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**INVESTIGATION OF THE DEVELOPMENT
OF LAMINAR BOUNDARY-LAYER INSTABILITIES ALONG
A COOLED-WALL HOLLOW CYLINDER
AT MACH NUMBER 8**

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Calspan Corporation/AEDC Operations**

January 1990

Final Report for August 3-14, 1989

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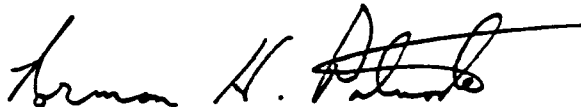
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NOMENCLATURE

ALPHA	Angle of attack, deg
C (t_n)	Coefficient in equation for calculating QDOT, $\text{Btu/ft}^2\text{-sec}^{1/2}\text{-}^\circ\text{R}$
CONFIG	Model configuration designation
CURRENT	Hot-wire anemometer heating current, mAmp
DATA TYPE	Code indicating nature of data tabulated: "2" - Model surface pressure and temperature measurements "4" - Mean boundary-layer profile measurements using pitot pressure probe "9" - Hot-film anemometer probe measurements
DEL	Boundary-layer total thickness, in.
DEL*	Boundary-layer displacement thickness, in.
DEL**	Boundary-layer momentum thickness, in.
DEW	Tunnel stilling chamber dew point temperature, $^\circ\text{F}$
DITTD	Enthalpy difference at boundary-layer thickness, DEL, ITTD-ITWL, Btu/lbm
DITTL	Local enthalpy difference, ITTL-ITWL, Btu/lbm
EBAR	Hot-wire anemometer mean voltage, mv
ERMS	Hot-wire anemometer output rms voltage, mv rms
FIL	Identification of data file used for plot
GAGE	Identification for coaxial thermocouple gage
H (TT), HT (TT)	Heat-transfer coefficient based on TT, $\text{QDOT}/(\text{TT}-\text{TW}), \text{Btu/ft}^2\text{-sec-}^\circ\text{R}$
ITT	Enthalpy based on TT, Btu/lbm
ITTD	Enthalpy based on TTD, Btu/lbm
ITTL	Enthalpy based on TTL, Btu/lbm
ITW	Enthalpy based on TW, Btu/lbm
ITWL	Enthalpy based on TWL, Btu/lbm

LRE	Local unit Reynolds number, in. ⁻¹
LRED	Unit Reynolds number at the boundary-layer thickness, DEL, in. ⁻¹
LRET	Local "normal shock" unit Reynolds number (based on MUTTL), in. ⁻¹
LRETD	"Normal shock" unit Reynolds number at boundary-layer thickness, DEL, (based on MUTTD), in. ⁻¹
M, MACH	Free-stream Mach number
MD	Local Mach number at boundary-layer thickness, DEL
ME	Mach number at boundary-layer edge
ML	Local Mach number
MU	Dynamic viscosity based on T, lbf-sec/ft ²
MUTD	Dynamic viscosity based on TD, lbf-sec/ft ²
MUTL	Dynamic viscosity based on TL, lbf-sec/ft ²
MUTTD	Dynamic viscosity based on TTD, lbf-sec/ft ²
MUTTL	Dynamic viscosity based on TTL, lbf-sec/ft ²
P	Free-stream static pressure, psia
POINT	Data point number
PP	Pitot probe pressure, psia
PPD	Pitot pressure at boundary-layer thickness, DEL, psia
PPE	Pitot pressure at boundary-layer edge, psia
PT	Tunnel stilling chamber pressure, psia
PT2	Free-stream total pressure downstream of a normal shock wave, psia
PW	Model surface pressure, psia
PWL	Model wall static pressure used for boundary-layer survey calculations, psia
Q	Free-stream dynamic pressure, psia

QDOT	Heat-transfer rate, Btu/ft ² -sec
RE	Free-stream unit Reynolds number, in. ⁻¹ or ft ⁻¹
RE/FT	Free-stream unit Reynolds number, ft ⁻¹
RHO	Free-stream density, lbm/ft ³
RHOD, RHD	Density at boundary-layer thickness, DEL, lbm/ft ³
RHOL, RHL	Local density, lbm/ft ³
RHOUD	(RHOD) * (UD), lbm/sec-ft ²
RN	Radius of model leading edge, in.
RUN	Data set identification number
ST(TT)	Stanton number based on stilling chamber temperature (TT), $ST(TT) = \frac{QDOT}{(RHO) (V)(ITT-ITW)}$
T	Free-stream static temperature, °R, or °F
ΔT	Temperature difference, °F
TAP	Pressure orifice identification number
T/C	Identification number of model surface thermocouples
TD	Static temperature at boundary-layer thickness, DEL, °R
TDRK	Temperature of Druck probe transducer, °F
THETA	Peripheral angle on the model measured from ray on model top, positive clockwise when looking upstream, deg
TL	Local static temperature, °R
TT	Tunnel stilling chamber temperature, °R, or °F
TTD	Total temperature at boundary-layer thickness, DEL, °R
TTE	Total temperature at boundary-layer edge, °R
TTL	Local total temperature, °R
TW	Coaxial thermocouple gage surface temperature, °R

TW (t_j) Coaxial thermocouple gage surface temperature at time point t_j , $j = 1$ to n , °R

TWL Model wall temperature used for boundary-layer survey calculations, °R

TWTR Water supply temperature, °R

t_j Time point number j , $j = 1$ to n , sec

UD Local velocity component parallel to model surface at boundary-layer thickness, DEL, ft/sec

UE Local velocity component parallel to model surface at boundary-layer edge, ft/sec

UL Local velocity component parallel to model surface, ft/sec

V Free-stream velocity, ft/sec

X Axial location measured from leading edge of model, in.

XC Calculated X location of survey station, in.

XSTA Nominal X location of survey station, in.

ZA Anemometer probe height, distance to probe centerline along normal to model surface, in.

ZP Pitot-pressure probe height, distance to probe centerline along normal to model surface, in.



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1.0 INTRODUCTION

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element Numbers JPF170 and 65807F, Control Numbers 1999 and 9T03, at the request of the Wright Research and Development Center (WRDC/FIMG), Wright-Patterson Air Force Base, Ohio 45433-6553, and the AEDC Directorate of Aerospace Flight Dynamics Test (AEDC/DOF). The WRDC project manager was Kenneth F. Stetson and the AEDC/DOF program manager was Capt. N. H. Patnode. The results were obtained by the Calspan Corporation/AEDC Operations, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Base, Tennessee 37389-5000. The test was conducted in the AEDC Hypersonic Wind Tunnel (B) on August 3-14, 1989, under the AEDC Project Number C010VB (Calspan Project Number V--B-2R).

The objective of this test was to investigate the development of hypersonic laminar boundary-layer flow instabilities along a hollow cylinder model. The test was the eighth in a series of cooperative efforts between WRDC/FIMG and AEDC/DOF. The first seven tests have investigated various aspects of boundary-layer stability on sharp and blunt cones. Representative documentation of the previous seven tests is given in Refs. 1-4. Selected results of the previous tests are presented in Refs. 5-9.

An existing water-cooled hollow cylinder model from the AEDC model inventory was used for the test. The principal measurements of this investigation were hot-wire anemometer probe data acquired above the top (zero) ray of the model. These data were supplemented by surveys of the model boundary layer using a pitot pressure probe. Model surface pressure, temperature, and heat-flux were also measured. Data were acquired at Mach number 8 for zero model angle of attack. In general the testing was done at free-stream unit Reynolds numbers of 1.0- and 1.5-million per foot. A limited amount of heat-transfer data was obtained at a unit Reynolds number of 2.0 million per foot.

Inquiries to obtain copies of the test data should be directed to AEDC/DOF, Arnold Air Force Base, Tennessee 37389-5000, or to WRDC/FIMG, Wright-Patterson Air Force Base, Ohio 45433-6553. A microfiche record has been retained at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

The AEDC Hypersonic Wind Tunnel B (Fig. 1) is a closed-circuit wind tunnel with a 50-in.-diameter test section. Two axisymmetric contoured nozzles are available to provide Mach numbers of 6 and 8, and the tunnel may be operated continuously over a range of pressure from 20 to 300 psia at Mach number 6, and 50 to 900 psia at Mach number 8,

with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 1350°R) are obtained through the use of a natural gas fired combustion heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral, external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel and airflow calibration information may be found in Ref. 10.

2.2 TEST ARTICLE

The test article used in this investigation (Fig. 2) was a hollow cylinder model with a length of 59.5 in., an O.D. of 10.0-in., and an I.D. of 8.1 in., out of AEDC model inventory. The cylinder was composed of two concentric shells of 0.2-in. wall thickness separated by stiffeners with provision for circulating cooling water in the space between the shells. The model had a removable leading edge section of 3.74-in. axial length with a sharp leading edge of 0.004-in. radius. The leading edge was beveled on the inside with an entry angle bevel of 15 deg. This section capped the upstream end of the coolant passage between the inner and outer shells of the cylinder. Cooling water was carried to the upstream end of the passage by eight tubes, evenly spaced circumferentially, where it was introduced just inside the leading edge section and allowed to diffuse to the downstream sealed end of the coolant passage. The water passage was full at all times during testing. A photograph of the test installation is shown in Fig. 3.

In order that air flow through the inner bore of the cylinder be unobstructed, it was necessary that the model support be attached to the outer surface of the model. The test article was mounted on the Tunnel B sector using a specially designed sting and a collar which attached over the aft 7.5 in. of the cylinder length (Fig. 2). The collar had an O.D. of 10.72 in. The leading edge of the collar was beveled to reduce the flow disturbance produced in the boundary layer by the joint. Surveys of the boundary layer were made 15 in. or more upstream of the leading edge of this collar. Cooling water was supplied to and drained from the cylinder through manifolds in the collar. Covered channels in the collar were provided to route the instrumentation tubes and leads from the cylinder to the sting.

The model was instrumented for the present test with 26 pressure orifices along four rays of the cylinder: eight orifices along the 15-deg ray and six orifices along each of the rays at 90, 180, and 270 deg. Coaxial thermocouple gages were installed at 27 locations along the 345-deg ray. The locations of the orifices and gages are listed in Table 1. Gages and the leads were encased in stainless steel tubing to seal them from the water flowing around them inside the coolant passage. Tubes from the pressure orifices and for the gage leads were sealed in the flange where they passed through the downstream end of the coolant passage.

2.3 FLOW-FIELD SURVEY MECHANISM

Surveys of the flow field were made using a retractable survey system (X-Z Survey Mechanism) designed and fabricated by the AEDC. This mechanism makes it possible to change survey probes while the tunnel remains in operation. The mechanism is housed in an air lock immediately above a port in the top of the Tunnel B test section. Access to the test section is through a 40-in.-long by 4-in.-wide opening which is sealed by a pneumatically operated door when the mechanism is retracted. Separate drive motors are provided to (1) insert the mechanism into the test section or retract it into the housing (Z drive), (2) position the mechanism at any desired axial station over a range of 35 in. (X drive), and (3) survey a flow field of approximately 10-in. depth (Z' drive). A pneumatically operated shield is provided to protect the probes during injection and retraction through the tunnel boundary layer, during changes in tunnel conditions, and at all times when the probes are not in use (Figs. 3 and 4a).

The probes required for flow-field survey measurements were rake-mounted on the X-Z mechanism (Fig. 4) at the foot of the Z' drive strut that was extended or retracted to accomplish the survey. The angle of the survey strut with respect to the vertical was fixed by manually sweeping the strut to the selected angle between 5 deg (swept upstream) and -15 deg (swept downstream) and locking the strut in position. In the present test, the sweep angle of the strut was set at -6.5 deg to allow surveys to be made as far aft on the model as XSTA = 37 in.

A sketch of the survey probe rake is shown in Fig. 4b. The top and rear surfaces of the rake were designed to mate to the Z' drive strut of the X-Z Survey Mechanism. The rake was provided with four 0.10-in. I.D. tubes through which were mounted the hot-wire anemometer and pitot pressure probes. One tube was used in the present test for housing a "touch-sensor" probe that caused the survey mechanism to halt when the probe made contact with the model surface. The tubes were fitted with clamps attached to the rake to hold the probes in position. One of the probe tubes of the rake was located in a removable section. This feature facilitated the replacement of fragile probes and allowed for critical probe alignments to be made under a laboratory microscope, as required for the hot-wire probe.

2.4 FLOW-FIELD SURVEY PROBES

The hot-wire anemometer probes (Fig. 5a) were fabricated by AEDC. Platinum, 10-percent-rhodium wires, drawn by the Wollaston process, of 20-micro-in. nominal diameter and approximately 140 diameters in length were attached to sharpened 3-mil nickel wire supports using a bonding technique developed by Philco-Ford Corporation (Ref. 11). The wire supports were inserted in an alumina cylinder of 0.032-in. diameter and 0.25-in. length, which was, in turn, cemented to an alumina cylinder of 0.093-in. diameter and 3.0-in.

length that carried the hot-wire leads through the probe holder of the survey mechanism.

The pitot pressure probe (Fig. 5b) had a cylindrical tip of 0.007-in. inside diameter. This probe was fabricated by cold-drawing a stainless steel tube through a set of wire-drawing dies until the desired inside diameter was obtained. The outside surface of the drawn tube was subsequently electropolished to a diameter of 0.015 in. to minimize interference with the flow field surveyed.

In addition to the probes used for survey measurements, a "touch-sensor" probe was used to halt the probe drive mechanism prior to contact of the other probes with the model. (See Sections 2.3 and 3.1.) The probe was made by brazing a lead wire to a piece of 0.031-in.-0.0. steel tubing. This tubing was telescoped in a larger diameter tube (0.093-in. O.D.) and electrically isolated from the larger tube using Pyrocera[®] cement. The inner tubing was bent to make contact with the model surface as required. A similar "touch-sensor" wire was attached to the probe shield (Section 2.3) to stop the probe drive mechanism prior to contact of the shield with the model. (See Section 3.1.)

2.5 TEST INSTRUMENTATION

2.5.1 Standard Instrumentation

The measuring devices, recording devices, and calibration methods for all parameters measured during this test are listed in Table 2. Also, Table 2 identifies the standard wind tunnel instruments and measuring techniques used to define test parameters such as the model attitude, the model surface conditions, probe positions, and probe measurements. Additional special instrumentation used in support of this test effort is discussed in the succeeding subsections.

2.5.2 Model Surface Instrumentation

The locations of the model instrumentation are listed in Table 1. The surface pressure orifices (TAP 1 - TAP 26) on the model had a diameter of 0.040 in.; and the pressures were measured using one-psid Druck[®] transducers or 2.5 psid ESP transducers included in the Tunnel B Standard Pressure System.

Coaxial surface thermocouple gages were used to measure the model surface heating rates and surface temperatures. The coax gage consists of an electrically insulated Chromel[®] center enclosed in a cylindrical Constantan sleeve. After assembly and installation in the model, the gage materials are blended together with a file creating thermal and electrical contact in a thin layer at the surface of the gage. The gage is used to monitor the surface temperature time history at a rate of 15 points per second. Assuming the surface thermocouple behaves as a homogeneous, one-dimensional, semi-infinite solid, its temperature time history can be used to define the corresponding time history of the incident heat flux. A complete description of this gage and the

data reduction procedure can be found in Refs. 12 and 13. The recording and calibrating procedures for this type gage are summarized in Table 2.

2.5.3 Hot-Film Anemometry Instrumentation

Flow fluctuation measurements were made using hot-wire anemometry techniques. Constant-current hot-wire anemometer instrumentation with auxiliary electronic equipment was furnished by AEDC. The anemometer current control (Philco-Ford Model ADP-13) which supplies the heating current to the sensor is capable of maintaining the current at any one of 15 preset values individually selected using push-button switches. The anemometer amplifier (Philco-Ford Model ADP-12), which amplifies the wire-response signal, contains the circuits required to compensate the signal electronically for thermal lag which is a characteristic of the finite heat capacity of the sensor. A square-wave generator (Shapiro/Edwards Model G-50) was used in determining the time constant of the sensor whenever required. The sensor heating current and mean voltage were fed to autoranging digital voltmeters for a visual display of these two parameters and to a Bell and Howell Model VR3700B magnetic tape machine and to the tunnel data system for recording. The sensor response a-c voltage was fed to an oscilloscope for visual display of the raw signal and to a wave analyzer (Hewlett-Packard Model 8553B/8552B) for visual display of the spectra of the fluctuating signal and was recorded on magnetic tape for subsequent analysis by AEDC. A detailed description of the hot-wire anemometer instrumentation is given in Ref. 14.

The a-c response signal from the hot-wire anemometer probe was recorded using the Bell and Howell Model VR3700B magnetic tape machine in the FM-WBII mode. This channel, when properly calibrated and adjusted, has a signal-to-noise ratio of 35 db at 1-v rms output and a frequency response of +1 to -3 db over a frequency range of 0 to 500 kHz. A sine wave generator was used to check each channel at several discrete frequencies, using an rms-voltmeter which was periodically calibrated on the 1-, 10-, and 100-v ranges. The sensor heating current and mean voltage signals from the hot-wire anemometer were also tape-recorded, using the FM-WBI mode. Magnetic tape recordings were made with a tape speed of 60 or 120 in./sec.

2.5.4 Pitot Probe Pressure Instrumentation

Pitot probe pressures were measured during surveys of the model boundary layer using a 15-psid Druck transducer calibrated for 10-psid full scale. As the probe was moved across the boundary layer, the small size of the pitot probe (Section 2.4) required a time delay between points in order to stabilize the pressure within the probe tubing between orifice and transducer. In order to reduce the lag time, the pitot pressure transducer was housed in a water-cooled package attached to the trailing edge of the strut on which the probe rake was mounted (Section 2.3). The distance between orifice and transducer was approximately 18 inches. The resultant lag time was about one second.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

A summary of the nominal test conditions is given below.

M	PT, psia	TT, °R	V, ft/sec	Q, psia	T, °R	P, psia	RE/FT x 10 ⁻⁶
7.94	225	1,310	3,855	1.06	98	0.024	1.0
7.96	340	1,310	3,857	1.58	98	0.036	1.5
7.98	453	1,310	3,859	2.10	97	0.047	2.0

A summary of the test runs for the present investigation using the cooled-wall hollow cylinder model is given in Table 3. Only heat-transfer data were acquired at RE/FT = 2.0 million.

In the continuous-flow Tunnel B, the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank, and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the sequence is reversed; the model is retracted into the tank which is then vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

Probes mounted to the X-Z mechanism (Section 2.3) are deployed for measurements by the following sequence of operations: the air lock is closed, secured over the mechanism, and evacuated; and the access door to the tunnel test section is opened. The various drive systems are used to inject the probes into the test section and position the probes at a designated survey station along the length of the model, the shield protecting the probes is raised exposing them to the flow, and the flow field is traversed to selected probe heights. When the traverse has been concluded, the shield is closed over the probes, and the mechanism is repositioned along the model. When the surveys are completed or when a probe is to be replaced, the X-Z Mechanism is retracted from the flow, and the test section access door is closed. The air lock is then opened to allow personnel access to the mechanism.

The survey probe height relative to the model was monitored using a high-magnification, closed-circuit television (CCTV) system. The video camera was fitted with a telescopic lens system which gave a magnification factor of 20 for the monitor image. The probe and model were back-lighted using the collimated light beam from the Tunnel B

shadowgraph system which produced high-contrast silhouettes of the model and probe (Fig. 6). The camera was mounted on a horizontal-vertical traversing mount to facilitate alignment of the camera with the probe at various model stations visible through the test section windows. The video camera was interfaced with an image analyzer/digitizer system which was used to measure the distance between the probe and model surface using computer-assisted image analysis techniques. For each measurement the lower edge of the probe and the upper edge of the model surface were located by an operator using a cursor with the video image. The system was calibrated prior to testing by the same operator using the same technique to locate edges separated by a known distance.

A hardcopy of the video image of the probes and model edge was provided in near real-time, showing, by means of a graphics line, the location of the edges measured and displaying a printout of the measured distance and other pertinent information. The accuracy of this measurement technique was determined to be better than ± 0.0007 in. over a range of 0.003 to 0.2 in. under air-off conditions. The video images used for test measurements were recorded on disk for post test review, if needed.

The flow-field surveys were accomplished in the following sequence: (1) the survey mechanism was positioned at the desired model axial station (XSTA) by the controller operating in either manual or automatic mode and locked in axial position, (2) the survey mechanism was driven downward toward the surface by the controller until the "touch-sensor" wire (Section 2.4) attached to the probe shield made contact with the model surface, (3) final adjustments of probe instrumentation were made and the shield was raised, (4) the survey mechanism was driven toward the model surface by the controller until the "touch-sensor" probe (Section 2.3) made contact with the surface, (5) measurements of probe positions relative to the surface and to each other were made using the image analyzer and the information was manually entered into the data system, (6) the probes were traversed across the flow field in selected increments by the controller in either manual or automatic mode to acquire the desired data, (7) the axial position of the survey mechanism was unlocked and the mechanism was repositioned at the next survey station along the model.

3.2 DATA ACQUISITION

The primary test technique used in the present investigation of the development of instabilities in a laminar boundary layer was hot-wire anemometry. In addition, mean-flow boundary-layer profile data (pitot pressure profiles) were acquired in order to define the flow environment in the vicinity of the hot-wire. All boundary-layer measurements were made above the top (zero) ray of the model. Surface pressures and temperatures on the model were measured to supplement the profile data. The various types of data acquired are summarized in Table 3. Model stations for surveys are also listed in Tables 3a and 3b.

3.2.1 Hot-Wire Anemometry Data

The hot-wire anemometer data acquired during the present testing were of two general categories: (1) continuous-traverse surveys of the boundary layer to map the response of the hot-wire anemometer as a function of distance from the surface and (2) discrete-point hot-wire measurements using the wire operated at one or two wire heating currents at one or more locations on a profile.

Data of the first category were acquired with the hot wire operated using a single heating current, in the present case the maximum (practical) current. The probe was generally translated in a continuous manner from near the model surface outward beyond the edge of the boundary layer. These data were recorded as analog plots of the hot-wire response (rms of the a-c voltage component) versus probe height above the model surface. The plot was used primarily for the purpose of determining the station in the boundary-layer profile where the hot-wire output reached a maximum value.

Discrete-point hot-wire data (second category) were acquired at locations determined from the continuous-traverse surveys (first category data). The point of maximum rms voltage output of the hot wire, the "maximum energy point" of the profile, was selected for quantitative measurements at each model station. The quantitative data were acquired using each of two wire heating currents; one current was nominal-zero to obtain a measurement of the electronic noise of the anemometer instrumentation. The other current was the maximum (practical) current. Each wire heating current, wire mean voltage (d-c component) and the rms value of the wire voltage fluctuation (a-c component) were measured 40 times using the Tunnel B data system. At the same time, the hot wire parameters were recorded (generally, a five-second record duration) on magnetic tape with a tape transport speed of 120 in./sec.

Discrete-point hot-wire data were also obtained simultaneously with the boundary-layer profile data (Section 3.2.2). In this case a measurement and recording of the electronic noise was made only at the start of the traverse and was assumed to be valid for all points of the profile. The tape recording duration was 5 sec and a tape transport speed of 60 in./sec was used.

3.2.2 Profile and Surface Data

Mean-flow boundary-layer profiles extended from a height of 0.05 in. above the model surface to a distance of 1.5 times the boundary-layer thickness. A profile typically consisted of 47 data points (heights). The probe direction of travel was at an angle of 6.5 deg with respect to the vertical (Section 2.3).

Model surface pressures, temperature distributions, and heat-flux distributions were acquired to supplement the boundary-layer surveys. The surface pressures and temperatures were obtained throughout the test.

3.3 DATA REDUCTION

3.3.1 Hot Wire Anemometer Data

In the present discussion, as it pertains to the reduction of hot-wire anemometer data, only the basic measurements tabulated in the data package that accompanies this report will be considered. (Examples of the tabulations are shown in the Sample Data.) The data processing associated with spectral analysis, modal analysis, and determination of amplification rates of laminar disturbances is beyond the scope of this report. However, extended data reduction of the present hot-wire results to achieve these analyses is planned.

The basic measurements associated with quantitative hot-wire data are the following: wire heating current (CURRENT), wire mean voltage (EBAR), and the rms value of the wire fluctuating response voltage (ERMS). The average value of 40 measurements of each of the three parameters was determined for each nominal wire heating current employed, and the results were tabulated under the designation "DATA TYPE 9" together with certain associated model, flow field, and tunnel conditions. (See Sample 1.)

3.3.2 Flow-Field Survey Data

The mean flow-field data reduction ("DATA TYPE 4") included calculation of the local Mach number and other local flow parameters, determination of the height of each probe relative to the model surface, definition of the boundary-layer total thickness, and evaluation of the displacement and momentum thicknesses. Sample tabulated data are shown in Sample 2, and typical plotted results are shown in Fig. 7. The data reduction procedures are outlined as follows.

The local Mach number in the flow field around the model was determined using the measured pitot pressure (PP) and the model static pressure (PWL). The total temperature distribution across the boundary layer on the cooled-wall hollow cylinder was calculated, using a computer code (Ref. 15), as a function of local Mach number. The normalized distribution used is shown in Fig. 8. In earlier tests of this type with cone models (Refs. 1-4), the total temperature distribution across the boundary layer was measured using an unshielded thermocouple probe. Attempts to use a similar probe in the present measurements in conjunction with the hot-wire probe and pitot pressure probe resulted in an unacceptable mutual interference among the probes.

The height of each probe above the model surface, in the normal direction, was calculated for each point in a given flow-field survey, taking into consideration the following parameters: the initial vertical distance determined from the CCTV image, the distance traversed from the initial position employing the survey probe drive, the sweep angle of the survey strut, the lateral displacement of the probe from the vertical plane of symmetry of the model, and the radius of the model.

3.3.3 Model Surface Pressure and Temperature Data

Model surface pressures and temperatures were tabulated under the designation "DATA TYPE 2" and "DATA TYPE 4." The data presented as DATA TYPE 2 (see Sample 3) represent a single measurement of each pressure and each temperature. These data were, in general, acquired when the survey probes were positioned to minimize interference with the surface measurements at $X \leq 37$ in.

Model surface measurements were also included among the DATA TYPE 4 results. In this case, surface conditions were measured each time that probe data were acquired. The surface data presented in these tabulations represent the average of the 47 values measured at each orifice and each thermocouple. It should be noted that pressures along the 15-, 90-, and 270-deg rays were often influenced by the presence of the survey probes and the Z' survey strut. The extent of the influence was governed by the location of the probes above the model. It is recommended in general that only the pressures measured along the 180-deg ray be used from the surface data tabulated under DATA TYPE 4.

Measured pressure distributions are shown in Fig. 9 for the two test conditions $RE/FT = 1.0$ and 1.5 million. For the former case (Fig. 9a), the mean value of the surface pressures (at $THETA = 15, 90,$ and 270 deg) is approximately $PW/P = 1.1$. For the case of $RE/FT = 1.5$ million (Fig. 9b), the mean value is essentially $PW/P = 1.0$. In either case, the estimated measurement uncertainty band associated with the ratio PW/P is relatively wide. It was desired to have within the uncertainty band a systematic relationship between PW/P and X for use in specifying the surface pressure PWL to be employed in the boundary-layer calculations at a given X station and RE/FT . The following procedure was used to develop such a relationship: (1) It was assumed that the Mach number ME at the edge of the boundary layer did not vary significantly with X along the region of surveys and was equal to the test-section free-stream Mach number, and (2) The pitot pressure PPE at the edge of the boundary-layer was used with this Mach number (ME) and the Rayleigh pitot equation to calculate the value of PWL . The resultant variation of PWL/P versus X is represented by the sloped line in each of the Figs. 9a and 9b.

3.3.4 Heat-Transfer Data

The coax gage heat flux at each instrumented location was computed for each time point (t_n) from the measured surface temperature by the following equation derived from semi-infinite solid considerations

$$QDOT(t_n) = \frac{2C(t_n)}{\sqrt{\pi}} \sum_{j=1}^n \frac{TW(t_j) - TW(t_{j-1})}{\sqrt{t_n - t_j} + \sqrt{t_n - t_{j-1}}} \quad (1)$$

The coax gage surface temperature, $TW(t_j)$, was computed from the thermocouple millivolt output using a curve fit to thermocouple

reference tables. The value of the coefficient $C(t_n)$ was an effective scale factor for the coax gage which was calculated from

$$C(t_n) = 5.26 \times 10^{-4} \left[\frac{TW(t_n) + TW(t_1)}{2} \right] + 0.12688 \quad (2)$$

which accounts for the density, specific heat, and thermal conductivity of the gage materials.

To reduce the effects of any noise in the gage output, the values of QDOT were averaged for fifteen consecutive readings after the test article reached the tunnel centerline. The gage surface temperature was also averaged for the heat-transfer data.

An example of the tabulated heat-transfer data is shown in Sample 4.

3.4 MEASUREMENT UNCERTAINTIES

In general, instrumentation calibrations and data uncertainty estimates were made using methods presented in Ref. 16. Measurement uncertainty (U) is a combination of bias and precision errors defined as

$$U = \pm (B + t_{95} S)$$

where B is the bias limit, S is the standard deviation, and t_{95} is the 95th percentile point for the two-tailed Student's "t" distribution, which equals approximately 2 for degrees of freedom greater than 30.

Estimates of the measured data uncertainties for this test are given in Table 2. In general, measurement uncertainties are determined from in-place calibrations through the data recording system and data reduction program. The propagation of the estimated bias and precision errors of the measured data through the data reduction was determined for free-stream parameters in accordance with Ref. 16, and is summarized in Table 4.

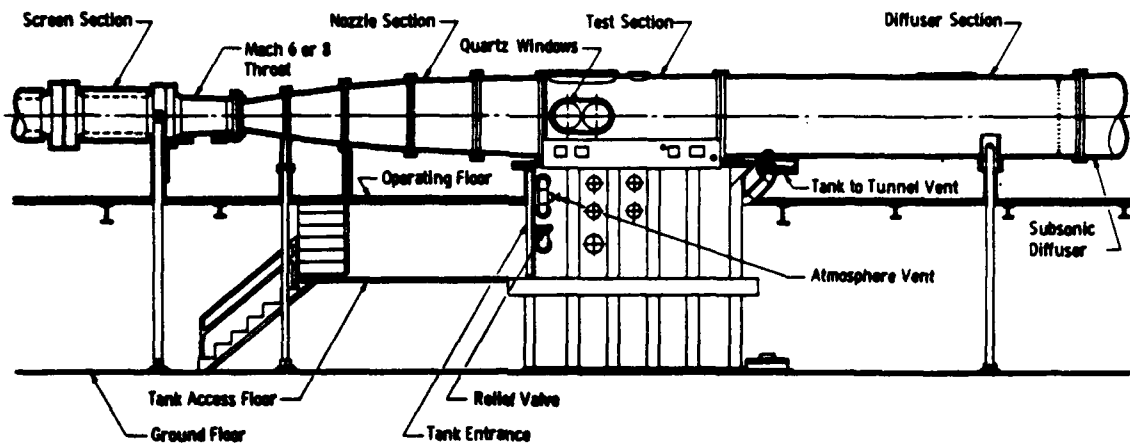
4.0 DATA PACKAGE PRESENTATION

Basic hot-wire anemometer data, boundary-layer profile data, and model surface data from the test were reduced to tabular and graphical form for presentation as a Data Package. Examples of the basic data tabulations are shown in the Sample Data.

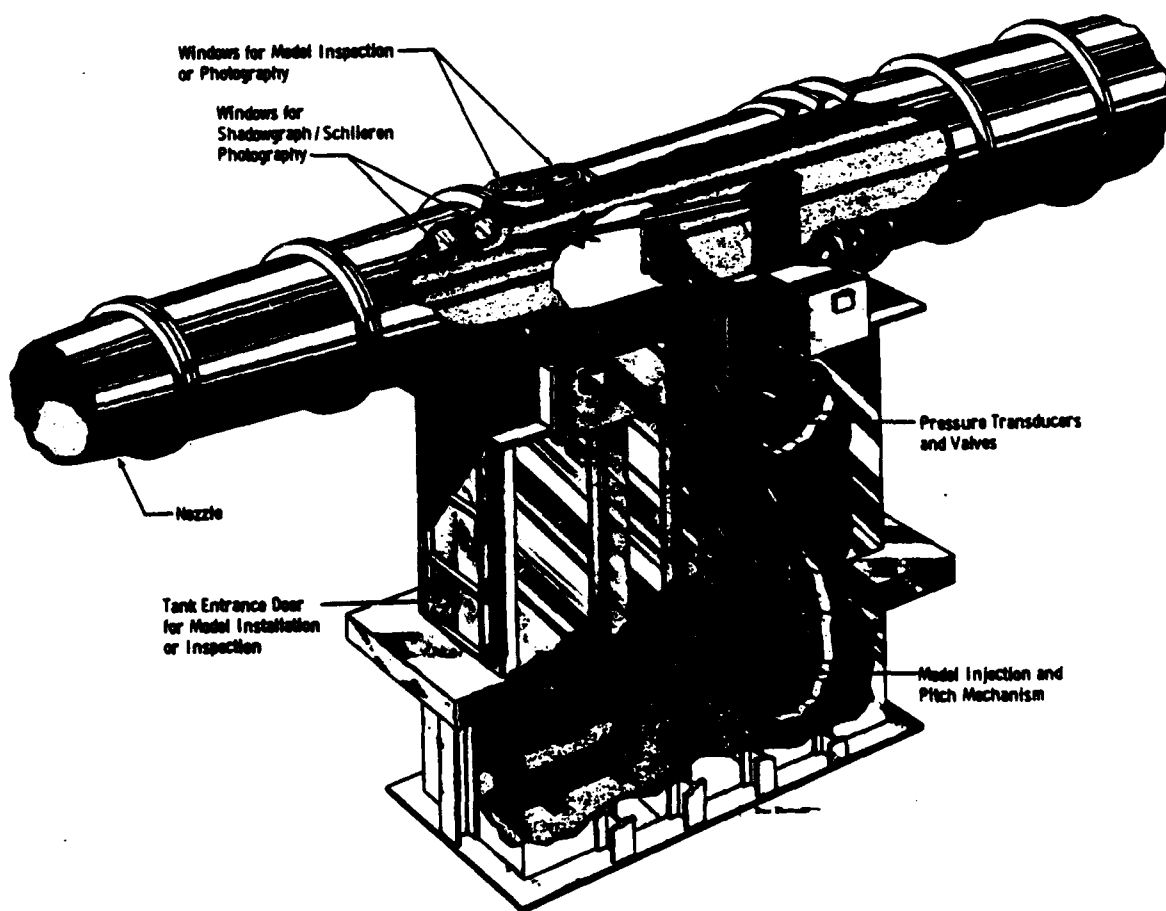
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a. Tunnel assembly



b. Tunnel test section

Figure 1. AEDC Hypersonic Wind Tunnel B

All dimensions
are in inches.

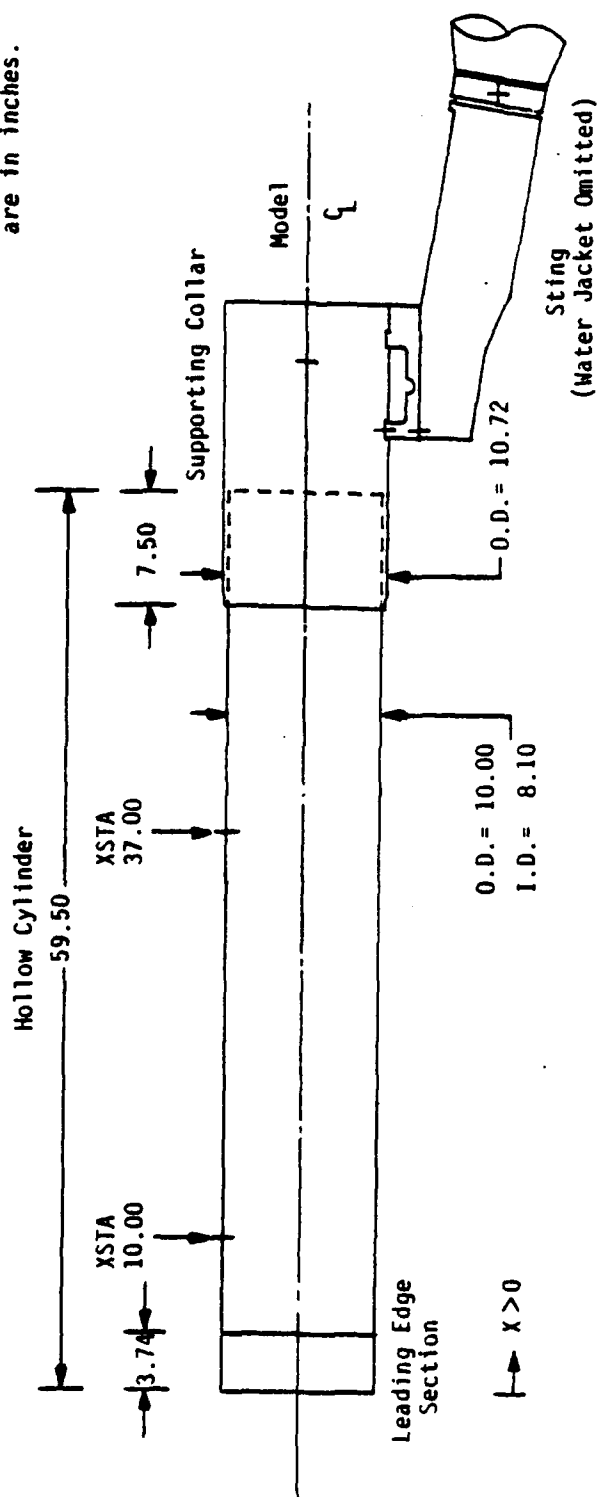


Figure 2. Model Geometry

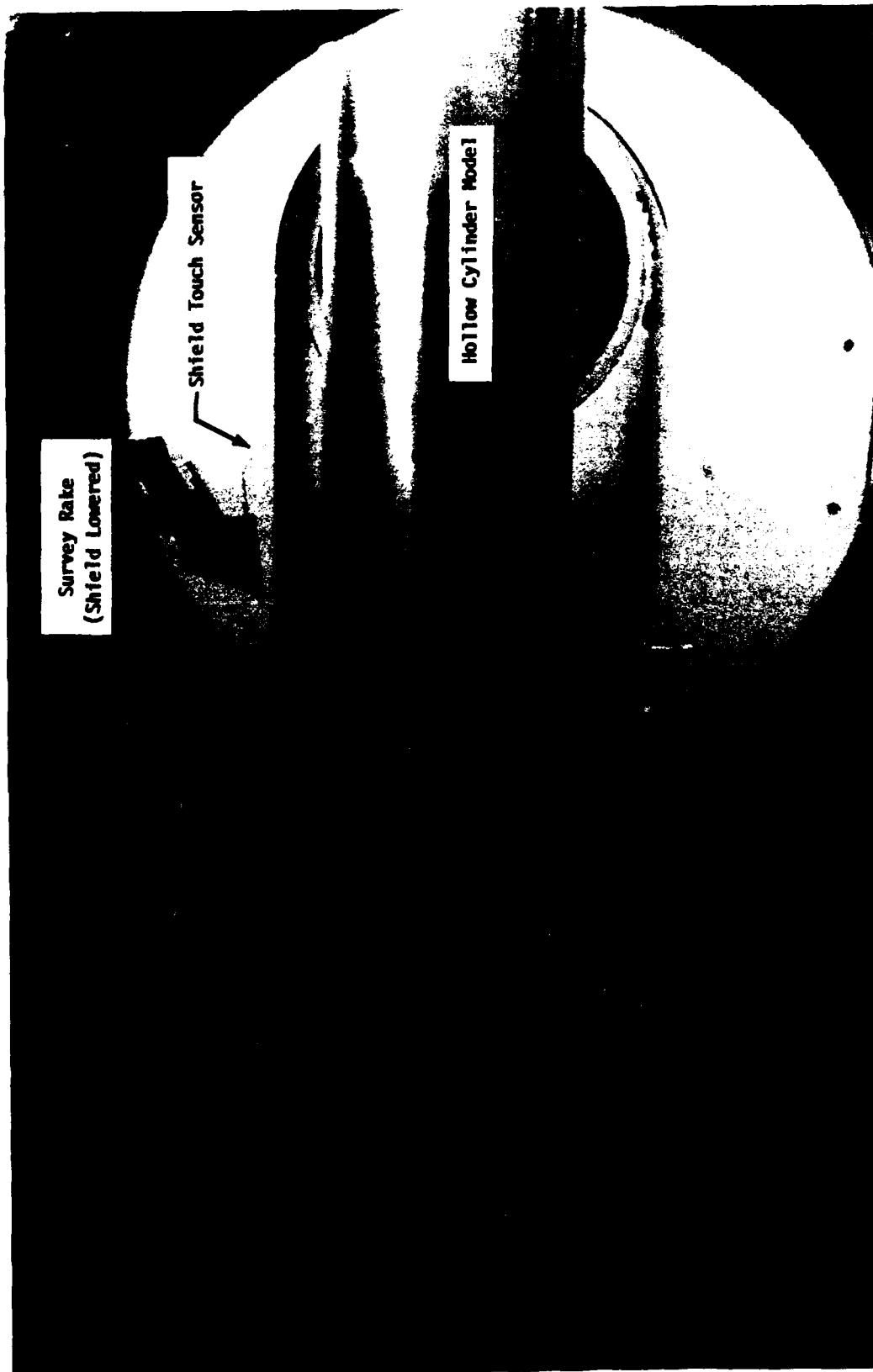
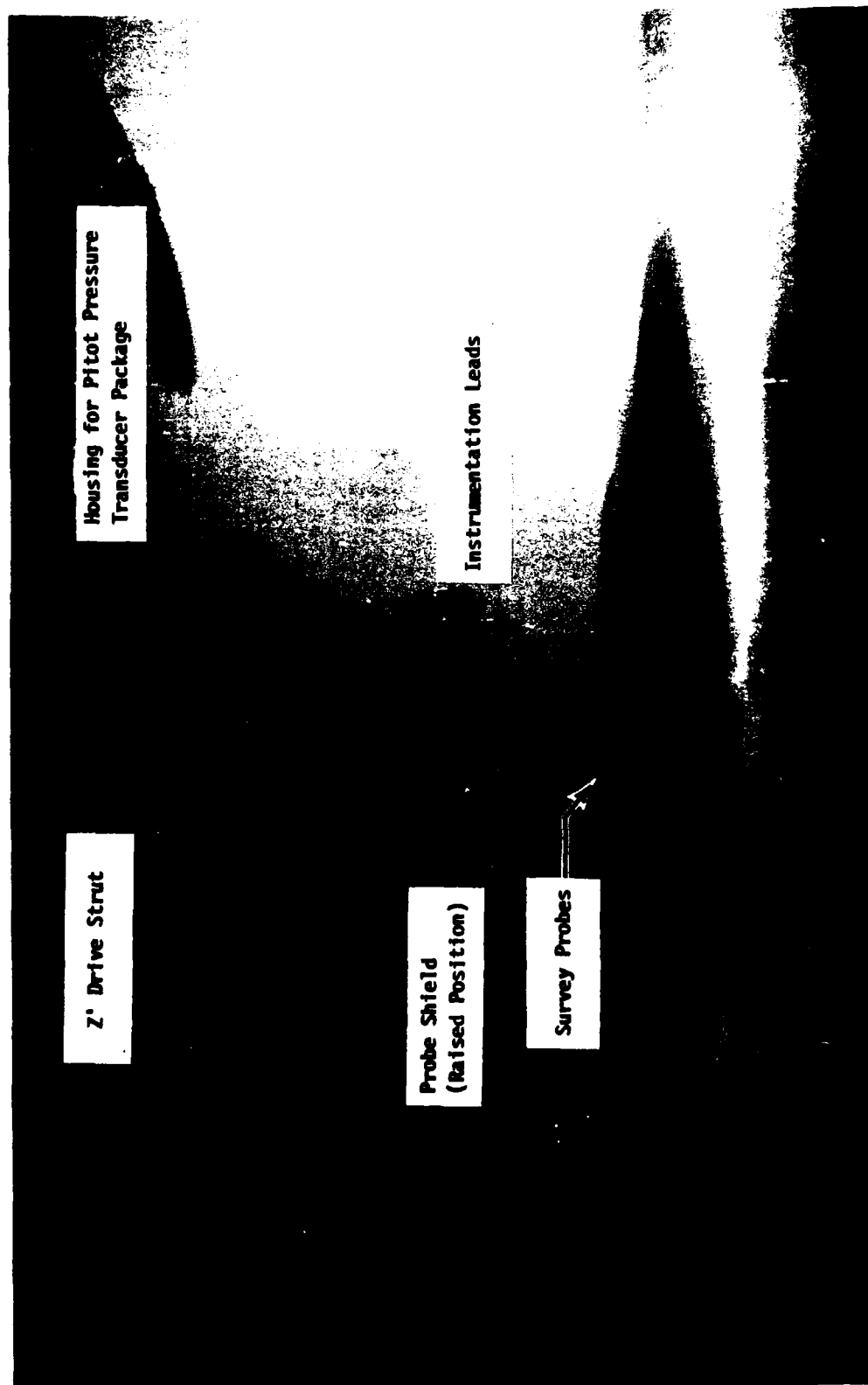
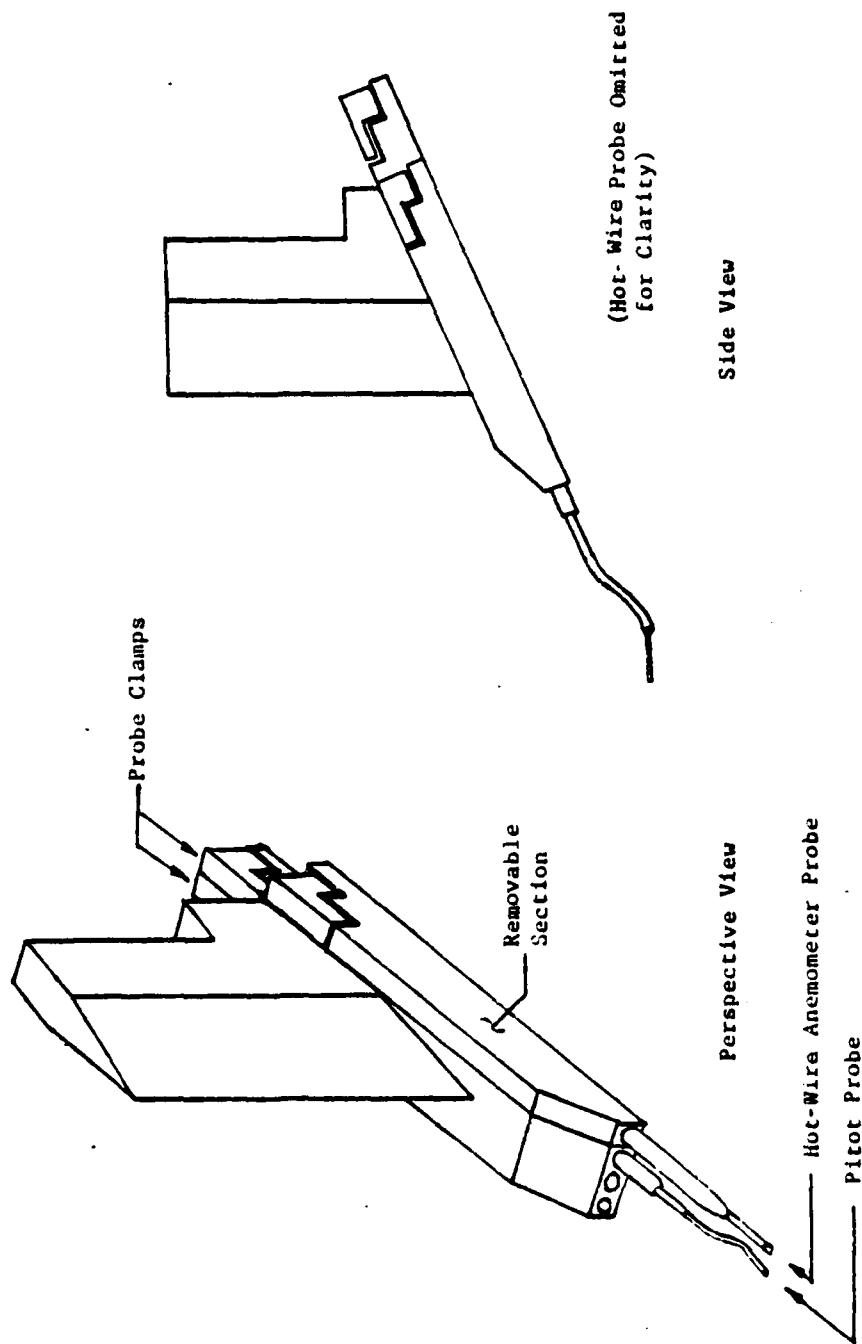


Figure 3. Test Installation

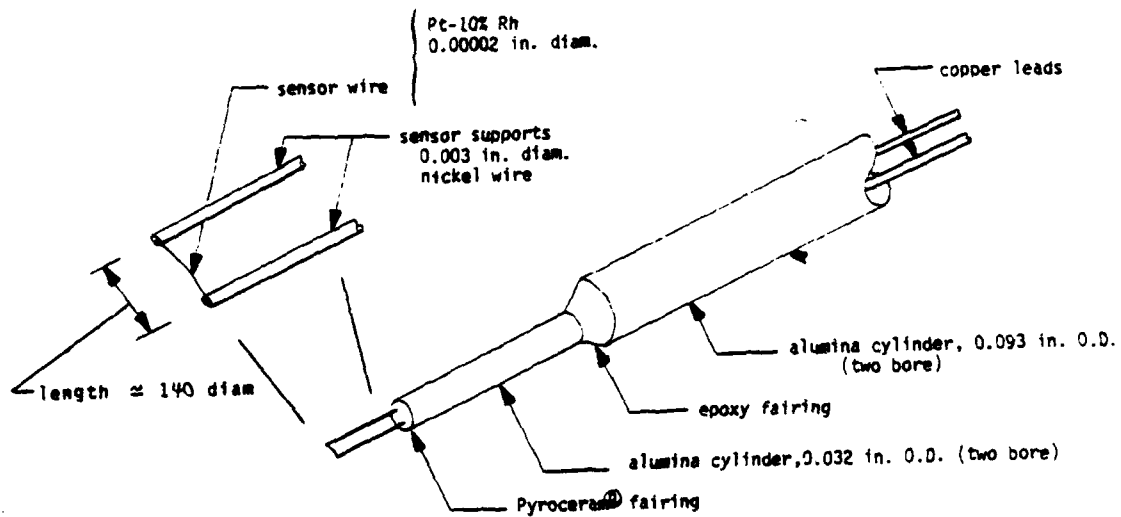


a. Survey Rake Installation
Figure 4. Survey Probe Rake

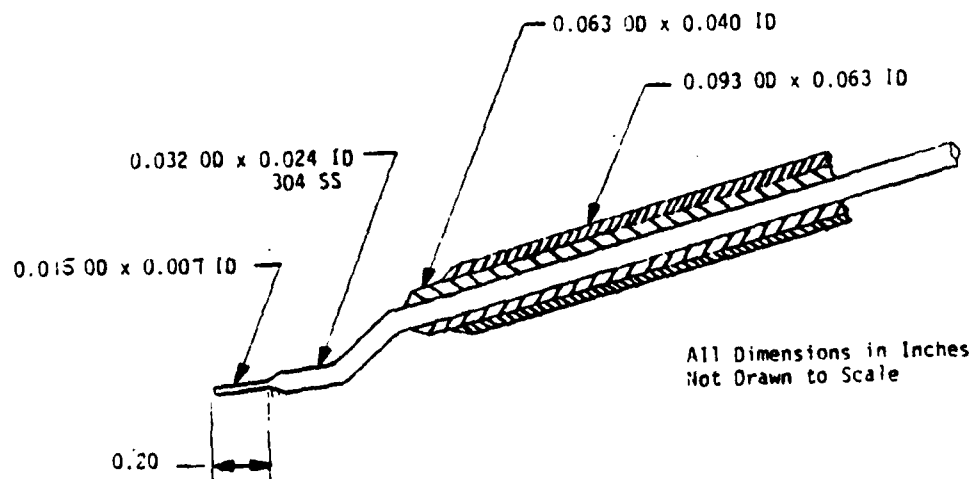


b. Survey Rake Details

Figure 4. (Concluded).



a. Hot-Wire Anemometer Probe



b. Pitot probe

Figure 5. Probe Details

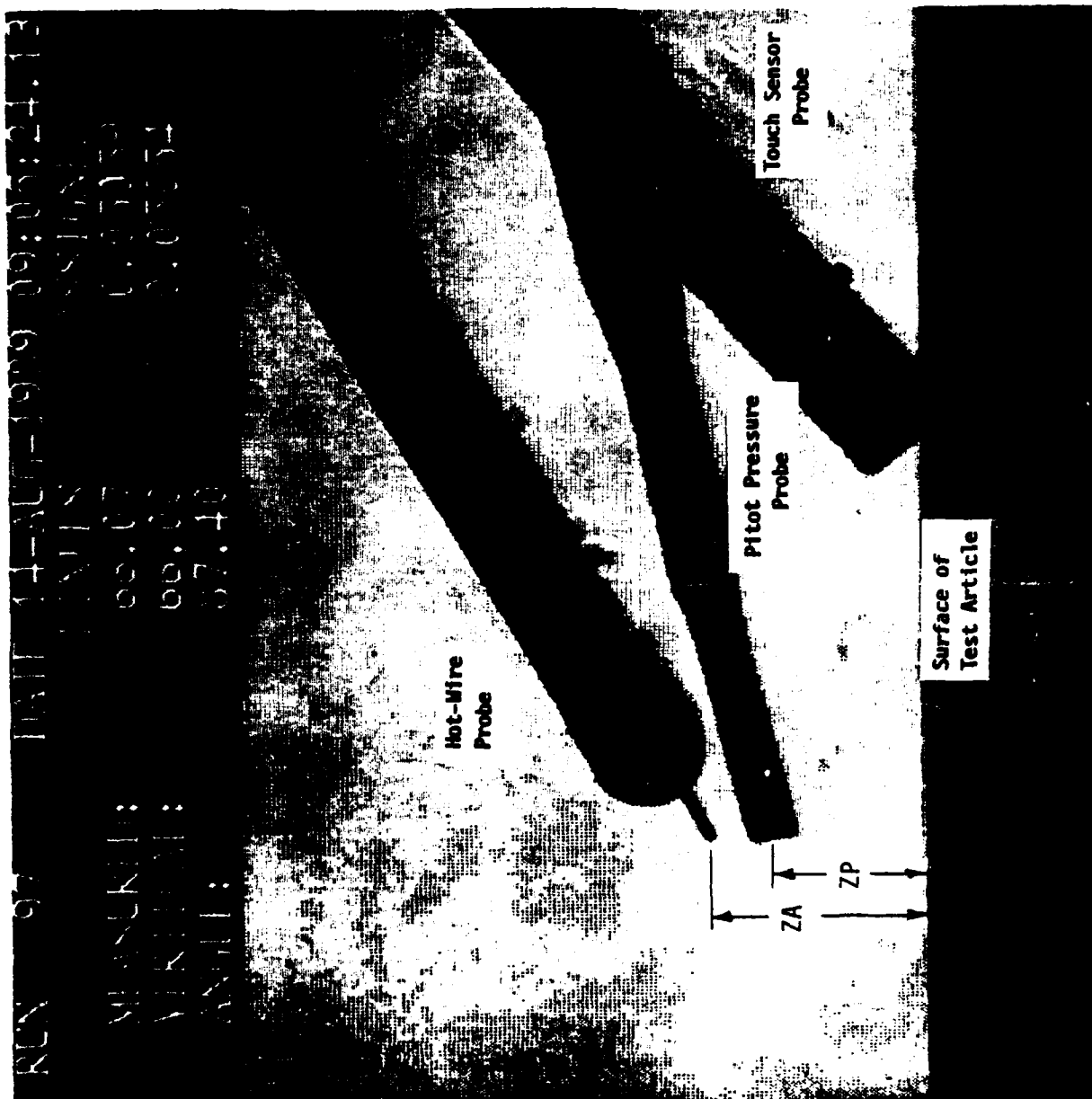


Figure 6. Video Image of Probe and Model Edges

SYN FIL RUN
 □ A 97

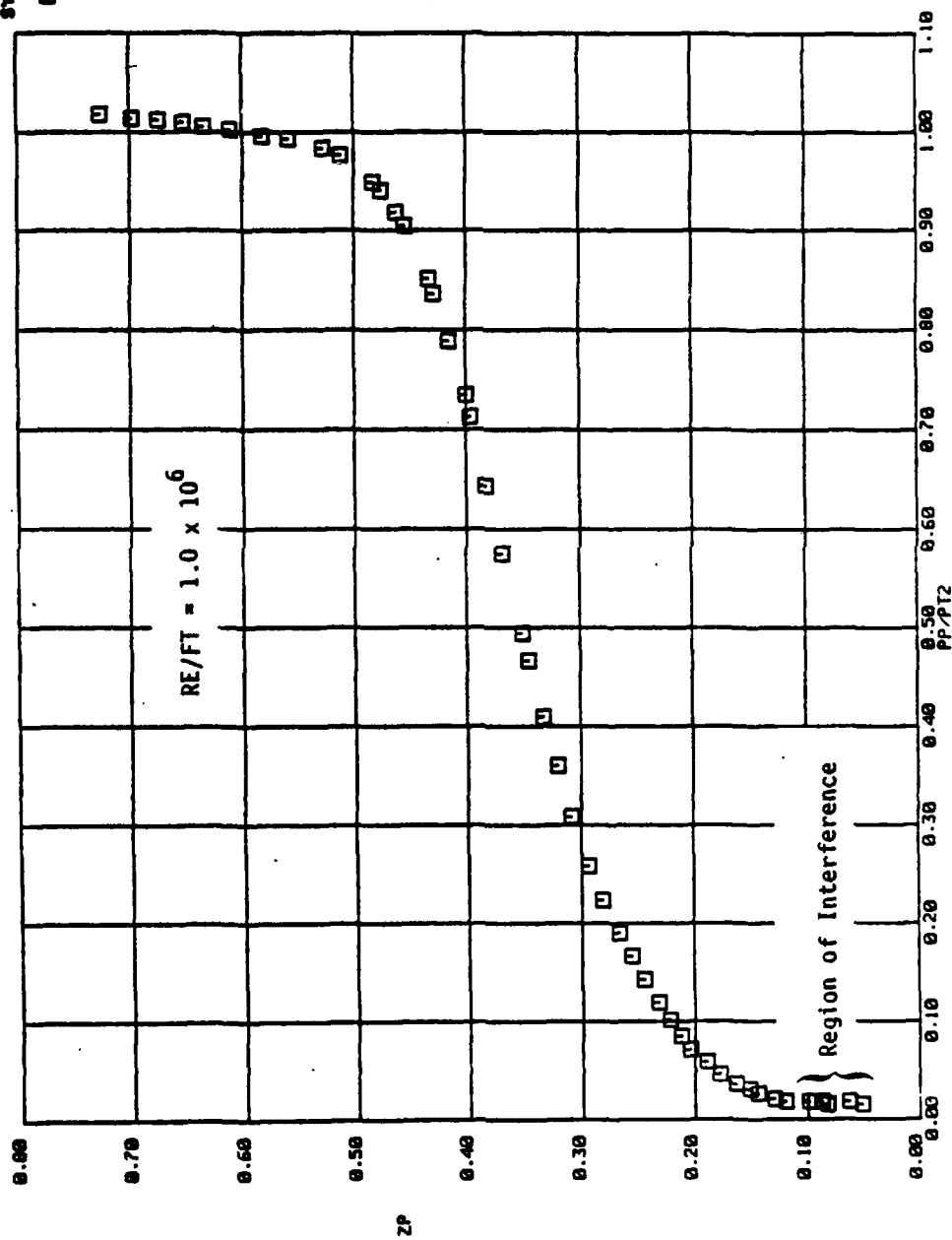


Figure 7. Typical Results of a Boundary-Layer Survey

SYMB FIL RUN
 □ A 97

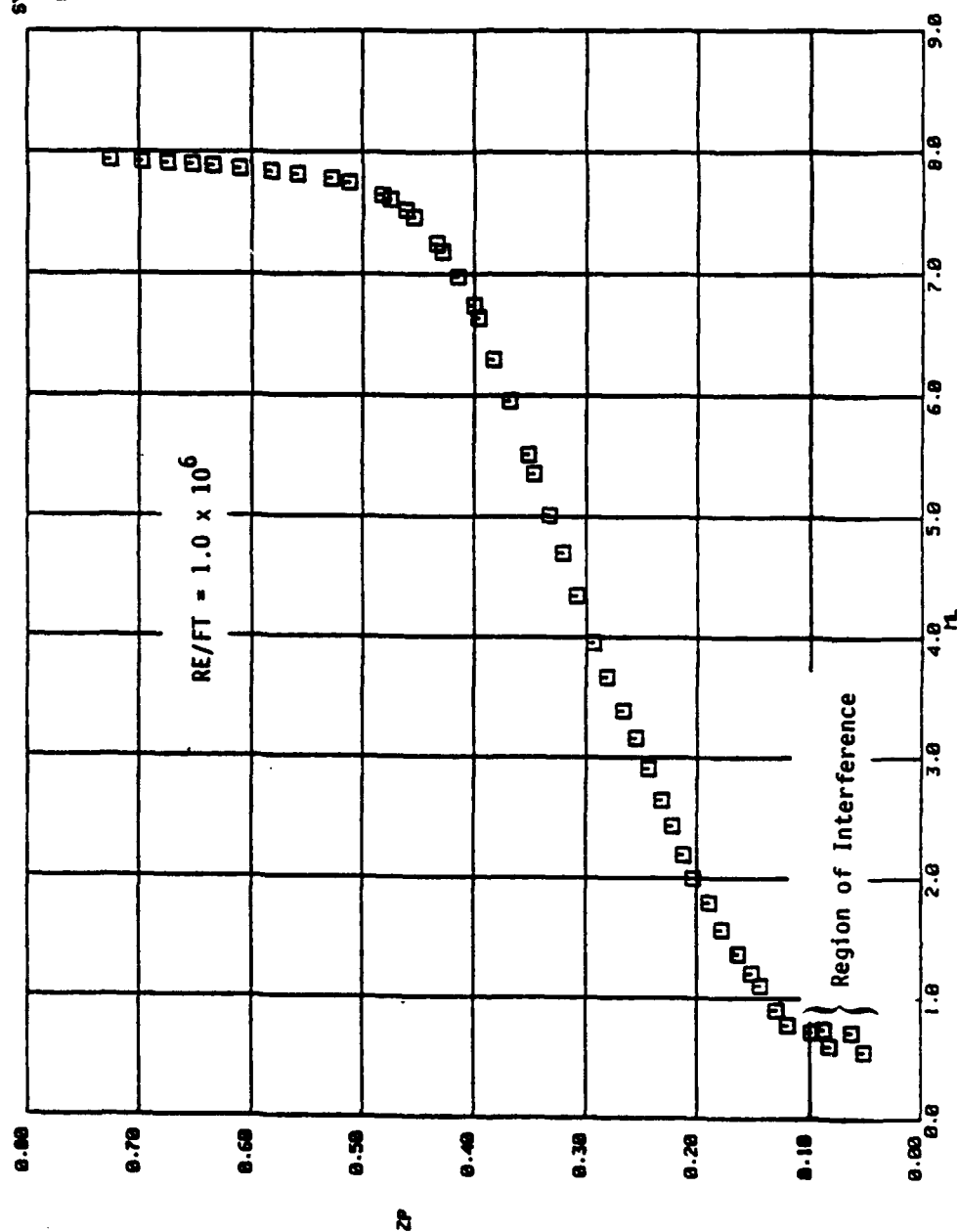


Figure 7. (Continued)

SYMB FIL RUN

□ A 97

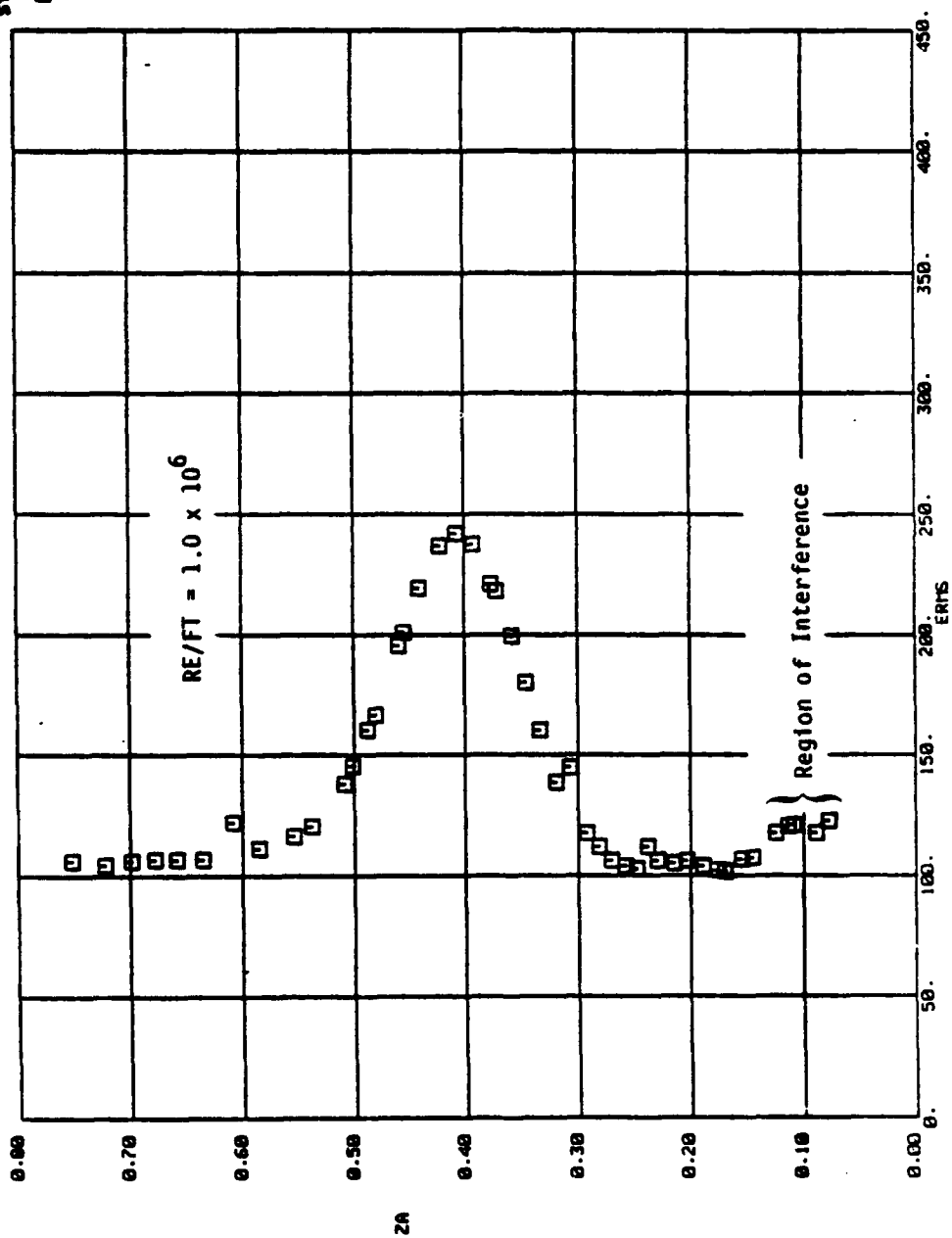


Figure 7. (Concluded)

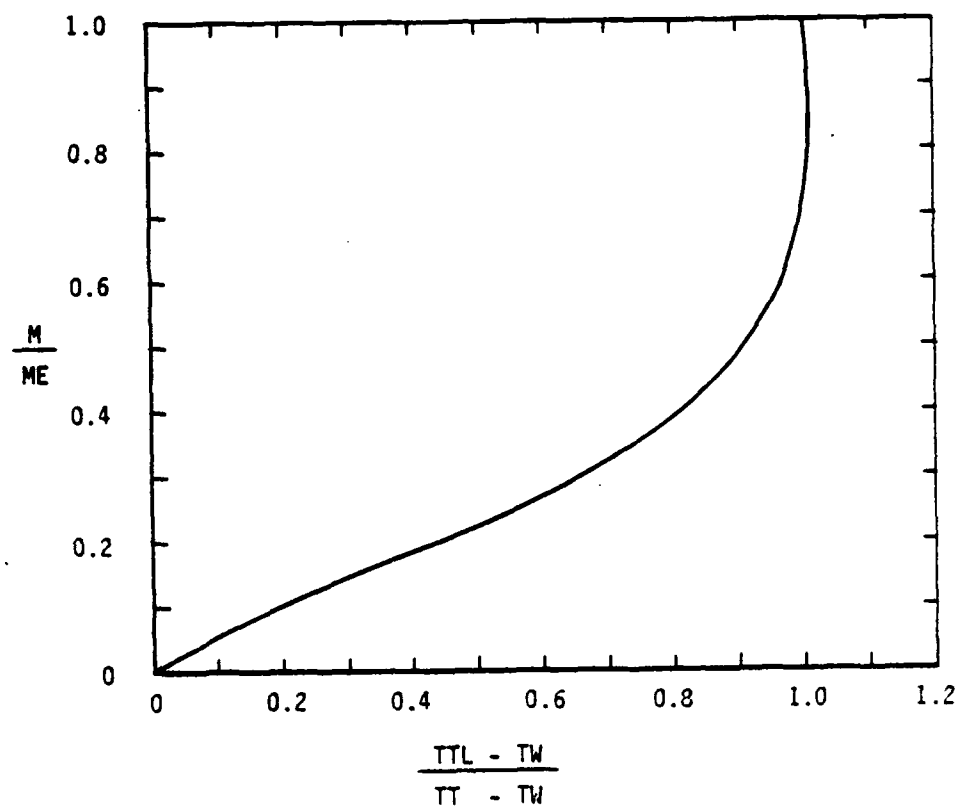


Figure 8. Computer-Generated Boundary-Layer Total Temperature Profile

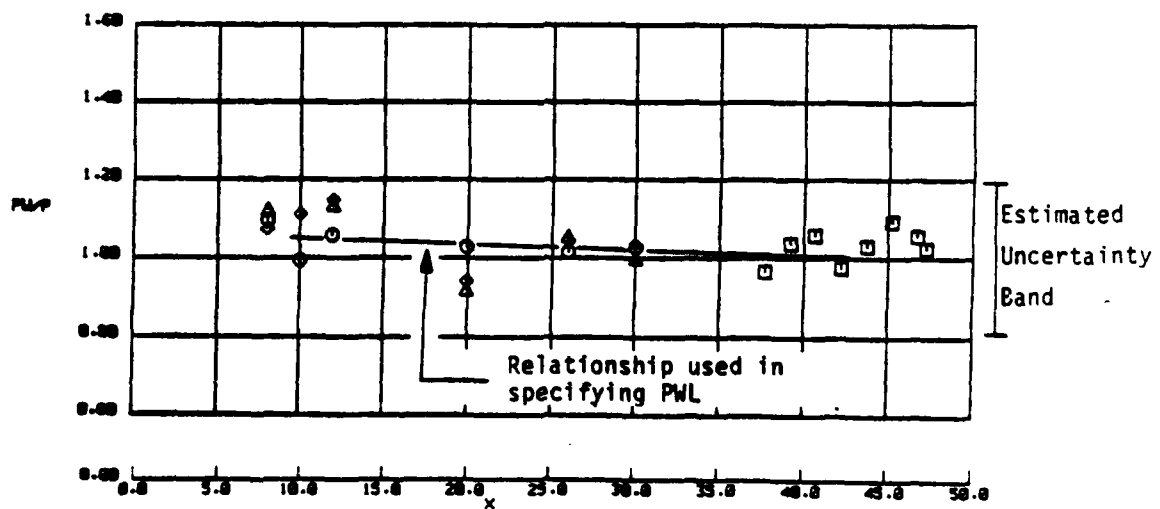
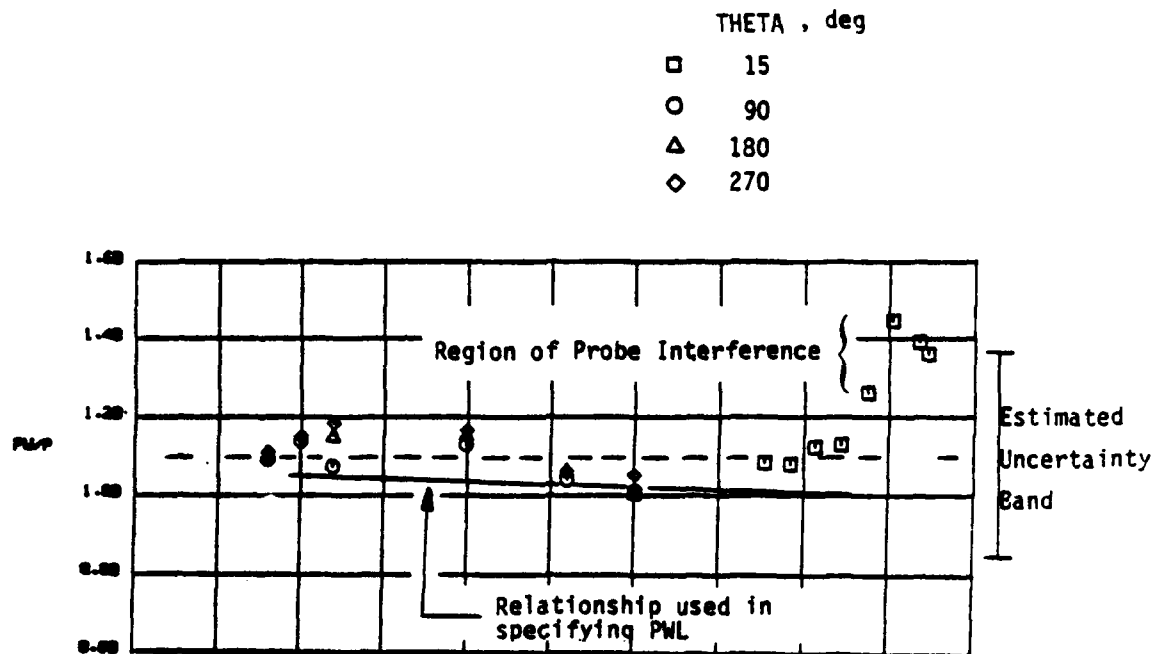


Figure 9. Model Surface Pressure Distributions

TABLE 1. MODEL INSTRUMENTATION LOCATIONS

PRESSURE ORIFICE LOCATIONS			COAXIAL THERMOCOUPLE LOCATIONS		
TAP	X (in)	THETA (deg)	T/C	X (in)	THETA (deg)
1	37.721	15	1	6.996	345
2	39.215	15	2	7.982	345
3	40.712	15	3	15.980	345
4	42.224	15	4	16.978	345
5	43.709	15	5	17.983	345
6	45.216	15	6	19.972	345
7	46.728	15	7	21.966	345
8	47.226	15	8	22.988	345
9	7.973	90	9	23.981	345
10	9.971	90	10	24.966	345
11	11.973	90	11	25.966	345
12	19.969	90	12	26.975	345
13	25.971	90	13	27.966	345
14	29.973	90	14	28.970	345
15	7.970	180	15	29.964	345
16	9.971	180	16	31.966	345
17	11.968	180	17	32.969	345
18	19.971	180	18	33.964	345
19	25.974	180	19	34.954	345
20	29.969	180	20	35.964	345
21	7.970	270	21	36.970	345
22	9.967	270	22	37.969	345
23	11.966	270	23	38.957	345
24	19.970	270	24	39.958	345
25	25.971	270	25	40.958	345
26	29.973	270	26	41.956	345
			27	42.962	345

TABLE 2. ESTIMATED UNCERTAINTIES OF MEASURED PARAMETERS

Parameter Designation	Steady-State Estimated Measurement*							Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index (S)		Bias (B)	Uncertainty $\pm (B + 1.95S)$							
	Percent of Reading	Unit of Measurement		Degree of Freedom	Percent of Reading	Unit of Measurement					
Stilling Chamber Pressure (PT), psi		± 0.1 psi			± 0.1 psi		± 0.3 psi	Piezoelectric Pressure Transducer	Digital data acquisition system	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the standards laboratory	
		$\pm 1^\circ\text{F}$			$\pm 2^\circ\text{F}$		$\pm 4^\circ\text{F}$				
Total Temperature (TT), °F		$\pm 1^\circ\text{F}$		± 0.375		$\pm (0.375\% + 2^\circ\text{F})$		Chromel-Alumel Thermocouple	Digital Thermometer and Micro Processor Averaged (TTP) Digital Thermometer for Redundant (TTR)	Thermocouple verification of NBS conformity/voltage substitution calibration	
		$\pm 1^\circ\text{F}$		± 0.375		$\pm (0.375\% + 2^\circ\text{F})$					
Angle of Attack (ALPHA), deg		± 0.025 deg	0°				± 0.05 deg	Potentiometer	Digital data acquisition system/analog-to-digital converter	Heidenhain rotary encoder ROD700 Resolution: 0.0006" Overall accuracy: 0.001"	
Pitot Pressure (PP), psi		± 0.002 psi	± 0.010 psi				± 0.014 psi	Druck ± 15 psid strain gage transducers	Analog to digital converter/digital data acquisition system	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the standards laboratory	
Model Pressure (PW), psi		.00075 psi	± 1.0	> 30			$\pm (0.0015\text{ psi} + 1.0\%)$	Druck ± 1 psid strain gage transducers	Analog to digital converter/digital data acquisition system	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the standards laboratory	
		.002 psi	± 0.1	> 30			$\pm (0.004\text{ psi} + 0.1\%)$				
		.002 psi		> 30		± 0.003 psi	< 2.5 psid	ESPE 2.5 psid strain gage transducer			
Model Temperature (TW), °F		$\pm 1^\circ\text{F}$	$\pm 2.2^\circ\text{F}$	> 30			$\pm 4.2^\circ\text{F}$	Coastal surface thermocouple gage	Digital data acquisition system/analog-to-digital converter	Thermocouple verification of NBS conformity/voltage substitution calibration	
		$\pm 1^\circ\text{F}$	± 0.375	> 30			$\pm (0.375\% + 2^\circ\text{F})$				

*Reference: Abernethy, R.B. et al and Thompson, J.W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5, February 1973.

Note: + Bias assumed to be zero

TABLE 2. CONCLUDED

Parameter Designation	Steady-State Estimated Measurement*								Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index (S)			Bias (B)		Uncertainty $\pm (B + 195S)$						
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement					
Probe Height Relative to Model Surface (ZP), in.		± 0.001 in.	> 30		± 0.002 in.		± 0.004 psi	< 9.0 in.	Potentiometer and Optical	Digital data acquisition system/analog-to-digital converter	Precision Micrometer	
Survey Station (XSTA), in.		± 0.011 in.	> 30		± 0.012 in.		± 0.034 in.	< 26 in.	Potentiometer and Optical Graticule	Digital data acquisition System A/D Converter Optically Positioned Zero	Precision Micrometer	
Heat Transfer (QDOT), Btu/ft ² sec		± 0.05 Btu/ft ² sec	> 30	5		$\pm 5\%$	± 0.1 Btu/ft ² sec	< 1 Btu/ft ² sec	Coaxial surface thermocouple gage	Analog to digital converter/digital data acquisition system	Radiant heat source and secondary standard	
ERMS, mv CURRENT, ma EBAR, mv	± 0.5 ± 0.5 ± 0.5			0 + 0 + 0 +		± 1 ± 1 ± 1		< 1200 mv < 5 ma < 300 mv	Philco Ford Corp. Model #ADP-12/13 Hot-wire Anemometer System	Digital data acquisition system/analog-to-digital converter	Precision Digital Voltmeter	

*Reference: Abernethy, R.B. et al and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5, February 1973.

Note: + Bias assumed to be zero

TABLE 3 TEST RUN SUMMARY

a. Hot-Wire Boundary-Layer Measurements at Location of Maximum Disturbance Energy - Run Summary

NOMINAL X STATION RUN NUMBERS																					
RE/FT x 10 ⁴	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1.0	65	64	63	62	61	60	59	58	57	56	55	54	53	52	51	50	49	48	47	46	45
1.5	84	83	82	81	80	79	78	77	76	75	74	73	72	71	70	69					66

b. Boundary-Layer Profiles - Run Summary

RE/FT x 10 ⁻⁶	NOMINAL X STATION RUN NUMBERS											
	10		20	22	24	26	28	30	32	34	36	37
1.0	99		98					97				96
1.5	95		94	93	92	91	90	89	88	87	86	

TABLE 3. CONCLUDED
c. Model Surface Data - Run Summary

RE/FT x 10⁻⁶	Pressure and Temperature Data	Heat-Transfer Data
1.0	12, 19, 23, 24, 30, 44, 67, 100	1-4, 26, 27, 31-33
1.5	68, 85	5-9
2.0	--	10, 11

TABLE 4. ESTIMATED UNCERTAINTIES OF CALCULATED PARAMETERS

Parameter Designation	Precision Index (S)			Bias (B)		Uncertainty $\pm (B + 1.5S)$		RE/FT $\times 10^{-4}$ Nom.	MACH, Nominal
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement		
P, psi PT2, psia Q, psi T, °F V, ft/sec RHO, lbm/ft ³ MU, lbf-sec/ft ² M RE, per ft	1.23		<30	0.05		2.51		1.0	8.0
	0.85			0.05		1.75			
	0.85			0.05		1.75			
	0.36			0.24		0.96			
	0.04			0.12		0.20			
	0.88			0.25		2.02			
	0.36			0.24		0.96			
	0.19 + +			0 +		0.38			
	0.53			0.37		1.42			
P, psi PT2, psia Q, psi T, °F V, ft/sec RHO, lbm/ft ³ MU, lbf-sec/ft ² M RE, per ft	0.82		<30	0.03		1.67		1.5	8.0
	0.57			0.03		1.17			
	0.57			0.03		1.17			
	0.25			0.24		0.74			
	0.04			0.12		0.20			
	0.59			0.24		1.42			
	0.25			0.24		0.74			
	0.13 + +			0 +		0.26			
	0.36			0.37		1.09			

NOTE: + Bias assumed to be zero

+ + Determined from test section repeatability and uniformity during tunnel calibration

DATE COMPUTED 6-NOV-89
 DATE RECORDED 14-AUG-89
 TIME RECORDED 3:00:07
 TIME COMPUTED 08:01:29
 PROJECT NUMBER C010VB

CONFIG: HOLLOW CYLINDER (DIAM = 10 IN., RN = 0.0025 IN.)
 XSTA = 30.00 IN.

HYPERSONIC BOUNDARY-LAYER STABILITY

RUN NUMBER 46 PAGE 1

DATA TYPE 9
 HOT WIRE ANEMOMETER DATA

POINT	CURRENT (MAMP)	EBAR (MW)	ERMS (MW)	PT (PSIA)	TT (DEG R)	P (PSIA)	Q (PSIA)	T (DEG R)	RE (PER IN)	ZA (IN.)
1	1.000	228.22	226.30	2.240E+02	1.300E+03	2.407E-02	1.000E+00	9.810E+01	0.300E+04	3.875E-02
2	-0.001	258.84	180.54	2.236E+02	1.300E+03	2.414E-02	1.004E+00	9.817E+01	0.305E+04	4.150E-01
3	1.004	258.84	200.56	2.236E+02	1.300E+03	2.414E-02	1.004E+00	9.817E+01	0.305E+04	4.150E-01

ALPHA = 0.02 DEG XC 20.10 (IN)

MACH 7.93

PT = 224.00 PSIA P = 2.407E-02 PSIA
 TT = 1300.07 DEGR T = 9.810E+01 DEGR

Sample 1. Hot-Wire Anemometer Data

DATE COMPUTED 25-OCT-89
 DATE RECORDED 14-AUG-89
 TIME RECORDED 9:21:17
 TIME COMPUTED 07:24:55
 PROJECT NUMBER C010VB

HYPERSONIC BOUNDARY-LAYER STABILITY

RUN NUMBER 97

CONFIG: HOLLOW CYLINDER (DIAM = 10 IN., RN = 0.0025 IN.)
 XSTA = 30.00 IN.

DATA TYPE 4
 FLOW FIELD SURVEYS

POINT	PT	PT2	PT1	P	PP	PWL	TWL	ZA	ERUS
(PSIA)	(DEC R)	(PSIA)	(PSIA)	(PSIA)	(PSIA)	(PSIA)	(DEC R)	(IN)	(IN RMS)
1	224.52	1.965	0.024	0.0519	0.030	0.025	548.0	0.0777	122.581
2	224.42	1.964	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
3	224.42	1.964	0.024	0.0528	0.031	0.025	548.0	0.0777	122.581
4	224.22	1.964	0.024	0.0528	0.035	0.025	548.0	0.0777	122.581
5	224.43	1.964	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
6	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
7	224.11	1.961	0.024	0.0528	0.031	0.025	548.0	0.0777	122.581
8	224.22	1.962	0.024	0.0528	0.032	0.025	548.0	0.0777	122.581
9	224.22	1.962	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
10	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
11	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
12	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
13	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
14	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
15	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
16	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
17	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
18	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
19	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
20	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
21	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
22	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
23	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
24	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
25	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
26	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
27	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
28	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
29	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
30	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
31	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
32	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
33	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
34	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
35	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
36	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
37	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
38	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
39	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
40	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
41	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
42	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
43	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
44	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
45	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
46	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581
47	224.12	1.961	0.024	0.0528	0.034	0.025	548.0	0.0777	122.581

PHI = -0.01
 M = 7.93
 ALPHA = 0.0 DEG
 DEW = -57. DEG R

PT = 224.3
 TT = 1309.3
 PT2 = 1.962
 RE = 9.993E+05
 MU = 7.905E-06
 RHO = 6.594E-04

PSIA
 DEG R
 PER FT
 LBF-SEC/FT2
 LBM/FT3

P = 0.0240 PSIA
 PNL = 0.0245 PSIA
 TWL = 548.0 DEG R
 Y = 3851.9 FT/SEC
 Q = 98.2 PSIA
 DEG R

MEAN VALUES

Sample 2. Flow-Field Survey Data

HYPersonic BOUNDARY-LAYER STABILITY

RUN NUMBER 97

CONFIG: HOLLOW CYLINDER (DIAM = 10 IN., RN = 0.0025 IN.)
XSTA = 30.00 IN.

DATA TYPE 4
FLOW FIELD SURVEYS

LOOP	ZIP (IN)	PP/PPE	ML	ML/AE	TTL (DEG R)	TTL/TTE	TL (DEG R)	UL (FT/SEC)	UL/UE	LRE (PER IN)	LRET (PER IN)
1	519	015	01	071	649.7	496	4	781E	178	295E	295E
2	523	015	01	071	651.5	523	4	781E	177	295E	295E
3	527	016	01	076	650.1	520	4	781E	177	295E	295E
4	530	016	01	076	654.5	520	4	781E	177	295E	295E
5	536	016	01	076	661.4	520	4	781E	177	295E	295E
6	539	021	01	113	772.4	558	7	781E	182	295E	295E
7	546	026	01	132	792.2	608	7	781E	187	295E	295E
8	554	036	01	186	928.9	772	7	781E	224	295E	295E
9	558	045	01	237	978.8	835	7	781E	237	295E	295E
10	568	057	01	277	1025.7	897	7	781E	241	295E	295E
11	574	062	01	327	1059.7	915	7	781E	247	295E	295E
12	578	069	01	354	1130.4	935	7	781E	257	295E	295E
13	584	077	01	396	1247.9	997	7	781E	269	295E	295E
14	594	082	01	439	1324.9	1037	7	781E	273	295E	295E
15	604	089	01	481	1401.7	1077	7	781E	277	295E	295E
16	614	103	01	524	1478.7	1138	7	781E	287	295E	295E
17	628	117	01	567	1555.7	1199	7	781E	297	295E	295E
18	638	132	01	609	1632.7	1259	7	781E	307	295E	295E
19	648	146	01	651	1709.7	1319	7	781E	317	295E	295E
20	658	163	01	694	1786.7	1379	7	781E	327	295E	295E
21	668	177	01	737	1863.7	1439	7	781E	337	295E	295E
22	678	193	01	779	1940.7	1499	7	781E	347	295E	295E
23	684	203	01	821	2017.7	1559	7	781E	357	295E	295E
24	694	217	01	864	2094.7	1619	7	781E	367	295E	295E
25	704	232	01	906	2171.7	1679	7	781E	377	295E	295E
26	714	247	01	949	2248.7	1739	7	781E	387	295E	295E
27	724	263	01	991	2325.7	1799	7	781E	397	295E	295E
28	734	277	01	1034	2402.7	1859	7	781E	407	295E	295E
29	744	293	01	1076	2479.7	1919	7	781E	417	295E	295E
30	754	307	01	1119	2556.7	1979	7	781E	427	295E	295E
31	764	322	01	1161	2633.7	2039	7	781E	437	295E	295E
32	774	337	01	1204	2710.7	2099	7	781E	447	295E	295E
33	784	353	01	1246	2787.7	2159	7	781E	457	295E	295E
34	794	367	01	1289	2864.7	2219	7	781E	467	295E	295E
35	804	383	01	1331	2941.7	2279	7	781E	477	295E	295E
36	814	397	01	1374	3018.7	2339	7	781E	487	295E	295E
37	824	413	01	1416	3095.7	2399	7	781E	497	295E	295E
38	834	427	01	1459	3172.7	2459	7	781E	507	295E	295E
39	844	443	01	1501	3249.7	2519	7	781E	517	295E	295E
40	854	457	01	1544	3326.7	2579	7	781E	527	295E	295E
41	864	473	01	1586	3403.7	2639	7	781E	537	295E	295E
42	874	487	01	1629	3480.7	2699	7	781E	547	295E	295E
43	884	503	01	1671	3557.7	2759	7	781E	557	295E	295E
44	894	517	01	1714	3634.7	2819	7	781E	567	295E	295E
45	904	533	01	1756	3711.7	2879	7	781E	577	295E	295E
46	914	547	01	1799	3788.7	2939	7	781E	587	295E	295E
47	924	563	01	1841	3865.7	2999	7	781E	597	295E	295E
48	934	577	01	1884	3942.7	3059	7	781E	607	295E	295E
49	944	593	01	1926	4019.7	3119	7	781E	617	295E	295E
50	954	607	01	1969	4096.7	3179	7	781E	627	295E	295E
51	964	623	01	2011	4173.7	3239	7	781E	637	295E	295E
52	974	637	01	2054	4250.7	3299	7	781E	647	295E	295E
53	984	653	01	2096	4327.7	3359	7	781E	657	295E	295E
54	994	667	01	2139	4404.7	3419	7	781E	667	295E	295E
55	1004	683	01	2181	4481.7	3479	7	781E	677	295E	295E
56	1014	697	01	2224	4558.7	3539	7	781E	687	295E	295E
57	1024	713	01	2266	4635.7	3599	7	781E	697	295E	295E
58	1034	727	01	2309	4712.7	3659	7	781E	707	295E	295E
59	1044	743	01	2351	4789.7	3719	7	781E	717	295E	295E
60	1054	757	01	2394	4866.7	3779	7	781E	727	295E	295E
61	1064	773	01	2436	4943.7	3839	7	781E	737	295E	295E
62	1074	787	01	2479	5020.7	3899	7	781E	747	295E	295E
63	1084	803	01	2521	5097.7	3959	7	781E	757	295E	295E
64	1094	817	01	2564	5174.7	4019	7	781E	767	295E	295E
65	1104	833	01	2606	5251.7	4079	7	781E	777	295E	295E
66	1114	847	01	2649	5328.7	4139	7	781E	787	295E	295E
67	1124	863	01	2691	5405.7	4199	7	781E	797	295E	295E
68	1134	877	01	2734	5482.7	4259	7	781E	807	295E	295E
69	1144	893	01	2776	5559.7	4319	7	781E	817	295E	295E
70	1154	907	01	2819	5636.7	4379	7	781E	827	295E	295E
71	1164	923	01	2861	5713.7	4439	7	781E	837	295E	295E
72	1174	937	01	2904	5790.7	4499	7	781E	847	295E	295E
73	1184	953	01	2946	5867.7	4559	7	781E	857	295E	295E
74	1194	967	01	2989	5944.7	4619	7	781E	867	295E	295E
75	1204	983	01	3031	6021.7	4679	7	781E	877	295E	295E
76	1214	997	01	3074	6098.7	4739	7	781E	887	295E	295E
77	1224	1013	01	3116	6175.7	4799	7	781E	897	295E	295E
78	1234	1027	01	3159	6252.7	4859	7	781E	907	295E	295E
79	1244	1043	01	3201	6329.7	4919	7	781E	917	295E	295E
80	1254	1057	01	3244	6406.7	4979	7	781E	927	295E	295E
81	1264	1073	01	3286	6483.7	5039	7	781E	937	295E	295E
82	1274	1087	01	3329	6560.7	5099	7	781E	947	295E	295E
83	1284	1103	01	3371	6637.7	5159	7	781E	957	295E	295E
84	1294	1117	01	3414	6714.7	5219	7	781E	967	295E	295E
85	1304	1133	01	3456	6791.7	5279	7	781E	977	295E	295E
86	1314	1147	01	3499	6868.7	5339	7	781E	987	295E	295E
87	1324	1163	01	3541	6945.7	5399	7	781E	997	295E	295E
88	1334	1177	01	3584	7022.7	5459	7	781E	1007	295E	295E
89	1344	1193	01	3626	7099.7	5519	7	781E	1017	295E	295E
90	1354	1207	01	3669	7176.7	5579	7	781E	1027	295E	295E
91	1364	1223	01	3711	7253.7	5639	7	781E	1037	295E	295E
92	1374	1237	01	3754	7330.7	5699	7	781E	1047	295E	295E
93	1384	1253	01	3796	7407.7	5759	7	781E	1057	295E	295E
94	1394	1267	01	3839	7484.7	5819	7	781E	1067	295E	295E
95	1404	1283	01	3881	7561.7	5879	7	781E	1077	295E	295E
96	1414	1297	01	3924	7638.7	5939	7	781E	1087	295E	295E
97	1424	1313	01	3966	7715.7	5999	7	781E	1097	295E	295E
98	1434	1327	01	4009	7792.7	6059	7	781E	1107	295E	295E
99	1444	1343	01	4051	7869.7	6119	7	781E	1117	295E	295E
100	1454	1357	01	4094	7946.7	6179	7	781E	1127	295E	295E

PPE	=	2.000E+00	PSIA
ME	=	7.933E+00	DEG R
TTE	=	1.310E+03	FT/SEC
UE	=	0.302E+04	

UES
TWL/YTE = 0.4184
PWL = 0.024
TWL = 540.0

M = 7.93
 ALPHA = 0.0 DEG
 PHJ = -0.01

Sample 2. (Continued)

DATE COMPUTED 25-OCT-88
 DATE RECORDED 14-AUG-88
 TIME RECORDED 9:24:17
 TIME COMPUTED 9:24:55
 PROJECT NUMBER C018V8

HYPERSONIC BOUNDARY-LAYER STABILITY

RUN NUMBER 97

CONFIG: HOLLOW CYLINDER (DIAM = 10 IN., RN = 0.0025 IN.)
 XSTA = 30.00 IN.

DATA TYPE 4
 MODEL SURFACE MEASUREMENTS

TAP	X (IN)	THETA (DEG)	PW (PSIA)	PW/P	T/C	X (IN)	THETA (DEG)	TW (DEG R)	TW/TT
1	37.721	15	0.0462	1.0229	1	6.986	345	548.4	0.418
2	38.715	15	0.0515	2.1447	3	7.982	345	548.5	0.417
3	40.712	15	0.0430	1.0276	3	15.980	345	548.6	0.416
4	42.724	15	0.0318	1.3208	4	17.978	345	548.7	0.416
5	43.700	15	0.0291	1.2122	5	19.972	345	548.8	0.416
6	45.710	15	0.0300	1.2056	6	21.968	345	548.9	0.416
7	46.720	15	0.0283	1.2407	7	23.966	345	549.0	0.415
8	47.723	00	0.0275	1.1811	8	25.961	345	549.1	0.415
9	48.723	00	0.0292	1.1454	9	27.956	345	549.2	0.415
10	49.723	00	0.0278	1.2106	10	29.952	345	549.3	0.415
11	50.723	00	0.0273	1.1506	11	31.947	345	549.4	0.415
12	51.723	00	0.0284	1.3779	12	33.942	345	549.5	0.415
13	52.723	00	0.0259	1.1077	13	35.937	345	549.6	0.415
14	53.723	100	0.0275	1.0742	14	37.932	345	549.7	0.415
15	54.723	100	0.0289	1.1442	15	39.927	345	549.8	0.415
16	55.723	100	0.0280	1.2029	16	41.922	345	549.9	0.415
17	56.723	100	0.0284	1.2029	17	43.917	345	550.0	0.415
18	57.723	100	0.0266	1.1001	18	45.912	345	550.1	0.415
19	58.723	100	0.0247	1.3041	19	47.907	345	550.2	0.415
20	59.723	270	0.0279	1.1641	20	49.902	345	550.3	0.415
21	60.723	270	0.0285	1.1800	21	51.897	345	550.4	0.415
22	61.723	270	0.0262	1.2509	22	53.892	345	550.5	0.415
23	62.723	270	0.0280	1.2003	23	55.887	345	550.6	0.415
24	63.723	270	0.0262	1.1742	24	57.882	345	550.7	0.415
25	64.723	270	0.0258	1.1742	25	59.877	345	550.8	0.415
26	65.723	270	0.0258	1.0516	26	61.872	345	550.9	0.415

ALPHA = 0.0 DEG
 PHI = 0.0 DEG
 XC = 30.000

PT = 224.2 PSIA
 TT = 1389.3 DEG R
 RE = 7.335E+06 /FT

TORQ = 554.7 DEG R
 T = 0.240 PSIA
 T = 0.2344 DEG R

Sample 2. (Continued)

DATE COMPUTED 25-OCT-89
 DATE RECORDED 14-AUG-89
 TIME RECORDED 9:2:17
 TIME COMPUTED 87:24:55
 PROJECT NUMBER C016VB

HYPERSONIC BOUNDARY-LAYER STABILITY

RUN NUMBER 97

CONFIG: HOLLOW CYLINDER (DIAM = 10 IN., RH = 0.0025 IN.)
 XSTA = 30.00 IN.

DATA TYPE 4
 INTEGRAL EVALUATION

LOOP	ZP/DEL	PP/PPD	ML/MD	TTL/TTD	TL/TD	RHOL/RHOD	UL/AU	MUTL/MUTD	LRE/LRED	DITTL/DITTD	LRET/LRED
1	1.205E+01	1.841E+02	7.771E+02	4.833E+01	2.78E+00	1.895E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
2	1.461E+01	1.842E+02	7.867E+02	5.175E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
3	1.905E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
4	2.207E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
5	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
6	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
7	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
8	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
9	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
10	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
11	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
12	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
13	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
14	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
15	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
16	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
17	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
18	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
19	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
20	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
21	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
22	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
23	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
24	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
25	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
26	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
27	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
28	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
29	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
30	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
31	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
32	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
33	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
34	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
35	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
36	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
37	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
38	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
39	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
40	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
41	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
42	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
43	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
44	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
45	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
46	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02
47	3.337E+01	1.842E+02	8.033E+02	5.227E+01	3.40E+00	1.873E+01	7.85E+00	4.93E+00	7.44E+03	1.275E+01	4.85E+02

VALUES AT DELTA

DEL = 4.303E-01 IN
 DEL.. = 3.088E-01 IN
 DEL.. = 1.394E-02 IN
 LRED = 6.031E+04 PER IN

M = 7.93 DEC
 ALPHA = 0.0 DEC
 PHI = -0.01

RHOD = 5.710E-04 LBM/FT3
 RHOD.. = 2.171E+00 LBM/SEC-FT2
 MUTD = 0.326E-09 BPU/LBM
 DITTD = 1.935E+02 PER IN
 LRED = 7.857E+03 PER IN

Sample 2. (Concluded)

DATE COMPUTED 14-AUG-89
DATE RECORDED 14-AUG-89
TIME RECORDED 5:50:56
TIME COMPUTED 05:51:05
PROJECT NUMBER C010V8

HYPERSONIC BOUNDARY-LAYER STABILITY
RUN NUMBER 85 PAGE 1

CONFIG: HOLLOW CYLINDER (DIAM = 10 IN., RN = 0.0025 IN.)
XSTA = 0.00 IN.

DATA TYPE 2
MODEL SURFACE MEASUREMENTS

TAP	X (IN)	THETA (DEG)	PW (PSIA)	PW/P	T/C	X (IN)	THETA (DEG)	TW (DEG R)	TW/TT
1	37.721	15	0.9655	0.9655	1	0.946	345	0.418	
3	38.715	15	0.9378	1.0379	2	7.942	345	0.417	
4	42.224	15	0.9378	1.0379	3	15.940	345	0.417	
5	43.769	15	0.9378	0.9773	4	15.940	345	0.417	
6	45.216	15	0.9378	1.0379	5	17.938	345	0.418	
7	46.728	15	0.9378	1.0379	6	17.938	345	0.418	
8	47.236	15	0.9378	1.0379	7	19.932	345	0.418	
9	47.743	15	0.9378	1.0379	8	21.928	345	0.418	
10	8.971	90	0.9378	1.0379	9	23.924	345	0.418	
11	11.973	90	0.9378	1.0379	10	24.924	345	0.418	
12	18.968	90	0.9378	1.0379	11	25.924	345	0.418	
13	18.968	90	0.9378	1.0379	12	26.924	345	0.418	
14	28.971	90	0.9378	1.0379	13	27.924	345	0.418	
15	28.971	90	0.9378	1.0379	14	28.924	345	0.418	
16	8.971	180	0.9378	1.0379	15	30.924	345	0.418	
17	11.968	180	0.9378	1.0379	16	31.924	345	0.418	
18	19.971	180	0.9378	1.0379	17	32.924	345	0.418	
19	25.974	180	0.9378	1.0379	18	33.924	345	0.418	
20	28.969	180	0.9378	1.0379	19	34.924	345	0.418	
21	7.970	270	0.9378	1.0379	20	35.924	345	0.418	
22	9.967	270	0.9378	1.0379	21	36.924	345	0.418	
23	11.966	270	0.9378	1.0379	22	37.924	345	0.418	
24	18.970	270	0.9378	1.0379	23	38.924	345	0.418	
25	25.971	270	0.9378	1.0379	24	39.924	345	0.418	
26	28.973	270	0.9378	1.0379	25	40.924	345	0.418	
28	28.973	270	0.9378	1.0379	26	41.924	345	0.418	
					27	42.924	345	0.418	

TDRK = 550.7 DEG R
P = 0.6356 PSIA
Y = 97.8101 DEG R

PT = 338.6 PSIA
TT = 1310.7 DEG R
W = 7.958
RE = 0.156E+07 /FT

ALPHA = 0.0 DEG
PHI = 0.0 DEG

XC = 23.418

Sample 3. Model Surface Measurements

DATE COMPUTED: 4-AUG-89
 TIME COMPUTED: 02:48:07
 DATE RECORDED: 4-AUG-89
 TIME RECORDED: 2:45:26
 000000129

DATE COMPUTED: 4-AUG-89
 TIME COMPUTED: 02:48:07
 DATE RECORDED: 4-AUG-89
 TIME RECORDED: 2:45:26
 000000129

PAGE 1

HYPERSONIC 0.1 STABILITY VLL
 PROJECT NUMBER: C124VB

RUN NUMBER 5

DATA TYPE: SURFACE HEAT TRANSFER

HOLLOW CYLINDER (DIAM=10.0 IN.. RN=0.002 IN.)

GAGE NO.	X IN.	THETA DEG.	QDOT BTU/FT2-SEC	TM DEG R	HTU/FT2-SEC-R	ST(TT)
1	7.00	345.	0.266	541.35	3.45E-04	3.80E-04
2	7.98	345.	0.254	540.88	3.28E-04	3.47E-04
3	15.98	345.	0.189	540.89	2.45E-04	2.85E-04
4	16.98	345.	0.180	541.16	2.34E-04	2.47E-04
5	17.98	345.	0.150	541.13	1.95E-04	2.07E-04
6	19.97	345.	0.173	540.62	2.24E-04	2.30E-04
7	21.97	345.	0.182	540.83	2.38E-04	2.50E-04
8	22.99	345.	0.175	540.82	2.28E-04	2.41E-04
9	23.98	345.	0.156	540.57	2.03E-04	2.15E-04
10	24.97	345.	0.184	540.69	2.39E-04	2.53E-04
11	25.97	345.	0.177	540.57	2.30E-04	2.42E-04
12	26.98	345.	0.180	541.04	2.47E-04	2.61E-04
13	27.97	345.	0.212	541.30	2.75E-04	2.91E-04
14	28.97	345.	0.211	541.30	2.75E-04	2.91E-04
15	29.97	345.	0.243	542.19	3.17E-04	3.35E-04
16	31.97	345.	0.282	541.42	3.67E-04	3.87E-04
17	32.97	345.	0.312	541.30	4.28E-04	4.28E-04
18	33.96	345.	0.327	541.29	4.50E-04	4.50E-04
19	34.95	345.	0.362	541.72	4.71E-04	4.91E-04
20	35.96	345.	0.360	541.96	4.95E-04	5.23E-04
21	36.97	345.	0.413	541.56	5.30E-04	5.69E-04
22	37.97	345.	0.438	542.00	5.70E-04	6.03E-04
23	38.96	345.	0.438	542.12	5.70E-04	6.03E-04
24	39.96	345.	0.472	542.17	6.15E-04	6.51E-04
25	40.96	345.	0.526	542.13	6.77E-04	7.16E-04
26	41.96	345.	0.526	542.13	6.86E-04	7.23E-04
27	42.96	345.	0.526	542.13	6.86E-04	7.23E-04

PHI = -0.02 DEG
 M = 7.96
 ALPHA = -0.03 DEG
 DEW = -757.00 DEG.F

PI = 340.11 PSIA
 TI = 1309.67 DEG.R
 P = 1.50E+04 PSIA
 RE = 1.50E+06 PER FT
 MU = 7.85E-08 LBF-SEC/FT2

V = 3056.98 FT/SEC
 Q = 1.583 PSIA
 T = 97.84 DEG.R
 PT2 = 2.84 PSIA
 RHO = 9.857E-04 LBM/FT3

RUN NUMBER 5

Sample 4. Model Surface Heat-Transfer Data