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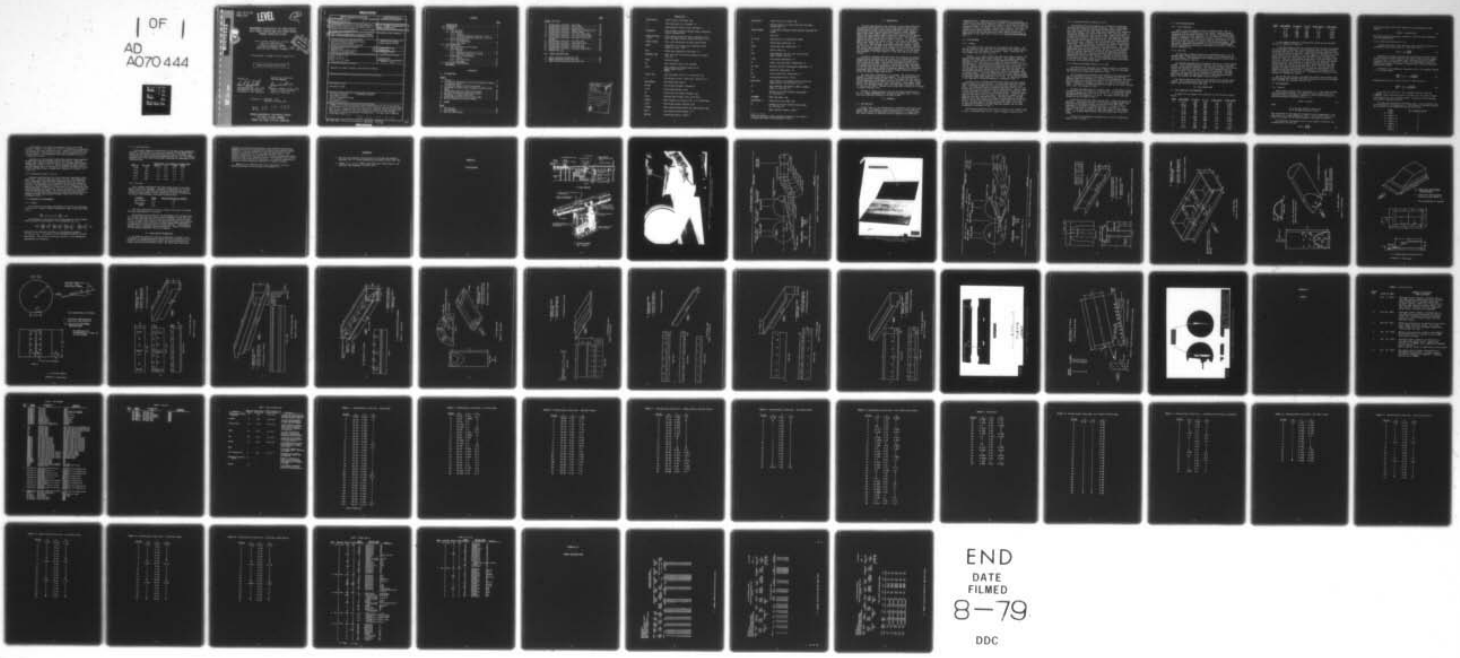

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AEROTHERMAL EVALUATION OF THE SPACE SHUTTLE SOLID ROCKET BOOSTER AND SOLID ROCKET MOTOR THERMAL PROTECTION SYSTEM

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A Sverdrup Corporation Company
von Karman Gas Dynamics Facility
Arnold Air Force Station, Tennessee

Period Covered: December 1977 thru January 1979

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FOR THE COMMANDER

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Huntsville, Alabama 35812

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ARNOLD ENGINEERING DEVELOPMENT CENTER
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Samples of insulation materials under consideration for use on the various protuberances of the Space Shuttle Solid Rocket Boosters and Solid Rocket Motors were tested to evaluate their survivability at simulated flight heating levels. Heat transfer calibration data were obtained by the use of the thin-skin technique on several protuberance configurations. All tests were conducted in the VKF Tunnel C.

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NOMENCLATURE

ALPHA-SECTOR	Tunnel sector pitch angle, deg
b	Thin-skin model wall thickness, ft
c	Model material specific heat, Btu/lbm-°R
CENTERLINE	Time at which injection reached tunnel centerline, Central Standard Time
CENTER-ROTATION (C.R.)	Axial station along the tunnel centerline about which the wedge rotates, inches (see Figs. 3 & 5)
CONFIG NUMBER	Code which designates the model being tested
DTWDT	Derivative of the model wall temperature with respect to time, °R/sec
DELT	Gardon gage temperature difference, °R
EXPOSURE TIME	Total time that the model was exposed to tunnel flow, sec
GROUP	Injection number
HO	Total enthalpy based on TO, Btu/lbm
H(TO)	Heat transfer coefficient based on TO, $\frac{\text{Q-DOT}}{\text{TO-TW}}$, Btu/ft^2-sec-°R
INJECT TIME	Time from model lift-off to centerline, sec
k	TPS material thermal conductivity, Btu/ft-hr-°R
MACH NUMBER	Free-stream Mach number
MU-INF	Free-stream viscosity, lbf-sec/ft^2
P-INF	Free-stream pressure, psia
PO	Tunnel stilling chamber pressure, psia
Q-DOT	Measured heat-transfer rate, Btu/ft^2-sec
Q-DOT-O	Heat-transfer rate based on TW = 0 °F, Btu/ft^2-sec
Q-INF	Free-stream dynamic pressure, psia
R ANGLE	Angle between wedge surface and ramp surface, deg
RE/FT	Free-stream Reynolds number, ft^{-1}
RHO-INF	Free-stream density, lbm/ft^3

ROLL-SECTOR	Tunnel sector roll angle, deg
S	Surface distance in axial direction from wedge leading edge, in.
SAMPLE NUMBER	A code which designates which material specimen was tested
t	Time, sec
TC, TC-NO	Abbreviation for thermocouple number
TE	Gardon gage temperature, °R
TGAGE	Gardon gage edge temperature, °R
ti	Initial time, sec
TIME	Time measured from when test article first enters tunnel flow, sec
T-INF	Free-stream temperature, °R
TO	Tunnel stilling chamber temperature, °R
TS1, TS2...	Material specimen thermocouple temperature, °F
TW	Model wall temperature, °R
TWi	Initial model wall temperature, °R
V-INF	Free-stream velocity, ft/sec
WEDGE ANGLE	Angle between free-stream velocity vector and wedge surface, deg (see Figs. 3 & 5)
X*	Axial distance from wedge or model leading edge, in. (see Fig. 6)
Y*	Lateral or vertical distance along model, in. (see Fig. 6)
YAW-MODEL	Model yaw angle, deg
YAW-SECTOR	Tunnel sector yaw angle, deg
Z*	Lateral or vertical distance along model, in. (see Fig. 6)
ρ	Model material density, lbm/ft^3

---

*Each user defined a unique coordinate system for the various configurations which are illustrated in Fig. 6.

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E02, Control Number 9E02-00-8, at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Huntsville, Alabama for the Lockheed Missile and Space Company (LMSC), Huntsville, Alabama and the Thiokol Corporation (Wasatch Division), Brigham City, Utah. The Lockheed Missile and Space Company project monitor was Mr. W. G. Dean,the Thiokol Wasatch Division project monitor was Mr. D. Furlong, and the NASA/MSFC project monitor was Mr. W. P. Baker. The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee. The overall task consisted of six separate test entries conducted in the von Karman Gas Dynamics Facility (VKF), Tunnel C, over the period from December 5, 1977 thru January 16, 1979 under ARO Project Number V41C-V9.

A series of material evaluation tests were conducted on material specimens being considered for use as part of the Thermal Protection System (TPS) on the Space Shuttle Solid Rocket Boosters (SRB) and Solid Rocket Motors (SRM). The material specimens consisted of several insulation materials attached to supports which were configured to represent the various protuberances on the SRB and SRM. The objective of the tests was to expose the material samples to an aerothermal environment which simulated the predicted flight conditions of the ascent and reentry flight trajectories.

The tests were accomplished in two phases. The intial phase was designed to calibrate the test environment. The second phase dealt with the materials evaluation where the various materials were tested. The VKF materials testing wedges were used to support the test articles during their exposures to the tunnel environment. Wedge angles ranged from 0 to 30 deg with nominal tunnel stilling chamber pressures of 200 to 1800 psia at 1900°R. Boundary-layer trips were installed on the wedges to promote turbulent flow.

Inquires to obtain copies of the test data should be directed to Mr. W. P. Baker, NASA/MSFC, EP44, Huntsville, Alabama 35812. A microfilm record has been retained in the VKF at AEDC.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel C (Fig. 1) is a closed-circuit, hypersonic wind tunnel with a Mach number 10 axisymmetric contoured nozzle and a 50-in.-diam test section. The tunnel can be operated continuously over a range of pressure levels from 200 to 2000 psia with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 2260°R) are obtained through the use of a natural gas fired combustion heater in series with an electric resistance 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 may be found in the Test Facilities Handbook (Ref. 1).

2.2 TEST HARDWARE

2.2.1 General

The overall project consisted of six separate test entries. For ease of reference, each test entry is assigned an entry number and will be referred to by that number as necessary. Table 1 correlates the entry number with the entry test date.

Entries 1, 2, 3 and 6 utilized the flat plate wedge to support the test articles during their tunnel exposures. This support wedge was designed at the VKF and built by the LMSC-Huntsville Division. It is basically a 15-in. wide by 41.5-in. long flat plate attached to a 13 deg wedge block. The protuberance models were bolted to the plate with the rear edge of the models near the downstream end of the plate. A 1/16-in. phenolic spacer was placed between the model and the plate to help minimize the heat conduction from the wedge into the model. An installation photograph of the wedge and a typical protuberance model is shown in Fig. 2. The basic wedge angle was 13 deg; however, offset sting adapters were used in conjunction with the tunnel pitch mechanism to provide a wedge angle range from 0 to 25 deg. An installation sketch of the wedge and its sting arrangement is presented in Fig. 3.

Entries 4 and 5 utilized the AEDC water-cooled materials testing wedge to support the test articles. A double-walled pan with cooling water circulating through the bottom and sides was attached to the wedge. The calibration models or material specimens were set into the pan and held in place by six adjustable jacking screws. Figure 4 shows a typical specimen installation. The pan was used to ensure that the test articles did not receive any back-side heating. Triangular-shaped supports were used to vary the angle of the pan with respect to the wedge and thus vary the heating rates. The basic angle of the AEDC wedge was 33.65 deg; however, the offset sting adapters in conjunction with the tunnel pitch mechanism provided a wedge angle range from 5 to 33 deg. The ramp angle of the pan was fixed at either 0 or 12 deg. An installation sketch of the AEDC wedge/pan assembly and its sting arrangement is presented in Fig. 5.

Both support wedges had steel balls attached near the leading edges to serve as boundary-layer trips in order to promote turbulent flow.

2.2.2 Calibration Models (Entries 1,2,5,6)

Heat-transfer data were obtained on 13 different protuberance configurations using the thin-skin technique. Nine of these models were supplied by LMSC and represented the SRB systems tunnel, aft kick ring, forward attach ring, range safety antenna cover, integrated electronics package, full scale attach ring, full scale kick ring, cylindrical protuberance, and aft skirt ring. These models were constructed with 0.0265-in. thick sheets of 304 stainless steel attached to either an aluminum or steel substructure. The remaining 4 models were supplied by the Wasatch Division of Thiokol and represented the SRM stiffener stub, stiffener ring, plant/field joint, and stiffener ring splice. These models were constructed of 0.030-in. thick sheets of 304 stainless steel attached to a steel substructure. Two of the models supplied by Thiokol (stiffener ring and stiffener ring splice) experienced structural problems during the test. The steel "skins" warped at several locations on the models and eventually separated from the substructures. Repairs were made by VKF personnel and no compromise of test objectives resulted. Sketches of all the models are presented in Fig. 6. All of the calibration models were tested on the flat plate wedge except for the plant/field joint model which was tested on the water-cooled wedge.

2.2.3 Materials Specimens (Entries 1,3,4,5,6)

The TPS materials specimens were tested in either a protuberance configuration or a panel configuration. Table 2 lists all the specimens tested and the particular details for each.

The protuberance TPS specimens were typically constructed by bonding the particular material or materials of interest to a metallic substrate which was configured to represent the protuberance. The specimens were made such that the dimensions of the substrate with the TPS material applied were nominally equivalent to those of the calibration model. A listing of the materials evaluated along with the brief description of each is presented in Table 3.

The panel specimens were of two basic types: an instrument island configuration and a flat specimen configuration. The instrument islands had nominal dimensions of 12 x 16-in. or 14 x 17-in. whereas the flat specimens were all nominally 12 x 16-in. The materials for both configurations are included in Table 3.

An additional model was tested during entry 5 which was supplied by MSFC-EH41. This model was a SRM clevis joint/pin retainer model which simulated the attachment between two sections of the SRM casing. A photograph of the model is presented in Fig. 7. A 0.033 x 1.5-in. steel strap was used to retain the shear pins which held the joint together. The strap was welded in place while under a 435 lb tensile force. All internal metal surfaces had been coated with Conoco HD-2 grease.

A total of 61 protuberance specimens and 11 panel specimens were tested in the 5 entries.

2.3. TEST INSTRUMENTATION

2.3.1 Test Conditions

Tunnel C stilling chamber pressure is measured with a 500- or 2500-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the accuracy (a bandwidth which includes 95-percent of the residuals, i.e. 2σ deviation) of the transducers is estimated to be within ±0.16 percent of pressure or ±0.5 psi, whichever is greater, for the 500-psid range and ±0.16 percent of pressure or ±2.0 psi, whichever is greater, for the 2500-psid range. Stilling chamber temperature measurements are made with Chromel® Alumel® (CR-AL) thermocouples which have an uncertainty of ±(1.5°F + 0.375 percent of reading in °F).

2.3.2 Test Data

The thin-skin calibration models were instrumented with up to 49 Chromel-Alumel thermocouples which were welded to the inner surface of the steel skins. The locations of the thermocouples are shown in Fig. 6 and listed in Tables 4 thru 16.

The material specimens were instrumented with up to 12 CR-AL thermocouples. These thermocouples were placed at the interface of the TPS material and the support substrate. The locations of these thermocouples varied from specimen to specimen because of the different points of interest on each. The exact locations were not supplied to the VKF; therefore, the locations are not presented in this report. The flat plate support wedge was instrumented with 10 high temperature Gardon gages. The location of these gages is given in Fig. 8.

The water-cooled pan surface was instrumented with 4 CR-AL thermocouples. Two of these were located along the pan centerline and the other 2 were located on either side wall.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

A summary of the nominal test conditions for the entries is given below:

ENTRY	MACH NUMBER	PO (psia)	TO (°R)	Q-INF (psia)	P-INF (psia)
1	10.17	1800	1900	2.69	0.037
	10.11	1200	1900	1.82	0.025
	10.08	800	1900	1.22	0.017
	10.02	300	1900	0.46	0.007
2	10.11	1200	1900	1.82	0.025
	10.08	800	1900	1.22	0.017
	10.00	220	1900	0.34	0.005
3	10.17	1800	1900	2.69	0.037
	10.11	1200	1900	1.82	0.025
	10.00	220	1900	0.34	0.005
4	10.17	1800	1900	2.69	0.037
5	10.17	1800	1900	2.69	0.037
	10.11	1200	1900	1.82	0.025

ENTRY	MACH NUMBER	PO (psia)	TO (°R)	Q-INF (psia)	P-INF (psia)
5	10.00	220	1900	0.34	0.005
6	10.17	1800	1900	2.69	0.037
	10.11	1200	1900	1.82	0.025
	10.08	800	1900	1.22	0.017
	10.00	220	1900	0.34	0.005

A test summary showing all configurations tested and the variables for each is presented in Table 17.

In the VKF 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, and the model is injected into the airstream. The fairing doors are closed for the runs which involve material specimens but are left open for the calibration model runs. 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. The sequence is repeated for each specimen or configuration change.

For all the test entries, instrumentation inputs were recorded using the VKF digital data scanner, beginning at wedge injection and continuing until the wedge was retracted from the flow.

3.2 DATA REDUCTION

3.2.1 General

Wedge surface heating rates from entries 1, 2, 3 and 6 were obtained with Gardon heat-rate gages. The gages are direct-reading heat flux transducers where output may be converted to heating rate by means of a laboratory-obtained calibration factor, i.e.,

$$\text{Q-DOT} = (\text{CF})(\Delta \text{E}) \tag{1}$$

where

ΔE is the gage millivolt output and
CF is the gage calibration factor.

The calibration for each gage was obtained by direct measurement of the gage output for a known heating rate input. The calibrations were performed by personnel of the VKF Aerodynamics Instrumentation Branch.

The conversion from heating rate to heat-transfer coefficient was accomplished by the relation

$$\text{H(TO)} = \frac{\text{Q-DOT}}{\text{TO}-\text{TW}} \tag{2}$$

and the "cold wall" (TW = 0°F) heating rate was determined by the equation

$$\text{Q-DOT-0} = \text{H(TO)(TO-460)} \tag{3}$$

The surface heating rates were utilized to verify the flow conditions over the wedge surface.

3.2.2 Calibration (Entries 1,2,5,6)

The data reduction of the thin-skin thermocouple data involves the calorimetric heat balance which in coefficient form is:

$$\text{H(TO)} = \rho b c \, \frac{\text{DTWDT}}{\text{TO-TW}} \tag{4}$$

Radiation and conduction losses are neglected in this heat balance, and data reduction simply requires evaluation of DTWDT from the temperature-time data. For the present test, radiation effects are assumed negligible, and the evaluation of DTWDT is accomplished by means of a procedure which makes it possible to identify any conduction influences which may be present.

Separation of variables and integration of Eq. (4) assuming constant ρ, b, c and TO yields

$$\frac{\text{H(TO)}}{\rho b c} (t - ti) = \ln\left[\frac{\text{TO-TWi}}{\text{TO-TW}}\right] \tag{5}$$

Differentiation of Eq. (5) with respect to time results in

$$\frac{\text{H(TO)}}{\rho b c} = \frac{d}{dt} \left[\ln\left[\frac{\text{TO-TWi}}{\text{TO-TW}}\right]\right] \tag{6}$$

Since the left side of Eq. (6) is assumed constant, plotting $\ln\left[\frac{\text{TO-TWi}}{\text{TO-TW}}\right]$ versus time should yield a straight line, the slope of which can be used in Eq. (6) to evaluate H(TO). Deviations from a straight line indicate conduction effects.

The data were evaluated in this manner and a linear portion of the curve was used for all thermocouples. The duration of the data reduction was a function of the heating rate and was as follows:

Range	No. of Points in Fit
$32 < \text{DTWDT}$	5
$16 < \text{DTWDT} \leq 32$	7
$8 < \text{DTWDT} \leq 16$	9
$4 < \text{DTWDT} \leq 8$	13
$2 < \text{DTWDT} \leq 4$	17
$1 < \text{DTWDT} \leq 2$	25
$\text{DTWDT} \leq 1$	41

The linearity of the fits was examined visually on the VKF graphics terminal. The length of the fit is established automatically according to the table given previously. However, the beginning time can be adjusted, and the choice is made based on examination of the plotted results. The thermocouple data were recorded at a rate of 15 samples per second.

Reduction of the thin-skin thermocouple data for models supplied by LMSC used a material density value of 494 lbm/ft^3, a material specific heat value of 0.122 Btu/lbm-°R, and a nominal skin thickness of 0.0265-in. (2.208 x 10^{-3} ft). Models supplied by Thiokol used a material density value of 501 lbm/ft^3, a material specific heat value of 0.114 Btu/lbm-°R, and a nominal skin thickness of 0.030-in. (2.5 x 10^{-3} ft).

3.2.3 Materials (Entries 1,3,4,5,6)

Material evaluation data for these tests were essentially photograhic data. These included 16mm motion pictures, 70mm shadowgraph still photographs, 16mm high speed shadowgraph motion pictures, pre and posttest photographs of the specimens and video-tape coverage of the runs. The tabulated data consisted of tunnel parameters and TPS sample data which included: (1) a time history of the temperature from the thermocouples on the substrate; and (2) a notation of the times at which photographs were taken. The thermocouple data were scanned at a rate of one loop every second and were converted from millivolts to temperature using least-squares polynomial curve fits of the data contained in Ref. 2.

3.3 UNCERTAINTY OF MEASUREMENTS

3.3.1 General

The accuracy of the basic measurements (PO and TO) was discussed in Section 2.3. Based on repeat calibrations, these errors were found to be

$$\frac{\Delta PO}{PO} = 0.16 \text{ to } 0.27\%, \quad \frac{\Delta TO}{TO} = 0.4\%$$

Uncertainties in the tunnel free-stream parameters were estimated using the Taylor series method of error propagation, Eq. (7),

$$(\Delta F)^2 = \left(\frac{\partial F}{\partial X_1} \Delta X_1\right)^2 + \left(\frac{\partial F}{\partial X_2} \Delta X_2\right)^2 + \left(\frac{\partial F}{\partial X_3} \Delta X_3\right)^2 \;.... + \left(\frac{\partial F}{\partial X_n} \Delta X_n\right)^2 \qquad (7)$$

where ΔF is the absolute uncertainty in the dependent parameter $F = f(X_1, X_2, X_3 \ldots X_n)$ and X_n is the independent parameter (or basic measurement). ΔX_n are the uncertainties (errors) in the independent measurements (or variables).

3.3.2 Test Conditions

The accuracy (based on 2σ deviation) of the basic tunnel parameters, PO and TO, (see Section 2.3) and the 2σ deivation in Mach number determined from test section flow calibrations were used to estimate uncertainties in the other free-stream properties using Eq. (7). The computed uncertainties in the tunnel free-stream conditions are summarized in the following table.

		Uncertainty, (±) percent of actual value			
MACH NO.	PO, psia	MACH NO.	PO	P-INF	Q-INF
10.00	220	1.4	0.16	9.3	6.5
10.02	300	1.4	0.16	9.3	6.5
10.08	800	1.0	0.27	6.6	4.6
10.11	1200	0.8	0.20	5.3	3.7
10.17	1800	0.8	0.16	5.3	3.7

3.3.3 Test Data

Heat transfer measurements were made during entries 1,2,5 and 6 using the thin-skin technique. Estimated uncertainties for the individual terms in the thin-skin data reduction equations were used in the Taylor series method of error propogation to obtain uncertainties in values of heat-transfer coefficient as given below:

Parameter	Range	Nominal Uncertainty, percent
Heat Transfer	10^{-4}	±10
Coefficient,	10^{-3}	± 7
H(TO)	10^{-2}	± 5

The total uncertainty in the heat transfer coefficient for Gardon heat gage measurements is ±6 percent.

No precision can be quoted for the photographic data (primary data for material specimens) but several pretest exposures of the test hardware in the tunnel were made to determine the optimum camera settings. For test entries 3 and 6, some of the ablated TPS material was deposited on the aft test section wall and the tunnel windows which resulted in the degradation of picture quality for these entries. These deposits however, did not compromise the test objectives. Figure 9 illustrates the TPS material deposits on the tunnel windows.

4.0 DATA PACKAGE PRESENTATION

The primary objective of this test program was to assist in the development of insulation materials which will be satisfactory for use as part of the Thermal Protection System for the Space Shuttle Solid Rocket Boosters and Solid Rocket Motors. The wind tunnel tests were designed to evaluate the performance of the different materials by exposing them to an environment which simulated the predicted flight conditions. Previous calibration tests had established the heat-transfer distribution for the specimens tested in entry 4. Additional calibrations were required for the other protuberance configurations tested in the remaining entries. The heating levels desired on all the configurations were obtained. All material specimens were returned to their respective suppliers for complete analysis.

Samples of the tabulated data from a calibration run and a materials specimen run are presented in Appendix III.

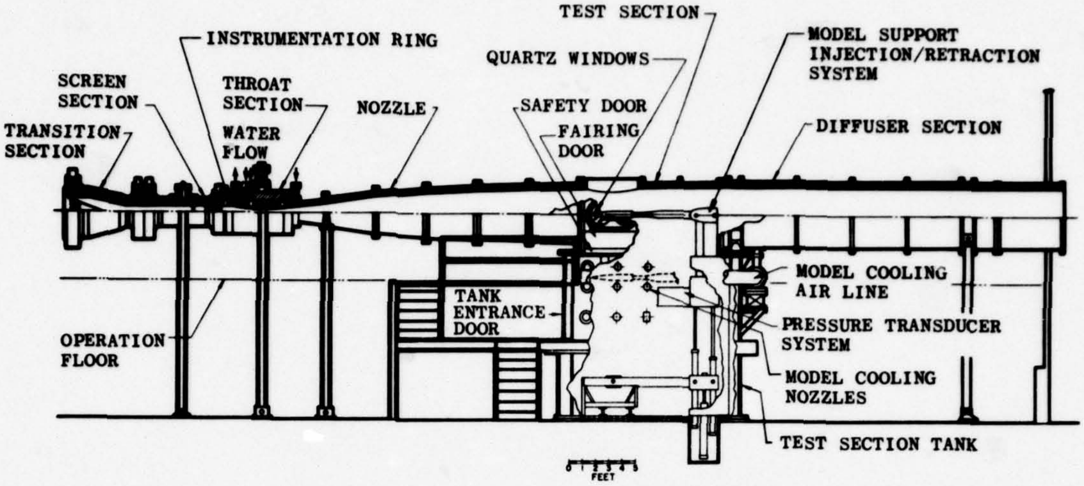
REFERENCES

1. Test Facility Handbook (Tenth Edition) "von Karman Gas Dynamics Facility, Vol. 3" Arnold Engineering Development Center, May 1974.

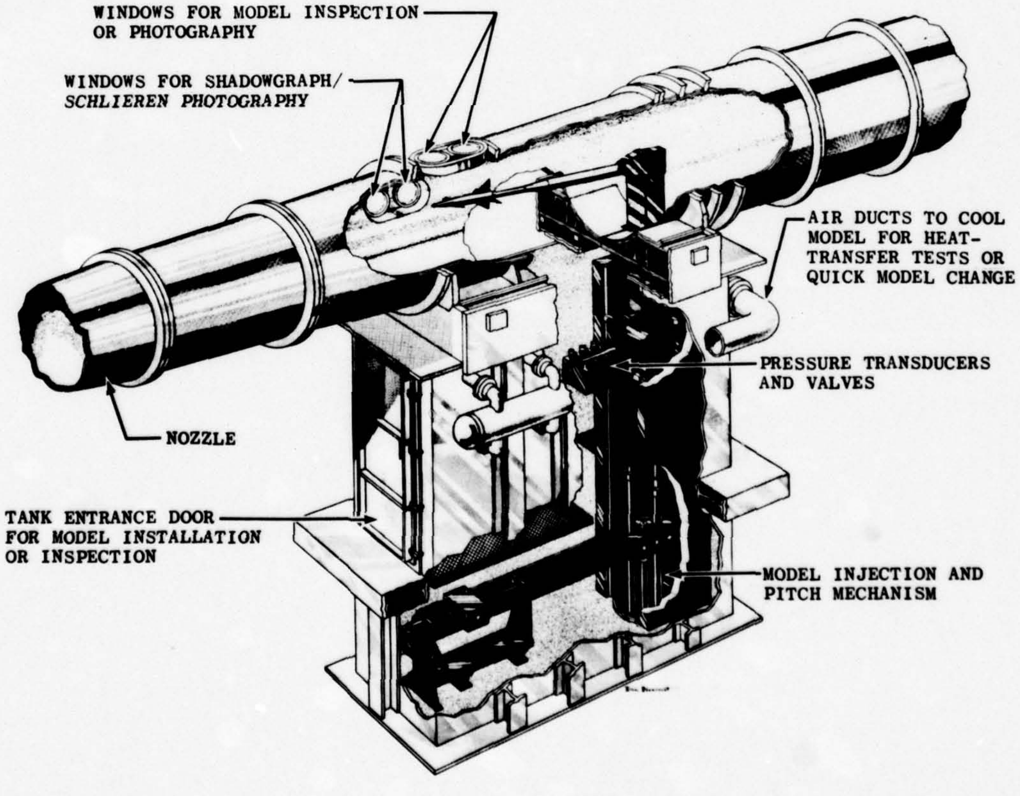
2. Powell, R. L., et al. "Thermocouple Reference Tables Based on the IPTS-68," NBS Monograph 125, March 1974.

APPENDIX I

ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section

Fig. 1 Tunnel C

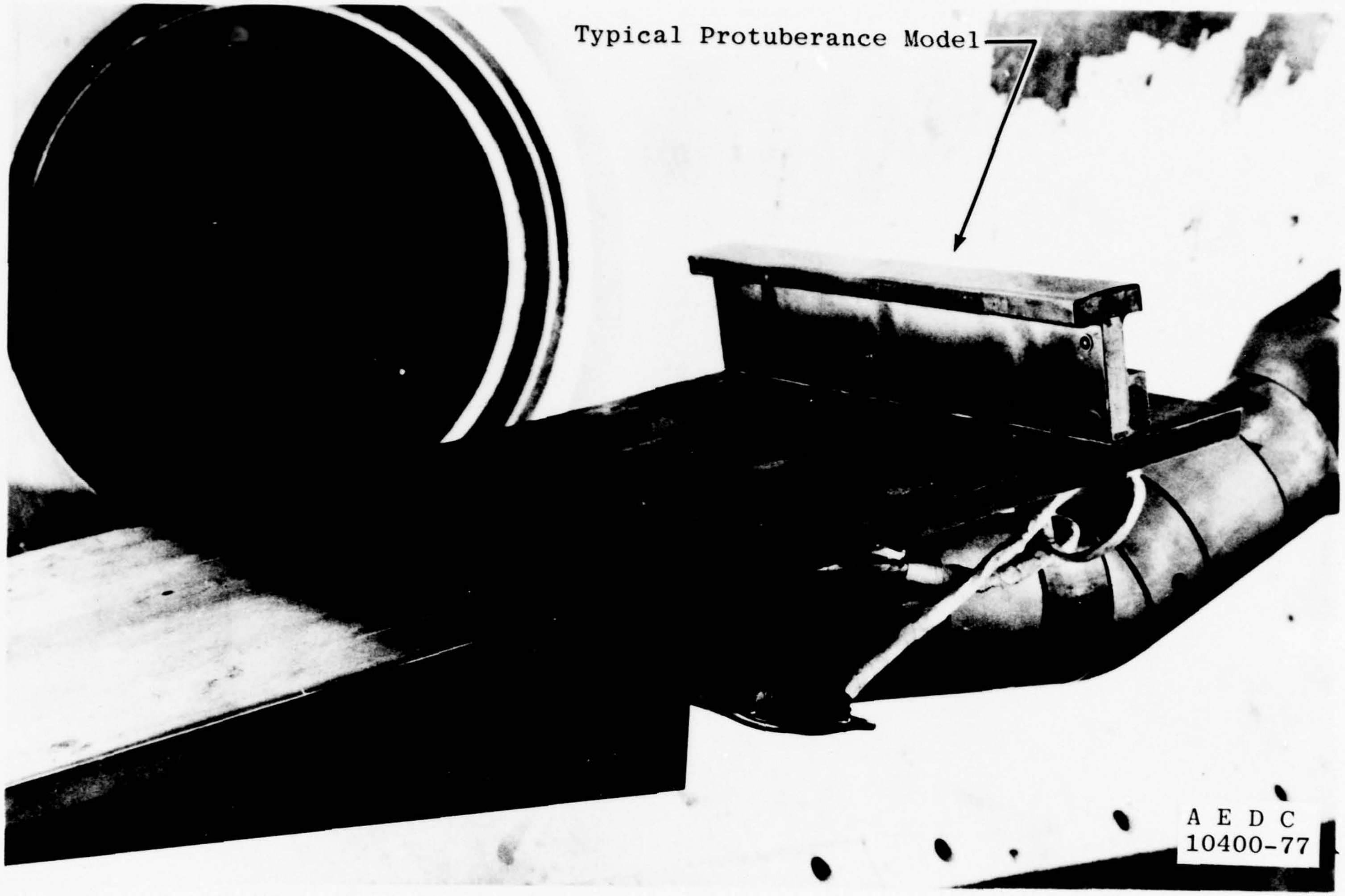
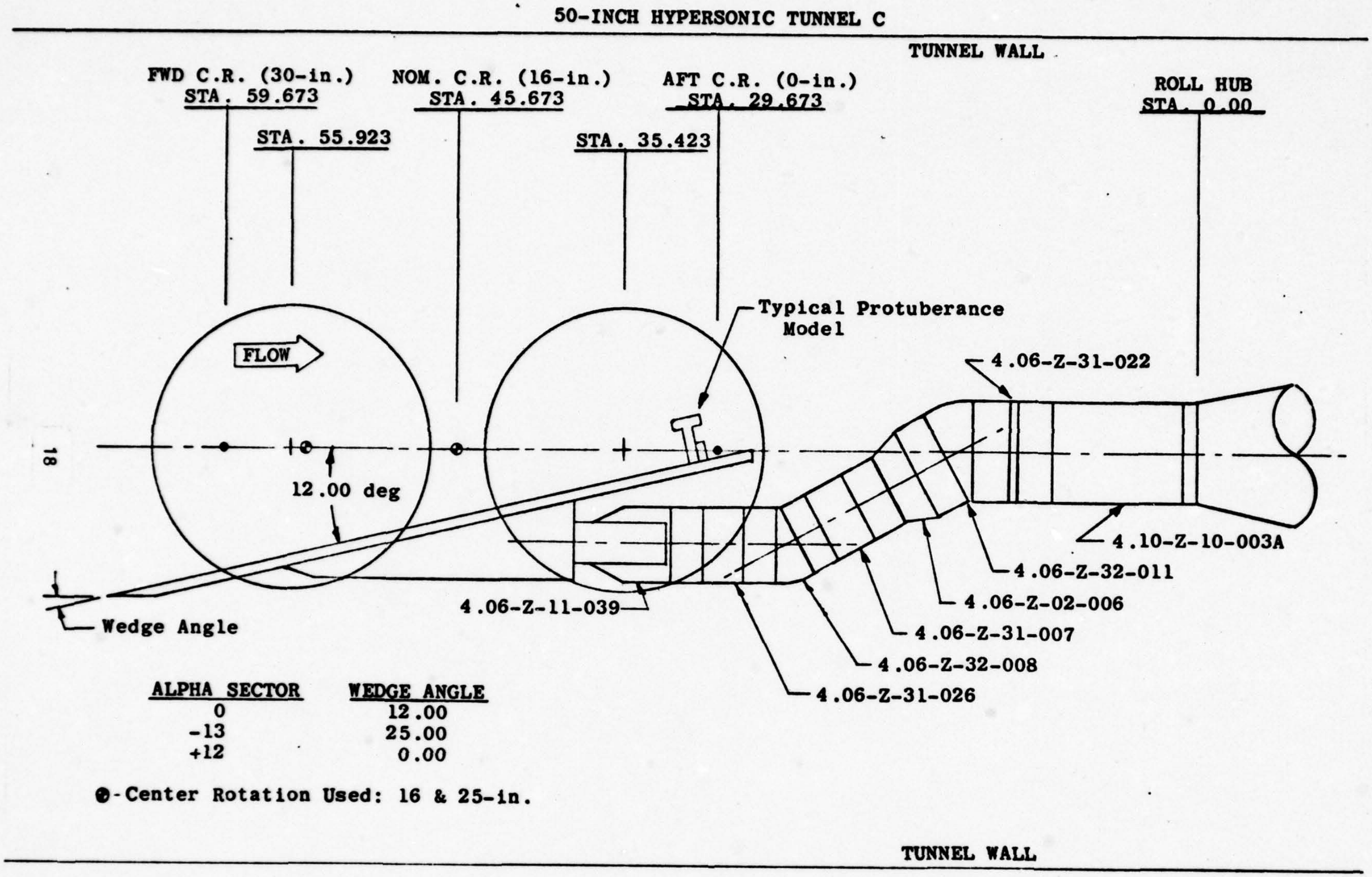


Figure 2. Installation Photograph of Flat-Plate Wedge and Typical Protuberance Model



ALPHA SECTOR	WEDGE ANGLE
0	12.00
-13	25.00
+12	0.00

⊕-Center Rotation Used: 16 & 25-in.

Figure 3. Installation Sketch of Flat-Plate Wedge

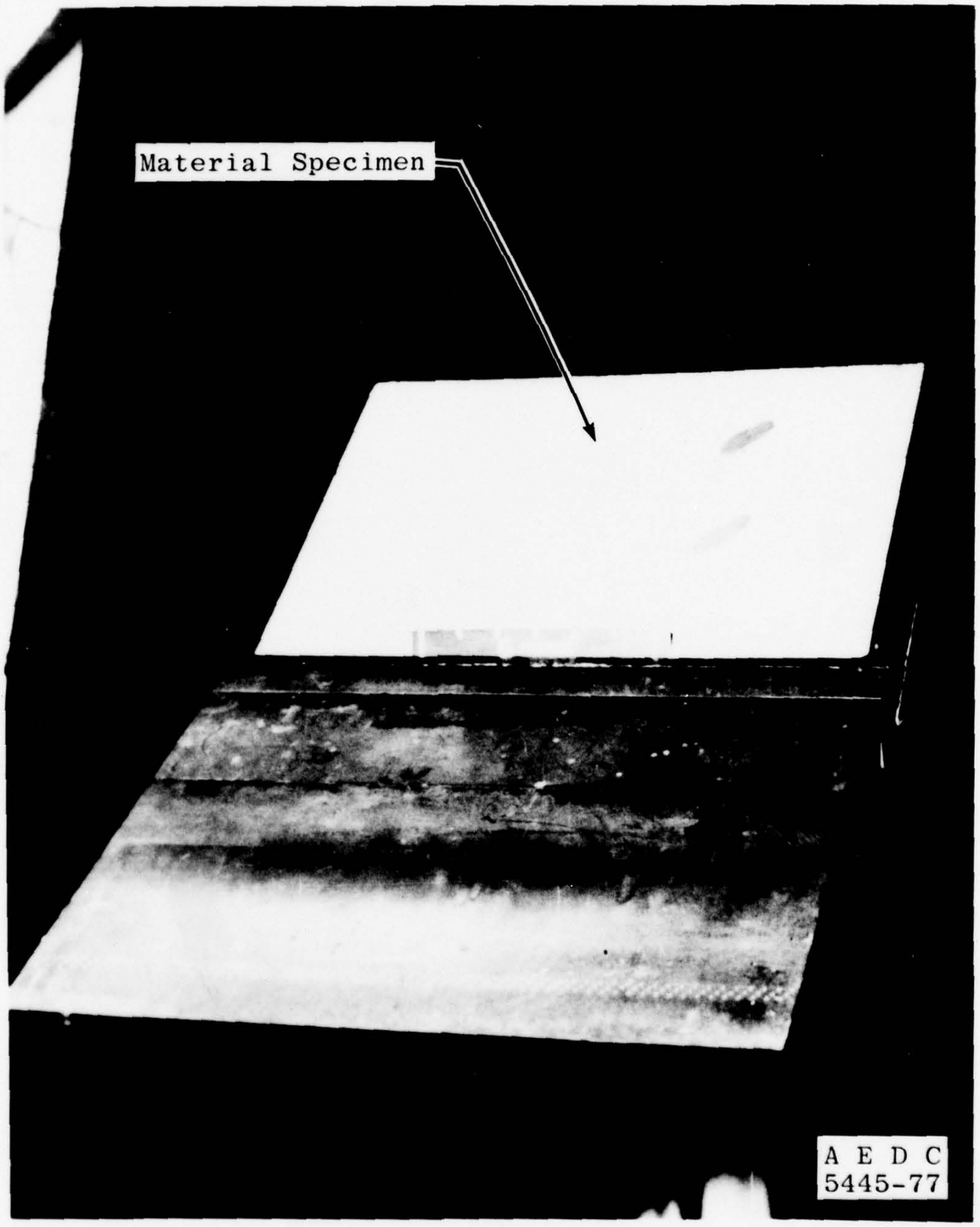
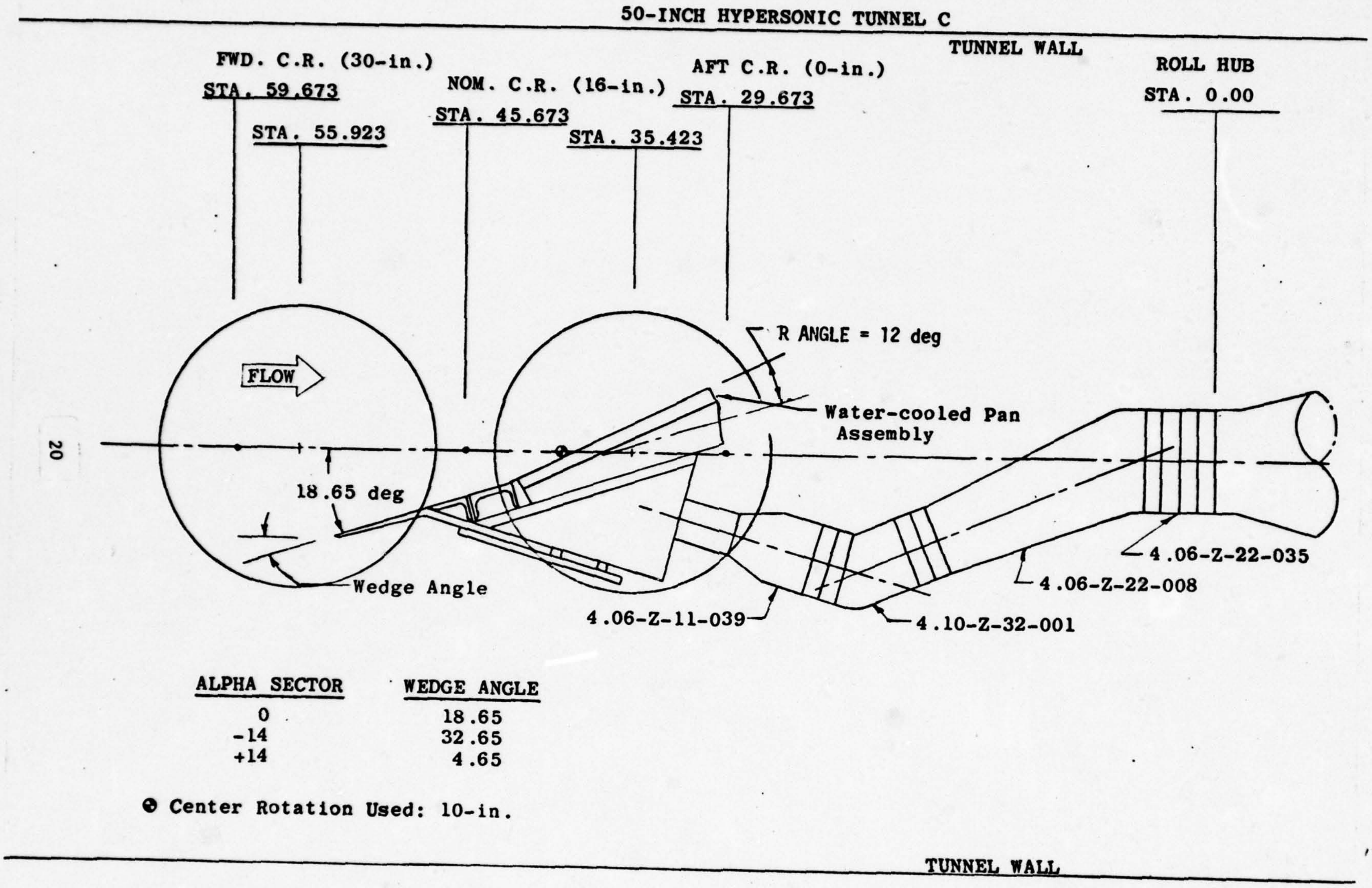


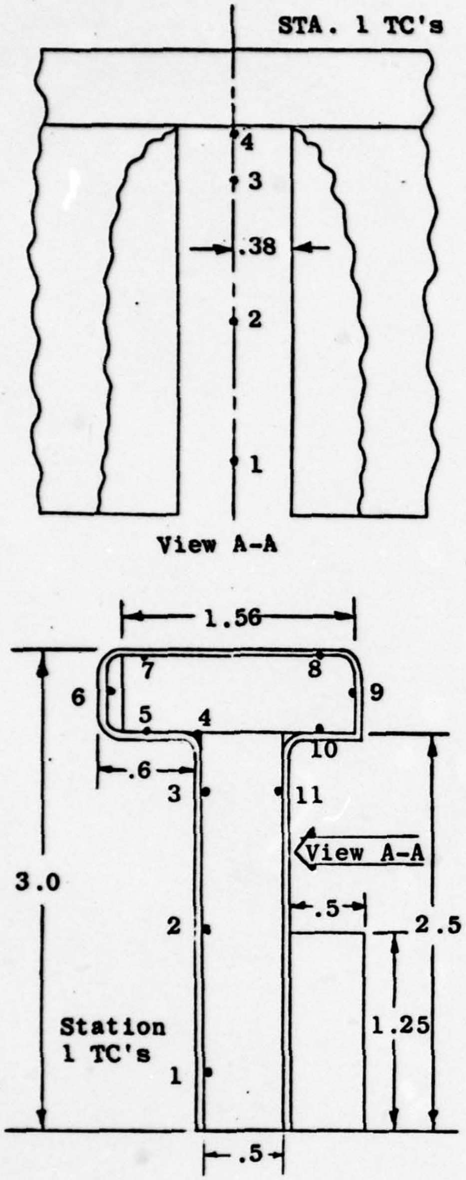
Figure 4. Photograph of Typical Panel Specimen on Water-Cooled Wedge

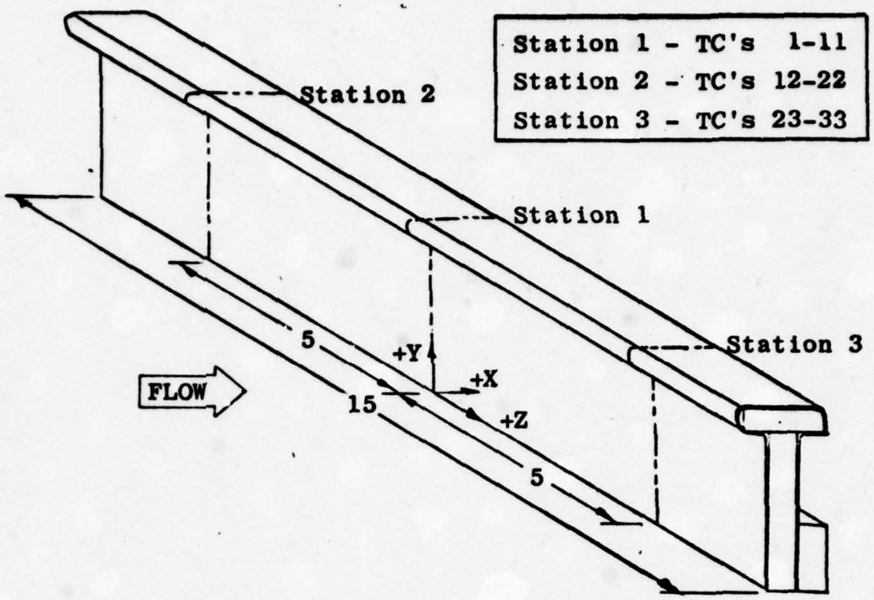


ALPHA SECTOR	WEDGE ANGLE
0	18.65
-14	32.65
+14	4.65

⊕ Center Rotation Used: 10-in.

Figure 5. Installation Sketch of Water-cooled Wedge





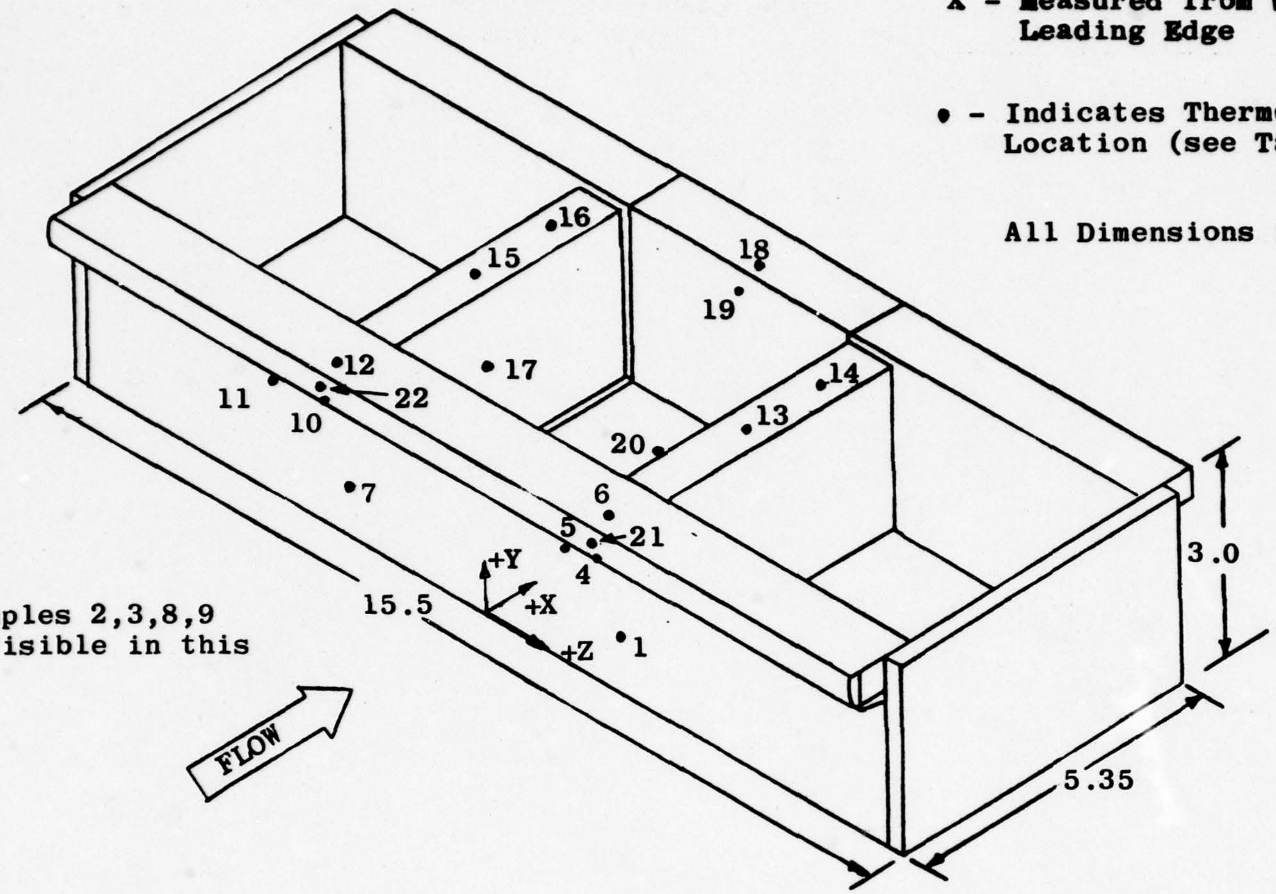
● - Indicates Thermocouple Location (see Table 4)

All Dimensions in Inches

X - Measured from Wedge Leading Edge

a. Kick Ring

Figure 6. Sketches of Thin-Skin Calibration Models



X - **Measured from Wedge Leading Edge**

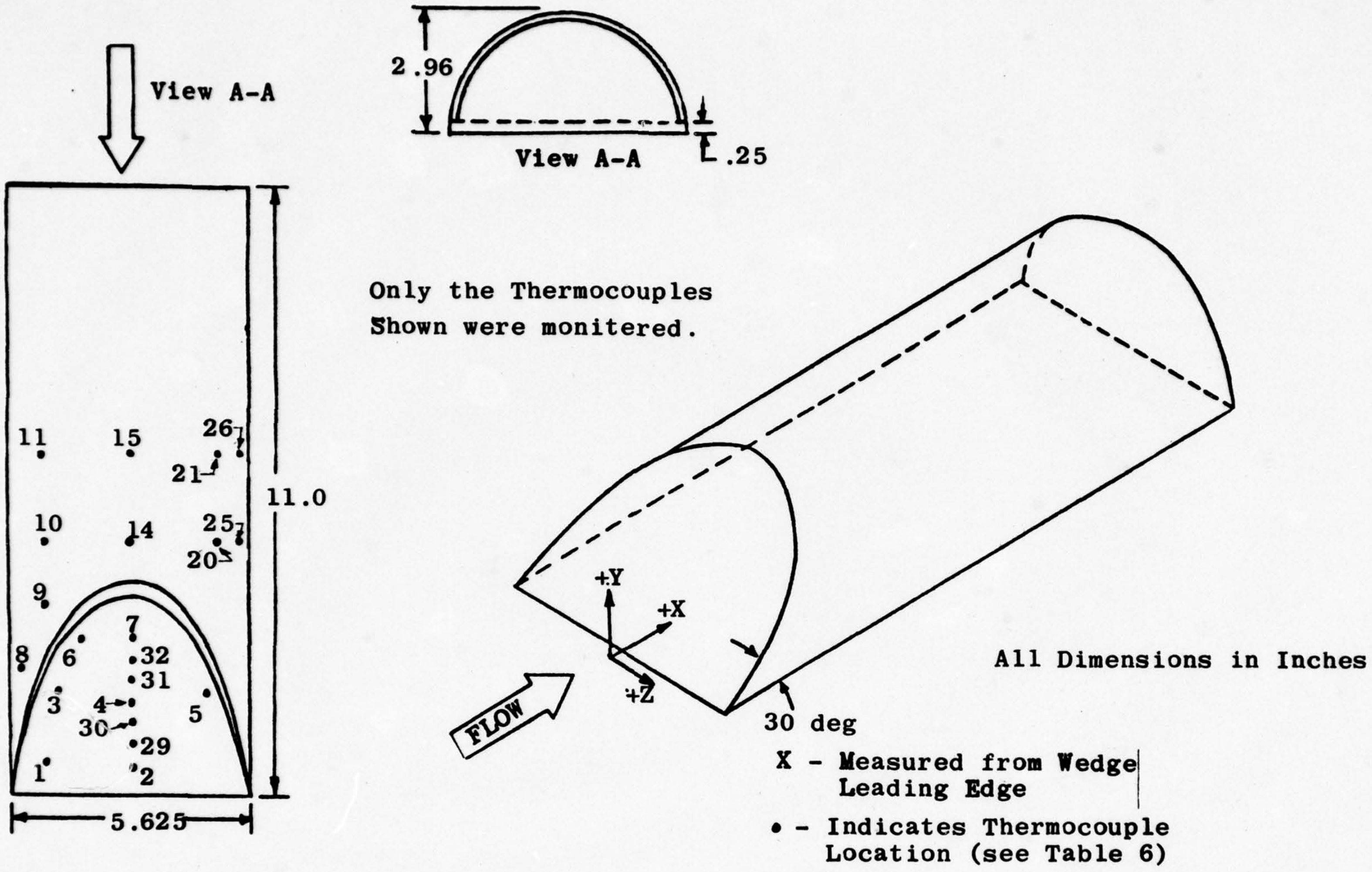
• - Indicates Thermocouple Location (see Table 5)

All Dimensions in Inches

Thermocouples 2,3,8,9 are not visible in this sketch.

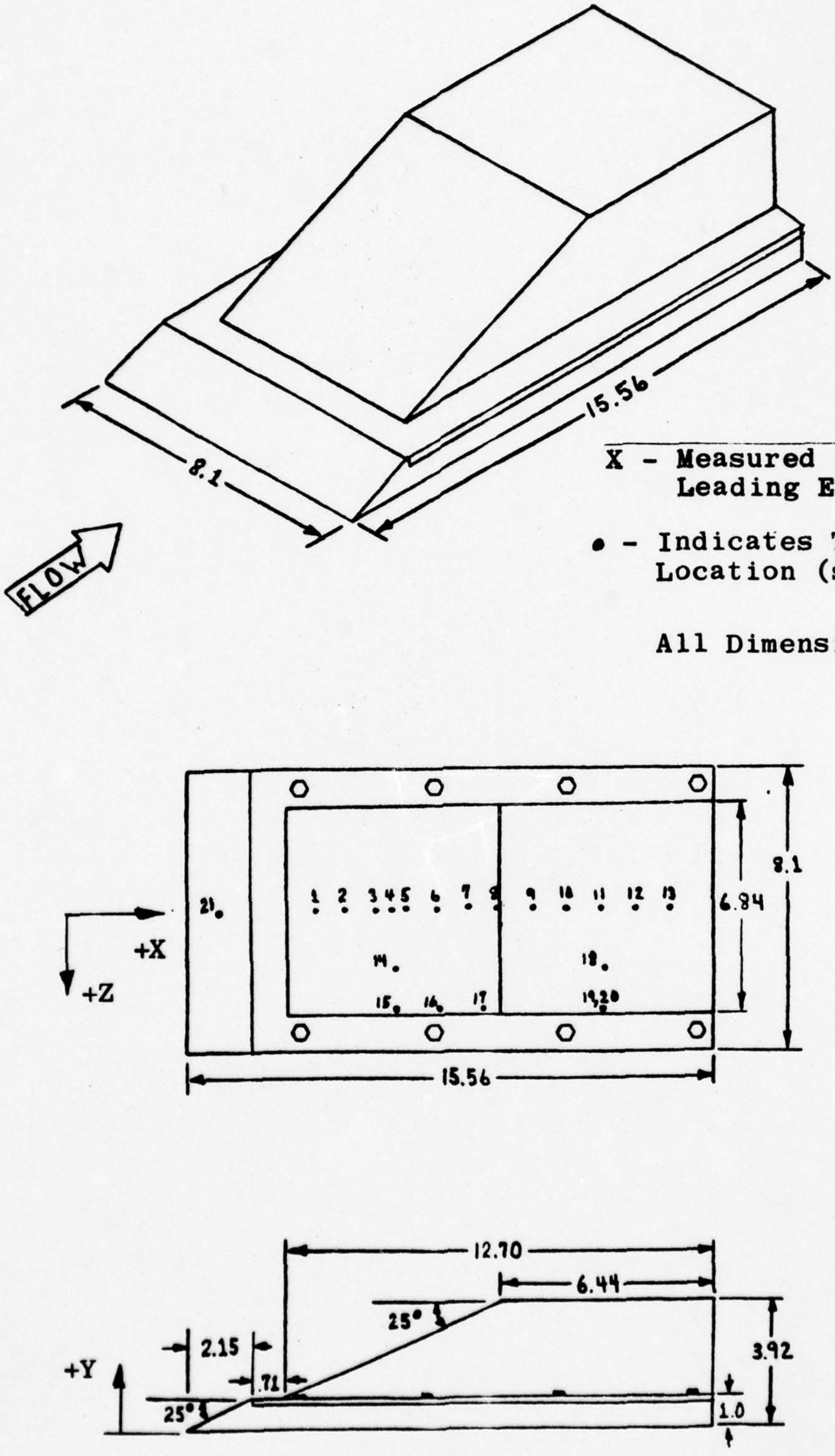
b. Attach Ring

Figure 6. Continued



c. Systems Tunnel

Figure 6. Continued



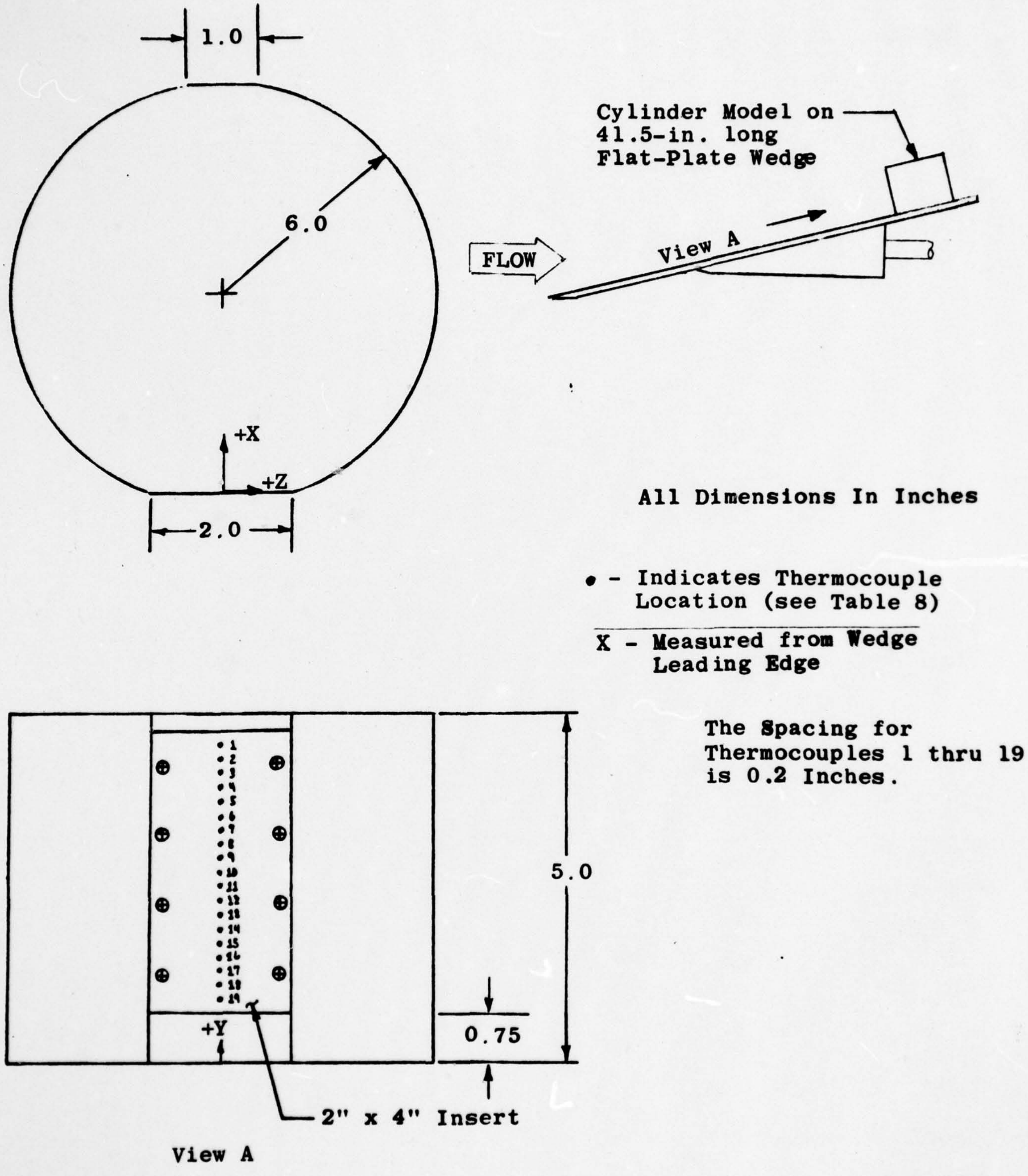
X - Measured from Wedge Leading Edge

● - Indicates Thermocouple Location (see Table 7)

All Dimensions in Inches

d. Range Safety Antenna Cover

Figure 6. Continued



All Dimensions In Inches

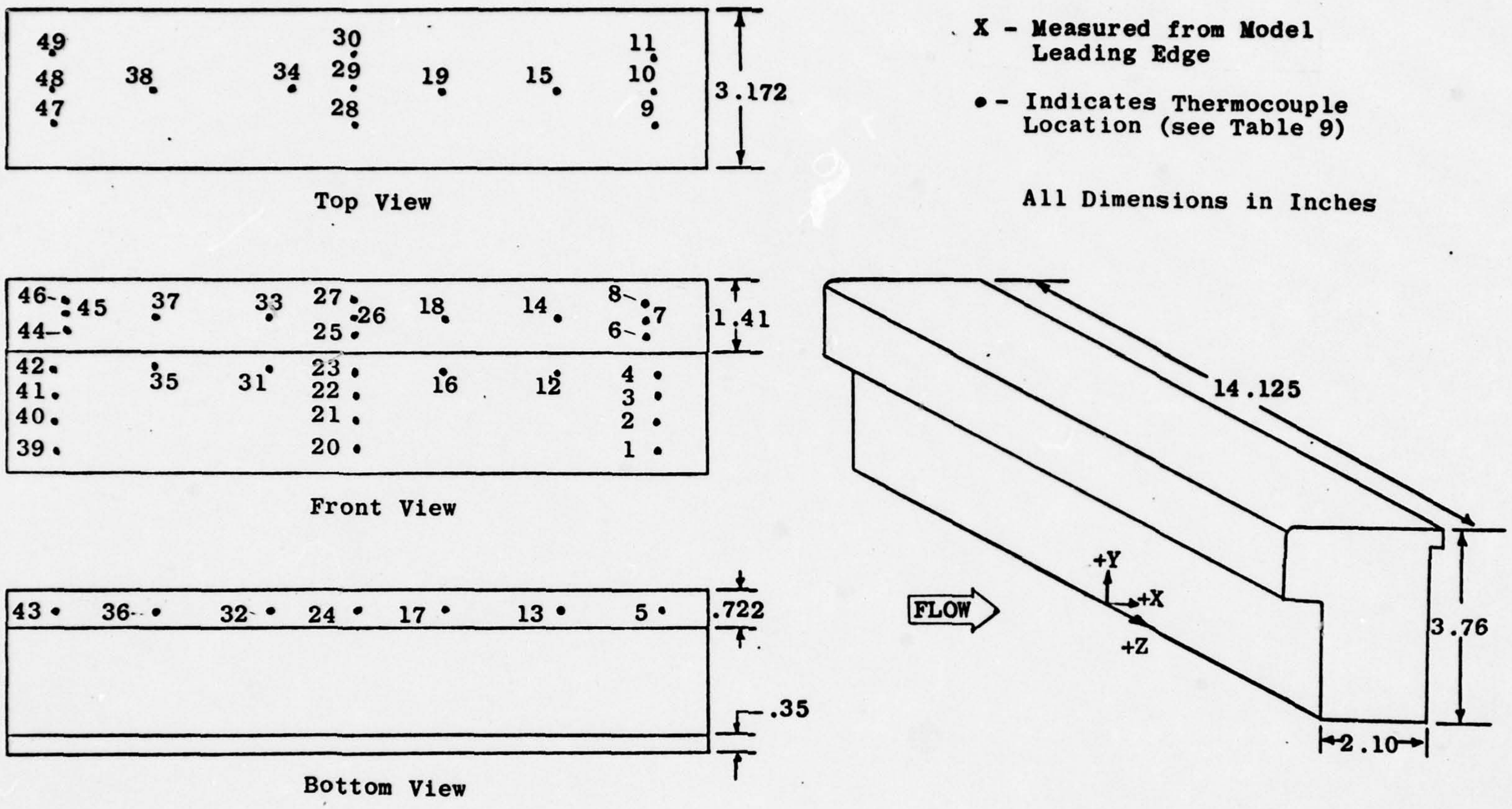
• - Indicates Thermocouple Location (see Table 8)

X - Measured from Wedge Leading Edge

The Spacing for Thermocouples 1 thru 19 is 0.2 Inches.

e. Cylinder Model

Figure 6. Continued



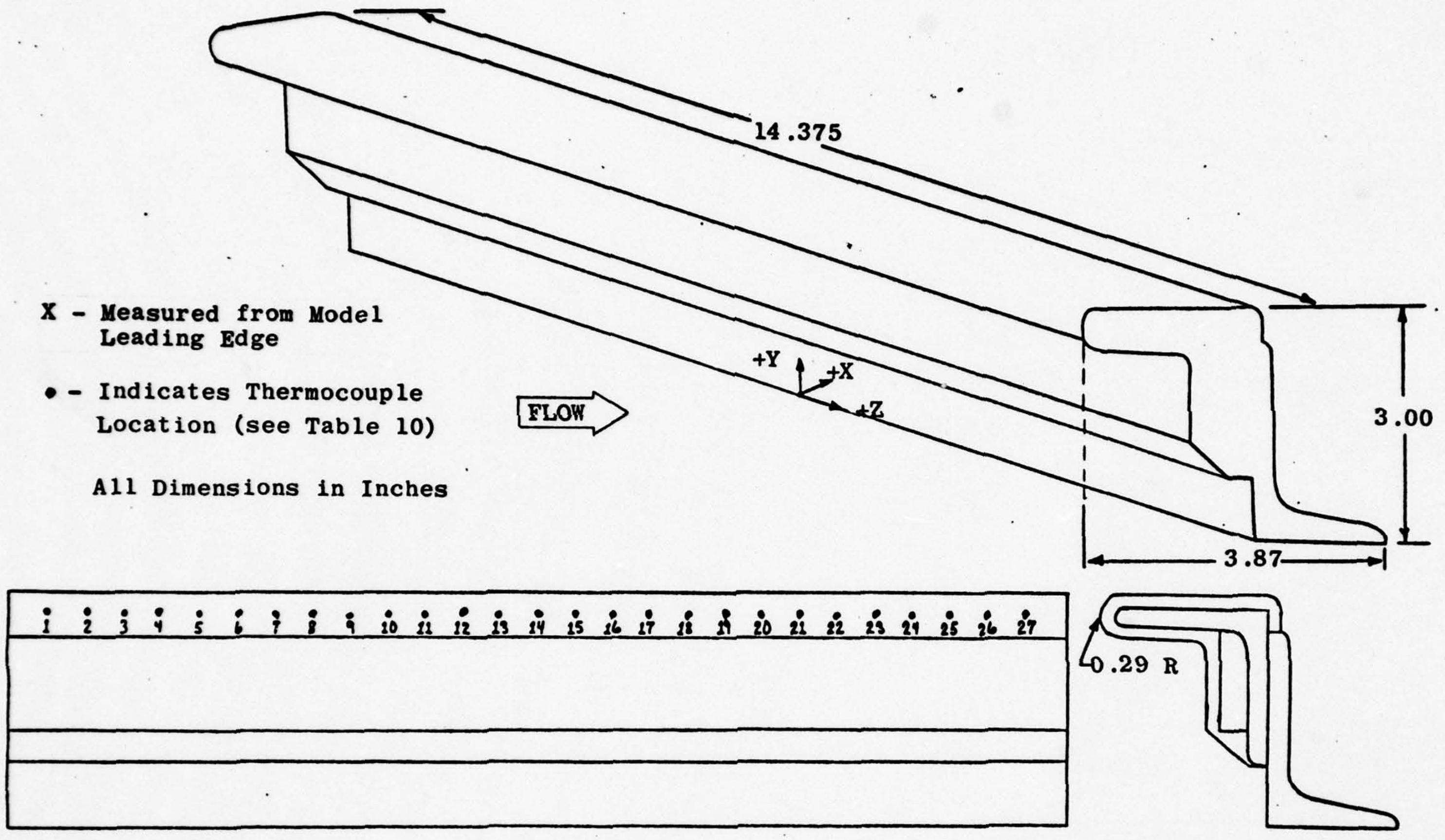
X - Measured from Model Leading Edge

● - Indicates Thermocouple Location (see Table 9)

All Dimensions in Inches

f. Full Scale Kick Ring

Figure 6. Continued



X - Measured from Model Leading Edge

● - Indicates Thermocouple Location (see Table 10)

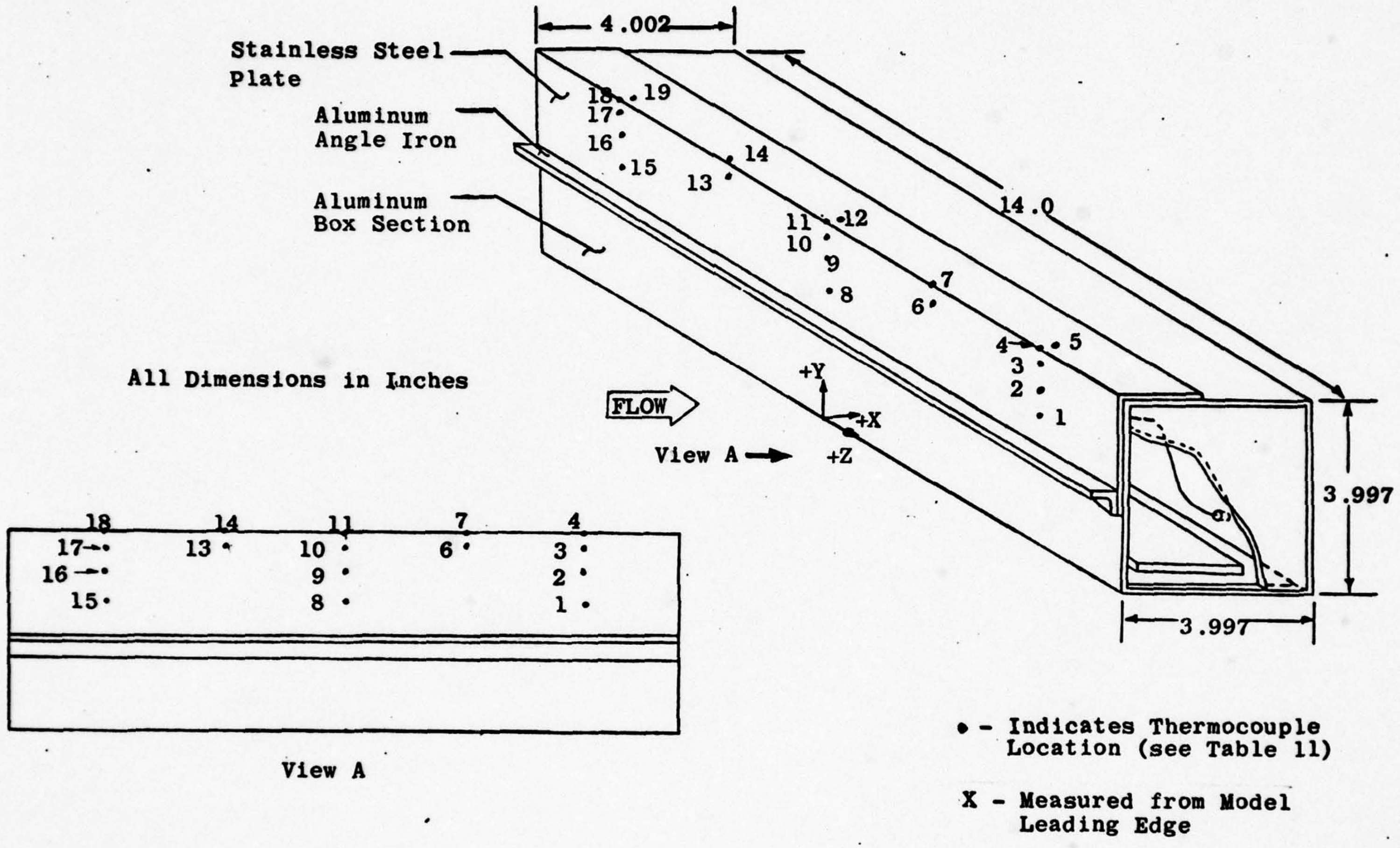
All Dimensions in Inches

Front View

Side View

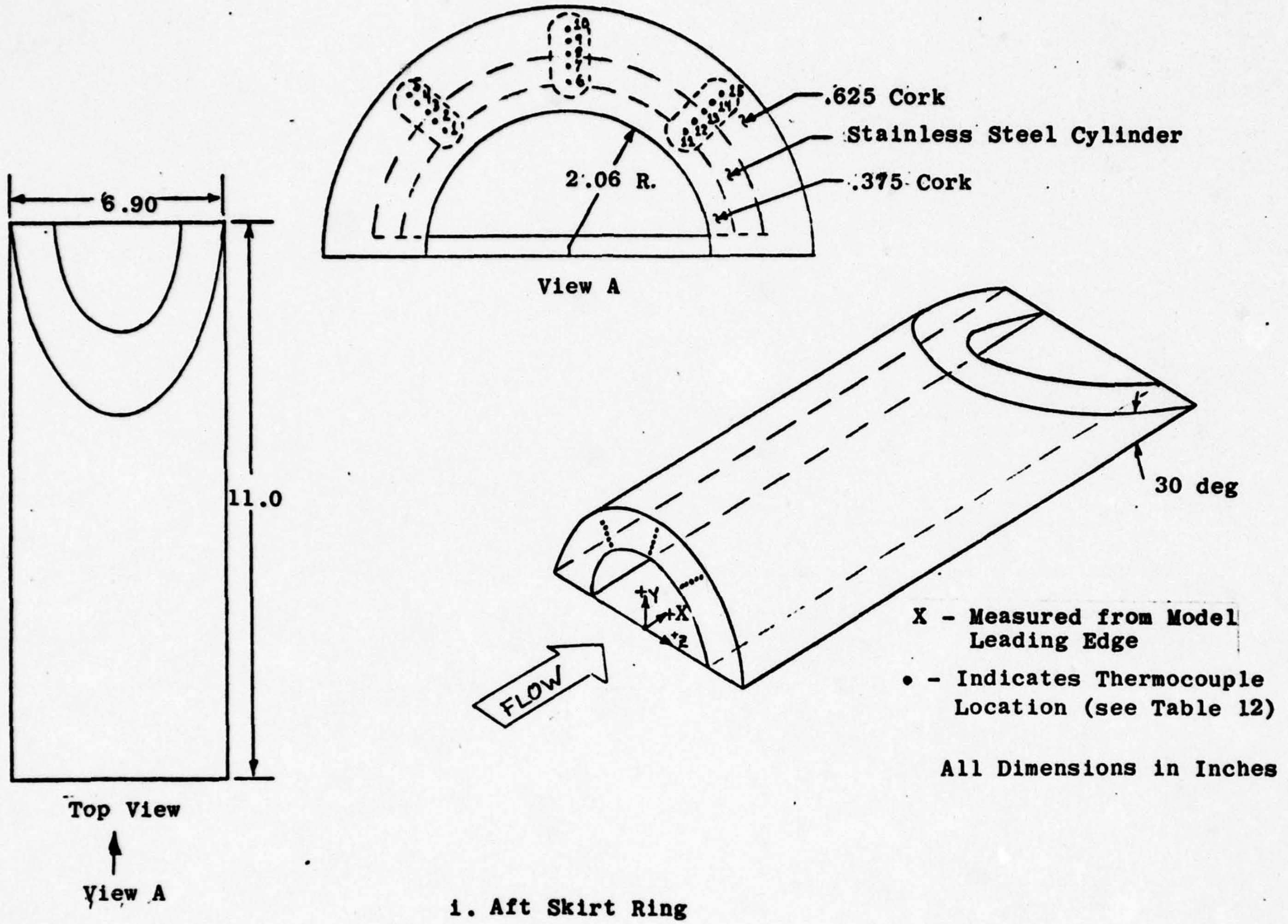
g. Full Scale Attach Ring

Figure 6. Continued



h. Integrated Electronics Assembly

Figure 6. Continued



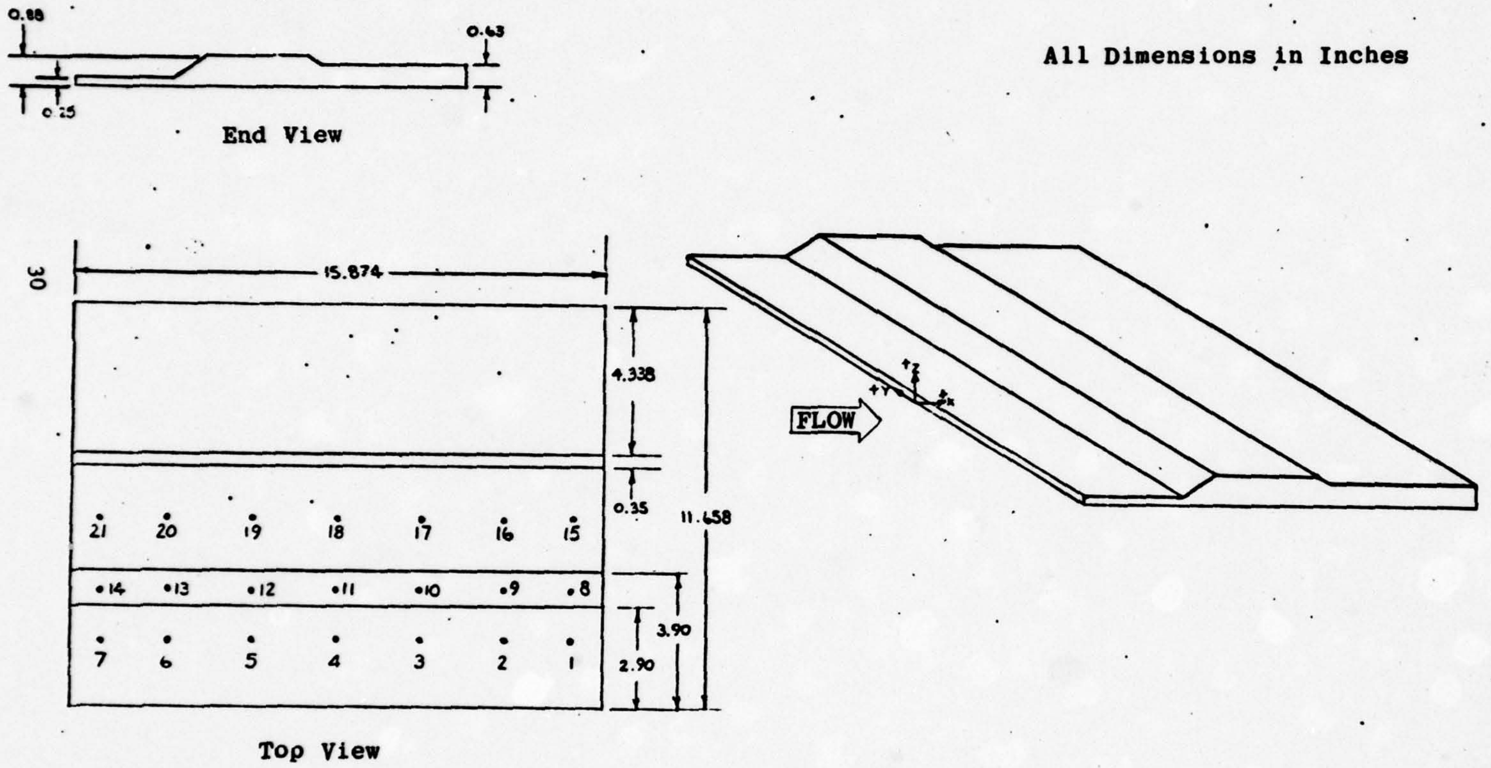
i. Aft Skirt Ring

Figure 6. Continued

X - Measured from Model Leading Edge

• - Indicates Thermocouple Location (see Table 13)

All Dimensions in Inches



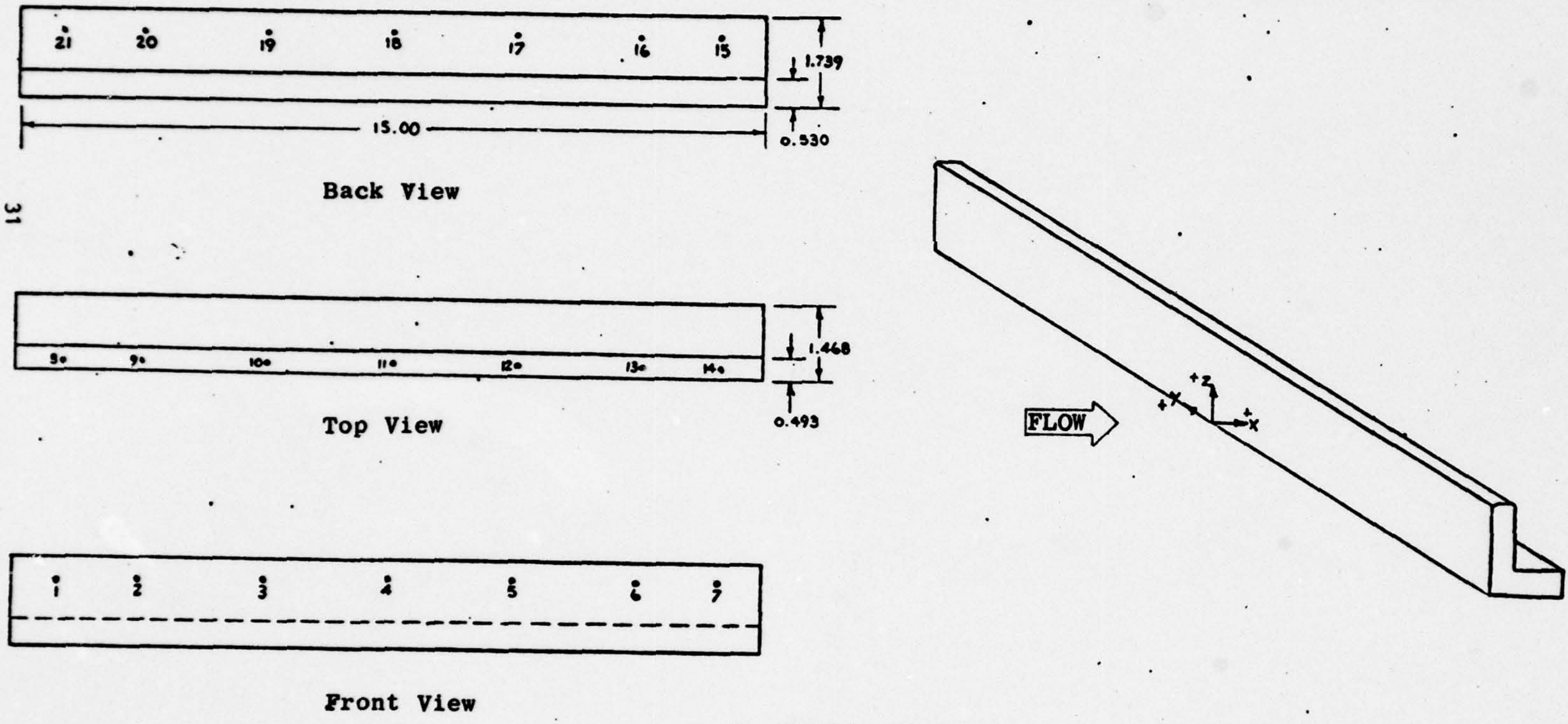
j. Plant/Field Joint

Figure 6. Continued

X - Measured from Model Leading Edge

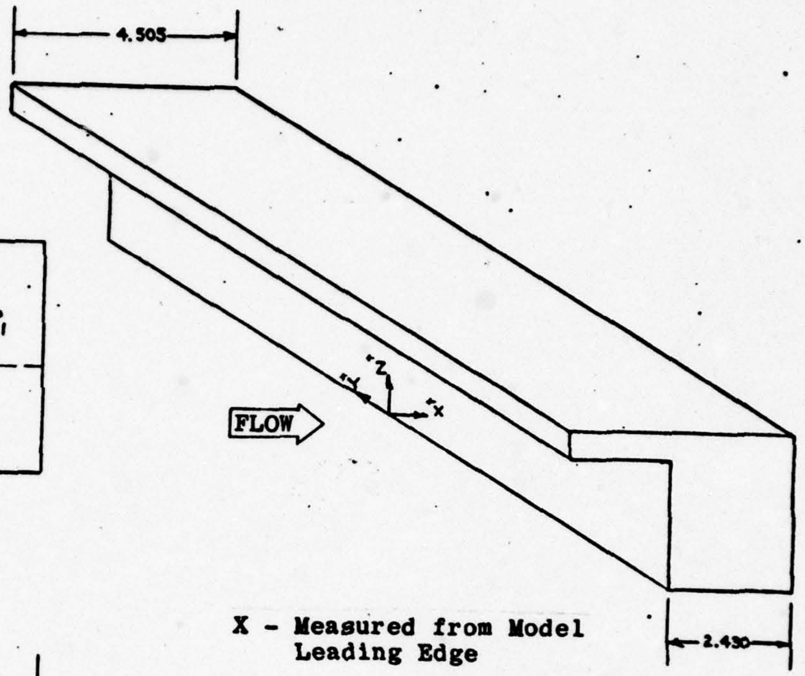
• - Indicates Thermocouple Location (see Table 14)

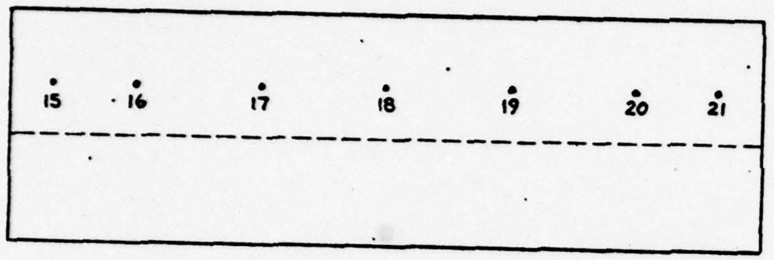
All Dimensions in Inches



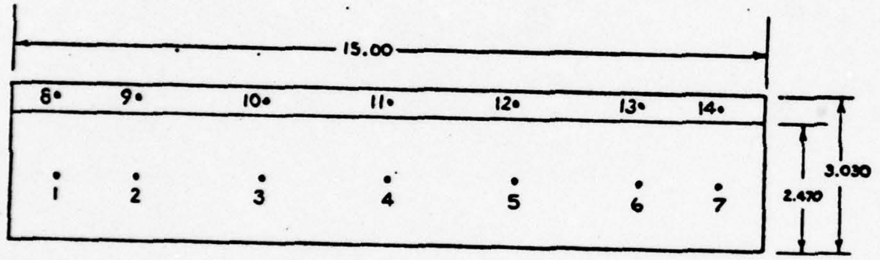
k. Stiffener Stub

Figure 6. Continued





Top View



Front View

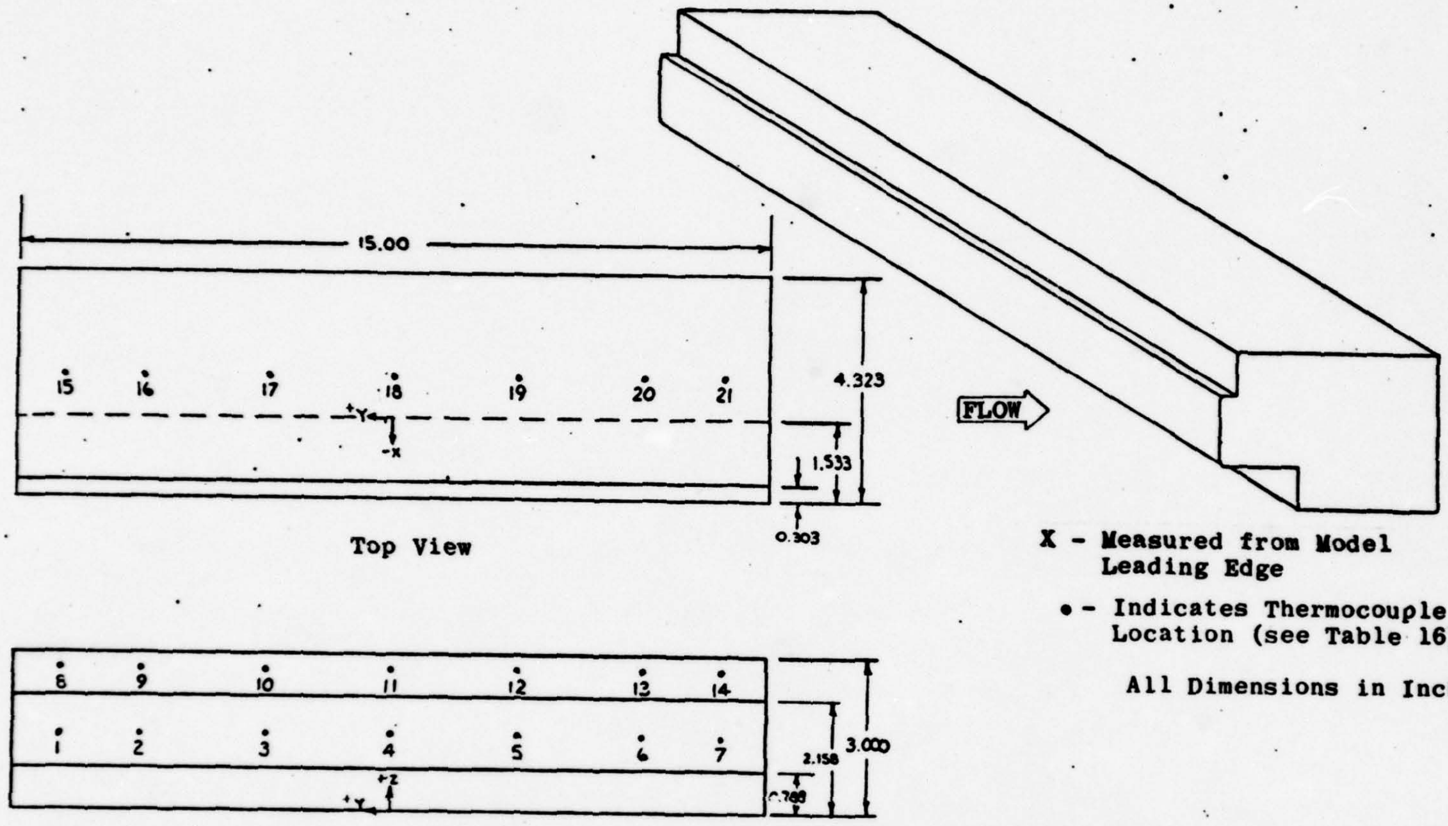
X - Measured from Model
Leading Edge

• - Indicates Thermocouple
Location (see Table 15)

All Dimensions in Inches

1. Stiffener Ring

Figure 6. Continued



Top View

Front View

X - Measured from Model Leading Edge

● - Indicates Thermocouple Location (see Table 16)

All Dimensions in Inches

m. Stiffener Ring Splice

Figure 6. Concluded

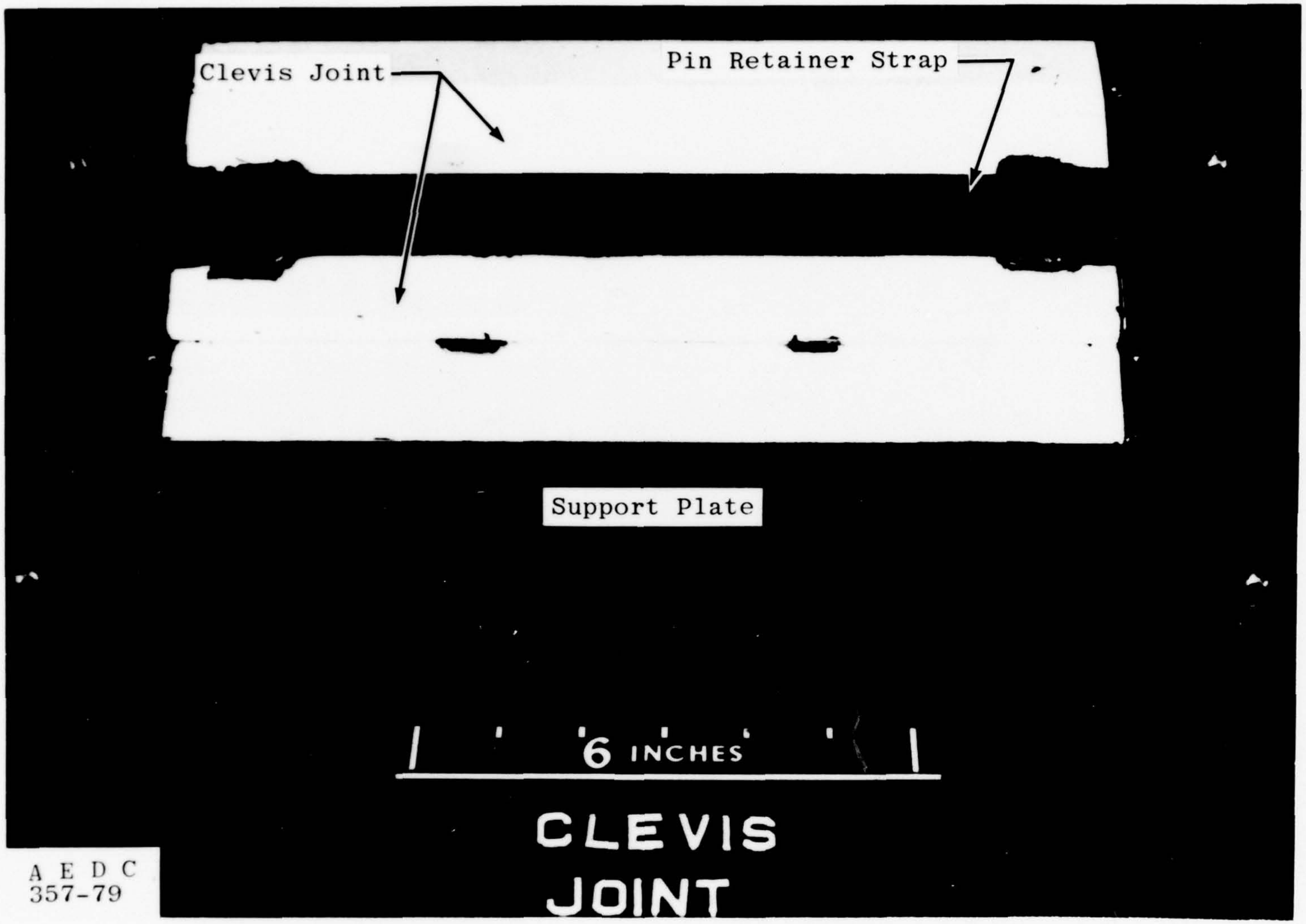


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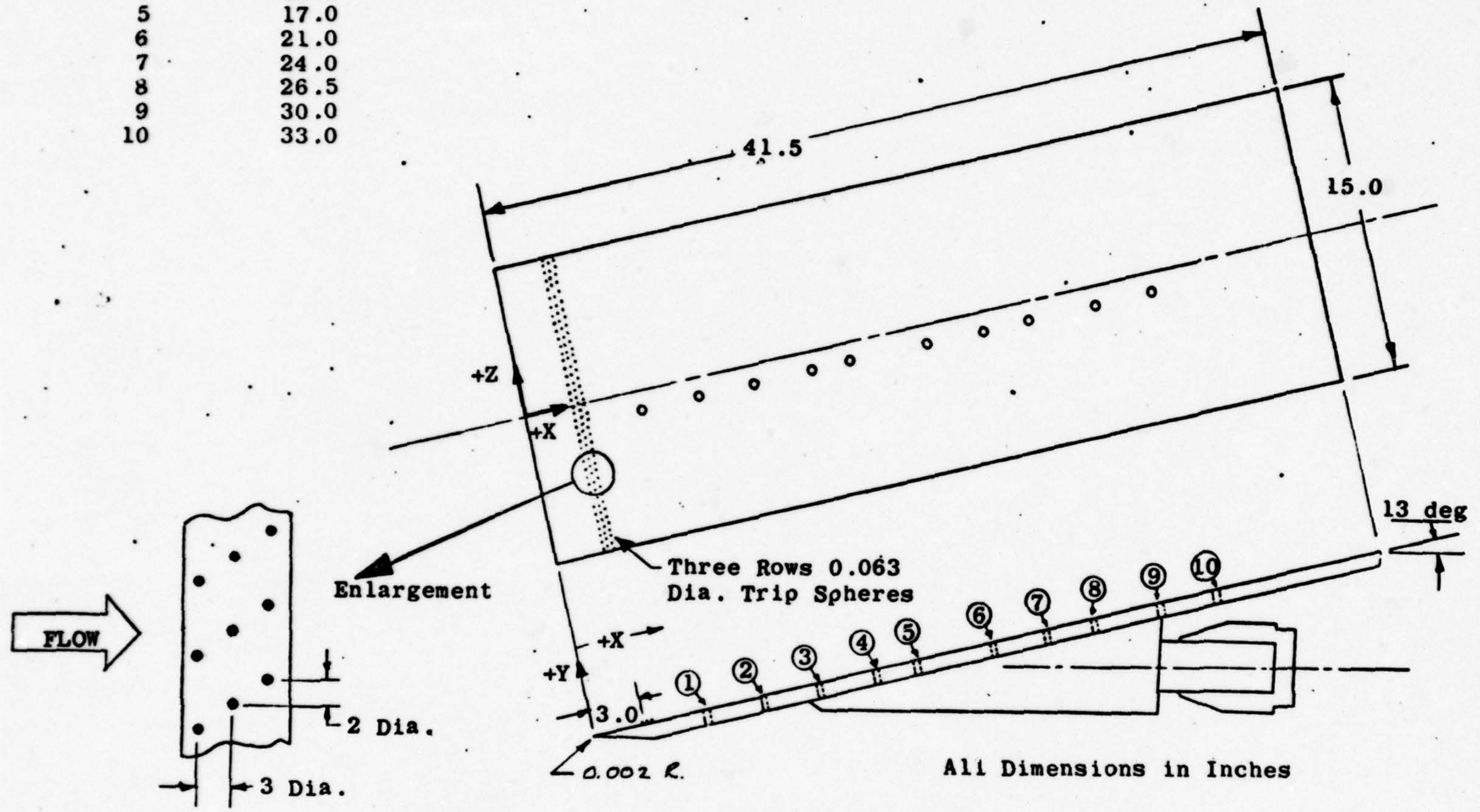
Figure 7. Photograph of Clevis Joint Model

Gardon Gage No.	X, Inches
1	6.0
2	9.0
3	12.0
4	15.0
5	17.0
6	21.0
7	24.0
8	26.5
9	30.0
10	33.0

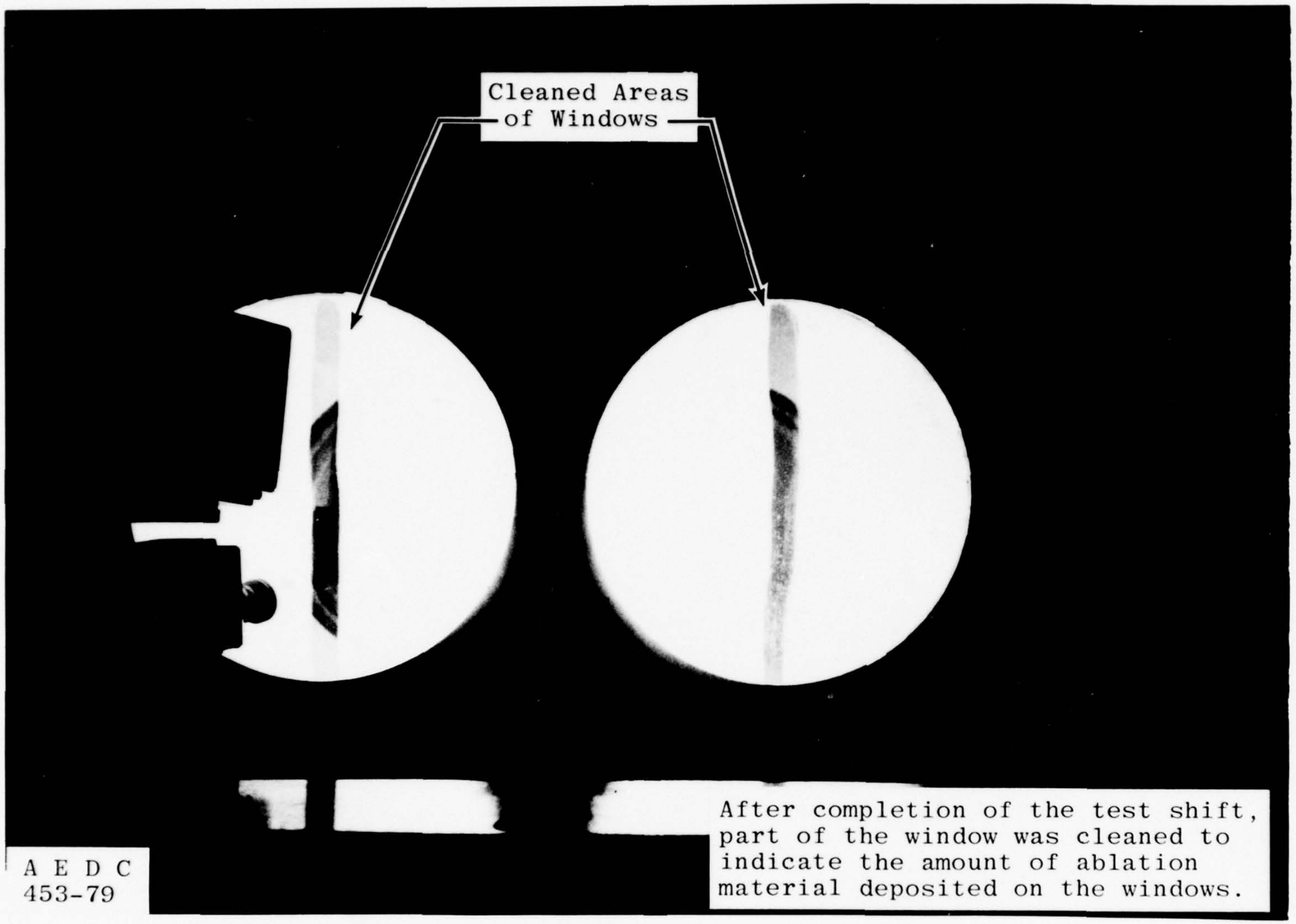
Gardon Gages are Located @ Z= -1.0 in.

o - Indicates Gardon Gage



All Dimensions in Inches

Figure 8. Gardon Gage Locations on Flat-Plate Wedge



After completion of the test shift, part of the window was cleaned to indicate the amount of ablation material deposited on the windows.

Figure 9. Material Deposits on Tunnel Windows

APPENDIX II

TABLES

TABLE 1. Test Entries

ENTRY NO.	DATE OF TEST	SUMMARY OF PRIMARY TEST CONTENTS
1	Dec. 5, 1977	Thin-skin heat transfer calibrations of the SRB Systems Tunnel, Kick Ring, Attach Ring, Range Safety Antenna Cover and Cylinder model. Materials evaluation of MA-25s, ESM, Phenolic Glass, MTA-3, SLA-220, Sheller Globe P-50 Cork, Dodge B-Stage Cork, and Cork over CPR-488.
2	May 22, 1978	Thin-skin heat transfer calibrations of the SRB full-scale Kick Ring and Attach Ring, the Integrated Electronics Assembly Cover, the Aft Skirt Ring, and the Systems Tunnel.
3	May 23, 1978	Materials evaluation of Sheller Globe P-50 Cork, EPDM, Phenolic Glass, V-44, Red Lead primer/top coat and Rust-oleum Zinc rich primer/top coat.
4	Jan. 12, 1979	Materials evaluation of MSA-1 and Chopped Silica Phenolic in conjunction with SRB Instrument Islands.
5	Jan. 15, 1979	Thin-skin heat transfer calibration of the SRM Plant/Field Joint. Materials evaluation of EPDM, Cork, MSA-2 and Chopped Silica Phenolic. Heat-transfer study of SRM Clevis Joint model.
6	Jan. 16, 1979	Thin-skin heat transfer calibration of the SRM Stiffener-Stub, Stiffener Ring, Stiffener Ring/Splice Assembly. Material evaluation of EPDM.

TABLE 2. TEST SPECIMENS

ENTRY NO.	SAMPLE NUMBER	CONFIGURATION TYPE	MATERIAL DESCRIPTION
1	KR-AEDC-1	Kick Ring	MA-25s
	KR-AEDC-2	Kick Ring	ESM
	KR-AEDC-5	Kick Ring	B-Stage Cork over CPR-488
	KR-AEDC-6	Kick Ring	B-Stage Cork over CPR-488
	KR-AEDC-7	Kick Ring	MTA-3
	KR-AEDC-8	Kick Ring	Phenolic Glass
	AR-AEDC-1	Attach Ring	MA-25s
	KR-MHGF-9	Kick Ring	Phenolic Glass
	ST-AEDC-1	Systems Tunnel	P-50 Cork
	ST-AEDC-2	Systems Tunnel	B-Stage Cork
	ST-AEDC-3	Systems Tunnel	P-50 Cork
	ST-AEDC-4	Systems Tunnel	B-Stage Cork
	AF-AEDC-2	Range Safety Antenna Cover	SLA-220
	AF-AEDC-4	Range Safety Antenna Cover	SLA-220
3	Z-1	Cylinder Model	Rust-oleum Zinc Rich Primer/Top Coat
	Z-2	Cylinder Model	Rust-oleum Zinc Rich Primer/Top Coat
	Z-3	Cylinder Model	Rust-oleum Zinc Rich Primer/Top Coat
	Z-4	Cylinder Model	Rust-oleum Zinc Rich Primer/Top Coat
	11	Cylinder Model	Red Lead Primer/Top Coat
	33	Cylinder Model	Red Lead Primer/Top Coat
	66	Cylinder Model	Red Lead Primer/Top Coat
	91	Cylinder Model	Red Lead Primer/Top Coat
	113	Cylinder Model	Red Lead Primer/Top Coat
	FSKR-48	Full Scale Kick Ring	Phenolic Glass with P-50 Cork
	FSKR-78	Full Scale Kick Ring	Phenolic Glass with P-50 Cork
	FSKR-80	Full Scale Kick Ring	Phenolic Glass with P-50 Cork
	FSKR-60	Full Scale Kick Ring	Phenolic Glass with P-50 Cork
	FSKR-68	Full Scale Kick Ring	Phenolic Glass with P-50 Cork
	FSKR-72	Full Scale Kick Ring	Phenolic Glass with P-50 Cork
	FSAR-52	Full Scale Attach Ring	Phenolic Glass with P-50 Cork
	FSAR-54	Full Scale Attach Ring	Phenolic Glass with P-50 Cork
	FSAR-76	Full Scale Attach Ring	Phenolic Glass with P-50 Cork
	FSAR-66	Full Scale Attach Ring	Phenolic Glass with P-50 Cork
	FSAR-58	Full Scale Attach Ring	Phenolic Glass with P-50 Cork
	FSAR-75	Full Scale Attach Ring	Phenolic Glass with P-50 Cork
	FSART-1	Full Scale Attach Ring (Thiokol)	EPDM Vulcanize Bonded
	FSART-3	Full Scale Attach Ring (Thiokol)	EPDM Vulcanize Bonded
	FSART-4	Full Scale Attach Ring (Thiokol)	EPDM Vulcanize Bonded
	FSART-2	Full Scale Attach Ring (Thiokol)	EPDM Vulcanize Bonded
	FSART-5	Full Scale Attach Ring (Thiokol)	EPDM Epoxy Bonded
	FSART-6	Full Scale Attach Ring (Thiokol)	EPDM Epoxy Bonded
	KR-AEDC-5	1/3 Scale Kick Ring	V44
	KR-AEDC-6	1/3 Scale Kick Ring	V44
	KR-AEDC-7	1/3 Scale Kick Ring	V44
	KR-AEDC-8	1/3 Scale Kick Ring	V44
	IEA-1	Integrated Electronics Assembly	P-50 Cork
	IEA-2	Integrated Electronics Assembly	P-50 and Phenolic Glass
	ASR-1	Aft Skirt Ring	P-50 Cork
4	2141(ISL 4-1)	Instrument Island with Dummy Calorimeter	B-Stage Cork with Chopped Silica Phenolic
	2142(ISL 4-2)	Instrument Island with Calorimeter	B-Stage Cork with Chopped Silica Phenolic
	2151(ISL 5-1)	Instrument Island with Dummy Radiometer	B-Stage Cork with Chopped Silica Phenolic
	2161(ISL 6-1)	Instrument Island with Dummy Calorimeter	MSA-1 with Chopped Silica Phenolic
	2162(ISL 6-2)	Instrument Island with Calorimeter	MSA-1 with Chopped Silica Phenolic
	2171(ISL 7-1)	Instrument Island with Pressure Impact Sensor	B-Stage with Chopped Silica Phenolic
	2172(ISL 7-2)	Instrument Island with Pressure Impact Sensor	B-Stage with Chopped Silica Phenolic
	2181(ISL 8-1)	Instrument Island with Acoustic Transducer	B-Stage Cork with Chopped Silica Phenolic
	2182(ISL 8-2)	Instrument Island with Acoustic Transducer	B-Stage Cork with Chopped Silica Phenolic
5	2152(ISL 5-2)	Instrument Island with Radiometer	B-Stage Cork with Chopped Silica
	3106(MSA2-6)	SRB "Clean" Body Panel	MSA-2
	4100	Full Scale Clevis Joint	Flight Hardware (Steel)
	111 (CW-1)	DFI Cableway	Sheet Cork
	115 (CW-2)	DFI Cableway	Sheet Cork
	114 (PFJ-I)	Plant/Field Joint	EPDM
	113 (PFJ-II)	Plant/Field Joint	EPDM
	112 (PFJ-III)	Plant/Field Joint	EPDM

TABLE 2. Continued

ENTRY NO.	SAMPLE NUMBER	CONFIGURATION TYPE	MATERIAL DESCRIPTION
6	611 (SS-I)	Stiffener Stub	EPDM
	612 (SS-II)	Stiffener Stub	EPDM
	711 (SRS-I)	Stiffener Ring Splice	EPDM
	712 (SRS-II)	Stiffener Ring Splice	EPDM
	713 (SRS-III)	Stiffener Ring Splice	EPDM
	811 (SR-I)	Stiffener Ring	EPDM
	812 (SR-II)	Stiffener Ring	EPDM
	813 (SR-III)	Stiffener Ring	EPDM

TABLE 3. Material Descriptions

Material	Density-ρ (lbm/ft^3)	Specific Heat-c (Btu/lbm-^oR)	Thermal Conductivity-k (Btu/ft-hr-^oR)	Description
ESM(Elastomeric Shield Material)	35	0.37	0.56×10^{-1}	A glass-fiber reinforced silicone foam formulated from PD200. Developed by General Electric.
SLA-220	15	0.22	0.475×10^{-1}	A silica filled elastomeric silicone resin developed by the Martin Marietta Company.
Phenolic Glass	92	0.22	1.83×10^{-1}	A high temperature E-glass laminate fabricated from F120 glass cloth and a phenolic resin laminate. Developed by the Hexcel Corp.
EPDM	69	0.43	1.7×10^{-1}	A silica filled synthetic copolymer of ethylene propylene and neoprene rubbers. Developed by the Thiokol Corp.
V44	80	0.44	1.26×10^{-1}	An asbestos filled synthetic rubber made by Kurkil Rubber Co. and Ohio Rubber Co.
MA-25s	25	0.30	0.483×10^{-1}	An eccosphere and silica fiber filled elastomeric silicone resin developed by the Martin Marietta Corp.
MTA-3	-	-	-	A trowelable formulation of P-50 cork and RTV511. Developed at the MSFC.
P-50 & B-Stage Cork	31	0.47	0.4×10^{-1}	Compressed cork available from Southland, Sheller Globe and Armstrong.
MSA(Marshall Sprayable Ablator)	16	-	-	Primarily a combination of Phenolic and Glass microballoons (beads), GE-7344 resin and Bentone (clay). Developed at the MSFC.
CPR-488	2.3	-	-	A two component isocyanurate foam developed by the CPR division of the Upjohn Company.

TABLE 4. Thermocouple Locations - Kick Ring

TC-NO.	X	Y	Z
1	37.97	0.375	0.0
2	37.97	1.250	
3	37.97	2.125	
4	37.97	2.500	
5	37.72	2.500	
6	37.37	2.750	
7	37.72	3.000	
8	38.72	3.000	
9	38.97	2.750	
10	38.72	2.500	
11	38.47	2.125	0.0
12	37.97	0.875	-5.0
13	37.97	1.250	
14	37.97	2.125	
15	37.97	2.500	
16	37.72	2.500	
17	37.37	2.750	
18	37.72	3.000	
19	38.72	3.000	
20	38.97	2.750	
21	38.72	2.500	
*22	38.47	2.125	-5.0
23	37.97	0.375	+5.0
24	37.97	1.250	
25	37.97	2.125	
26	37.97	2.500	
27	37.72	2.500	
28	37.37	2.750	
29	37.72	3.000	
*30	38.72	3.000	
*31	38.97	2.750	
*32	38.72	2.500	
*33	38.47	2.125	+5.0

*Not hooked up

TABLE 5. Thermocouple Locations - Attach Ring

TC-NO.	X	Y	Z
1	35.81	0.875	+2.5
2	35.81	2.0625	↑
3	35.81	2.5	
4	35.185	2.5	
5	35.185	3.0	↓
6	35.56	3.0	+2.5
7	35.81	0.875	-2.5
8	35.81	2.0625	↑
9	35.81	2.500	
10	35.185	2.5	
11	35.185	3.0	↓
12	35.56	3.0	-2.5
13	38.31	2.875	+2.5
14	39.81	2.875	+2.5
15	38.31	2.875	-2.5
16	39.81	2.875	-2.5
17	38.31	1.5	-2.5
18	40.81	3.0	0.0
19	40.56	2.75	0.0
20	38.31	0.375	0.0
21	35.185	2.75	2.5
22	35.185	2.75	-2.5

TABLE 6. Thermocouple Locations - Systems Tunnel

TC-NO.	X	Y	Z
1	32.80	0.75	-1.75
2	32.80	0.75	0.0
3	34.10	1.50	-1.50
4	34.10	1.50	0.0
5	34.10	1.50	1.50
6	35.40	2.25	-1.25
7	35.40	2.25	0.0
8	34.50	1.00	-2.75
9	36.00	2.00	-2.25
10	37.50	2.00	-2.25
11	41.50	2.00	-2.25
14	37.50	3.00	0.0
15	41.50	3.00	0.0
20	37.50	2.00	2.25
21	41.50	2.00	2.25
25	37.50	1.00	2.75
26	41.50	1.00	2.75
29	33.23	1.00	0.0
30	33.67	1.25	0.0
31	34.53	1.75	0.0
32	34.96	2.00	0.0

TABLE 7. Thermocouple Locations - Range Safety Antenna Cover

TC-NO.	X	Y	Z
1	30.71	1.423	0.0
2	31.61	1.845	↑
3	32.52	2.268	
4	32.97	2.479	
5	33.43	2.690	
6	34.33	3.113	
7	35.24	3.536	
8	36.14	3.92	
9	37.14	↑	
10	38.14		
11	39.14		
12	40.14	↓	↓
13	41.14	3.92	0.0
14	32.97	2.479	2.00
15	32.97	2.479	3.375
16	34.33	3.324	↕
17	35.69	3.536	3.375
18	39.14	3.92	2.00
19	39.14	3.92	3.375
20	39.14	2.45	3.375
21	27.86	0.507	0.0

TABLE 8. Thermocouple Locations - Cylinder Model

TC-NO.	X	Y	Z
1	34.50	4.63	0.0
2	↑	4.43	↑
3		4.23	
4		4.03	
5		3.83	
6		3.63	
7		3.43	
8		3.23	
9		3.03	
10		2.83	
11		2.63	
12		2.43	
13		2.23	
14		2.03	
15		1.83	
16		1.63	
17		1.43	
18	↓	1.23	↓
19	34.50	1.03	0.0

TABLE 9. Thermocouple Locations - Full Scale Kick Ring

TC-NO.	X	Y	Z
1	0.0	0.438	6.063
2	↕	1.00	↕
3	↕	1.50	↕
4	0.0	2.00	↕
5	-0.313	2.35	6.063
6	-0.722	2.73	5.813
7	↕	3.04	↕
8	-0.722	3.35	5.813
9	0.0905	3.76	6.063
10	0.778	↕	↕
11	1.466	3.76	6.063
12	0.0	2.00	4.063
13	-0.313	2.35	↕
14	-0.722	3.04	↕
15	0.778	3.76	4.063
16	0.0	2.00	1.75
17	-0.313	2.35	↕
18	-0.722	3.04	↕
19	0.778	3.76	1.75
20	0.0	0.438	0.0
21	↕	1.00	↕
22	↕	1.50	↕
23	0.0	2.00	↕
24	-0.313	2.35	↕
25	-0.722	2.73	0.0
26	-0.722	3.04	0.0
27	-0.722	3.35	↕
28	0.0905	3.76	↕
29	0.778	↕	↕
30	1.466	↕	0.0
31	0.0	2.00	-1.75
32	-0.313	2.35	-1.75

TABLE 9. Continued

TC-NO.	X	Y	Z
33	-0.722	3.04	-1.75
34	0.778	3.76	-1.75
35	0.0	2.00	-4.063
36	-0.313	2.35	↑
37	-0.722	3.04	↓
38	0.778	3.76	-4.063
39	0.0	0.438	-6.063
40	↑	1.00	↑
41	↓	1.50	│
42	0.0	2.00	↓
43	-0.313	2.35	-6.063
44	-0.722	2.73	-5.813
45	↕	3.04	↕
46	-0.722	3.35	-5.813
47	0.0905	3.76	-6.063
48	0.778	↕	↕
49	1.466	3.76	-6.063

TABLE 10. Thermocouple Locations - Full Scale Attach Ring

TC-NO.	X	Y	Z
1	-2.19	2.71	-6.44
2	↓	↓	-5.94
3	↓	↓	-5.44
4	↓	↓	-4.94
5	↓	↓	-4.44
6	↓	↓	-3.94
7	↓	↓	-3.44
8	↓	↓	-2.94
9	↓	↓	-2.44
10	↓	↓	-1.94
11	↓	↓	-1.44
12	↓	↓	-0.94
13	↓	↓	-0.44
14	↓	↓	0.06
15	↓	↓	0.56
16	↓	↓	1.06
17	↓	↓	1.56
18	↓	↓	2.06
19	↓	↓	2.56
20	↓	↓	3.06
21	↓	↓	3.56
22	↓	↓	4.06
23	↓	↓	4.56
24	↓	↓	5.06
25	↓	↓	5.56
26	↓	↓	6.06
27	↓	↓	6.56

TABLE 11. Thermocouple Locations - Integrated Electronics Assembly

TC-NO.	X	Y	Z
1	0.0	2.63	5.0
2	↑	3.25	|
3	|	3.75	|
4	↓	4.0	|
5	0.28	4.0	↓
6	0.0	3.75	2.5
7	↑	4.0	2.5
8	|	2.63	0.0
9	|	3.25	|
10	|	3.75	|
11	↓	4.0	|
12	0.28	4.0	↓
13	0.0	3.75	-2.5
14	↑	4.0	-2.5
15	|	2.63	-5.0
16	|	3.25	|
17	|	3.75	|
18	↓	4.0	|
19	0.28	4.0	↓

TABLE 12. Thermocouple Locations - Aft Skirt Ring

TC-NO.	X	Y	Z
1	0.0	1.871	-1.741
2	↓	2.004	-1.874
3	↓	2.136	-2.006
4	↓	2.269	-2.139
5	↓	2.402	-2.272
6	↓	2.593	0.0
7	↓	2.780	↓
8	↓	2.968	↓
9	↓	3.155	↓
10	↓	3.343	↓
11	↓	1.871	1.741
12	↓	2.004	1.874
13	↓	2.136	2.006
14	↓	2.269	2.139
15	↓	2.402	2.272

TABLE 13. Thermocouple Locations - Plant/Field Joint

TC-NO.	X	Y	Z
1	1.97	-7.00	0.22
2	↓	-5.00	↓
3	↓	-2.50	↓
4	↓	0.00	↓
5	↓	2.50	↓
6	↓	5.00	↓
7	↓	7.00	↓
8	3.39	-7.00	0.53
9	↓	-5.00	↓
10	↓	-2.50	↓
11	↓	0.00	↓
12	↓	2.50	↓
13	↓	5.00	↓
14	↓	7.00	↓
15	5.47	-7.00	0.85
16	↓	-5.00	↓
17	↓	-2.50	↓
18	↓	0.00	↓
19	↓	2.50	↓
20	↓	5.00	↓
21	↓	7.00	↓

TABLE 14. Thermocouple Locations - Stiffener Stub

TC-NO.	X	Y	Z
1	0.00	+6.60	+1.33
2	↓	5.00	↓
3	↓	2.50	↓
4	↓	0.00	↓
5	↓	-2.50	↓
6	↓	-5.00	↓
7	↓	-6.60	↓
8	+0.22	+6.60	+1.71
9	↓	5.00	↓
10	↓	2.50	↓
11	↓	0.00	↓
12	↓	-2.50	↓
13	↓	-5.00	↓
14	↓	-6.60	↓
15	+0.44	+6.60	+1.33
16	↓	5.00	↓
17	↓	2.50	↓
18	↓	0.00	↓
19	↓	-2.50	↓
20	↓	-5.00	↓
21	↓	-6.60	↓

TABLE 15. Thermocouple Locations - Stiffener Ring

TC-NO.	X	Y	Z
1	0.00	+6.60	+1.25
2	↓	5.00	↓
3	↓	2.50	↓
4	↓	0.00	↓
5	↓	-2.50	↓
6	↓	-5.00	↓
7	↓	-6.60	↓
8	-2.02	+6.60	+2.75
9	↓	5.00	↓
10	↓	2.50	↓
11	↓	0.00	↓
12	↓	-2.50	↓
13	↓	-5.00	↓
14	↓	-6.60	↓
15	+1.03	+6.60	+3.00
16	↓	5.00	↓
17	↓	2.50	↓
18	↓	0.00	↓
19	↓	-2.50	↓
20	↓	-5.00	↓
21	↓	-6.60	↓

TABLE 16. Thermocouple Locations - Stiffener Ring Splice

TC-NO.	X	Y	Z
1	-1.50	+6.60	+1.47
2	↓	5.00	↓
3		2.50	
4		0.00	
5		-2.50	
6		-5.00	
7		-6.60	
8	-1.20	+6.60	+2.73
9	↓	5.00	↓
10		2.50	
11		0.00	
12		-2.50	
13		-5.00	
14		-6.60	
15	+0.80	+6.60	+3.00
16	↓	5.00	↓
17		2.50	
18		0.00	
19		-2.50	
20		-5.00	
21		-6.60	

TABLE 17. SUMMARY TEST LOG

ENTRY	TEST DATE	PO(psia)	TO($^{\circ}$R)	WEDGE ANGLE(deg)	MATERIAL TESTED (NO.) AND TYPE	GROUP NO.
1	Dec. 5, 1977	1800	1900	0	Calibration	38
				5	Calibration	39
				10	Calibration	40
				12	Calibration	46
				15	Calibration	41
				20	Calibration	42
				20	(1)SLA-220	44
				25	Calibration	43
		1200		5	Calibration	12,13,14,15,16,17
					(2)MA-25s	9,18
					(1)ESM	10
					(3)Phenolic Glass	11,19,22
					(2)Cork on CPR-488	20,21
				5	(1)MTA-3	23
		800		18	Calibration	24,25
				23	Calibration	26
				18	(2)P50 Cork	27,29
				18	(2)B-Stage Cork	28,31
		300		5	Calibration	32
				10	Calibration	33
				15	Calibration	34
				20	Calibration	35
				20	(1)SLA-220	37
				25	Calibration	36
2	May 22,1978	1200	1900	0	Calibration	45,46
				2	Calibration	50
				7.5	Calibration	44,47
				15	Calibration	39,41,42,48
				23	Calibration	43,49
		800		18	Calibration	3,4,5,6,7,8
				23	Calibration	9
		200	1853	15	Calibration	10
		220	1900	0	Calibration	21,26
				5	Calibration	15,25
				10	Calibration	16,24
				15	Calibration	17,22,33,37,38
				23	Calibration	11,18,19,23,28,30,31,32, 34,35,36
3	May 23,1978	1800	1900	12	(4)Zinc Paint	53,54,55,56
				12	(5)Lead Paint	57,58,59,60,61
		1200		7.5	(4)Phenolic Glass with P-50 Cork	62,63,64,75
				2	(4)Phenolic Glass with P-50 Cork	65,66,67,74
				2	(3)EPDM	69,70,71
				5	(2)V-44	72,73
		220		15	(8)Phenolic Glass with P-50 Cork	76,77,78,80,82,83,85,96
				15	(4)EPDM	86,88,89,95
				15	(2)V-44	90,91
				5	(1)P-50 Cork	92
				23	(1)P-50 Cork	93
				23	(1)Phenolic Glass with P-50 Cork	94
4	Jan. 12,1979	1800	1900	30*	(3)MSA-1 with Chopped Silica Phenolic Island	1,2,10
				20*	(6)Cork with Chopped Silica Phenolic Island	3,4,5,6,11,12
				33*	(2)Cork with Chopped Silica Phenolic Island	7,8
				25*	(1)Cork with Chopped Silica Phenolic	13
5	Jan. 15,1979	220	1860	10	Calibration	5
				15	Calibration	4
				18	Calibration	6
				23	Calibration	1,2
				28	Calibration	3
			1885	15	Calibration	25
				16	Calibration	23
				18	Calibration	21
				18	(1)EPDM	26
				18	(1)Clevis Joint Calibration	28
				19	Calibration	24
				20	Calibration	22
				23	(1)EPDM	27

* R ANGLE = 12 deg.

TABLE 17. Continued

ENTRY	TEST DATE	PO(psia)	TO(°R)	WEDGE ANGLE(deg)	MATERIAL TESTED (NO.) AND TYPE	GROUP NO.
5	Jan. 15,1979	1200	1900	5	Calibration	7
				8	Calibration	13
				10	Calibration	8
				10	(1)EPDM	29
				15	(1)Sheet Cork	30
				15	Calibration	9
				18	Calibration	10
				23	Calibration	11
				28	Calibration	12
		1800		5	Calibration	14
				8	Calibration	15
				10	Calibration	16
				15	Calibration	17
				18	Calibration	18
				23	Calibration	19
				25	(1)Cork with Chopped Silica Phenolic Island	14
				25	(1)MSA-2	15
				28	(1) Sheet Cork	31
				28	Calibration	20
6	Jan. 16,1979	220	1900	2	Calibration	41
				5	Calibration	37,42,66
				5	(2)EPDM	69,70
				6	Calibration	71
				10	Calibration	38,43,67
				15	Calibration	39,44,68
				18	Calibration	40
		1200		5	Calibration	32,45,47,61
				5	(1)EPDM	73
				6	Calibration	50
				8	Calibration	51
				10	Calibration	33,46,62
				10	(1)EPDM	74
				15	Calibration	34,48,63
				18	Calibration	35,49,64
				18	(1)EPDM	72
				23	Calibration	36,65
		1800		5	Calibration	52,57
				5	(1)EPDM	76
				10	Calibration	53,58
				15	Calibration	54,59
				15	(1)EPDM	75
				18	Calibration	55,60
				23	Calibration	56

APPENDIX III

SAMPLE TABULATED DATA

```
SVERDRUP-ARO-INC
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
50 HYPERSONIC TUNNEL C
ARNOLD AIR FORCE STATION, TN.
DATE  12/05/77  PROJECT NO.  V41C-V9A
                                                                 NASA/LMSC SRB TPS TEST
                                                                 THINSKIN CALIBRATION PHASE

GROUP   CONFIG   MACH     PO       TO              ALPHA SECTOR  WEDGE ANGLE  ROLL SECTOR  YAW SECTOR   YAW MODEL
        NUMBER  NUMBER  (PSIA)   (DEGR)               (DEG)         (DEG)        (DEG)        (DEG)        (DEG)
  36       4    10.02    300.    1890.               -12.65         24.65         0.01         0.00         0.00

T-INF    P-INF     Q-INF     V-INF     RHO-INF      MU-INF        RE/FT          HO    HOUR MIN SEC MSEC INJECT
(DEGR)   (PSIA)    (PSIA)   (FT-SEC)   (LB/FT3)   (LB-SEC/FT2)   (FT-1)                                    TIME
  93.9   0.007      0.464    4760.    1.897E-04    7.557E-08    3.715E+05     475.      6   18  33  884    3.48

TC-NO     X        Y        Z          TW          DTWDT          Q-DOT            H(TO)            Q-DOT-O
         (IN)     (IN)     (IN)      (DEGR)     (DEGR/SEC)   (BTU/FT2-SEC)   (BTU/FT2-SEC-R)    (BTU/FT2-SEC)
    1  30.710     1.42     0.00      615.64       76.18           10.14         0.796E-02           11.38
    2  31.610     1.84     0.00      593.14       60.14            8.00         0.617E-02            8.63
    3  32.520     2.27     0.00      595.14       54.38            7.24         0.559E-02            7.99
    4  32.970     2.48     0.00      589.15       53.28            7.09         0.545E-02            7.80
    5  33.430     2.69     0.00      595.07       53.00            7.05         0.545E-02            7.79
    6  34.330     3.11     0.00      586.81       52.27            6.96         0.534E-02            7.63
    7  35.240     3.54     0.00      586.88       46.66            6.21         0.477E-02            6.82
    8  36.140     3.92     0.00      560.13       25.81            3.44         0.258E-02            3.69
    9  37.140     3.92     0.00      534.04        7.66            1.02         0.752E-03            1.08
   10  38.140     3.92     0.00      530.03        5.45            0.73         0.534E-03            0.76
   11  39.140     3.92     0.00      528.34        4.37            0.58         0.427E-03            0.61
   12  40.140     3.92     0.00      528.99        3.70            0.49         0.362E-03            0.52
   13  41.140     3.92     0.00      531.18        3.04            0.40         0.298E-03            0.43
   14  32.970     2.48     2.00      586.96       51.51            6.86         0.526E-02            7.52
   15  32.970     2.48     3.38      588.80       31.12            4.14         0.318E-02            4.55
   16  34.330     3.32     3.38      553.79        6.37            0.85         0.635E-03            0.91
   17  35.690     3.54     3.38      568.94       20.99            2.79         0.212E-02            3.02
   18  39.140     3.92     2.00      524.77        4.61            0.61         0.450E-03            0.64
   19  39.140     3.92     3.38      535.17        3.87            0.51         0.380E-03            0.54
   20  39.140     2.45     3.38      552.46        7.72            1.03         0.768E-03            1.10
   21  27.860     0.51     0.00      626.84       57.32            7.63         0.604E-02            8.64
```

1. Sample Tabulated Calibration Data

```
ARO INC.                                     50 INCH HYPERSONIC TUNNEL C                              MAY 23,1978
AEDC DIVISION
A SVERDRUP CORPOPATION COMPANY              NASA/LMSC SRB TPS MATERIALS TEST
VON KARMAN GAS DYNAMIC FACILTTY                         V41C-V9A                                      PAGE   2
ARNOLD AIR FORCE STATION, TENNFSSEE

GROUP   CUNFIG.       SAMPLE          NUMBER      MACH NO    PO PSIA   TO DEG R     ALPHA-SECTOR     WEDGE  ANGLE
  53      67        ZINC PAINT         Z-1         10.17      1796.     1900.           0.00           12.00

      T-INF         P-INF         Q-INF         V-INF        RHO-INF        MU-INF          RE/FT          HO
     (DEG R)       (PSIA)        (PSIA)       (FT/SEC)      (LBM/FT3)    (LB-SEC/FT2)     (FT-1)      (BTU/LBM)
      92.3         0.037         2.684         4789.5      1.084E-03      7.427E-08      2.173E+06       478.

      INJECT TIME         EXPOSURE TIME         MODEL YAW                                                CENTER-LINE
        (SEC)                 (SEC)               (DEG)                                                  HR  MIN  SEC
         3.2                   3.3                 0.0                                                   21   30   38

                                                GARDON CALIBRATION DATA

GAGE NO      X      Y       Z       S       TE          TGAGE        DELT         Q-DOT              H(TO)             Q-DOT-O
           (IN)   (IN)    (IN)    (IN)   (DEG R)       (DEG R)     (DEG R)   (BTU/FT2-SEC)   (BTU/FT2-SEC-R)    (BTU/FT2-SEC)

    1       6.0    0.0    -1.0     6.0   538.07        564.28       34.95         5.71            4.277E-03             6.16
    2       9.0    0.0    -1.0     9.0   537.89        561.71       31.76         5.13            3.835E-03             5.52
    3      12.0    0.0    -1.0    12.0   537.36        561.37       32.02         4.96            3.707E-03             5.34
    4      15.0    0.0    -1.0    15.0   538.34        559.39       28.08         4.75            3.542E-03             5.10
    5      17.0    0.0    -1.0    17.0   538.69        558.07       25.84         4.40            3.279E-03             4.72
    6      21.0    0.0    -1.0    21.0   537.71        559.20       28.65         4.53            3.380E-03             4.87
    7      24.0    0.0    -1.0    24.0   540.91        580.30       52.52         8.37            6.342E-03             9.13
    8      27.0    0.0    -1.0    27.0   542.42        584.50       56.11         9.17            6.973E-03            10.04
    9      30.0    0.0    -1.0    30.0   539.40        585.29       61.19        10.11            7.692E-03            11.08
   10      33.0    0.0    -1.0    33.0   547.20        616.97       93.03        14.64            1.141E-02            16.43
```

2. Sample Tabulated Gardon Gage Data

```
ARO INC.                                      50 INCH HYPERSONIC TUNNEL C                              MAY 23,1978
AEDC DIVISION
A SVERDRUP CORPORATION COMPANY               NASA/LMSC SRB TPS MATERIALS TEST
VON KARMAN GAS DYNAMIC FACILITY                         V41C-V9A                                       PAGE   1
ARNOLD AIR FORCE STATION, TENNESSEE

GROUP   CONFIG.       SAMPLE          NUMBER       MACH NO     PO PSIA    TO DEG R     ALPHA-SECTOR     WEDGE  ANGLE
  63      11        PG AND SC    FSKR-AEDC- 78     10.14       1201.      1894.          4.54            7.46

      T-INF          P-INF          O-INF          V-INF          RHO-INF        MU-INF         RE/FT          HO
     (DEG R)        (PSIA)         (PSIA)        (FT/SEC)        (LBM/FT3)    (LB-SEC/FT2)     (FT-1)       (BTU/LBM)
      92.3          0.025          1.795          4775.6        7.294E-04      7.427E-08     1.458E+06        477.

      INJECT TIME       EXPOSURE TIME        MODEL YAW                                                   CENTER-LINE
        (SEC)              (SEC)               (DEG)                                                     HR  MIN  SEC
         4.3               27.7                 0.0                                                      23   5    0

                                        WEDGE ATTITUDE AND TEMPERATURE HISTORY

 TIME      ALPHA      WEDGE       TS1        TS2        TS3        TS4        TS5        TS6        TS7
           SECTOR     ANGLE
 (SEC)     (DEG)      (DEG)     (DEG F)    (DEG F)    (DEG F)    (DEG F)    (DEG F)    (DEG F)    (DEG F)

  1.9       4.54       7.46       82.        83.        84.        85.      DELETE      83.        83.
  2.2       4.57       7.43       82.        83.        84.        85.      DELETE      83.        83.
                  SHADOWGRAPH TAKEN AT   2.2 SECONDS.
  2.7       4.57       7.43       82.        82.        84.        84.      DELETE      83.        83.
  7.4       4.57       7.43       81.        82.        84.        84.      DELETE      82.        82.
                  SHADOWGRAPH TAKEN AT   7.4 SECONDS.
  7.7       4.56       7.44       81.        82.        83.        84.      DELETE      82.        82.
 12.7       4.57       7.43       82.        83.        83.        84.      DELETE      83.        83.
 13.5       4.57       7.43       82.        83.        83.        84.      DELETE      83.        84.
                  SHADOWGRAPH TAKEN AT  13.5 SECONDS.
 17.7       4.57       7.43       85.        85.        83.        84.      DELETE      85.        87.
 18.9       4.57       7.43       86.        85.        83.        84.      DELETE      86.        88.
                  SHADOWGRAPH TAKEN AT  18.9 SECONDS.
 22.7       4.57       7.43       89.        88.        83.        84.      DELETE      88.        93.
 23.9       4.57       7.43       91.        89.        83.        84.      DELETE      89.        94.
                  SHADOWGRAPH TAKEN AT  23.9 SECONDS.
```

3. Sample Tabulated Material Specimen Data