Development of a Data Reduction Method
for a High Frequency Angle Probe

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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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Nomenclature

\( CP_1 \)  Total pressure calibration coefficient  
\( CP_\alpha \)  Angle of attack calibration coefficient  
\( f \)  Shedding frequency (Hertz)  
\( F_{\beta} \)  Yaw angle calibration coefficient  
\( H_{\alpha} \)  Dynamic pressure calibration coefficient  
\( KP_\alpha \)  Static pressure calibration coefficient  
\( M \)  Mach number  
\( P_* \)  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  
\( \alpha \)  Angle of attack  
\( \beta \)  Yaw angle  
\( \gamma \)  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 sen-
sors. 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 x 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 $\alpha$ covered a range of $-24^\circ$ to $+24^\circ$. Because of probe symmetry, the calibration for the yaw angle $\beta$ covered only a range of $0^\circ$ to $+24^\circ$. 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.

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

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

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

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

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

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 \(\beta\), \(F_{23}\) is influenced weakly by the angle of attack \(\alpha\) from -18° to +18°. At larger \(\alpha\) angles, \(\beta\) directional retrieval becomes more difficult as the \(F_{23}\) dependence on \(\alpha\) increases. Figure 3.b shows that the angle of attack \(\alpha\) is found primarily from the coefficient \(CP_4\). However, the effect on
$CP_a$ by $\beta$ is large enough to affect the retrieval of $\alpha$. The $KP_n$ coefficient, shown in Figure 3.c, depends strongly on $\alpha$ and $\beta$ 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 $\alpha$ and $\beta$. The coefficients $H_{23}$ and $CP_1$ are combined in the following equation to determine the total pressure.

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

(2.9)

Although not shown in Figure 3, the coefficients $CP_a$, $KP_n$, $H_{23}$, 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 ($\alpha$, $\beta$, 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, $P_n$, 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 $P_1$ and $P_s$, using the isentropic flow equation with the appropriate ratio of specific heats, $\gamma$.

\[
M^2 = \frac{2}{\gamma - 1} \left[ \left( \frac{P_1}{P_s} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]
\]  

(2.10)
Figure 3. Typical Angle Probe Calibration Curves for a Mach Number of 0.5
The angle of attack coefficient, $CP_a$, is calculated from Equation (2.5). For the initial pass only, the angle of attack $\alpha$ is set equal to 0°. In all future iterations, $\alpha$ will be assigned the $\alpha'$ value from the previous iteration. Using $F_{23}$, $M$, and $\alpha$, the yaw angle $\beta$ is determined through interpolation of the calibration data. The new value for the angle of attack, $\alpha'$, is similarly found from the values of $CP_a$, $M$, and $\beta$. With $\beta$, $\alpha'$, and $M$ now known, the $KP_a$ coefficient is interpolated from the calibration data. Manipulating Equation (2.6) and using $KP_a$, the new value for the static pressure, $P_1'$, is found. Also, interpolation with $\beta$, $\alpha'$, 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, $P_1'$. A new Mach number, $M'$, is found by using $P_1'$ and $P_1'$ 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
INPUT $P_1, P_2, P_3, P_4$

CALCULATE $F_{23}$

GUESS $P_s, P_T$

CALCULATE TOTAL MACH NO. $M$

CALCULATE $C_P$

FOR INITIAL PASS ONLY, GUESS $a = 0$. OTHERWISE, USE $a = a'$.

INTERPOLATE $B$ FROM $F_{23}, M, a$

INTERPOLATE $a'$ FROM $C_P, M$, and $B$

INTERPOLATE $K_P$ FROM $B, a'$, and $M$

CALCULATE $P_s'$ FROM $K_P$

INTERPOLATE $H_{23}$ FROM $B, a'$, and $M$

INTERPOLATE $C_P$ FROM $B, a'$, and $M$

CALCULATE $P_T'$ FROM $H_{23}$ and $C_P$

CALCULATE $M'$ FROM $P_s'$ and $P_T'$

DO $P_T'$ and $P_s'$ CONVERGE?

YES

$a, B, M, P_s, P_T$

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.
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,
\[ St = \frac{fd}{U} \]  

(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
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, \( \beta \), 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, \( \alpha \), 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 Spectra 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 $\alpha$ is defined lying in the x-y plane and the yaw angle $\beta$ 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 17: Fourier Spectra of Mach Number and Three Components (Air-Jet)

Air Jet Turbulence Experiment
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.
References


10. Ng, W. F., and Popernack, T. G., Jr., "A Combination Probe for High-Frequency Unsteady Aerodynamic Measurements in Transonic Wind Tunnels," accepted for

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 instantaneous 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 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 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 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.

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) ;B5DAT(1024)REAL B4DAT(1024)
INTEGER·¤·4 TRIG, PERIOD, AMPL, TOTAL, DUM
REAL TIME(1024)CHARACTER*1 TEXT(161)CHARACTER*14 FNAME;WRNAMEDATA WFILE/2/
DATA MFILE/2/
DATA SDFILE/2/

C WRITE(*;¥)' INSERT LECROY DATA DISK IN B DRIVE '
C WRITE(*;*)
C INPUT FILE SPECIFICATION OF DATA FILE
C WRITE(*;*)' ENTER DRIVE: FILENAME.TYPE OF DATA FILE '
C READ(*;'(A)')FNAME
c WRITE(*;*)
C OPEN DISK DATA FILE
C OPEN(SDFILE; FILE=FNAME; STATUS='OLD'; FORM='UNFORMATTED')
C READ FIRST SEVENTEEN BYTES OF HEADER (DATA PARAMETERS)
C READ(SDFILE)(HEADER(I);I = 1; 17)
C READ NEXT 161 BYTES OF HEADER (TEXT REMARKS ON DATA)
C READ(SDFILE)(TEXT(I); I = 1; 161)
C PRINT NUMBER OF DATA WORDS PER BLOCK
C LENGTH=HEADER(1)
C WRITE(*;*) 'NO. OF DATA WORDS/BLOCK =................ ',LENGTH
C PRINT NUMBER OF BITS PER DATA WORD
C WIDTH=HEADER(2)
C WRITE(*;*)'NO. OF BITS/WORD =.................... ',WIDTH
C CONVERT NEXT FOUR BYTES AND PRINT PERIOD OF SAMPLE
C PERIOD=HEADER(3)
C IF(PERIOD.LT.0)PERIOD=PERIOD+65536
C DUM=HEADER(4)*65536
C PERIOD=PERIOD+DUM
C WRITE(*;*)'THE SAMPLE PERIOD IS (0.1nSEC)=..... ',PERIOD
C PRINT OFFSET DATA
C OFFSET=HEADER(5)
C WRITE(*;*)'ZERO VOLT OFFSET =................... ',OFFSET
C CONVERT AND PRINT TRIGGER DATA
C TRIG=HEADER(6)
C IF(TRIG.LT.0)TRIG=TRIG+65536
C DUM=HEADER(7)*65536
C TRIG=TRIG+DUM
C WRITE(*;*)'TRIGGER OCCURRED AT................ ',TRIG
C CONVERT AND PRINT AMPLITUDE DATA
C AMPL=HEADER(8)
C IF(AMPL.LT.0)AMPL=AMPL+65536
C DUM=HEADER(9)*65536
C AMPL=AMPL+DUM
C WRITE(*;*)'AMPLITUDE =....................... ',AMPL
C PRINT START BYTE INFORMATION
C START=HEADER(10)
C WRITE(*;*)'START BYTE =..................... ',START
C PRINT NUMBER OF DATA BLOCKS
C BLKCNT=HEADER(11)
C WRITE(*;*)'NUMBER OF BLOCKS =................ ',BLKCNT
C PRINT TYPE OF DATA
C TYPE=HEADER(12)
C WRITE(*;*)'TYPE OF DATA =.................... ',TYPE
C PRINT NUMBER OF BLOCKS PER CHANNEL
C BLKCHN=HEADER(13)

Appendix A. Data Acquisition and Reduction Methods 45
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 ASK FOR KULITE SENSITIVITIES
WRITE(*,*)' ENTER SENSITIVITY OF KULITE #1,#2,#3,#4 (V/psi)'
READ(*,*)SEN1,SEN2,SEN3,SEN4
WRITE(*,*)' ENTER REF. PRESSURE OF KULITE (psia)'
READ(*,*)PATM
WRITE(*,*)' ENTER KULITE ZERO #1,#2,#3,#4 (VOLTS)'
READ(*,*)ZV1,ZV2,ZV3,ZV4

C START TO READ THE DATA FROM THE LECROY DISK
THE FIRST DATA BLOCK OF EACH CHANNEL IS READ
CH 1-BLOCK 1 CH 3-BLOCK 9
CH 2-BLOCK 5 CH 4-BLOCK 13

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 10
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 ONLY THE FIRST 1024 DATA POINTS OF EACH BLOCK ARE PROCESSED
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 COMPUTE THE TIME ARRAY
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 ASK FOR FILE TO WRITE DATA TO
WRITE(*,*)' INSERT BLANK DISK IN B DRIVE '
WRITE(*,*)
WRITE(*,*)' ENTER DRIVE: FILENAME.TYPE TO WRITE DATA TO '
READ(*,')A
WRNAME OPEN(NEWFILE, FILE=WRNAME, STATUS='NEW', FORM='FORMATTED')

C WRITE ABSOLUTE PRESSURES(psia) FROM KULITE TO DISK FILE
WRITE(NEWFILE,50)
FORMAT(5X,'TIME(SEC)',8X,' P1',10X,' P2',10X,' P3',10X,' P4')
DO 65 L=1,1024
WRITE(NEWFILE,70)TIME(L),B1DAT(L),B2DAT(L),B3DAT(L),B4DAT(L)
65 CONTINUE
70 FORMAT(1X,B13X,F10.6))

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CONTINUE
CLOSE(WFILE)
CLOSE(SOFILE)
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.

<table>
<thead>
<tr>
<th>TIME(SEC)</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000000</td>
<td>13.941740</td>
<td>13.817280</td>
<td>13.804740</td>
<td>13.918490</td>
</tr>
<tr>
<td>0.000100</td>
<td>13.950250</td>
<td>13.808660</td>
<td>13.815740</td>
<td>13.892910</td>
</tr>
<tr>
<td>0.000200</td>
<td>13.922590</td>
<td>13.797170</td>
<td>13.823990</td>
<td>13.890770</td>
</tr>
<tr>
<td>0.000300</td>
<td>13.934080</td>
<td>13.802920</td>
<td>13.840500</td>
<td>13.884380</td>
</tr>
<tr>
<td>0.000400</td>
<td>13.937910</td>
<td>13.825900</td>
<td>13.832250</td>
<td>13.854530</td>
</tr>
<tr>
<td>0.000500</td>
<td>13.918760</td>
<td>13.840260</td>
<td>13.823990</td>
<td>13.839600</td>
</tr>
<tr>
<td>0.000600</td>
<td>13.899610</td>
<td>13.834510</td>
<td>13.821240</td>
<td>13.826810</td>
</tr>
<tr>
<td>0.000700</td>
<td>13.895780</td>
<td>13.823020</td>
<td>13.804740</td>
<td>13.822550</td>
</tr>
<tr>
<td>0.000800</td>
<td>13.922590</td>
<td>13.823020</td>
<td>13.790990</td>
<td>13.822550</td>
</tr>
<tr>
<td>0.000900</td>
<td>13.957050</td>
<td>13.828770</td>
<td>13.807490</td>
<td>13.828940</td>
</tr>
</tbody>
</table>
A.3 Program ANGLE4

ANGLE4.FORTRAN

MODIFIED BY THOMAS G. POPERNACK JR.-VIRGINIA TECH. 1986
FOR USE WITH HIGH FREQUENCY ANGLE PROBE DEVELOPED BY DR. W.F. NG

OUTLINE FOR DATA REDUCTION ROUTINE- ANGLE4.FORTRAN

THE FOLLOWING ARE THE NON-DIMENSIONAL COEFFICIENTS USED IN THE DATA REDUCTION ROUTINE.

\[ F_{23} = \frac{(P_2-P_3)}{(P_2-P_1)+(P_3-P_1)} \]
\[ CP_4 = \frac{(P_4-PS)}{(PT-PS)} \]
\[ KP_2 = \frac{(P_2-PS)}{(P_2-P_1)+(P_3-P_1)} \]
\[ H_{23} = \frac{(PT-PS)}{((P_2-P_1)+(P_3-P_1))} \]
\[ CP_1 = \frac{(P_1-PS)}{(PT-PS)} \]

THE FOLLOWING IS A STEP-BY-STEP APPROACH TO THE DATA REDUCTION ROUTINE. INPUTS ARE TIME, P1, P2, P3, AND P4 WHILE THE OUTPUTS ARE yaw angle, angle of attack, total pressure, static pressure, total mach number, X-, Theta-, and PHI-DIRECTIONAL MACH NUMBERS.

STEP 1. INPUT ABSOLUTE VALUES (PSIA) FOR P1, P2, P3, AND P4.
STEP 2. CALCULATE THE VALUE FOR F23 FROM THE INPUT PRESSURES.
STEP 3. FOR THE FIRST PASS, GUESS THE VALUE FOR PS TO BE THE SMALLER OF P2 AND P3.
STEP 4. FOR THE FIRST PASS, GUESS THE VALUE FOR PT TO BE EQUAL TO P1.
STEP 5. WITH THE VALUES FOR PS AND PT, CALCULATE A TOTAL MACH NUMBER, M, AND ITS DIRECTIONAL COMPONENTS (X-, Theta-, PHI-DIRECTION).
STEP 6. CALCULATE THE VALUE FOR CP4 FROM THE INPUT PRESSURES AND THE GUESSED VALUES.
STEP 7. FOR THE INITIAL PASS ONLY, GUESS THE PHI ANGLE=0 DEGREES OTHERWISE, SET PHI ANGLE= PHI PRIME.
STEP 8. FIND THETA FROM THE VALUES OF F23, M, AND PHI BY COMPARING THE THREE VALUES TO THE CALIBRATION DATA.
STEP 9. FIND PHI PRIME FROM THE VALUES OF CP4, M, AND THETA BY COMPARING THE THREE VALUES TO CALIBRATION DATA.
STEP 10. FIND THE CORRESPONDING COEFFICIENT VALUES FOR KP3, H23, AND CP1 FROM THE VALUES OF THETA, PHI PRIME, AND TOTAL MACH NUMBER (M).
STEP 11. CALCULATE A VALUE FOR PS PRIME FROM KP3.
STEP 12. CALCULATE A VALUE FOR PT PRIME FROM H23 AND CP1.
STEP 13. CALCULATE A VALUE FOR M PRIME (TOTAL MACH NUMBER PRIME) FROM PS PRIME AND PT PRIME.
STEP 14. CHECK CONVERGENCE ON STATIC AND TOTAL PRESSURE. IF THE CONVERGENCE CRITERIA OF A CHANGE IN PRESSURE OF 0.001 PSI IS NOT MET, RETURN TO STEP 3. WHEN THE CONVERGENCE CRITERIA IS MET, DISCONTINUE THE LOOP AND RETURN TO STEP 1 FOR THE NEXT POINT. THE MAXIMUM NUMBER OF ITERATIONS IS 25.
STEP 15. AFTER ALL DATA POINTS ARE USED, TIME AVERAGED VALUES ARE CALCULATED FOR ALL FLOW QUANTITIES.

SUBROUTINE DESCRIPTIONS

ANGLE4.FORTRAN
THIS IS THE MAIN DATA REDUCTION ROUTINE.
- DATA (TIME, P1, P2, P3, P4) ARE READ IN FROM A SEPARATE FILE
  (FILE DEFINITION IS #15)
- DATA ARE WRITTEN BACK OUT TO ANOTHER FILE AS A CHECK TO
  MAKE SURE THE DATA IS READ IN ACCURATELY (FILE
  DEFINITION IS #16)
- INITIAL GUESSES FOR PS, PT, AND MACH NUMBER ARE MADE
- ALL SUBROUTINES FOR DATA REDUCTION ARE CALLED
- CONVERGENCE CRITERIA ARE SET FOR NUMBER OF ITERATIONS
  AND CONVERGENCE LIMITS ON PS (MOST SENSITIVE)
- AVERAGING OF ALL REDUCED DATA VALUES ARE DONE AND STORED
  IN A FILE (FILE DEFINITION IS #3)
- ALL REDUCED DATA IS STORED IN A FILE (FILE DEFINITION
  IS #2)

BLOCK DATA ANGLE
- THIS DATA FILE CONTAINS ALL THE CALCULATED CALIBRATION
  COEFFICIENTS FOR MACH NUMBERS OF 0.1, 0.24, 0.50, AND 0.75.
  THESE COEFFICIENTS ARE F23, CP4, H23, KP2, AND CP1.
  SYMMETRY OF THE PROBE REDUCES THE NUMBER OF CALIBRATION
  POINTS FOR SOME OF THESE VALUES.

SUBROUTINE MACH
- THIS SUBROUTINE CALCULATES THE TOTAL MACH NUMBER AND ITS
  DIRECTIONAL COMPONENTS (X-, THETA-, PHI-) BASED ON STATIC
  AND TOTAL PRESSURES.

SUBROUTINE WORK
- THIS SUBROUTINE CALCULATES FLOW ANGLES, STATIC PRESSURE, AND
  TOTAL PRESSURE FROM THE CALIBRATION CURVES.
  THE SUBROUTINE ALSO CALLS FOR MACH NUMBER CALCULATIONS.

SUBROUTINE INP
- THIS SUBROUTINE CALCULATES AN INTERPOLATED CALIBRATION
  CURVE FOR ANY GIVEN MACH NUMBER FROM THE ORIGINAL
  CALIBRATION CURVES.

SUBROUTINE INTPOL
- THIS SUBROUTINE DOES SIMPLE LINEAR INTERPOLATION.

SUBROUTINE CHEC
- THIS SUBROUTINE SET NUMBERS LESS THAN E-8 TO E-8. THIS IS
  USED TO KEEP DENOMINATORS FROM GOING TO ZERO. A PROBLEM
  LIKE THIS WOULD OCCUR IF P2=P3.

SUBROUTINE RENAME
- THIS SUBROUTINE RENAMES ARRAYS INTO GENERIC ARRAYS FOR
  EASIER PROGRAMMING.

=================================================================
UNIT (FILE) DEFINITIONS

UNIT 2 - REDCED OUTPUT A
  ALL REDUCED DATA IS STORED IN THIS FILE

UNIT 3 - AVERGD OUTPUT A
  AVERAGED VALUES OF REDUCED DATA IS STORED IN THIS FILE

UNIT 4 - UNCONV DATA A
  TIME VALUE OF UNCONVERGED DATA IS STORED IN THIS FILE

UNIT 15- INPUT DATA A
  DATA FILE CONTAINING TIME, P1, P2, P3, AND P4

UNIT 16- ECHO INPUT A
  ECHO DUMMY FILE OF DATA FILE IN UNIT 15

=================================================================

FOR NASA PAPERS:
  THE ANGLE OF ATTACK (ALPHA) IS THE NEGATIVE OF THE PHI ANGLE AND
  THE ANGLE OF YAW (BETA) IS THE NEGATIVE OF THE THETA ANGLE.

------ STEP 1 ------
READ IN PROBE DATA INTO AN ARRAY 'DATA'.
DATA ARE READ IN THE FOLLOWING FORMAT:
TIME(S), P1, P2, P3, P4 (PSIA)

'NDATA' IS THE NUMBER OF DATA POINTS TO BE EXAMINED.
FOR THE ABOVE ARRAY SIZES, THE MAXIMUM NUMBER OF POINTS TO BE EXAMINED IS 1250.
FOR THIS TEST, THE NUMBER OF POINTS IS 1024.

FOR THIS VERSION, THE ECHO FILE WRITE STATEMENTS FOR UNIT #16 HAVE BEEN CHANGED BY PLACING A 'C' IN COLUMN 1 OF THESE TWO STATEMENTS. NOH, THE ECHO FILE IS NOT CREATED.

WRITE(16,77)
77 FORMAT(8X,'TIME',9X,'P1',9X,'P2',9X,'P3',9X,'P4')
NDATA=1024
DO 500 J=1,NDATA
READ(15,78)(DATA(J,I),I=1,5)
78 FORMAT(1X,5(3X,F10.6))
N=J
WRITE(16,79)(DATA(J,I),I=1,5)
79 FORMAT(1X,5(3X,F10.6))
500 CONTINUE

THE NEXT TWO LINES ARE FOR WRITING COLUMN TITLES FOR FILES.
WRITE(3,160)
WRITE(3,170)

'NN' IS THE NUMBER OF DATA POINTS EXAMINED.
DO 90 I=1,NN
F(I) IS THE TIME ASSOCIATED WITH THE DATA POINT.
F(I)=DATA(I,1)
90 DO 30 JJ=2,5
THIS STEP LOADS THE P ARRAY WITH THE 4 PRESSURES FROM THE 'DATA' ARRAY.
30 P(JJ-1)=DATA(I,JJ)

'P2P3' IS A COMMON DENOMINATOR IN MANY OF THE COEFFICIENTS USED.
P2P3=P(2)-P(1)+P(3)-P(1)
CALL CHEC(P2P3)

------- STEP 2 -------
FF23=(P(2)-P(3))/P2P3

------- STEP 3 -------
FOR THE FIRST GUESS, ASSUME P(STATIC) TO BE THE SMALLER OF P2 AND P3. ALSO, ASSUME P(TOTAL) TO BE P(1). 'PL' IS AN INTERMEDIATE VARIABLE USED TO DENOTE THE GUESSED VALUE OF THE STATIC PRESSURE.
IF(P(2).GT.P(3))GOTO 35
PL=P(2)
GOTO 36
35 PL=P(3)

FIRST GUESS FOR MACH NUMBER, PT, PS

------- STEP 4 -------
PT=P(1)
PS=PL

------- STEP 5 -------

CALCULATE AN INITIAL MACH NUMBER BASED ON PS AND PT.
CALL MACH(PT,PS,45.,0.,XMT,D1,D2,D3)

THESE NEXT STEPS ARE SIMILAR TO A 'DO LOOP'. THEY CHECK ON THE CONVERGENCE OF PS AND PT AND ALLOW FOR 25 ITERATIONS.
FIRST, CP4 IS CALCULATED AND THEN THE 'WORK' SUBROUTINE IS USED TO

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C FIND NEW VALUES FOR PT, PS, XMT(MACH NO.), AND XFEE(PHİ 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 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
C4D 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 COEFFICIENT TO GO TO INFINITY.
C CALL CHEC(PTPS)

C------- STEP 6 -------
C CALCULATE AN INITIAL VALUE FOR CP4
C CP4=(P(4)—PS)/PTPS
C
C------- STEP 7 -------
C CALL WORK(CP4,FF23,P2P3,PT,XMT,PS,PSN,P,XFEE,PTN)

C------- STEP 14 -------
C CHECK CONVERGENCE ON PS (MOST SENSITIVE) AND ALLOW FOR 25
C ITERATIONS.
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 LFLAG=0
C IF(ABS(PS—PSN).LT..001)LFLAG=1
C IF(ABS(PT—PTN).LT..001)LFLAG=LFLAG+1
C IF (LFLAG.EQ.2) GO TO 70
C IF(PSLT.25)IGOTO 60
C NO=NO+1
C URF=0.5
C PS=PS+URF*(PSN—PS)
C PT=PT+URF*(PTN—PT)
C GOTO 40
C WRITE(4,) 'UNCONVERGED DATA ACCEPTED AT T='F(1)
C DO LOOP STORES CONVERGED DATA FROM 'F' ARRAY INTO 'FINE' ARRAY.
C FOR ONE DATA POINT, THE ITERATION PROCESS IS NOW COMPLETE.
C GO BACK TO LINE 47 AND GET THE NEXT DATA POINT.

C DO 110 IAV=1,9
C F(IAV)=0
C DO 100 IBV=1,NN—1
C F(IAV)=F(IAV)+FINE(IBV,IAV)
C 100 CONTINUE
C F(IAV)=F(IAV)/(FLOAT(NN—1))
C 110 CONTINUE
C
C Appendix A. Data Acquisition and Reduction Methods
STORE REDUCED DATA IN AN OUTPUT FILE

```
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)F(I,J),J=1,9,I,ITER(I)
150 FORMAT(1X,F6.4,1X,2(F9.5,1X],6(F7.3,1Xl,1X,I2)
151 CONTINUE
160 FORMAT(/,15X,'*** SPHERE PROBE AVERAGED REDUCED DATA ***')
```

--- STEP 15 ---

STORE AVERAGED REDUCED DATA IN AN OUTPUT FILE

```
WRITE(3,190)F
190 FORMAT(1X,F6.4,2X,2(F5.1,1X],6(F7.5,1X))
STOP
```

END

-------------------

[block data angle]

```
COMMON /BTET2/TET(10),NTET,NMACH
COMMON /BPHI2/NPHI,PHI(10)
COMMON /BTET3/COP4(10,4),C6CP4(10,4),C12CP4(10,4)
COMMON /BTET4/H0H25(10,4),H6H23(10,4),H12H23(10,4)
COMMON /BPHI4/40K2P(10,4),X6KP2(10,4),X12KP2(10,4)
COMMON /BTET5/18CP(10,4),Z6CP1(10,4),Z12CP1(10,4)
COMMON /BPHI5/Z12CP(10,4),Z24CP1(10,4),Z18CP(10,4)
COMMON /BPHI6/FN24(10,4),FN18(10,4),FN12(10,4)
```

IN THIS VERSION THERE ARE: 5 THETA ANGLES
0,6,12,18,24 DEG.
9 PHI ANGLES
-24,-18,-12,-6,0,6,12,18,24 DEG.
4 MACH NUMBERS
0.1,0.24,0.5,0.75

---

CALIBRATION DATA WERE TAKEN AT VPI'S USING THE ANGLE PROBE AND THE AIR JET DEVELOPED BY J. ROSSON. DATA FOR MACH NO.'S 0.243, 0.5, AND 0.75 WAS TAKEN BY J. ROSSON AND M. WATTS FROM JULY 29-31,1985. DATA FOR MACH NO. 0.1 WAS TAKEN BY M. FLETCHER FROM JAN. 27-31,1986.

NOMENCLATURE:
FN24=FN24 VALUES FOR ALL CALIBRATION THETA ANGLES SET AT A PHI ANGLE OF -24 DEG. (N=NEGATIVE)
COP4=CP4 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 0 DEG.
C=CP4
H0H25=H25 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 6 DEG.
H=H25
Z12CP1=CP1 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 12 DEG.
Z=CP1
Z18CP1=CP1 VALUES FOR ALL PHI ANGLES SET AT A THETA ANGLE OF 18 DEG.
Z=CP1

---

Appendix A. Data Acquisition and Reduction Methods 53
DATA NMACH/4/
DATA NTET/5/
DATA NPHI/9/

C DATA PHI/-24.,-18.,-12.,-6.,0.,6.,12.,18.,24.,24. /
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
E VALUE IS REPEATED TO MAKE THE ARRAY MANIPULATION EASIER.

N=NEGATIVE, I.E., N24=—24 DEG. PHI ANGLE

C DATA FOR ALL OTHER NUMBERS (CP4, H2S, 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.

AN EXAMPLE; C6CP4 CORRESPONDS TO THETA=6 DEG.

DATA CCPCP4/
1 0.1,.7407,.6058,.6415,.3019,.1607,0.000,-.1687,-.4444,-.6654,
2 0.243,.7416,.6098,.6425,.3025,.1607,.3545,.3197,.4734,.6928,
3 0.5,.2439,.6459,.3034,.1607,.3545,.3197,.4734,.6928,
4 0.75,.3165,.6649,.9205,.1212,.1212,.1212,.1212,.1212,
5 0.75,.7367,.6162,.4896,.3555,.2212,.0000,.2449,.4661,.6399/

Appendix A. Data Acquisition and Reduction Methods
<table>
<thead>
<tr>
<th>DATA C12CP4/</th>
<th>C12CP4/</th>
<th>C12CP4/</th>
<th>C12CP4/</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1, 0.590, 0.547, 0.490, 0.444, 0.279, 0.150, -0.245, -0.365, -0.482, -0.593</td>
<td>0.1, 0.590, 0.547, 0.490, 0.444, 0.279, 0.150, -0.245, -0.365, -0.482, -0.593</td>
<td>0.1, 0.590, 0.547, 0.490, 0.444, 0.279, 0.150, -0.245, -0.365, -0.482, -0.593</td>
<td>0.1, 0.590, 0.547, 0.490, 0.444, 0.279, 0.150, -0.245, -0.365, -0.482, -0.593</td>
</tr>
<tr>
<td>0.2, -0.635, -0.583, -0.531, -0.443, -0.361, -0.245, -0.156, -0.156, -0.245, -0.361</td>
<td>0.2, -0.635, -0.583, -0.531, -0.443, -0.361, -0.245, -0.156, -0.156, -0.245, -0.361</td>
<td>0.2, -0.635, -0.583, -0.531, -0.443, -0.361, -0.245, -0.156, -0.156, -0.245, -0.361</td>
<td>0.2, -0.635, -0.583, -0.531, -0.443, -0.361, -0.245, -0.156, -0.156, -0.245, -0.361</td>
</tr>
<tr>
<td>0.3, 0.243, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156, 0.245</td>
<td>0.3, 0.243, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156, 0.245</td>
<td>0.3, 0.243, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156, 0.245</td>
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<td>0.4, 0.745, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156, 0.245, 0.156, 0.156</td>
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</tr>
<tr>
<td>0.5, 0.750, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
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<td>0.5, 0.750, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
<td>0.5, 0.750, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
</tr>
<tr>
<td>0.6, 0.765, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
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<td>0.7, 0.780, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
<td>0.7, 0.780, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
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<tr>
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<td>0.8, 0.795, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
<td>0.8, 0.795, 0.590, 0.556, 0.512, 0.441, 0.377, 0.313, 0.245, 0.156, 0.156</td>
</tr>
</tbody>
</table>

Appendix A. Data Acquisition and Reduction Methods
Appendix A. Data Acquisition and Reduction Methods
BETA=THETA FLOW ANGLE
FEE =PHI FLOW ANGLE
XMT =MACH NO. (TOTAL)
XMTH=MACH NO. (IN THETA DIRECTION)
XMTF=MACH NO. (IN PHI DIRECTION)

AZ=PT/PS
IF(AZ.LE.1.0) GO TO 20
XMT=((((PT/P$)**.286)-1.)/.2)**.5
GO TO 10

CHANGE XMT=1 TO XMT=0 NG 7/24/81

CHANGE XMT=0.

CONTINUE
BETAR=BETA*.01745
FEER=FEE*.01745
BB=(((TAN(BETAR))**2)
AA=(((TAN(BETAR))**2)
XMT=(XMT/((1+AA+BB)**.5))
XMTH=MACH NO. (THETA DIRECTION)
XMFE=MACH NO. (PHI DIRECTION)
GO TO 101

XMT=.5

XMT=(((XMT*XMT)-(XMTH*XMTH)-(XMFE*XMFE))**.5
IF(ABS(XMT-XMT1).LE.0.0001) GO TO 101
XMT1=((XMT*XMT)-(XMTH*XMT)-(XMFE*XMT))**.5
XMTH=(({XMT-XMT1}/2)
GO TO 40

101 RETURN

SUBROUTINE NORK

SUBROUTINE NORK(CP4,FF23,P2P3,PT,XMT,PS,PSN,P,XFEE,PTN)

THIS SUBROUTINE CALCULATES FLOW ANGLES, STATIC PRESSURE, AND TOTAL PRESSURE AND CALLS FOR MACH NUMBER CALCULATION. THE INTERPOLATIONS ARE ON MACH NUMBER.

CP4 =CP4
FF23=F23
P2P3=(P2-P1)+(P3-P1)
PT =TOTAL PRESSURE
XMT =TOTAL MACH NUMBER
PS =STATIC PRESSURE
PSN =STATIC PRESSURE (NEW)
P =ARRAY OF P1, P2, P3, AND P4
XFEE=CALCULATED PHI ANGLE
PTN =TOTAL PRESSURE (NEW)

COMMON /BETET2/TET(10),MTET,MACH
COMMON /BPHELZ/NPHI,PHI(10)
COMMON /DAT/F9.0),PL,SI
COMMON /BETET/BETET4/CCP4(10,4),C6CP4(10,4),C12CP4(10,4)
COMMON /BETET/BETET5/CCP3(10,4),H6H23(10,4),H12H31(10,4)
COMMON /BETET/BETET6/CCP2(10,4),X6K2P1(10,4),X12K2P1(10,4)
COMMON /BETET/BETET7/CCP1(10,4),Z6CP1(10,4),Z12CP1(10,4)
COMMON /BETET/BETET8/CCP0(10,4),X24K2P1(10,4),H18H23(10,4)
COMMON /BETET9/CCP1(10,4),C24CP4(10,4)
COMMON /BPHIL4/FN4(10,4),F01(10,4),F6(10,4)
COMMON /BPHIL5/FN1(10,4),F01(10,4),F24(10,4)

REAL P(4)
REAL CLOM(10,4),CHIGH(10,4),HYPL(10,4)
REAL HDLM(10,4),H1HIGH(10,4),HYPL(10,4)
REAL XLOM(10,4),XHIGH(10,4),XYPL(10,4)
REAL ZLOM(10,4),ZHIGH(10,4),ZYPL(10,4)
REAL YPRIME(10),XY(10,2)
REAL YHPRIME(10),HY(10,2)
REAL YKPRIME(10),XY(10,2)
REAL YFPRIME(10),FY(10,2)
REAL FLOW(10,4),FHIGH(10,4),FMPL(10),FMPLU(10)

C----- STEP 8 ----- 
C***************************************************************************
C THIS NEW METHOD BY TOM POPERNACK 2/17/86
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** 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  
C IF(XFEE.LE.-12.)GO TO 102  
C  
C IF(XFEE.LE.-6.)GO TO 103  
C  
C IF(XFEE.LE.0.)GO TO 104  
C  
C IF(XFEE.LE.6.)GO TO 105  
C  
C IF(XFEE.LE.12.)GO TO 106  
C  
C IF(XFEE.LE.18.)GO TO 107  
C  
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=-2.4  
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=16.0  
GOTO 150
C
108 CALL RENAME(F18,F24,FLOW,FHIGH)  
FEEL=16.0  

Appendix A. Data Acquisition and Reduction Methods
FFEH=24.0
GOTO 150

C USE 'INP' SUBROUTINE TO CALCULATE AN INTERMEDIATE CALIBRATION
C CURVE (FMPL) AT THE LOWER PHI ANGLE BOUND AT THE GUESSED MACH NUMBER
C
CALL INP(FLON, NTET, NMACH, FMPL, XMT)

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 LOAD THE INTERMEDIATE CALIBRATION CURVES AND THE PHI ANGLE BOUNDS
C INTO AN ARRAY (FY) TO FIT THE 'INP' SUBROUTINE FORMAT.

DO 44 I=1,10
   N=I+1
   FY(N,1)=FMPL(I)
   FY(N,2)=FMPU(I)
44 CONTINUE
FY(1,1)=FFEH
FY(1,2)=FFEH

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 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---- STRIP 9 -----

*** PHI ANGLE DETERMINATION ***

C CALIBRATION CURVES FOR CP4, H23, KP2, AND CP1 ARE CALCULATED
C CONCURRENTLY.

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
C
GOTO 204

C CALIBRATION DATA IS RENAMED TO GENERIC ARRAYS TO FIT 'INP'
C SUBROUTINE.
C
201 CALL RENAME(C0CP4, C6CP4, CLON, CHIGH)
   CALL RENAME(H0H23, H6H23, HLOM, HHIGH)
   CALL RENAME(X0KP2, X6KP2, XLOM, XHIGH)
   CALL RENAME(Z0CP1, Z6CP1, ZLOM, ZHIGH)
   TETL=6.0
   TETH=6.0
   GOTO 250

202 CALL RENAME(C6CP4, C12CP4, CLOM, CHIGH)
   CALL RENAME(H6H23, H12H23, HLOM, HHIGH)
   CALL RENAME(X6KP2, X12KP2, XLOM, XHIGH)
   CALL RENAME(Z6CP1, Z12CP1, ZLOM, ZHIGH)
   TETL=6.0
   TETH=12.0
   GOTO 250

203 CALL RENAME(C12CP4, C18CP4, CLOM, CHIGH)
   CALL RENAME(H12H23, H18H23, HLOM, HHIGH)
   CALL RENAME(X12KP2, X18KP2, XLOM, XHIGH)
   CALL RENAME(Z12CP1, Z18CP1, ZLOM, ZHIGH)
   TETL=12.0
   TETH=18.0
   GOTO 250

204 CALL RENAME(C18CP4, C24CP4, CLOM, CHIGH)
   CALL RENAME(H18H23, H24H23, HLOM, HHIGH)
   CALL RENAME(X18KP2, X24KP2, XLOM, XHIGH)
   CALL RENAME(Z18CP1, Z24CP1, ZLOM, ZHIGH)
   TETL=18.0
   TETH=24.0

Appendix A. Data Acquisition and Reduction Methods
USE 'INP' SUBROUTINE TO CALCULATE AN INTERMEDIATE CALIBRATION CURVES AT THE LOWER TETA ANGLE BOUND AT THE GUESSED MACH NUMBER.
250 CALL INP(CLON,NPHI,NMACH,YMPL,XMT)
   CALL INP(HLON,NPHI,NMACH,HYPL,XMT)
   CALL INP(XLON,NPHI,NMACH,XYPL,XMT)
   CALL INP(ZLON,NPHI,NMACH,ZYPL,XMT)

USE 'INP' SUBROUTINE TO CALCULATE AN INTERMEDIATE CALIBRATION CURVES AT THE UPPER TETA ANGLE BOUND AT THE GUESSED MACH NUMBER.

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)

LOAD THE INTERMEDIATE CALIBRATION CURVES AND THE TETA ANGLE BOUNDS INTO AN ARRAY TO FIT THE 'INP' SUBROUTINE FORMAT.

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)
   XXY(N,1)=XYPL(I)
   XXY(N,2)=XYPU(I)
   XCY(N,1)=ZYPL(I)
   XCY(N,2)=ZYPU(I)
33 CONTINUE

CALCULATE OTHER CALIBRATION CURVES USING THE TWO CURVES DETERMINED ABOVE AT THE TETA ANGLE.

CALL INP(XY,NPHI,2,YPRIME,TETA)
   CALL INP(HY,NPHI,2,YHPRIM,TETA)
   CALL INP(XXY,NPHI,2,YKPRIM,TETA)
   CALL INP(XCY,NPHI,2,YCPRIM,TETA)

STEP 10 ------

USE THE 'INTPOL' SUBROUTINE TO LINEARLY INTERPOLATE ON PHI FROM THE 'PHI' ARRAY. THE VALUE OF CP4 IS USED TO BACK OUT PHI.
VALUES FOR H23, KP2, AND CP1 ARE CALCULATED USING THE NEW VALUE FOR THE PHI ANGLE.

CALL INTPOL(CP4,NPHI,YPRIME PHI,FEE)
   CALL INTPOL(FEE,NPHI PHI,YPRIM,PHI)
   CALL INTPOL(FEE,NPHI PHI,YKPRIM,PHI)
   CALL INTPOL(FEE,NPHI PHI,YCPRIM,PHI)

RESET XFEE TO THE NEW PHI ANGLE

XFEE=FEE

STEP 11 ------

PSN CALCULATION (NEW STATIC PRESSURE)

PSN=PL-XP2*P2P3

STEP 12 ------

PTN CALCULATION (NEW TOTAL PRESSURE)

PTN=PI+H*(1.-CP1)*P2P3

LOAD 'F' ARRAY WITH VALUES

F(2)=THETA
F(3)=FEE
**F(4)=PTN**

**F(5)=PSN**

--- STEP 13 ---

**CALCULATION OF MACH NUMBERS**

CALL MACH(PTN,PSN,F(2),FEE,XMTN,XMF,XMTH,XMFI)

RESET XMNT TO NEWLY DETERMINED MACH NUMBER.

COMPLETE LOADING 'F' ARRAY WITH MACH NUMBERS.

XMNT=XMTN
F(6)=XMTN
F(7)=XMF
F(8)=XMTH
F(9)=XMFI

RETURN

END

**SUBROUTINE INP**

SUBROUTINE INP(XY,IP,IM,Y,XM)

THIS SUBROUTINE CALCULATES AN INTERPOLATED CALIBRATION CURVE (Y) FOR ANY GIVEN MACH # (XM) FROM ORIGINAL CALIBRATION VALUES (XY), IP ANGLES FOR IM MACH #'S

XY=CALIBRATION CURVE ARRAY
IP=NUMBER OF CALIBRATION ANGLES USED
IM=NUMBER OF MACH NUMBERS USED
Y=CALCULATED CURVE OF INTERPOLATED CALIBRATION COEFFICIENTS
XM=CALCULATED TOTAL MACH NUMBER

REAL XY(10,4),Y(10),Z(4),X(4)

DO 5 J=1,IM
5 X(J)=XY(1,J)

IP1=IP+1
DO 50 I=2,IP1
10 Z(I)=XY(I,J)

INTERPOLATION THROUGH MACH #

CALL INTPOL(XM,IM,X,Z,Y)
50 Y(I-1)=YI
RETURN

END

**SUBROUTINE INTPOL**

SUBROUTINE INTPOL(X,NPT,XH,RH,Y)

THIS SUBROUTINE DOES LINEAR INTERPOLATION

X=GIVEN POINT X-COMPONENT
NPT=NUMBER OF POINTS IN CURVE
XH=ARRAY CONTAINING X-COMPONENTS OF POINTS ON THE CURVE
RH=ARRAY CONTAINING Y-COMPONENTS OF POINTS ON THE CURVE
Y=INTERPOLATED Y-COMPONENT FOR GIVEN X OF (X,Y) PAIR

DIMENSION XH(10),RH(10)

IF(XH(1).LT.XH(NPT))GOTO 20
20 IF(XH(1).GT.XH(NPT))GOTO 51

IF(XR.XH(NPT))GOTO 20
40 Y=RH(NPT)
GOTO 40
10 IF(XR.XH(1))GOTO 51
Y=RH(1)

Appendix A. Data Acquisition and Reduction Methods 61
GOTO 40  

20 IF (X .LT. XH(NPT)) GO TO 30  
Y = RH(NPT)  
GOTO 40  
30 IF (X .GT. XH(I)) GO TO 52  
Y = RH(I)  
C  
40 RETURN  
C  
51 JUMP = 1  
GOTO 50  
52 JUMP = 2  
C  
50 CONTINUE  
C  
DO 60 I = 1, NPT - 1  
GOTO (55, 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  
C  
SUBROUTINE CHEC  
C  
IN THIS SUBROUTINE, NUMBERS LESS THAN E-8 ARE SET EQUAL TO E-8.  
X = NUMBER TO BE TESTED  
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  
SUBROUTINE RENAME  
C  
IN THIS SUBROUTINE, THE OLD ARRAYS ARE RENAMED TO NEW GENERIC ARRAYS.  
OLDL = OLD ARRAY NAME  
OLDH = OLD ARRAY NAME  
CLON = NEW NAME OF OLDL  
CHIGH = NEW NAME FOR OLDH  
REAL OLDL(10,4), OLDH(10,4), CLON(10,4), CHIGH(10,4)  
C  
DO 10 M = 1, 10  
DO 11 N = 1, 4  
CLON(M,N) = OLDL(M,N)  
CHIGH(M,N) = OLDH(M,N)  
11 CONTINUE  
10 CONTINUE  
RETURN  
END  

Appendix A. Data Acquisition and Reduction Methods
A.4 Data File ANGOUT

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

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<th>TIME</th>
<th>THETA</th>
<th>PHI</th>
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<th>MT</th>
<th>MX</th>
<th>MTH</th>
<th>MPH</th>
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<td>0.429</td>
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</tr>
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Appendix A. Data Acquisition and Reduction Methods
The vita has been removed from the scanned document.