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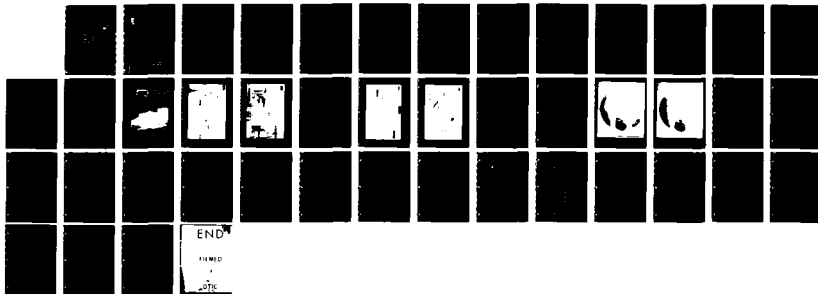
SUPERSONIC AND SUBSONIC WIND TUNNEL HEAT-TRANSFER
MEASUREMENTS IN THE BAS. (U) ARNOLD ENGINEERING
DEVELOPMENT CENTER ARNOLD AFS TN W R HAWKINS ET AL.
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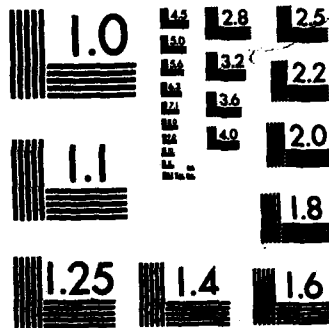
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SUPERSONIC AND SUBSONIC WIND TUNNEL HEAT-TRANSFER
MEASUREMENTS IN THE BASE CAVITY REGION OF THE
SHUTTLE SOLID ROCKET BOOSTER DURING SIMULATED REENTRY

W. R. Hawkins and K. W. Nutt
Calspan Field Services, Inc.

September 1982

Final Report for Period August 16-20, 1982

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Aeronautical Systems Branch
Deputy for Operations

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FOR THE COMMANDER

J. M. Rampy
JOHN M. RAMPY, Director
Aerospace Flight Dynamics Testing
Deputy for Operations

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Tests were conducted on the aft section of the Space Shuttle Solid Rocket Booster at Mach numbers 3.75 and 0.5 at selected angles of attack from 90-180 deg simulating reentry attitudes. The tests were conducted in the AEDC Supersonic Wind Tunnel A to obtain heat-transfer coefficients in the base cavity region.		

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NOMENCLATURE

A0	Intercept of linear curve fit (see Eq. 7)
A1	Slope of linear curve fit (see Eq. 8)
ALPB1	Model sting prebend angle, deg (see Fig. 4)
ALPB2	Model adaptor prebend angle, deg (see Fig. 4)
ALPHA	Model angle of attack, deg (see Fig. 4)
ALPI	Indicated sector pitch angle, deg
C1	Gardon gage calibration factor measured at 530°R, Btu/ft ² -sec/mv
C2	Temperature corrected Gardon gage calibration factor, Btu/ft ² -sec/mv (see Eq. 1)
CONFIGURATION	Model configuration designation (see Fig. 5)
DEL	Angle between cylinder local stagnation line and gage or pressure tap
E	Gardon gage output, mv
H-BG, HBG	Reference heat-transfer coefficient on a yawed cylinder of radius 2.19 in. as determined by the Beckwith-Gallagher Method (see Appendix V, Eq. 1) Btu/ft ² -sec-°R
H(TAW)	Heat-transfer coefficient determined from curve-fit of measured heat-flux and wall temperature, Btu/ft ² -sec-°R (see Eq. 8)
H(TT)	Heat-transfer coefficient based on TT, QDOT/(TT-TW), Btu/ft ² -sec-°R
GAGE NUMBER	Gage number designation (see Table 3)
KG	Gardon gage temperature calibration factor, °R/mv
LAMDA	Angular complement of ALPHA, deg ALPHA-90
M, MACH NUMBER	Free-stream Mach number
MU, Mu	Dynamic viscosity based on free-stream temperature, lbf-sec/ft ²
n	Number of points used for linear least-squares curve fit of QDOT versus TW
P	Free-stream static pressure, psia
PHI	Model roll angle, deg
PM	Measured model pressure, psia
PSKT	Average of the four aft skirt measured internal pressures, psia
PT	Tunnel stilling chamber pressure, psia

PT2	Total pressure downstream of a normal shock, psia
Q	Free-stream dynamic pressure, psia
QDOT	Heat transfer rate, Btu/ft ² -sec
R2	Linear regression coefficient
RE	Free-stream Reynolds number, ft ⁻¹
RHO	Free-stream density, lbm/ft ³
RUN	Data set identification number
ST(TAW)	Computed Stanton number based on TAW, assumes specific heat of air constant, $ST(TAW) = \frac{H(TAW)}{(.24)(RHO)(V)}$
T	Free-stream static temperature, °R
TAP NUMBER	Pressure orifice identification number
TAW	Computed adiabatic wall temperature at each gage location from extrapolation of curve-fit to zero heat flux, °R (see Fig. 8)
TE	Static temperature at boundary-layer edge, °R (see Appendix V, Eq. 4)
TGDEL	Temperature differential between the center and the edge of the Gardon gage disc, °R
TGE	Gardon gage edge temperature, °R
THB	Angular location of model instrumentation measured from + Z in the model fixed coordinate system (see Fig. 7)
THIGH	Highest temperature for which the heating rate versus TW/TT curve was fit, °R
TLOW	Lowest temperature for which the heating rate versus TW/TT curve was fit, °R
TT	Tunnel stilling chamber temperature, °R or °F
TW	Gage surface temperature, °R (see Eq. 3)
V	Free-stream velocity, ft/sec
Y,Z	Orthogonal fixed body axis system directions (see Fig. 7)

1.0 INTRODUCTION

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E02, Control Number 9E02, at the request of National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Huntsville, Alabama, for Remtech, Inc., Huntsville, Alabama. The NASA project managers were Ed Brewer and Peter Sulyma and the Remtech project engineers were Leroy Hair and Carl Engel. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The tests were performed in the Supersonic Wind Tunnel A in the von Karman Gas Dynamics Facility during the period from August 16, 1982 through August 20, 1982, under AEDC Project Number C742VA, (Calspan Project Number V41A-1R).

The primary objective of this test was to determine the internal heating environment on the shuttle solid rocket booster (SRB) skirt base cavity region during simulated reentry conditions.

Data were obtained at Mach numbers 3.75 and 0.5 on a 3-percent scale SRB model at free-stream unit Reynolds numbers of 4.2×10^6 and 3.4×10^6 , respectively. Runs were conducted at selected angles of attack and roll angles both with and without the nozzle extension.

To increase the temperature difference between the model surface and the recovery temperature, the model was cooled prior to injection during the supersonic phase using the Tunnel A vortex cooling system. The tunnel was operated with the maximum stagnation temperature available (280°F). During the subsonic phase the direction of heat transfer was reversed to take advantage of an increased driving potential, $TT-TW$. The Tunnel A auxiliary mass flow system was used to heat the model to approximately 280°F prior to injection. The tunnel was operated at a stagnation temperature of nominally 100°F .

A summary of the test data transmitted to the sponsor (NASA/MSFC) and the user (REMTECH) is presented in Table 1. Inquiries to obtain copies of the test data should be directed to NASA-MSFC, ED33, Huntsville, Alabama 35812. A microfilm record of the final tabulated data has been retained at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel A (Fig. 1) is a continuous, closed-circuit, variable density wind tunnel with an automatically driven flexible-plate-type nozzle and a 40- by 40-in. test section. The tunnel normal operating range is from Mach 1.5 to 6 at maximum stagnation pressures from 29 to 200 psia, respectively, and stagnation temperatures up to 750°R at Mach number 6.

Minimum operating pressures range from about one-tenth to one-twentieth of the maximum at each Mach number. 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.

Although primarily a supersonic tunnel, Tunnel A can also be operated at subsonic Mach numbers to 0.8 by reducing the diffuser area until choking occurs at this point. The stagnation pressure for the present test was approximately 17 psia. A description of the tunnel and airflow calibration information may be found in the Test Facilities Handbook, Ref. 1.

2.2 TEST HARDWARE

Figure 2 is a photograph of the 3-percent scale model of the aft 40 percent of the SRB installed in the Tunnel A test section. Figure 3 shows the SRB model and the heating/cooling manifold installed in the Tunnel A tank. Figure 4 is the tunnel installation sketch showing the location of the sting prebend angles. The model was constructed of 17-4 stainless steel and supplied to AEDC by NASA/MSFC. The heat-transfer gages were installed at the AEDC. Three configurations were tested. These consisted of the short nozzle, the long nozzle and the short nozzle with the Nevins barrier (see Fig. 5). The intent of the Nevins barrier is to reduce heating in the skirt cavity during reentry.

2.3 TEST INSTRUMENTATION

The measuring devices, recording devices, and calibration methods used for all measured parameters are listed in Table 2a along with the estimated measurement uncertainties. Heat-transfer rate measurements were obtained with thermopile Gardon gages which were supplied and calibrated by the AEDC. The thermopile gage utilizes vapor-deposited layers of antimony and bismuth to form a thermopile on the back surface of the sensing foil. Gage sizes of 1/4 in. and 1/8 in. with sensing foil thicknesses of 0.01 in. and 0.005 in., respectively, were used. The gages were instrumented with Iron-Constantan thermocouples which provided the gage edge temperature measurement. Gage edge temperatures together with the thermopile output were used to determine the gage surface temperatures and corresponding gage heat-transfer rate. These data were then used to compute the local heat-transfer coefficient. A total of 32 Gardon® gages were installed in the model. A photograph showing the general gage arrangement for the short nozzle configuration is shown in Fig. 6. A sketch showing the general arrangement of the model instrumentation is presented in Fig. 7 and body locations are shown in Table 3.

Surface pressure on the model and the tunnel nozzle wall static were measured with the standard Tunnel A pressure system. The system is equipped with 15-psid, Bell and Howell transducers which are referenced to a near vacuum.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

A summary of the nominal test conditions at each Mach number is given below.

<u>M</u>	<u>PT, psia</u>	<u>TT, °F</u>	<u>P, psia</u>	<u>RE x 10⁻⁶/ft</u>
3.75	64	280	0.6	4.2
0.5	17	100	14.4	3.4

A test summary showing all configurations tested and the variables for each is presented in Table 4.

3.2 TEST PROCEDURES

In the AEDC continuous flow wind tunnels (A, B, C), 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 model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. A given injection cycle is termed a run, and all the data are identified in the data tabulations by a run number.

The test procedure was as follows:

1. During the supersonic test phase (M = 3.75) the model was cooled with an air distribution manifold (see Fig. 3) ensuring that the temperature was approximately 50°F and all gage edge thermocouples were within ±20°F of each other as judged by a video display of the temperature data.
2. The model was then injected at the desired test attitude, taking about 13 sec to reach the tunnel centerline and another 6 sec to travel to the forward test section.
3. At lift-off, a single loop of data was recorded followed by an 11-sec delay before data taking was resumed at approximately two-sec intervals until the model reached the full forward position. Subsequent single loops of data were taken at controlled time intervals as the measured heating rate decreased with time. (Nominally 90 sec).
4. The model was then retracted and the data recording was terminated. After each test run the model was cooled and prepared for a subsequent injection.

5. During the subsonic test phase ($M = 0.50$) the test procedure was identical except that the model was heated using the auxiliary mass flow system and the manifold distribution system described for the supersonic phase. The model was heated to approximately 280°F and the total temperature in the tunnel was maintained at nominally 100°F .

3.3 DATA REDUCTION

All free-stream parameters were computed assuming a perfect gas isentropic expansion from the tunnel stilling chamber and utilizing the measured pressure and temperature in the stilling chamber and the calibrated Mach number in the test section. Subsonically, the Mach number was determined by the ratio of tunnel stilling chamber and test section static pressure.

The thermopile Gardon gages used in the model are direct reading heat-flux transducers whose output may be converted to heating rate by means of a scale factor (see Table 5). The thermopile Gardon gage scale factor has been found to be a function of temperature, and therefore must be corrected for gage temperature changes according to the following equation.

$$C2 = C1 [4.72878 - (2.83765 \times 10^{-2})(\text{TGE}) + (7.82707 \times 10^{-5})(\text{TGE})^2 - (9.44869 \times 10^{-8})(\text{TGE})^3 + (4.30151 \times 10^{-11})(\text{TGE})^4] \quad (1)$$

The heat flux to the thermopile gage can be calculated for any data point by the following equation:

$$\text{QDOT} = (E)(C2) \quad (2)$$

The gage wall temperature is given by

$$\text{TW} = \text{TGE} + 0.75 \text{ TGDEL} \quad (3)$$

where the factor 0.75 represents the average, or integrated, value across the gage and

$$\text{TGDEL} = (\text{KG})(E) \quad (4)$$

The "optional" Gardon gage data reduction procedure was used to compute the heat-transfer coefficient. This technique provides a method for extrapolating to adiabatic wall temperature. This is important in Tunnel A where the difference between the model wall temperature and the adiabatic wall temperature is small. This small temperature difference causes the calculation of the heat-transfer coefficient to be sensitive to deviations from the actual adiabatic wall temperature. The special data reduction procedure is based on the concept that

$$h(\text{TAW}) = \frac{\text{QDOT}}{\text{TAW} - \text{TW}} \quad (5)$$

where $H(TAW)$ is assumed to be constant. Rearranging Equation (5) gives

$$QDOT = [H(TAW)][TAW] - [H(TAW)][TW] \quad (6)$$

where $[H(TAW)][TAW]$ is a constant. Therefore, Equation (6) can be written in the form of a straight line

$$QDOT = A0 + A1(TW) \quad (7)$$

Since $A0$ and $A1$ are constant, a comparison of Equations (6) and (7) gives

$$H(TAW) = -A1 \quad (8)$$

Setting $QDOT = 0$ in Equation (7) and solving for TW leads to the following relationship:

$$TAW = \frac{-A0}{A1} \quad (9)$$

The actual steps in the data reduction procedure are to obtain a linear curve fit of $QDOT$ versus TW for each gage (a typical plot is shown in Fig. 8) and evaluate $A0$ and $A1$ in Equation (7). The quality of the curve fit is verified by examining the plotted data on a graphics display terminal. When the curve fit has been verified, the heat transfer coefficient can be calculated from Equation (8) and the adiabatic wall temperature can be determined from Equation (9). The value of TAW is checked to see if it is within the following range:

$$0.8 \leq \frac{TAW}{TT} \leq 1.01 \quad (10)$$

If Equation (10) is not satisfied, an asterisk is printed next to the value of TAW in the tabulated data.

The Stanton number based on adiabatic wall temperature may then be calculated by assuming a constant specific heat for air by:

$$ST(TAW) = \frac{H(TAW)}{(.24)(RHO)(V)} \quad (11)$$

Appendix V contains a theoretical method (Ref. 2) for computing the stagnation-line heat-flux to a yawed cylinder. This method was used as the reference value for the experimentally derived heating coefficients. Representative plots are shown in Appendix IV.

A linear regression coefficient ($R2$) was used to indicate the quality of curve fit for the $QDOT$ versus TW plots where

$$QDOT = A0 + (A1)(TW)$$

The linear regression coefficient is defined by:

$$R^2 = \frac{\left[\sum (QDOT)_i (TW)_i - \frac{\sum (QDOT)_i \sum (TW)_i}{n} \right]^2}{\left[\sum (TW)_i^2 - \frac{(\sum (TW)_i)^2}{n} \right] \left[\sum (QDOT)_i^2 - \frac{(\sum (QDOT)_i)^2}{n} \right]} \quad (12)$$

The closer this value approaches 1.0, the better the quality of curve fit indicated.

In certain instances of very low heating, a valid linear curve fit could not be determined using the "optional" Gardon gage technique. In these cases, the "standard" Gardon gage heat-transfer coefficient was calculated by averaging 5 loops of measured QDOT and gage-edge temperature after full-forward was attained. In this case:

$$H(TAW) = H(TT) = \frac{QDOT}{TT-TW}, \text{ Btu/ft}^2\text{-sec-}^\circ\text{R}$$

These gages are annotated with an A in the Tabulated Data.

3.4 UNCERTAINTY OF MEASUREMENTS

In general, instrumentation calibrations and data uncertainty estimates were made using methods recognized by the National Bureau of Standards (NBS). Measurement uncertainty is a combination of bias and precision errors defined as:

$$U = \pm(B + t_{95}S) \quad (13)$$

where B is the bias limit, S is the sample standard deviation and t_{95} is the 95th percentile point for the two-tailed Student's "t" distribution (95-percent confidence interval), which for sample sizes greater than 30 is taken equal to 2.

Estimates of the measured data uncertainties for this test are given in Table 2a. The data uncertainties for the measurements are determined from in-place calibrations through the data recording system and data reduction program.

Propagation of the bias and precision errors of measured data through the calculated data was made in accordance with Ref. 3 and the results are given in Table 2b.

4.0 DATA PACKAGE PRESENTATION

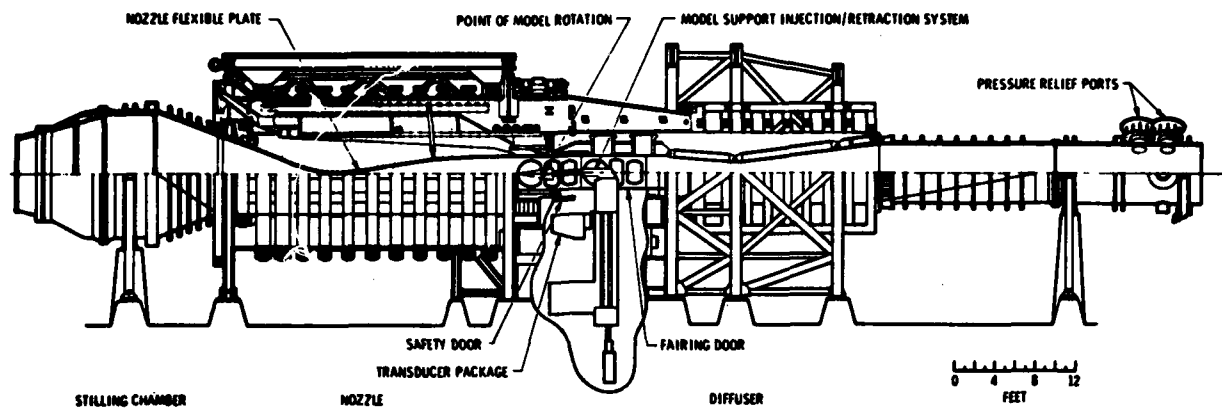
Sample data tabulations are presented in Appendix III. In addition to the tunnel conditions, the measured adiabatic wall temperatures (TAW) and calculated heating coefficients H(TAW) are tabulated for each run. The model pressure data are included for each run to aid in evaluating the calculated heating coefficients. In addition, shadow-graphs were taken of each run to aid in the flow-field determination. Representative examples of these data are presented in Fig. 9.

During model testing some gages became inoperative. These gages are labeled as inoperative on the tabulated data.

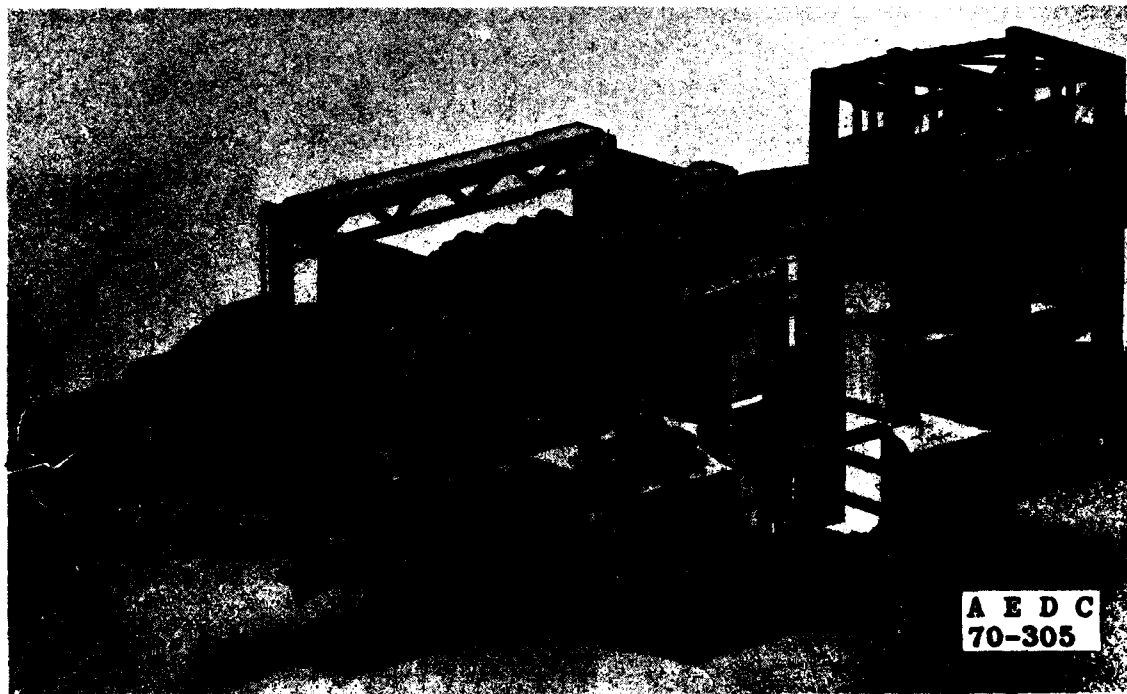
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1. Test Facilities Handbook (Eleventh Edition). "Von Karman Gas Dynamics Facility Vol. 3". Arnold Engineering Development Center, April 1981.
2. Beckwith, I. E. and Gallagher, J. J. "Local Heat Transfer and Recovery Temperatures on a Yawed Cylinder at a Mach Number of 4.15 and High Reynolds Numbers," NASA TR R-104, 1961.
3. Abernethy, R. B., Thompson, J. W., et al. "Handbook of Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 (AD755356), February 1973.

APPENDIX I
ILLUSTRATIONS



a. Tunnel assembly



**b. Tunnel test section
Fig. 1 Tunnel A**

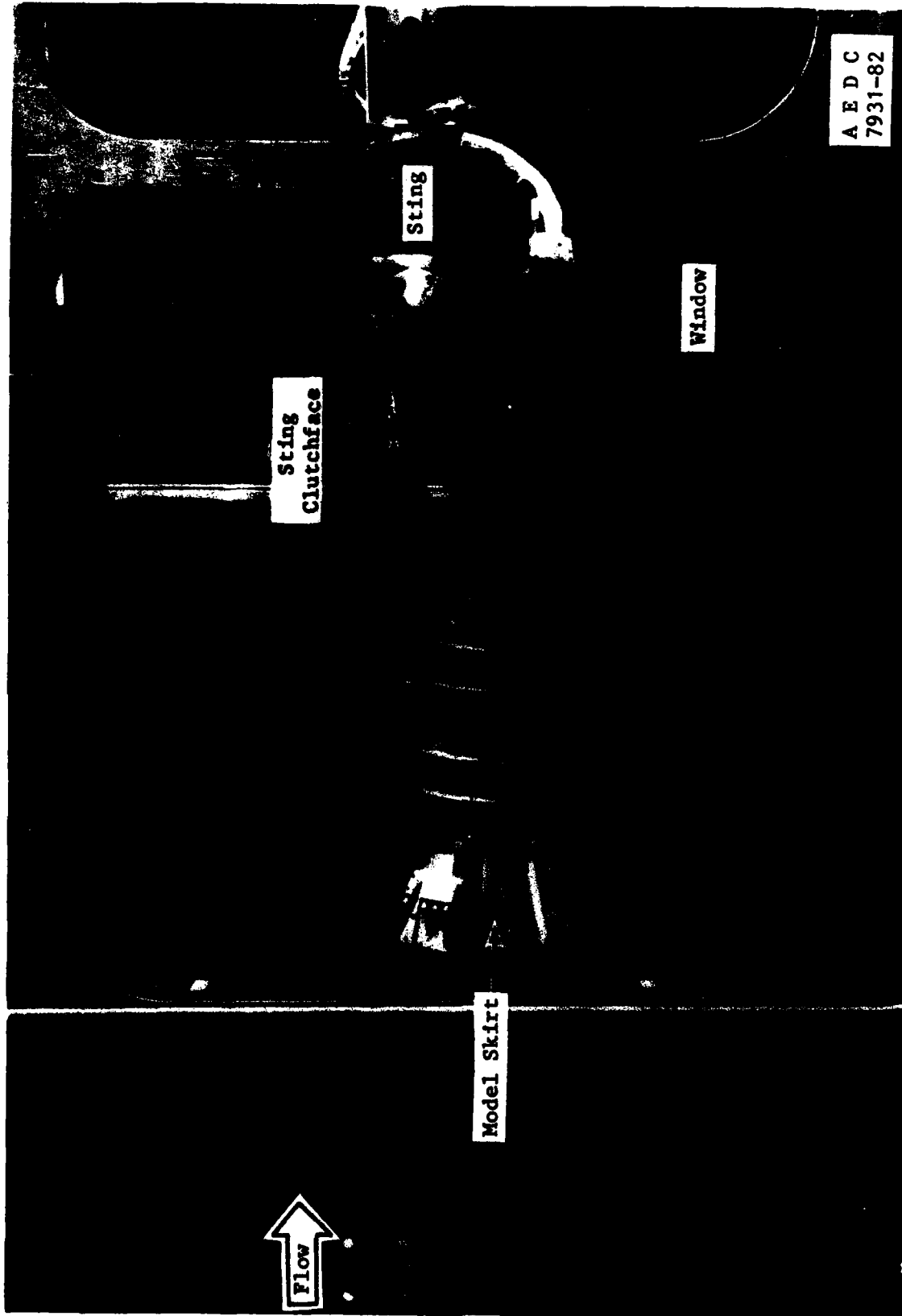


Figure 2. Shuttle Solid Rocket Booster Model in Tunnel A

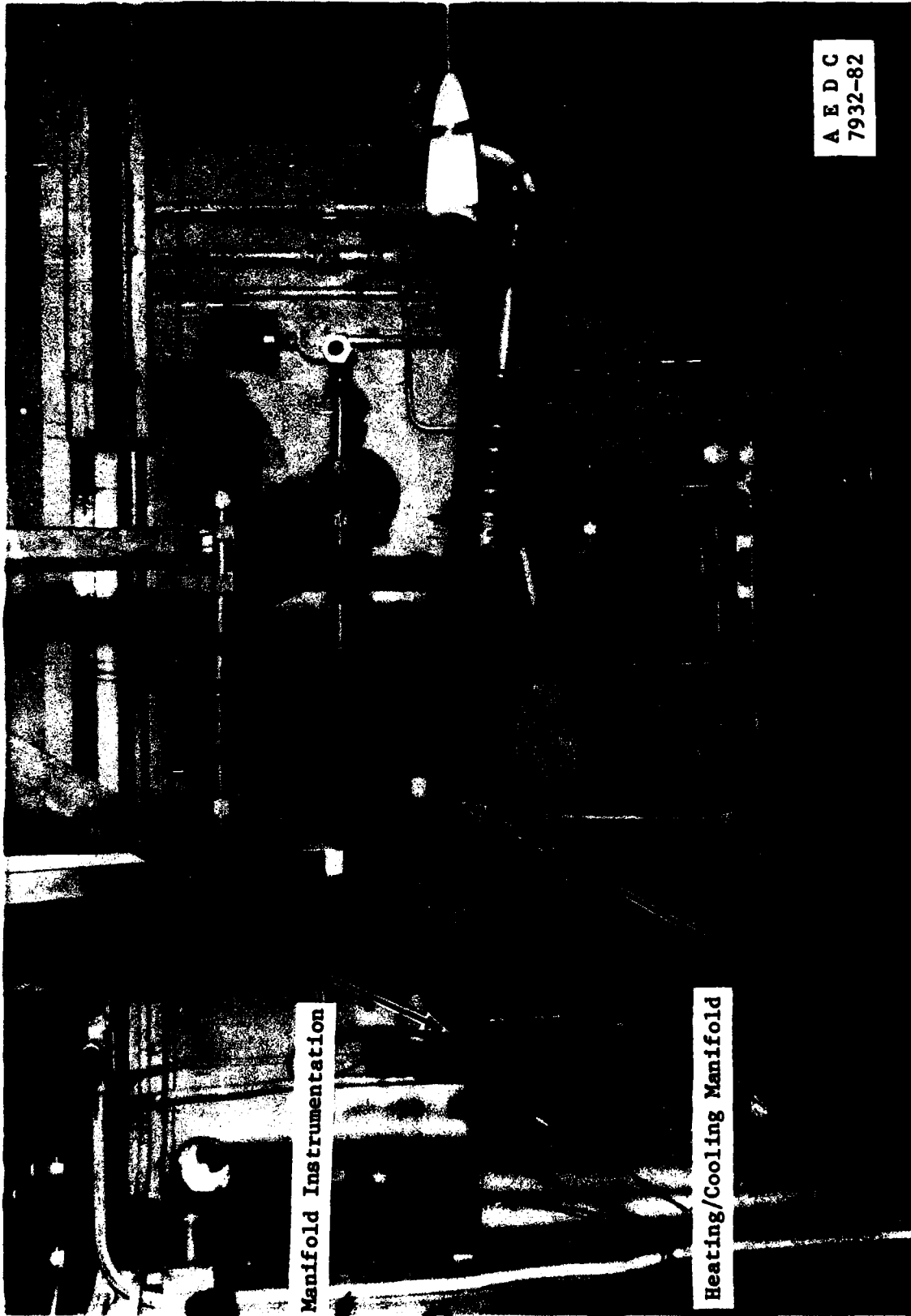
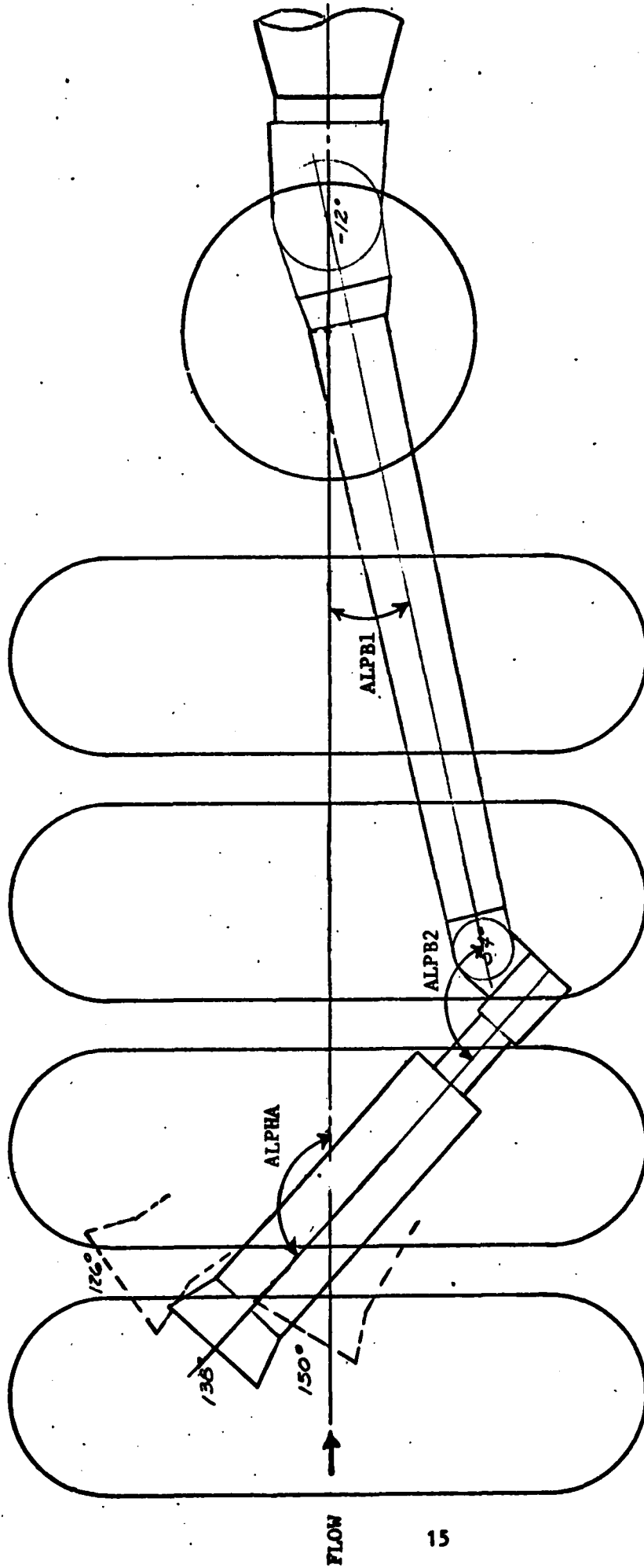


Figure 3. Installation Photograph in Tunnel A Tank

40-INCH SUPERSONIC TUNNEL A

TUNNEL WALL



TUNNEL WALL

PIN A
DOOR EDGE

Figure 4. Tunnel Installation Sketch

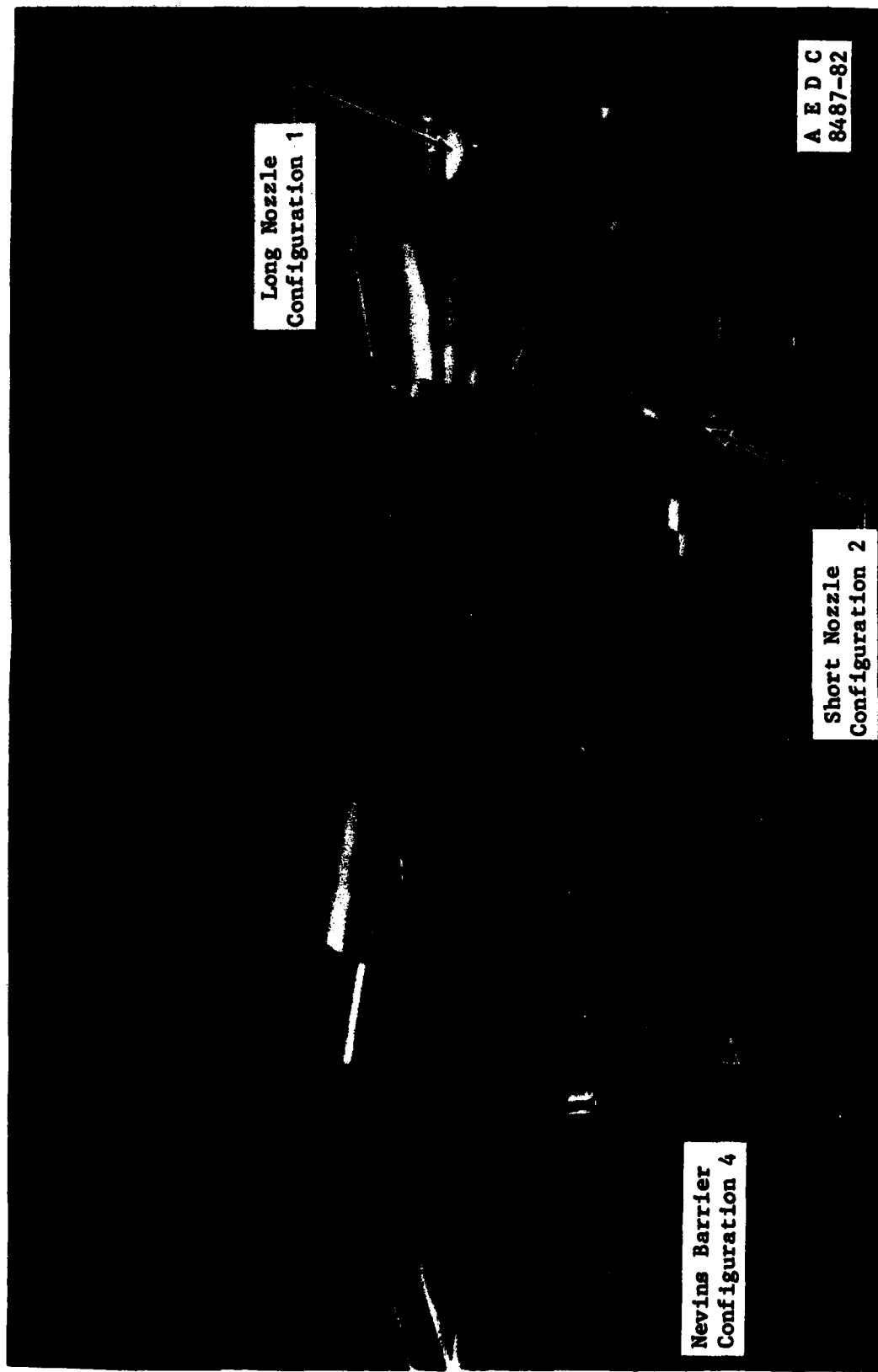


Figure 5. Model Configurations Tested

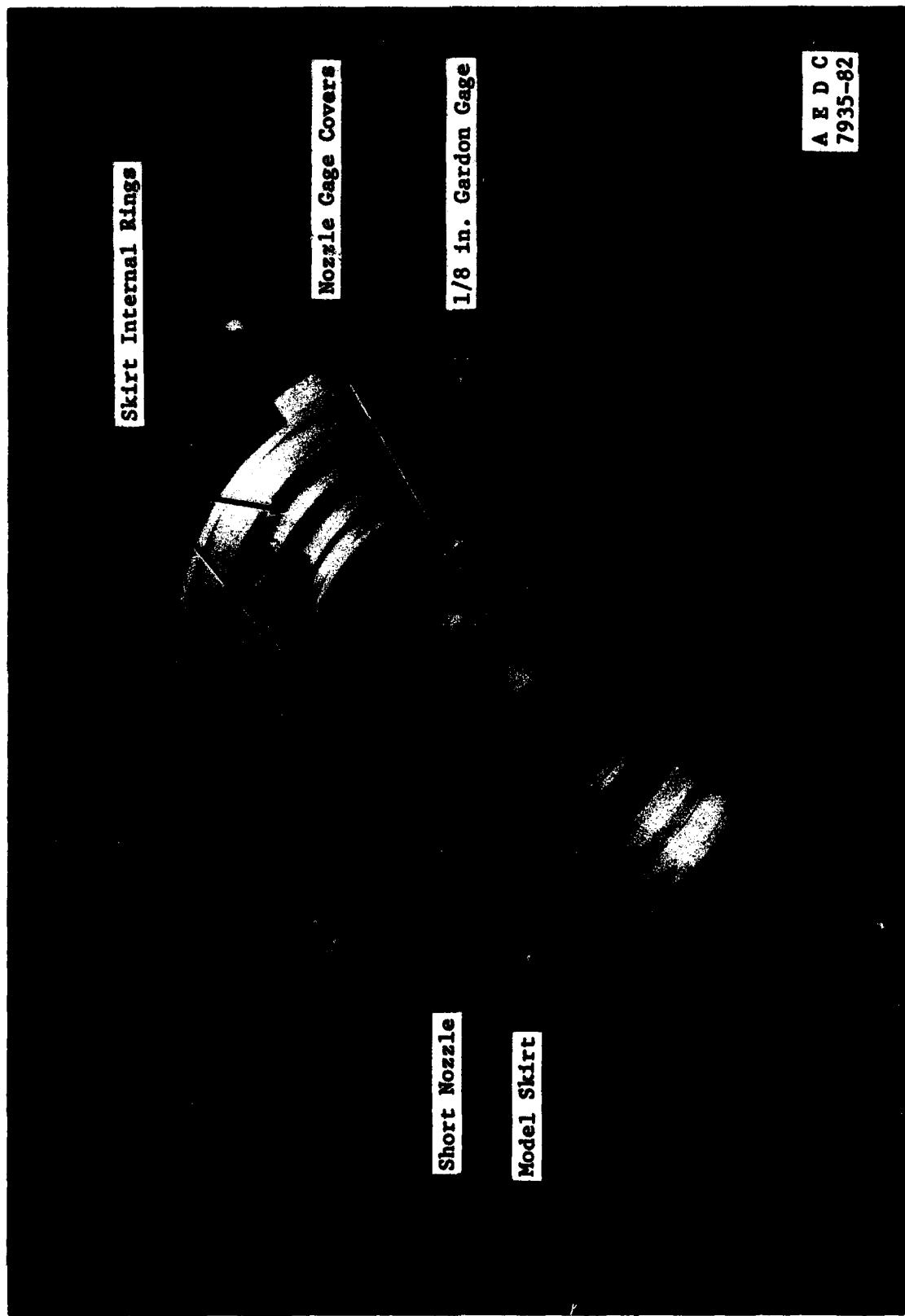
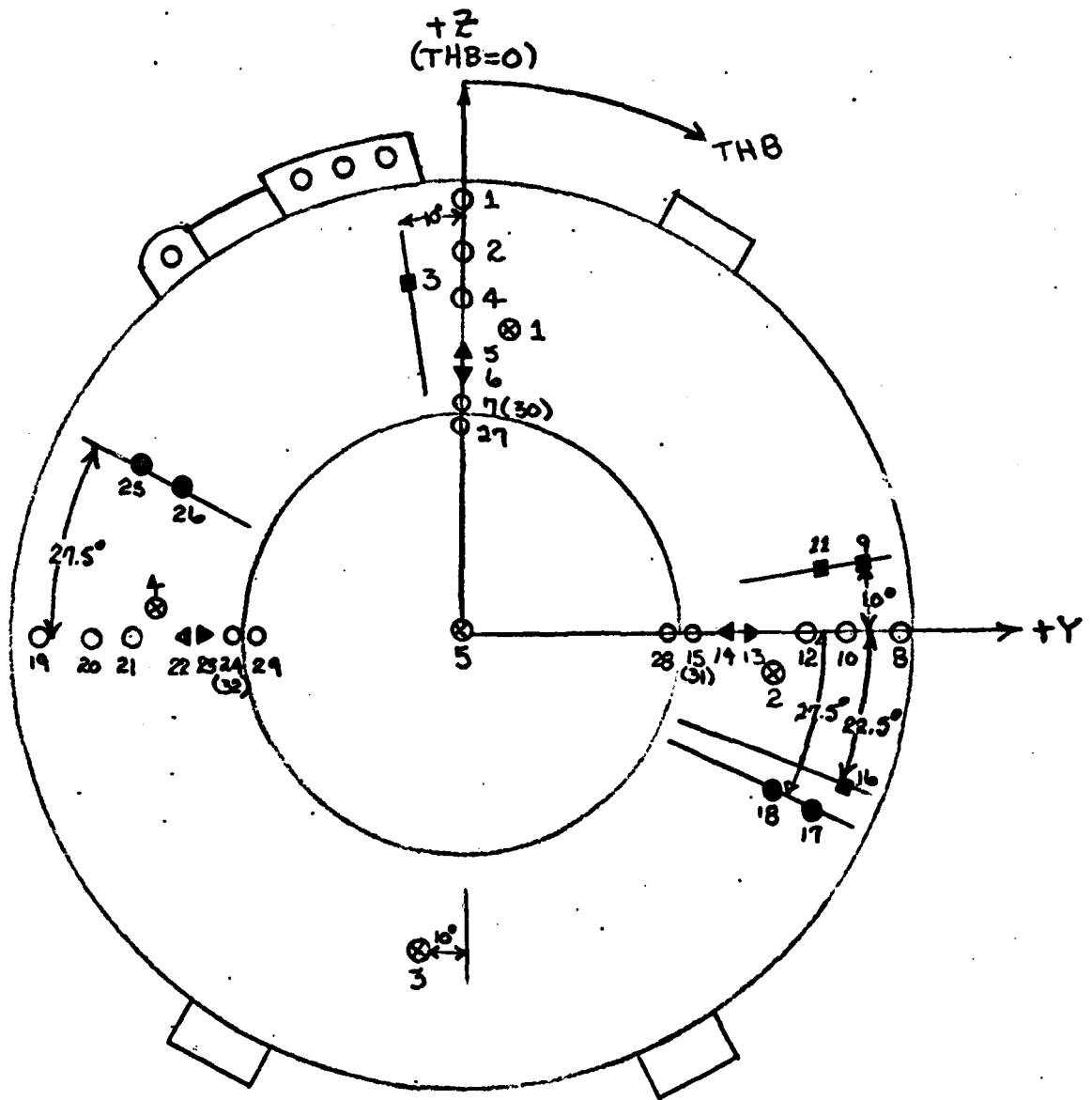


Figure 6. Photograph of Short Nozzle Configuration Showing General Gage Arrangement



Gardon[®] Gages

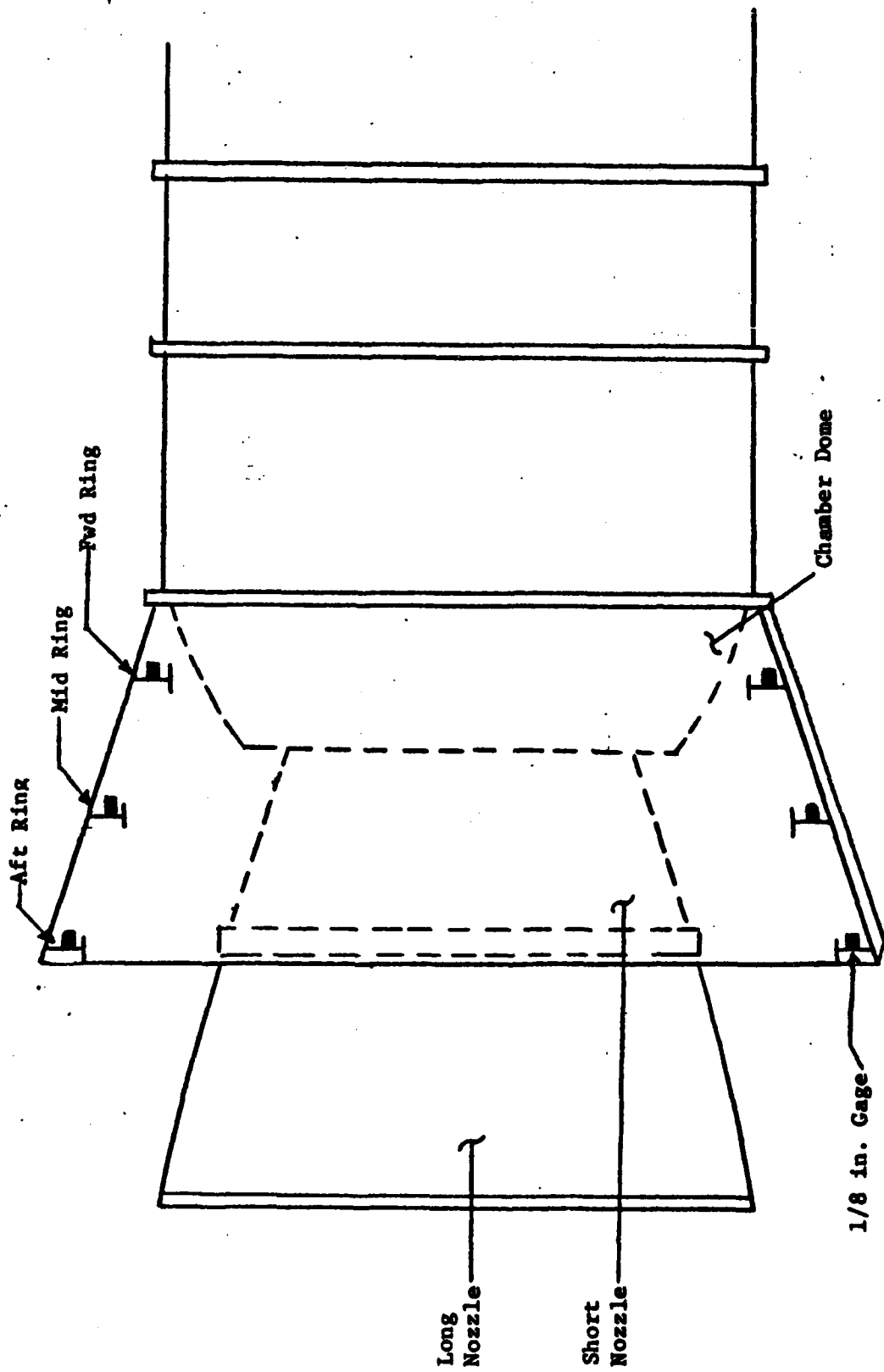
- Facing aft on rings
- On nozzle surface
- ▴ Chamber Dome
- Internal Skin
- Facing fwd on rings

Pressure

- ⊗ Chamber Dome

a. View Looking Aft

Figure 7. Model Instrumentation Sketch



b. Side View
 Figure 7. Concluded

0110

A



0021

Run Number

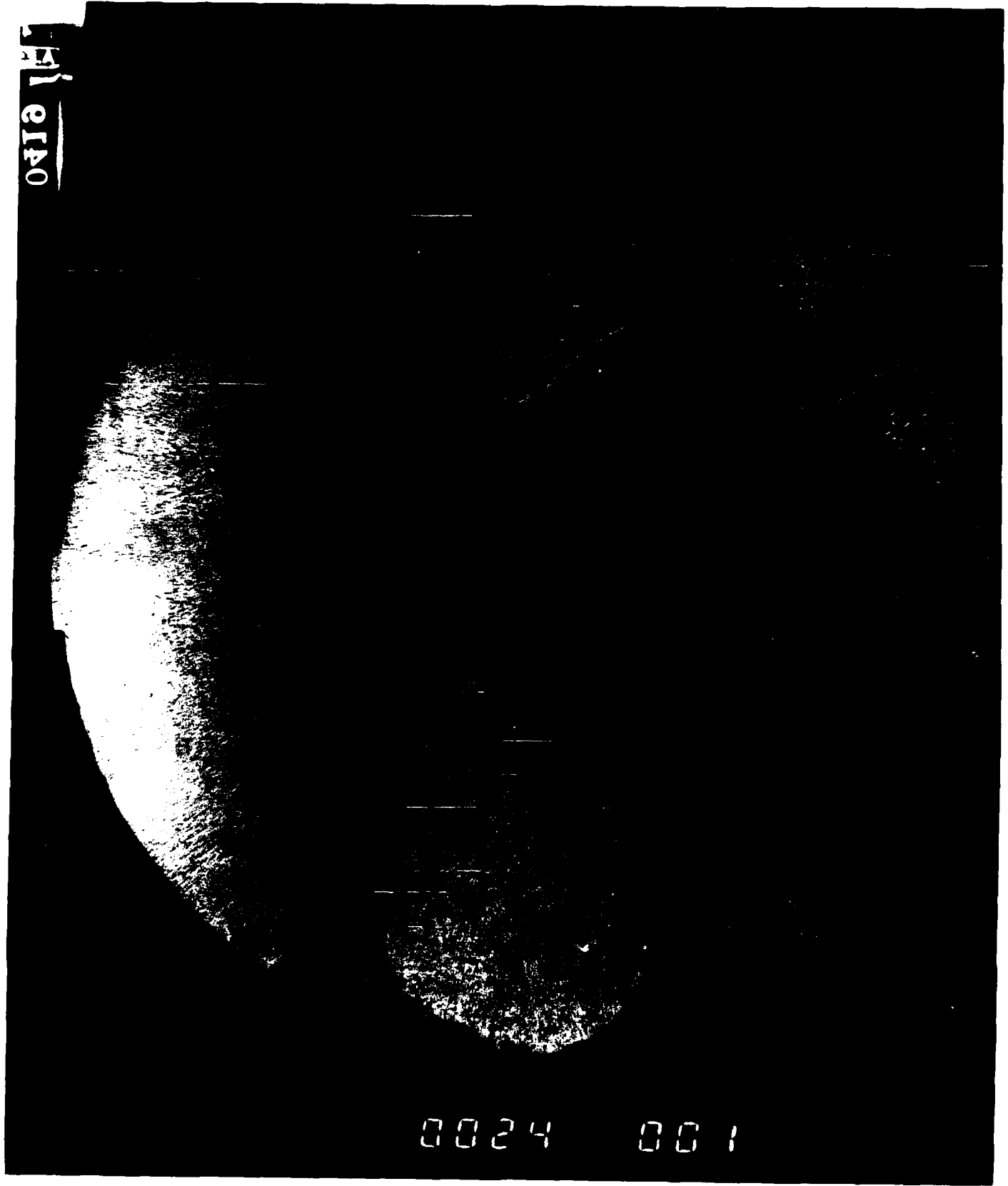
001

Camera Frame Sequence Number

a. $M = 3.75$, $\text{ALPHA} = 168$

Figure 9. Shadowgraph Depicting Model Flow Field

0410 14



0024 001

b. $M = 3.75$, $\text{ALPHA} = 138$

Figure 9. Concluded

APPENDIX II

TABLES

TABLE 1. Data Transmittal Summary

The following items were transmitted to the User and Sponsor:

<u>User</u>	<u>Sponsor</u>
Leroy M. Hair Remtech, Inc. 2603 Artie St. Suite 21 Huntsville, AL 35805	Peter Sulyma ED-33 NASA/MSFC Huntsville, AL 35812

<u>Item</u>	<u>No. of Copies</u>	<u>No. of Copies</u>
Test Summary Report	3	3
Final Data Package	2	2
70 mm Shadowgraph Stills rolls 0418, 0419, 0421	1 contact print 1 positive trans- parency	1 contact print 1 duplicate negative
Specimen Pretest Photos	1 each 8x10 prints	1 each 8x10 prints
Installation Photos	1 each 8x10 prints	1 each 8x10 prints

TABLE 2. ESTIMATED UNCERTAINTIES
a. Basic Measurements

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT*						Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
	Precision Index $\pm(\sigma)$		Bias $\pm(B)$		Uncertainty $\pm(S + tps)$					
	Percent of Reading	Date of Measurement	Percent of Reading	Date of Measurement	Percent of Reading	Date of Measurement				
FT, psia	0.007	>30	0.3	>30	$\pm(0.25 + 0.014)$	60	Boill and Brevel force balance pressure transducer	Digital Data acquisition system analog-to-digital converter	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the Standards Laboratory	
REFERENCE PRESSURES (PREF), microns	284	>30	10	>30	$\pm(10\% + 50)$	1000	Hastings vacuum gage	Digital data acquisition system	Comparison to facility reference gage	
TIME COUNT CONVERTER sec	SCALE-4	>30	(Hastings(see) 100) \pm [Hastings(see) 100] $\times 10^{-3}$	>30		0 to 365 days	Syston Domeser time code generator	Digital data acquisition system	Instrument lab calibration against Bureau of Standards	
TT, °F	1	>30	10 ⁻³	>30	4	0-300	Chromel-Alumel thermocouple	Doric temperature instrument digital multiplier	Thermocouple verification of NBS conformity/voltage substitution calib.	
TT, °F (Fe-Cr)	1	>30	1.0	>30	4	50 to 300	Fe-Cr thermocouple	Low-level multiplex system	Voltage substitution calibration, secondary standard	
MD, lbm/in.² ALP1, deg	0.035	>30	1.0	>30	1.0	± 15	Potentiometer	Digital data acquisition system analog-to-digital converter	Seidman rotary encoder MD 700 Resolution: 0.0006° Overall accuracy: 0.001°	

* Thompson, J. W. and Abernethy, R. B. et al. "Handbook Uncertainty in Gas Turbine Measurements," AEDC-TN-73-9 (AD 740386), February 1973.

† Assumed to be zero

TABLE 2. Concluded
b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT*							Range
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$		
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement	
PT2, psia	0.69		30	0.20		1.58		All
Q, psia	0.67		30	0.20		1.54		All
ME	0.49		30	0.48		1.46		All
M		0.008	30		0+		0.016	3.75
		0.02	30		0+		0.02	0.5
ALPHA, deg		1			0+		2	All
QDOT, BTU/ft ² -sec	2.0		30	4.0		8.0		1-3

*Abernethy, R. B. et al. and Thompson, J. W. "Handbook Uncertainty in Gas Turbine Measurements." AEDC-TR-73-5 (AD 755356), February 1973.

+Assumed to be zero

TABLE 3. Model Instrumentation

GAGE NO.	THB (deg)	LOCATION
1	0	Aft ring facing aft
2	0	Mid ring facing aft
3	350	Mid bay on skin
4	0	Fwd ring facing aft
5	2.5	Chamber dome side
6	357.5	Chamber dome facing aft
*7 (30)	0	Nozzle
8	90	Aft ring facing aft
9	80	Aft bay on skin
10	90	Mid ring facing aft
11	80	Mid bay on skin
12	90	Fwd ring facing aft
13	92.5	Chamber dome side
14	87.5	Chamber dome facing aft
*15 (31)	90	Nozzle
16	112.5	Aft bay on skin
17	117.5	Mid ring facing fwd
18	117.5	Fwd ring facing fwd
19	270	Aft ring facing aft
20	270	Mid ring facing aft
21	270	Fwd ring facing aft
22	272.5	Chamber dome side
23	267.5	Chamber dome facing aft
*24 (32)	270	Nozzle
25	297.5	Mid ring facing fwd
26	297.5	Fwd ring facing fwd
*27	0	Nozzle extension
*28	70	↓
*29	270	↓

PRESSURE GAGE NO.	THB (deg)	LOCATION
1	10	Chamber dome facing aft
2	100	↓
3	190	↓
4	280	↓
5	0	Inside nozzle cavity

* Denotes long nozzle gages

() Denotes short nozzle gages

TABLE 4. Test Summary

Runs 1-39 M = 3.75				Runs 40-68 M = 0.50			
RUN NO.	CONFIGURATION	ALPHA	PHI	RUN NO.	CONFIGURATION	ALPHA	PHI
1	2	180	90	35	1	138	300
2	↓	168	↓	36	↓	126	↓
3	↓	162	↓	37	↓	114	↓
4	↓	168	270	38	↓	180	↓
5	↓	150	↓	39	↓	162	↓
6	↓	138	↓	40	↓	174	270
7	↓	126	↓	42	↓	162	↓
8	↓	114	↓	43	↓	174	↓
9	↓	90	↓	44	↓	168	↓
10	↓	150	300	45	↓	150	↓
11	↓	138	↓	46	↓	138	↓
12	↓	126	↓	47	↓	126	↓
13	↓	168	↓	48	↓	114	↓
14	↓	162	↓	49	↓	90	↓
15	↓	162	330	50	↓	162	330
16	↓	150	↓	51	↓	150	↓
17	↓	126	↓	52	↓	126	↓
18	4	162	↓	53	↓	150	300
19	4	180	↓	54	↓	138	↓
20	1	180	270	55	↓	126	↓
21	↓	168	↓	56	↓	162	↓
22	↓	162	↓	57	↓	168	↓
23	↓	150	↓	58	2	180	↓
24	↓	138	↓	59	↓	138	270
25	↓	126	↓	60	↓	114	↓
26	↓	114	↓	61	↓	90	↓
27	↓	90	330	62	↓	162	↓
28	↓	150	↓	63	↓	174	↓
29	↓	126	↓	64	↓	162	330
30	↓	162	↓	65	↓	162	300
31	↓	162	300	66	↓	180	↓
32	↓	168	↓	67	↓	138	↓
33	↓	174	↓	68	↓	114	↓
34	↓	150	↓				

Configuration 1 - Long nozzle

Configuration 2 - Short nozzle

Configuration 3 - Long nozzle with Nevins barrier (not tested)

Configuration 4 - Short nozzle with Nevins barrier

TABLE 5. Heat Gage Calibration Factors

a. Runs 1 - 19

DATA REDUCTION CONSTANTS

GAGE NO.	C1 (BTU/ft ² -sec/mv)	KG (°R/mv)	GAGE DIA (in.)
1	3.03	8.5	0.125
2	1.85	5.2	0.125
3	2.59	7.3	0.125
4	1.86	5.2	0.125
5	2.31	6.5	0.125
6	1.78	5.0	0.125
8	2.38	7.8	0.125
9	0.653	4.4	0.250
10	2.66	7.4	0.125
11	0.921	6.3	0.250
12	2.66	7.4	0.125
13	1.86	5.2	0.125
14	2.90	8.1	0.125
16	0.849	5.8	0.250
17	2.23	6.2	0.125
18	1.95	5.5	0.125
19	1.95	5.5	0.125
20	2.36	6.6	0.125
21	2.04	5.7	0.125
22	1.83	5.1	0.125
23	2.25	6.3	0.125
24	0.817	5.6	0.250
25	2.06	5.8	0.125
26	2.41	6.7	0.125
30	0.647	4.4	0.250
31	0.685	4.7	0.250
32	0.704	4.8	0.250

NOTE: The change in calibration factor for a selected gage resulted from gage replacement during the test.

TABLE 5. Continued

b. Runs 20 - 39

DATA REDUCTION CONSTANTS

GAGE NO.	C1 (BTU/ft ² -sec/mv)	KG (°R/mv)	GAGE DIA (in.)
1	3.03	8.5	0.125
2	3.14	8.8	0.125
3	2.59	7.3	0.125
4	1.86	5.2	0.125
5	2.31	6.5	0.125
6	1.78	5.0	0.125
7	0.669	4.5	0.250
8	2.38	7.8	0.125
9	0.653	4.4	0.250
10	2.66	7.4	0.125
11	0.921	6.3	0.250
12	2.66	7.4	0.125
13	1.86	5.2	0.125
14	2.90	8.1	0.125
15	0.647	4.4	0.250
16	0.849	5.8	0.250
17	2.38	6.7	0.125
18	1.95	5.5	0.125
19	2.45	6.9	0.125
20	2.36	6.6	0.125
21	2.04	5.7	0.125
22	1.83	5.1	0.125
23	3.43	9.6	0.125
24	0.817	5.6	0.250
25	2.06	5.8	0.125
26	2.41	6.7	0.125
27	0.599	4.1	0.250
28	0.784	5.3	0.250
29	0.715	4.9	0.250

TABLE 5. Concluded

c. Runs 40 - 68

DATA REDUCTION CONSTANTS

GAGE NO.	C1 (BTU/ft ² -sec/mv)	KG (°R/mv)	GAGE DIA (in.)
1	3.03	8.5	0.125
2	3.14	8.8	0.125
3	2.59	7.3	0.125
4	3.19	8.9	0.125
5	2.31	6.5	0.125
6	1.78	5.0	0.125
7	1.07	3.6	0.250
8	3.08	8.6	0.125
9	0.653	4.4	0.250
10	2.66	7.4	0.125
11	0.921	6.3	0.250
12	2.66	7.4	0.125
13	1.86	5.2	0.125
14	2.90	8.1	0.125
15	1.18	4.0	0.250
16	0.849	5.8	0.250
17	2.38	6.7	0.125
18	1.95	5.5	0.125
19	2.45	6.9	0.125
20	2.36	6.6	0.125
21	2.63	7.4	0.125
22	1.83	5.1	0.125
23	3.43	9.6	0.125
24	1.10	3.7	0.250
25	2.06	5.8	0.125
26	2.41	6.7	0.125
27	0.533	4.7	0.250
28	1.16	3.9	0.250
29	1.05	3.6	0.250
30	0.284	4.4	0.250
31	0.685	4.7	0.250
32	0.704	4.8	0.250

APPENDIX III

SAMPLE TABULATED DATA

DATE COMPUTED 23-SEP-82
 TIME COMPUTED 12:21:57
 DATE RECORDED 16-AUG-83
 TIME RECORDED 19: 9:30
 PROJECT NUMBER V A IR

ARVIN/CALSPAN FIELD SERVICES, INC.
 AEC DIVISION GAS DYNAMICS FACILITY
 AMSCOLD AIR FORCE STATION, TENNESSEE
 NASA/RENTCH SP8 INTERNAL HEATING

RUB	CONFIGURATION	MACH	PT	TT	ALPHA	ALPI	ALP01	ALP02	PHI	PTS	PSKY
(DEGR)	(PSIA)	(FT/SEC)	(PSIA)	(DEGR)	(DEGR)	(DEGR)	(DEGR)	(DEGR)	(DEGR)	(PSIA)	(PSIA)
1	SHORT NOZZLE	3.75	64.11	743.7	180.0	-6.0	0.0	0.0	90.0	1.101E+01	1.085E+01
7		V	RHO	MU	H (BTU/FT2-SEC-R)	RE	M-BG	M-BG	H (BTU/FT2-SEC-R)	PT2	PSKY
(DEGR)	(PSIA)	(FT/SEC)	(LBM/FT3)	(LBF-SEC/FT2)	(FT-1)	(BTU/FT2-SEC-R)	(BTU/FT2-SEC-R)	(BTU/FT2-SEC-R)	(BTU/FT2-SEC-R)	(PSIA)	(PSIA)
195.1	5.925E-01	5.93	0.199E-03	1.570E-07	4.168E+06	4.046E-03	4.046E-03	4.046E-03	4.046E-03	1.101E+01	1.085E+01
GAGE	IHS	DEL	TAN	TAW/TT	S(TAN)	M(TAN)/	M(TAN)/	H(TAN)/	H(TAN)/	TLOW	R2
NUMBER	(DEGR)	(DEGR)	(DEGR)	(BTU/FT2-SEC-R)	(TAN)	H-BG	H-BG	PTS+0.0	PTS+0.0	(DEGR)	(DEGR)
1	INOPERATIVE	350.0	746.6	1.0039	2.152E-03	2.607E+00	2.607E+00	1.596E-03	1.596E-03	560.2	690.5
2	INOPERATIVE	0.0	743.9	1.0003	2.711E-03	3.385E+00	3.385E+00	2.010E-03	2.010E-03	601.6	705.0
3	INOPERATIVE	2.5	729.7	0.9812	2.068E-03	2.582E+00	2.582E+00	1.533E-03	1.533E-03	550.1	657.4
4	INOPERATIVE	37.5	756.3	1.0170	3.485E-03	4.352E+00	4.352E+00	2.585E-03	2.585E-03	568.2	671.8
5	INOPERATIVE	0.0	706.7	0.9503	2.624E-03	3.277E+00	3.277E+00	1.946E-03	1.946E-03	618.4	706.8
6	INOPERATIVE	90.0	740.2	0.9953	2.671E-03	3.335E+00	3.335E+00	1.991E-03	1.991E-03	575.8	697.3
7	INOPERATIVE	0.0	731.5	0.9836	2.071E-03	2.586E+00	2.586E+00	1.536E-03	1.536E-03	595.6	708.3
8	INOPERATIVE	0.0	757.3	1.0184	2.269E-03	2.833E+00	2.833E+00	1.622E-03	1.622E-03	577.8	707.0
9	INOPERATIVE	0.0	740.0	0.9950	2.516E-03	3.142E+00	3.142E+00	1.866E-03	1.866E-03	596.1	691.0
10	INOPERATIVE	2.5	776.6	1.0443	1.358E-03	1.695E+00	1.695E+00	1.007E-03	1.007E-03	549.3	641.5
11	INOPERATIVE	0.0	719.3	0.9659	2.738E-03	3.418E+00	3.418E+00	2.030E-03	2.030E-03	553.2	632.4
12	INOPERATIVE	2.5	739.2	0.9940	1.699E-03	2.084E+00	2.084E+00	1.237E-03	1.237E-03	558.0	632.8
13	INOPERATIVE	17.5	742.9	0.9990	2.897E-03	3.617E+00	3.617E+00	2.188E-03	2.188E-03	577.9	697.7
14	INOPERATIVE	27.5	744.0	1.0004	1.423E-03	1.777E+00	1.777E+00	1.055E-03	1.055E-03	575.7	682.5
15	INOPERATIVE	180.0	735.9	0.9896	4.516E-03	5.639E+00	5.639E+00	3.349E-03	3.349E-03	623.8	733.3
16	INOPERATIVE	270.0	744.0	1.0005	4.062E-03	5.071E+00	5.071E+00	3.012E-03	3.012E-03	607.0	729.8
17	INOPERATIVE	180.0	724.4	0.9741	4.097E-03	5.116E+00	5.116E+00	3.038E-03	3.038E-03	593.6	711.8
18	INOPERATIVE	177.5	743.7	1.0000	2.182E-03	2.724E+00	2.724E+00	1.618E-03	1.618E-03	583.4	729.2
19	INOPERATIVE	152.5	736.0	0.9924	3.504E-03	4.376E+00	4.376E+00	2.599E-03	2.599E-03	571.0	707.8
20	INOPERATIVE	152.5	728.3	0.9793	2.459E-03	3.070E+00	3.070E+00	1.833E-03	1.833E-03	560.0	702.1
21	INOPERATIVE	0.0	748.1	1.0059	2.065E-03	2.579E+00	2.579E+00	1.531E-03	1.531E-03	570.0	723.9
22	INOPERATIVE	180.0	750.0	1.0204	3.887E-03	4.853E+00	4.853E+00	3.802E-03	3.802E-03	570.0	723.9

DATE COMPUTED 23-SEP-82
 TIME COMPUTED 1212159
 DATE RECORDED 16-AUG-82
 TIME RECORDED 19: 9:20
 PROJECT NUMBER V A 1R

ARVIN/CALSPAN FIELD SERVICES, INC.
 MSC DIVISION
 VON KAMAN GAS DYNAMICS FACILITY
 AMBOLD AIR FORCE STATION, TENNESSEE
 HARA/SENTECH SR3 INTERNAL HEATING

ROW	CONFIGURATION	MACH NUMBER	PT (PSIA)	TT (DEGR)	ALPHA (DEG)	ALP01 (DEG)	ALP02 (DEG)	PHI (DEG)
1	SHORT NOZZLE	3.75	64.11	743.7	100.0	0.0	0.0	90.0
Y			RHO (LBM/FT3)	MU (LBM-SEC/FT2)	RE (FT-1)	E-06 (BTU/FT2-SEC-R)	PT2 (PSIA)	PENT (PSIA)
196.1		5.83	9.199E-03	1.570E-07	4.168E+06	0.046E-03	1.101E+01	1.086E+01
TAP NUMBER	DEL (DEG)	PH (PSIA)	PH/PT2 (PT2-PH)/PT2					
1	0.0	1.0407E+01	9.5281E-01	4.7194E-02				
2	10.0	1.0355E+01	9.4086E-01	5.9137E-02				
3	100.0	1.0577E+01	9.6102E-01	3.0995E-02				
4	170.0	1.0034E+01	9.8436E-01	1.5641E-02				
5	0.0	1.0029E+01	9.9300E-01	0.9972E-03				

APPENDIX IV
SAMPLE PLOTTED DATA

MACH NO.

3.750 7.00

PT
PSIA
64.11

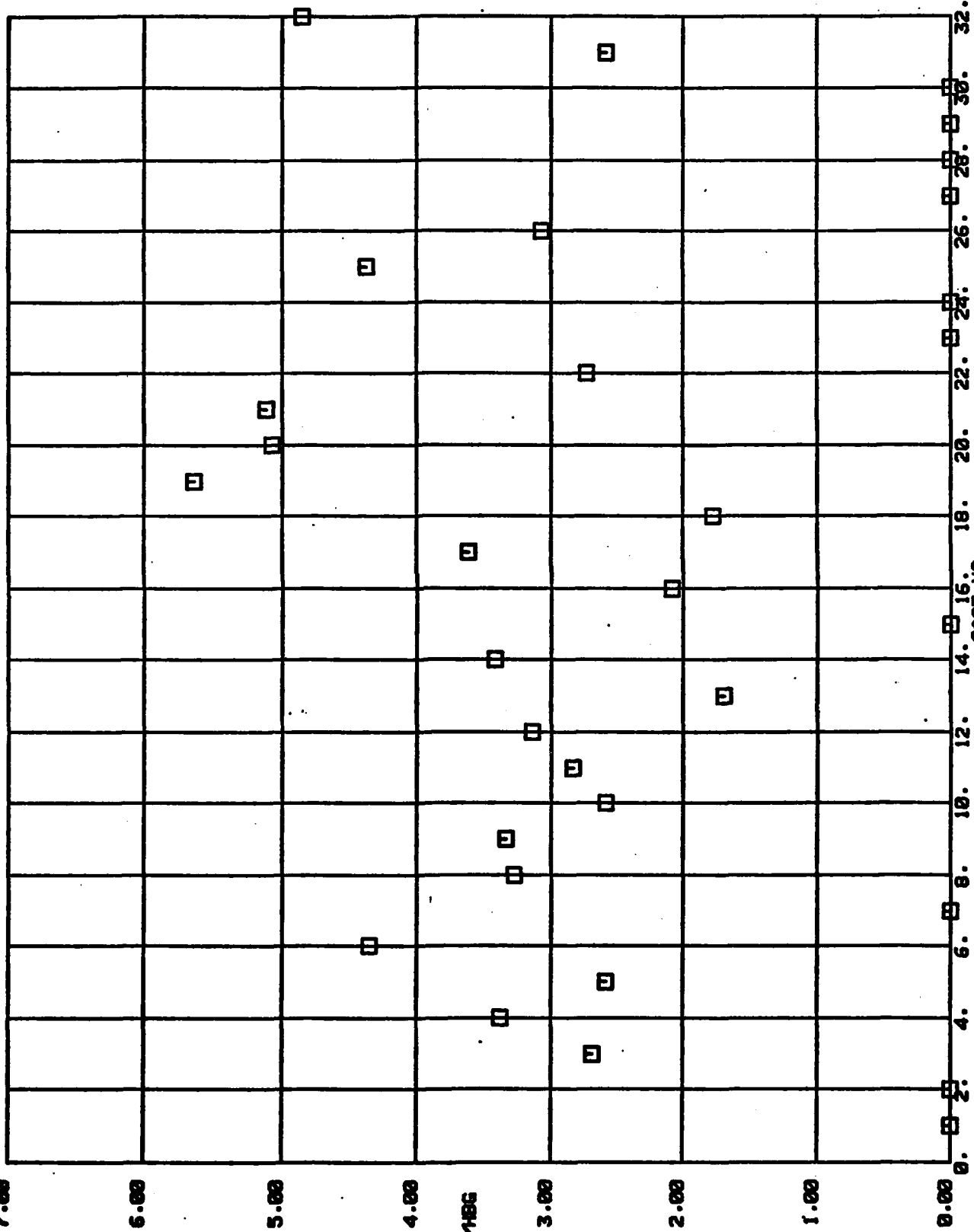
TT
DEG R
743.7

CONFIG
2

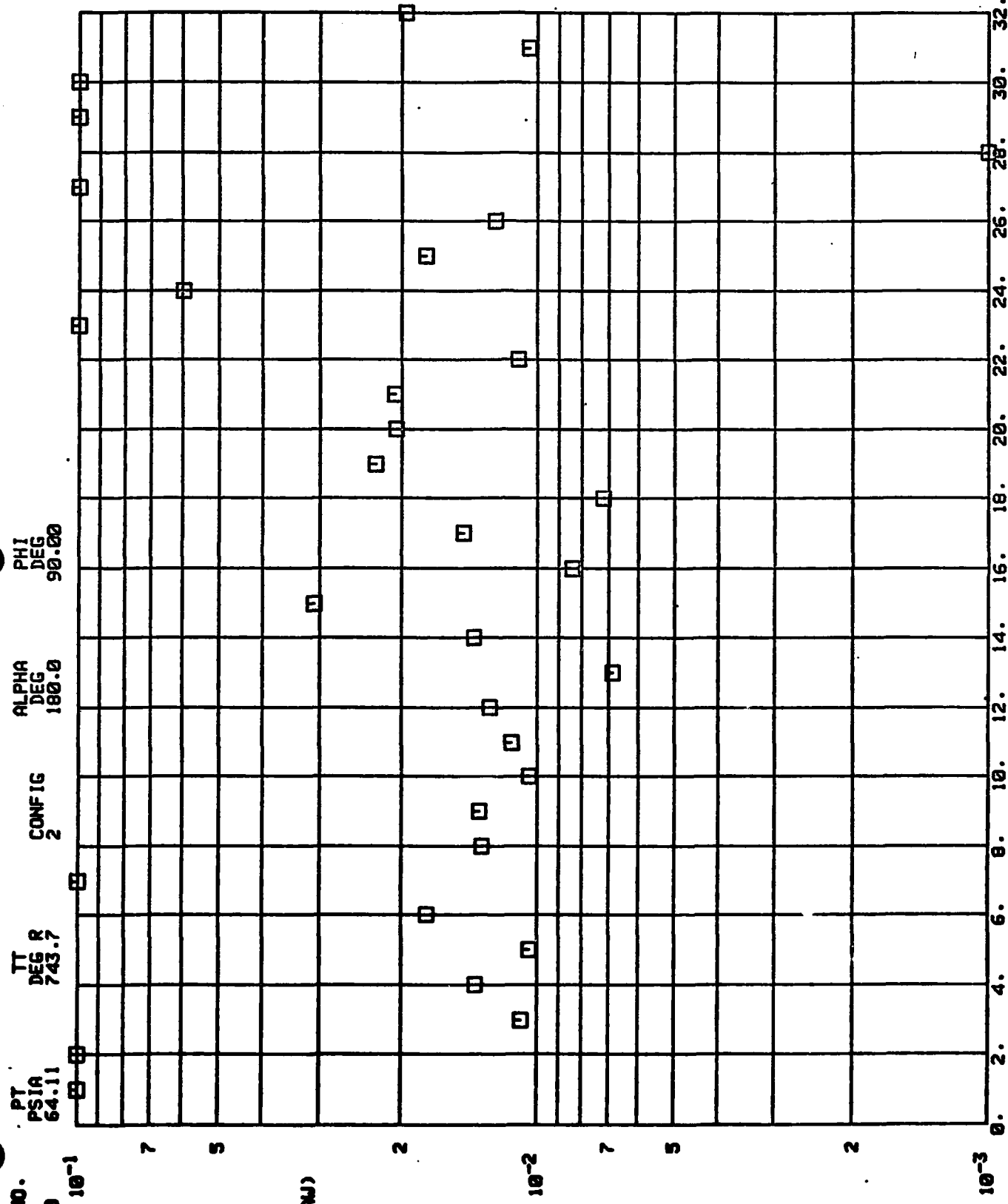
ALPHA
DEG
180.0

PHI
DEG
90.00

SYMB RUN
□ 1



PT PSIA 64.11
TT DEG R 743.7
CONFIG 2
ALPHA DEG 180.0
PHI DEG 90.00
SYMB RUN
□ 1



WICH NO.
3.750

h_c (BTU/ft²-R)

MACH NO.
3.750

PT
PSIA
64.11

TT
DEG R
743.7

CONFIG
2

ALPHA
DEG
180.0

PHI
DEG
90.00

1.20

1.10

1.00

0.90

0.80

0.70

0.60

0.50

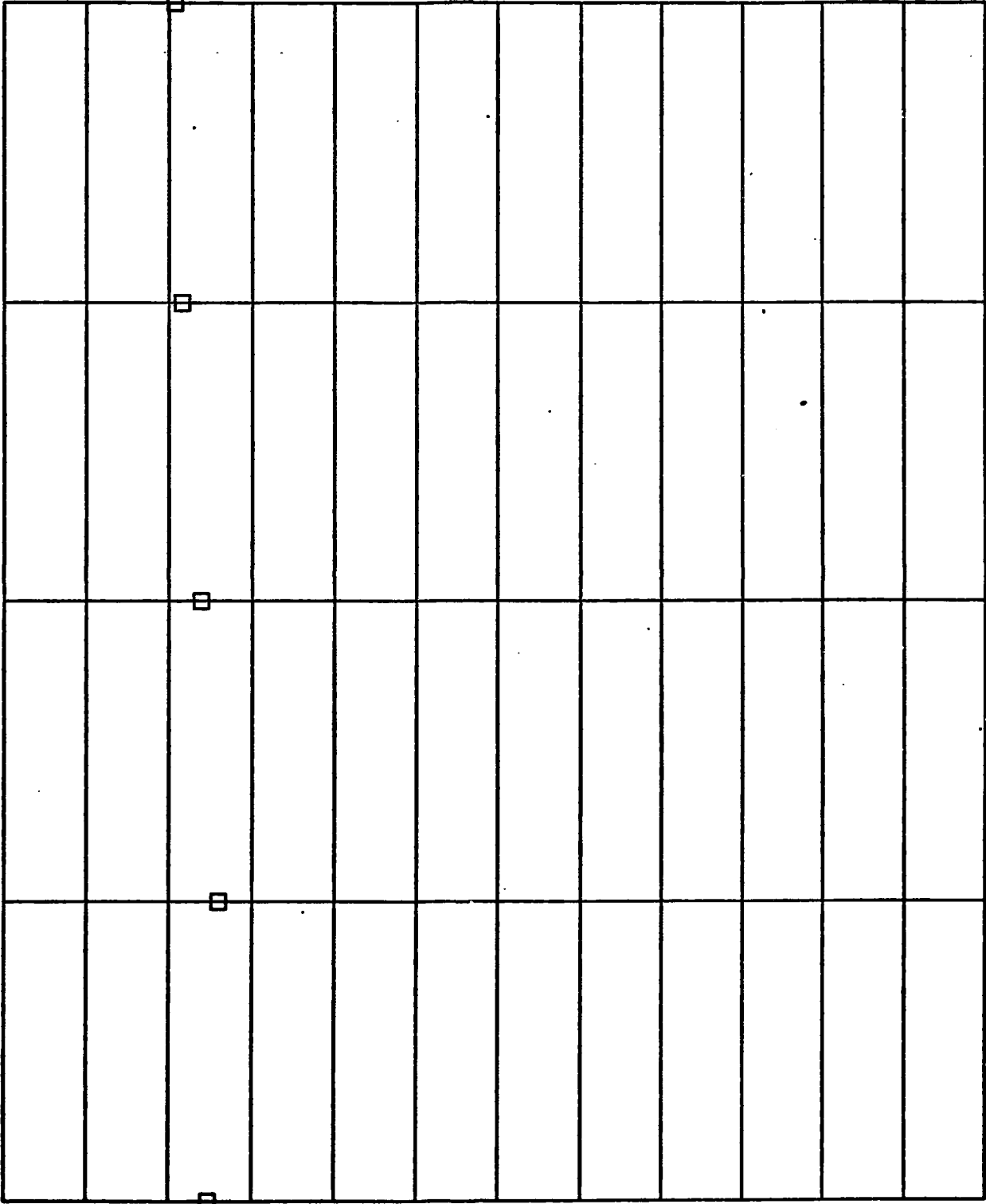
0.40

0.30

0.20

0.10

0.00



SYMB RUN

□ 1

38 PM/PT2

119

P TAP

MACH NO.

3.750

PT

PSIA
64.11

TT

DEG R
743.7

CONFIG
2

ALPHA
DEG
180.0

PHI
DEG
90.00

10⁻²

7

5

HTAW/PT2.8

2

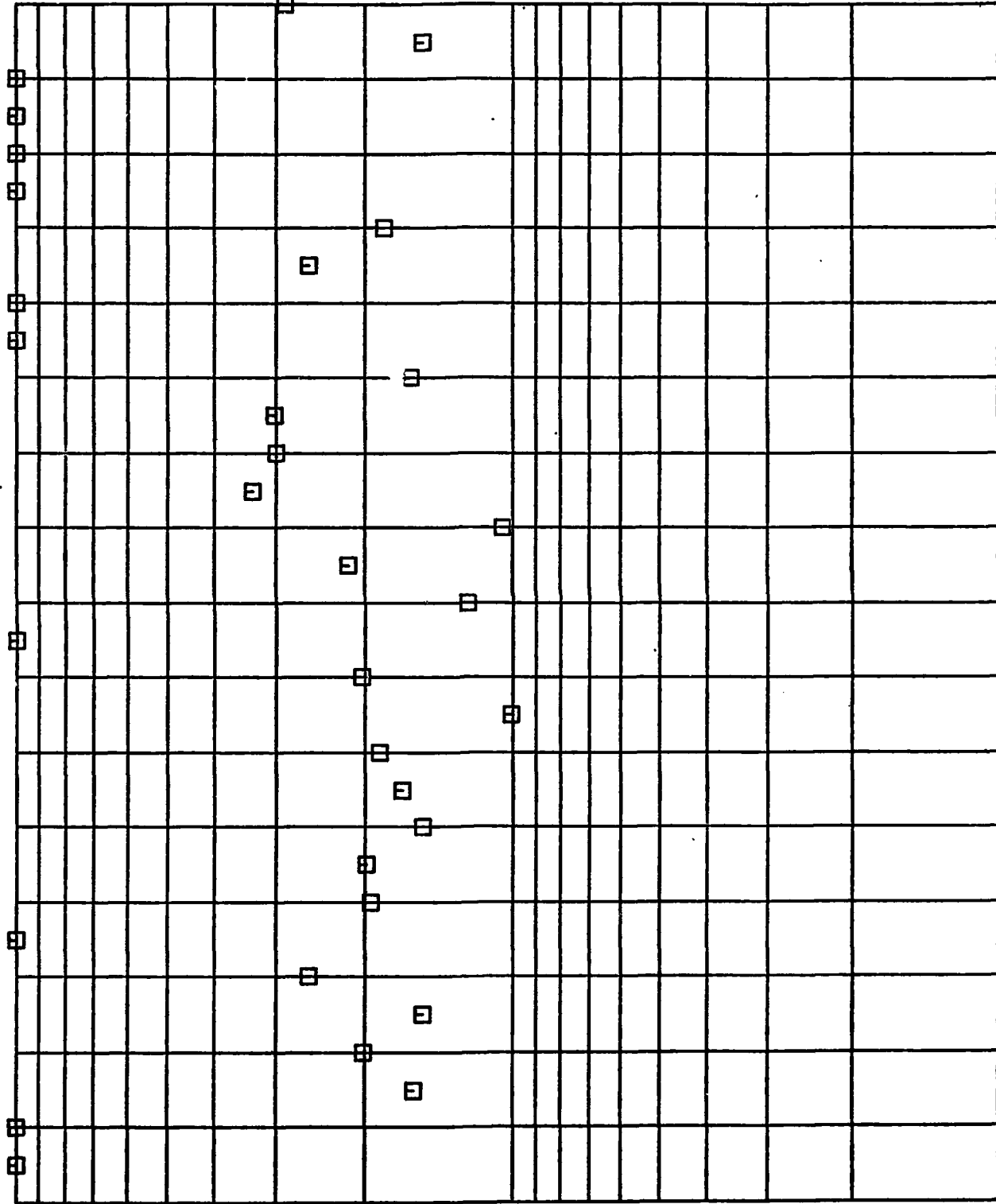
10⁻³

7

5

2

10⁻⁴



SYB RUN
1

APPENDIX V

THEORETICAL METHOD FOR COMPUTING LOCAL HEAT TRANSFER
AND RECOVERY TEMPERATURE ON A YAWED CYLINDER

APPENDIX V

A theoretical method based on Ref. 2 was used to compute stagnation line heat-flux reference values (H-BG) for a yawed cylinder. This reference was calculated from the equation:

$$H-BG = 0.152 \left[\frac{V \sin(LAMDA)}{\text{Mu-BG}} \right]^{0.6} \left[(\text{RHO}^*) (\text{Mu}^*) \right]^{0.8} \left[\text{DUDX} \right]^{0.2}, \text{BTU/ft}^2\text{-sec-}^\circ\text{R} \quad (1)$$

where

$$LAMDA = |\text{ALPHA} - 90| \quad (2)$$

If ALPHA > 175; set LAMDA = 85 deg

If ALPHA < 95; set LAMDA = 5 deg

$$\text{DUDX} = 321.11 \left[\text{TE} (1.0 - \text{PRAT}) \right]^{0.5}, \text{ 1/sec for cylinder of radius} = 2.19 \text{ in.} \quad (3)$$

where:

$$\text{TE} = \text{TT} - V \left[\sin(LAMDA) \right]^2 / 12012 \quad (4)$$

$$\text{MN} = M \cos(LAMDA) \quad (5)$$

If MN ≥ 1

$$\text{PRAT} = (1.2 \text{ MN}^2)^{-3.5} \left[(7 \text{ MN}^2 - 1) / 6 \right]^{2.5} \quad (6)$$

$$\text{If MN} \leq 1, \text{ PRAT} = \left(1 + \frac{\text{MN}^2}{5} \right)^{-3.5} \quad (7)$$

$$\text{RHO}^* = 0.0838 P / [(T^*)(\text{PRAT})] \quad (8)$$

$$T^* = 264.75 + 0.38 \text{ TE} + 0.22 (\text{TAW})_{\text{BG}}, \text{ }^\circ\text{R} \quad (9)$$

$$(\text{TAW})_{\text{BG}} = T + \left[\cos^2(LAMDA) + 0.897 \sin^2(LAMDA) \right] \frac{V^2}{12012}, \text{ }^\circ\text{R} \quad (10)$$

$$\text{Mu-BG} = 7.30779 \frac{\text{TT}^{1.5}}{\text{TT} + 198.7} \times 10^{-7}, \text{ slugs/ft-sec} \quad (11)$$

$$\text{Mu}^* = 7.30779 \frac{T^{*1.5}}{T^* + 198.7} \times 10^{-7}, \text{ slugs/ft-sec} \quad (12)$$

NOTE: Beckwith-Gallagher equations supplied
by REMTECH

3-8

DT