITH MACH NUMBERS.
C
      XMT=XMTN
      F(6)=XMTN
      F(7)=XMX
      F(8)=XMTH
      F(9)=XMFI
C
        RETURN
        END
C
C///////////////////////////////////////////////////////////////////////
C\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
C      SUBROUTINE INP
C
C**********************************************************************
C
        SUBROUTINE INP(XY,IP,IM,Y,XM)
C
C     THIS SUBROUTINE CALCULATES AN INTERPOLATED
C     CALIBRATION CURVE  ( Y ) FOR ANY GIVEN
C     MACH #  ( XM ) FROM ORIGINAL CALIBRATION
C     VALUES  ( XY ) , IP ANGLES FOR IM MACH #'S
C
C     XY=CALIBRATION CURVE ARRAY
C     IP=NUMBER OF CALIBRATION ANGLES USED
C     IM=NUMBER OF MACH NUMBERS USED
C     Y =CALCULATED CURVE OF INTERPOLATED CALIBRATION COEFFICENTS
C     XM=CALCULATED TOTAL MACH NUMBER
C
        REAL XY(10,4),Y(10),Z(4),X(4)
C
      DO 5 J=1,IM
 5    X(J)=XY(1,J)
C
        IP1=IP+1
        DO 50 I=2,IP1
          DO 10 J=1,IM
 10       Z(J)=XY(I,J)
C     INTERPOLATION THROUGH MACH #
C
        CALL INTPOL(XM,IM,X,Z,YI)
 50     Y(I-1)=YI
        RETURN
        END
C
C///////////////////////////////////////////////////////////////////////
C\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
C      SUBROUTINE INTPOL
C
C**********************************************************************
C
C
      SUBROUTINE INTPOL(X,NPT,XH,RH,Y)
C
C     THIS SUBROUTINE DOES LINEAR INTERPOLATION
C
C     X  =GIVEN POINT X-COMPONENT
C     NPT=NUMBER OF POINTS IN CURVE
C     XH =ARRAY CONTAINING X-COMPONENTS OF POINTS ON THE CURVE
C     RH =ARRAY CONTAINING Y-COMPONENTS OF POINTS ON THE CURVE
C     Y =INTERPOLATED Y-COMPONENT FOR GIVEN X OF (X,Y) PAIR
C
      DIMENSION XH(10),RH(10)
C
      IF(XH(1).LT.XH(NPT))GOTO 20
C
C
      IF(X.GT.XH(NPT))GOTO 10
      Y=RH(NPT)
      GOTO 40
C
 10   IF(X.LT.XH(1))GOTO 51
        Y=RH(1)
```

```
      GOTO 40
C
 20   IF(X.LT.XH(NPT))GO TO 30
      Y= RH(NPT)
      GO TO 40
 30   IF(X.GT.XH(1)) GO TO 52
      Y=RH(1)
C
 40     RETURN
C
 51   JUMP=1
      GOTO 50
 52   JUMP=2
C
 50   CONTINUE
C
      DO 60 I=1,NPT-1
      GOTO (53,54),JUMP
 53   IF(X.LT.XH(I).AND.X.GE.XH(I+1))GOTO 70
      GOTO 60
 54   IF(X.GT.XH(I).AND.X.LE.XH(I+1))GOTO 70
 60   CONTINUE
      WRITE(6,*)'   OUT OF RANGE X = ',X
      RETURN
 70   DX=XH(I+1)-XH(I)
      DY=RH(I+1)-RH(I)
      A=RH(I)
      B=X-XH(I)
      CALL CHEC(B)
      C=DY/DX
      Y=A+(B*C)
      RETURN
      END
C
C//////////////////////////////////////////////////////////////////////
C\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
C         SUBROUTINE CHEC
C
C*********************************************************************
C
C    IN THIS SUBROUTINE, NUMBERS LESS THAN E-8 ARE SET EQUAL TO E-8.
C
C    X=NUMBER TO BE TESTED
C
        SUBROUTINE CHEC(X)
        REAL X
C
      IF(ABS(X).GT.1.0E-08)RETURN
        IF(X.LE.0)GOTO 10
        IF(X.LT.1.0E-08)X=1.0E-08
        RETURN
 10   IF(X.GT.-1.0E-08)X=-1.0E-08
        RETURN
        END
C
C//////////////////////////////////////////////////////////////////////
C\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\
C    SUBROUTINE RENAME
C
C*********************************************************************
C
      SUBROUTINE RENAME(OLDL,OLDH,CLOW,CHIGH)
C
C   IN THIS SUBROUTINE,THE OLD ARRAYS ARE RENAMED TO NEW GENERIC
C   ARRAYS.
C
C     OLDL =OLD ARRAY NAME
C     OLDH =OLD ARRAY NAME
C     CLOW =NEW NAME OF OLDL
C     CHIGH=NEW NAME FOR OLDH
C
      REAL OLDL(10,4),OLDH(10,4),CLOW(10,4),CHIGH(10,4)
C
      DO 10 M=1,10
        DO 11 N=1,4
        CLOW(M,N)=OLDL(M,N)
        CHIGH(M,N)=OLDH(M,N)
 11   CONTINUE
 10   CONTINUE
      RETURN
      END
```

A.4 Data File ANGOUT

This is a sample file of the reduced output of ANGLE4.

```
NUMBER OF DATA POINTS=        1024
 TIME      THETA      PHI       PT       PS       MT       MX       MTH      MPHI   ITER


0.0000    -0.751    -7.902  15.243  13.404   0.433    0.429   -0.006   -0.059    9
0.0000    -0.268    -7.064  15.240  13.371   0.437    0.433   -0.002   -0.054    9
0.0001    -0.040    -7.459  15.186  13.368   0.431    0.427    0.000   -0.056    9
0.0001    -0.048    -7.295  15.186  13.333   0.435    0.432    0.000   -0.055    9
0.0002    -0.277    -7.157  15.241  13.270   0.449    0.446   -0.002   -0.056    9
0.0002    -0.465    -6.929  15.323  13.201   0.467    0.463   -0.004   -0.056    9
0.0002    -1.202    -8.376  15.362  13.059   0.488    0.482   -0.010   -0.071    9
0.0003    -1.707    -8.841  15.367  12.968   0.499    0.493   -0.015   -0.077    9
0.0003    -1.227    -7.769  15.526  12.917   0.520    0.515   -0.011   -0.070   10
0.0004     0.074    -3.391  15.617  12.929   0.527    0.526    0.001   -0.031   10
```

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