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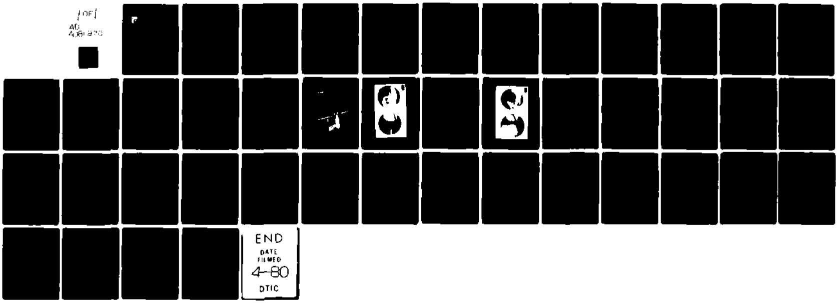

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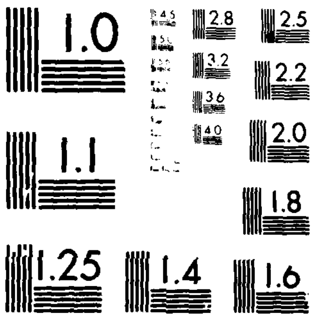
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AEROTHERMAL TESTS OF THE THERMAL PROTECTION SYSTEM MATERIALS FOR THE SPACE SHUTTLE SOLID ROCKET BOOSTERS AND SOLID ROCKET MOTORS

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A Sverdrup Corporation Company
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Period Covered: January 1979 thru April 1979

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

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FOR THE COMMANDER

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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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III. SAMPLE TABULATED DATA

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 test article 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
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
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
PORT NUMBER	Model pressure measurement port number (see Fig. 6)
PRESSURE	Pressure measured by the corresponding port, 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-MODEL	Model roll angle, deg
ROLL-SECTOR	Tunnel sector roll angle, deg
SAMPLE NUMBER	A code which designates which material specimen was tested
t	Time, sec (Equation 2)
TC1, TC2 ...	Material specimen thermocouple temperature, °F
TC-NO	Abbreviation for thermocouple number
ti	Initial time, sec (Equation 2)
TIME	Time measured from when test article first enters tunnel flow, sec
T-INF	Free-stream temperature, °R
TO	Tunnel stilling chamber temperature, °R
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, Y, Z	Calibration model thermocouple coordinates, in. (see Fig. 6 and Table 3)
YAW-MODEL	Model yaw angle, deg
ρ	Model material density, lbm/ft^3

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 9E02-00-9, at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Huntsville, Alabama and the Thiokol Corporation (Wasatch Division), Brigham City, Utah. The Thiokol/Wasatch Division project monitor was Mr. D. Furlong, and the NASA/MSFC-EP44 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 five separate test entries conducted in the von Karman Gas Dynamic Facility (VKF), Tunnel C, over the period from January 17, 1979 thru April 2, 1979 under ARO Project Number V41C-80.

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 initial 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 225 to 1800 psia at 1900°R. Boundary-layer trips were installed on the wedges to promote turbulent flow.

The test program also included a short test shift for the Martin Marietta Corporation (MMC) at the request of the NASA-MSFC/ED34. The purpose was to provide additional information in support of a previous test project for the MMC conducted in January 1979 under ARO Project No. V41C-62. The pertinent test information can be found in Ref. 1 and is not discussed in this report. The test results from the partial shift are included in the data package.

Inquiries 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 Ref. 2.

2.2 TEST HARDWARE

2.2.1 General

The overall project consisted of five 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 and 4 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. An installation photograph of the wedge and a typical protuberance model is shown in Fig. 2. The wedge 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. 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 2, 3 and 5 utilized the AEDC water-cooled materials testing wedge to support the test articles. Figure 4 shows a typical specimen installation. A double-walled pan with cooling water circulating through the bottom and sides was attached to the wedge. The material specimens were set into the pan and held in place by six adjustable jacking screws. 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 10 to 30 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 (Entry 1)

The calibration models consisted of three different protuberance configurations from the SRB. All three of the models were supplied by MSFC-EP44 and represented the SRB range safety antenna cover, full scale kick ring and full scale attach ring. Heat-transfer data were obtained on all three configurations using the thin-skin technique. Pressure data were also obtained on the attach and kick ring models. All the models were constructed with 0.0265-in. thick sheets of 304 stainless steel attached to an aluminum and steel substructure. Sketches of the three models are presented in Fig. 6. All of the calibration models were tested on the flat plate wedge.

2.2.3 Materials Specimens (Entries 2, 3, 4, 5)

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 range safety antenna cover protuberance models were constructed by bonding SLA-220 insulation material to a flight item fiberglass cover.

The protuberance TPS specimens of the attach and kick rings were constructed in two ways. The specimens with instrumentation islands located on them were made by epoxy bonding HEXCEL 4S-4120 material, which is a high silica content glass ablative material with phenolic resin, to a steel attach ring substrate model. The remaining protuberance specimens were constructed by mechanically fastening HEXCEL 4S-4120 material to a steel substrate configurated to represent the attach ring and kick ring. All of these protuberances were supplied by MSFC-EP44 and tested on the flat-plate wedge.

The panel specimens were of three basic types: B-stage cork verification panels, MSA-2 material development panels and SRB TPS paint evaluation panels. All of the specimens had nominal dimensions of 12 x 16-in. with variable thicknesses as listed in Table 2. The materials for each type were bonded to a 0.125-in. thick aluminum sheet which then was mounted in the water-cooled adapter. These specimens were also supplied by MSFC-EP44.

Nine additional specimens were tested during entires 2, 3 and 5 which were supplied by Thiokol and MSFC-EH41. These specimens included four cork panels and five SRM clevis joint/pin retainer models. The cork panels had nominal dimensions of 12 x 16-in. and consisted of cork TPS material bonded to an aluminum sheet similar to the specimens supplied by MSFC-EP44. The clevis joint models were made of steel and simulated the attachment region between two sections of the SRM casing. Different methods of retaining the shear pins which held the joint together were being investigated. The specimens provided by Thiokol were supported by the water-cooled adapter during their tests while the MSFC-EH41 models were supported by phenolic blocks during their exposures.

A total of 12 protuberance specimens and 53 panel specimens were tested in the four 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 heat-transfer rates on the calibration models were obtained using the thin-skin technique. Each of the models were instrumented with up to 25 Chromel-Alumel thermocouples which were welded to the inner surface of the steel skins. Pressures on the kick ring and attach ring models were measured with two and four ports respectively, using the Tunnel C standard pressure system as described in Ref. 3. The locations of the thermocouples and pressure ports are shown in Fig. 6 and listed in Table 3.

The material specimens were instrumented with up to 12 CR-AL thermocouples. These thermocouples were typically 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. Several of the protuberance specimens tested during entry 4 had an internal cavity where the pressure was monitored along with the thermocouple data. This internal pressure was also measured with the Tunnel C standard pressure system.

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

Data on the ablation of the materials were obtained through photographic coverage by AEDC and pre- and post-test thickness measurements. This coverage consisted of two 16 mm motion picture cameras, 70 mm shadowgraph still photographs, video-tape coverage of the runs, and pre- and post-test photographs of the specimens.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

3.1.1 General

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

ENTRY	MACH NUMBER	PO, psia	TO, °R	WEDGE ANGLE, deg	R ANGLE, deg	Q-DOT-O Btu/ft^2-sec
1	10.17	1800	1900	15-23	-	*
	10.08	800	1900	0-23	-	*
2	10.17	1800	1900	15-30	0	6-11
	10.17	1800	1900	15-25	12	17-20
3	10.17	1800	1900	10-30	0	4-11
	10.17	1800	1900	25	12	20
	10.11	1200	1900	12-23	0	**
4	10.17	1800	1900	15-23	-	#
	10.08	800	1900	0,23	-	#
	10.02	300	1900	5	-	#
	10.00	225	1900	20	-	#
5	10.17	1800	1900	10-30	0	4-11
	10.17	1800	1900	20,25	12	19,20
	10.00	220	1900	14-25	0	**

* These were thin-skin calibration tests of protuberance models where the "cold-wall" heating rates varied across the models.

** These heating rates were inferred by Thiokol from previously obtained data and were not supplied to the author.

These heating rates were as determined in Entry 1.

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

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.

The run times of the specimens for all the entries were determined by user test personnel monitoring the runs.

Normally the entire run is made at a constant wedge angle; however, for one run in entry 2 and for 15 runs in entry 5, the wedge was pitched through a prescribed angle-of-attack sequence. This sequence is shown in Fig. 7 and additional details of this technique may be found in Ref. 4. The technique was used to simulate the variable heat-transfer rates experienced during flight. The sequence or trajectory was accomplished manually for the panel in entry 2 but was controlled automatically using the computer controlled VKF Model Attitude Control System (MACS) in entry 5.

3.1.2 Data Acquisition

For all the test entries, instrumentation outputs were recorded using the VKF digital data scanner, under the control of the random access data system (RADS). A complete data loop consisted of the tunnel condition parameters plus the various instrumentation which might be on the test article for a given group. For the heat-transfer and pressure calibration groups of entry 1, the data were scanned continuously at the rate of 15 loops per second. For the remaining entries, the data rate was either one loop of data every one, two or five seconds, depending on the estimated exposure time of the material specimen. In all cases, the data acquisition sequence was started at wedge injection and continued until the wedge was retracted from the flow.

3.2 DATA REDUCTION

For each group, the tabulated data begin with a listing of the tunnel conditions and test article information required to characterize the group and use the data. Following this, the test article data are presented.

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

$$H(TO) = \rho bc \frac{DTWDT}{TO-TW} \qquad (1)$$

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. (1) assuming constant ρ, b, c and TO yields

$$\frac{H(TO)}{\rho bc}(t-ti) = \ln\left[\frac{TO-TWi}{TO-TW}\right] \quad (2)$$

Differentiation of Eq. (2) with respect to time results in

$$\frac{H(TO)}{\rho bc} = \frac{d}{dt}\left[\ln\left[\frac{TO-TWi}{TO-TW}\right]\right] \quad (3)$$

Since the left side of Eq. (3) is assumed constant, plotting $\ln\left[\frac{TO-TWi}{TO-TW}\right]$ versus time should yield a straight line, the slope of which can be used in Eq. (3) 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 < DTWDT	5
16 < DTWDT ≤ 32	7
8 < DTWDT ≤ 16	9
4 < DTWDT ≤ 8	13
2 < DTWDT ≤ 4	17
1 < DTWDT ≤ 2	25
DTWDT ≤ 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 heating rate was then determined by the relation

$$\text{Q-DOT} = \rho bc(\text{DTWDT}) \quad (4)$$

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

$$\text{Q-DOT-O} = H(TO)(TO-460). \quad (5)$$

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. (2.208×10^{-3} ft).

Data from the thermocouples located on the material specimens were converted from millivolts to temperature using least-squares polynomial curve fits of the data contained in Ref. 5.

The material specimen exposure time, denoted on the data as EXPOSURE TIME, was measured from the time the model actually entered the tunnel flow.

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

$$\frac{\Delta PO}{PO} = 0.16 \text{ to } 0.25\%, \quad \frac{\Delta TO}{TO} = 0.4\%$$

Uncertainties in other parameters were estimated using the Taylor series method of error propagation, Eq. (6),

$$(\Delta F)^2 = \left(\frac{\partial F}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial F}{\partial X_2}\Delta X_2\right)^2 + \left(\frac{\partial F}{\partial X_3}\Delta X_3\right)^2 \cdots + \left(\frac{\partial F}{\partial X_n}\Delta X_n\right)^2 \qquad (6)$$

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 indpendent 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 deviation in Mach number determined from test section flow calibrations are summarized in the following table.

		Uncertainty, (±) percent of actual value		
MACH NUMBER	PO, psia	MACH NUMBER	PO	TO
10.00	225	1.4	0.22	0.4
10.02	300	1.4	0.16	
10.08	800	1.0	0.25	
10.11	1200	0.8	0.16	
10.17	1800	0.8	0.16	↓

The uncertainty in wedge angle of attack, as determined from calibrations, is estimated to be ±0.1 deg.

3.3.3 Test Data

Heat transfer measurements were made during entry 1 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 (Eq. 6) 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 measurement uncertainty for the Tunnel C standard pressure system which was used to measure the pressures in entries 1 and 4 is ±0.3 percent; however, the pressure port fittings of the models/specimens were found to have internal leaks during pretest checkouts (see Section 4.0 for additional remarks). This makes it impossible to quote an uncertainty on the actual measured values.

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.

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 (Ref. 6) had established the heat-transfer distribution for the panel specimens tested in entries 2, 3 and 5. Additional calibrations were required for the other protuberance configurations tested in entry 4. The heating levels desired on all the configurations were obtained. All material specimens were returned to their respective suppliers for complete analysis. The pressure ports on the calibration models were found to have internal leaks (section 3.3.3). The repair of these leaks would have required disassembly of the models and would have resulted in a long delay in the start of the test shift. Therefore, the Lockheed test representatives requested that the models be tested as they were since the pressure data was a secondary objective.

As mentioned earlier, this test project included some additional testing for the MMC. A total of 11 groups of heat-transfer calibration data were obtained for them to assist in the evaluation of a flight transducer for the Space Shuttle External Tank. This data has been included in the Final Data Package of the present project. Information pertinent to the use of the MMC data can be found in Ref. 1 and the data package.

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

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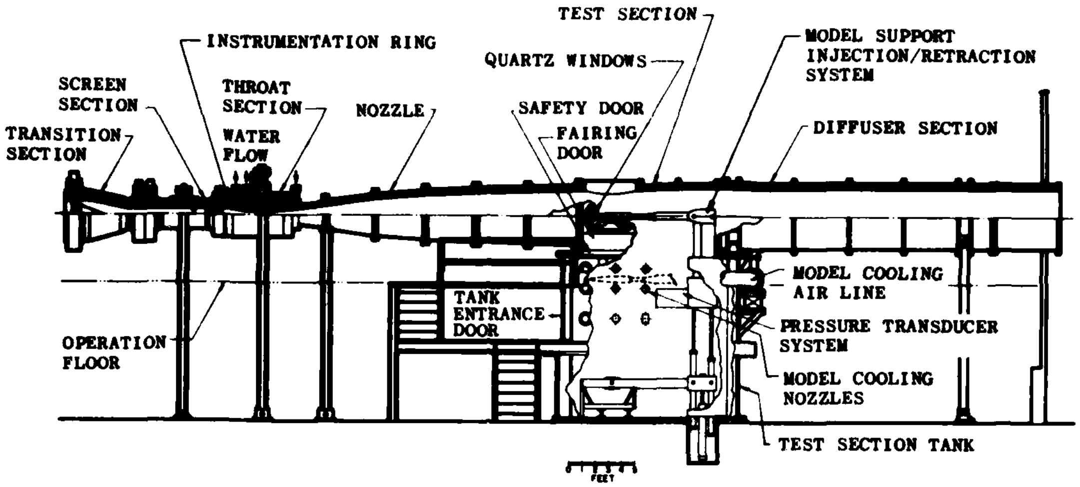
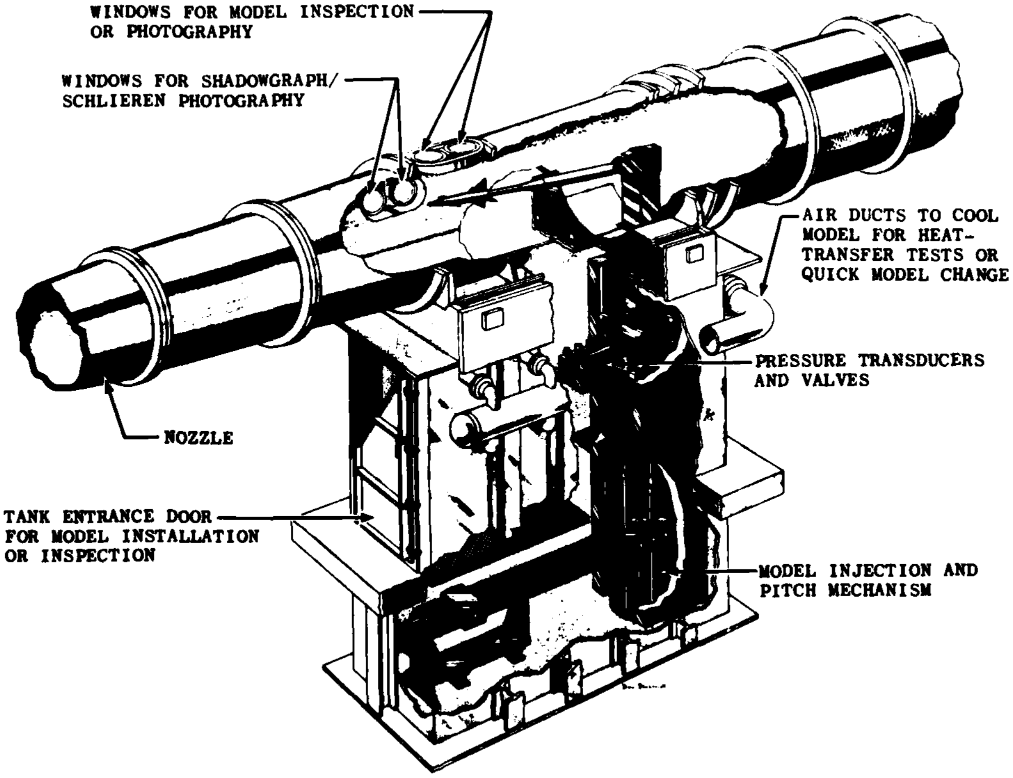
APPENDIX I

ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section
Fig. 1 Tunnel C

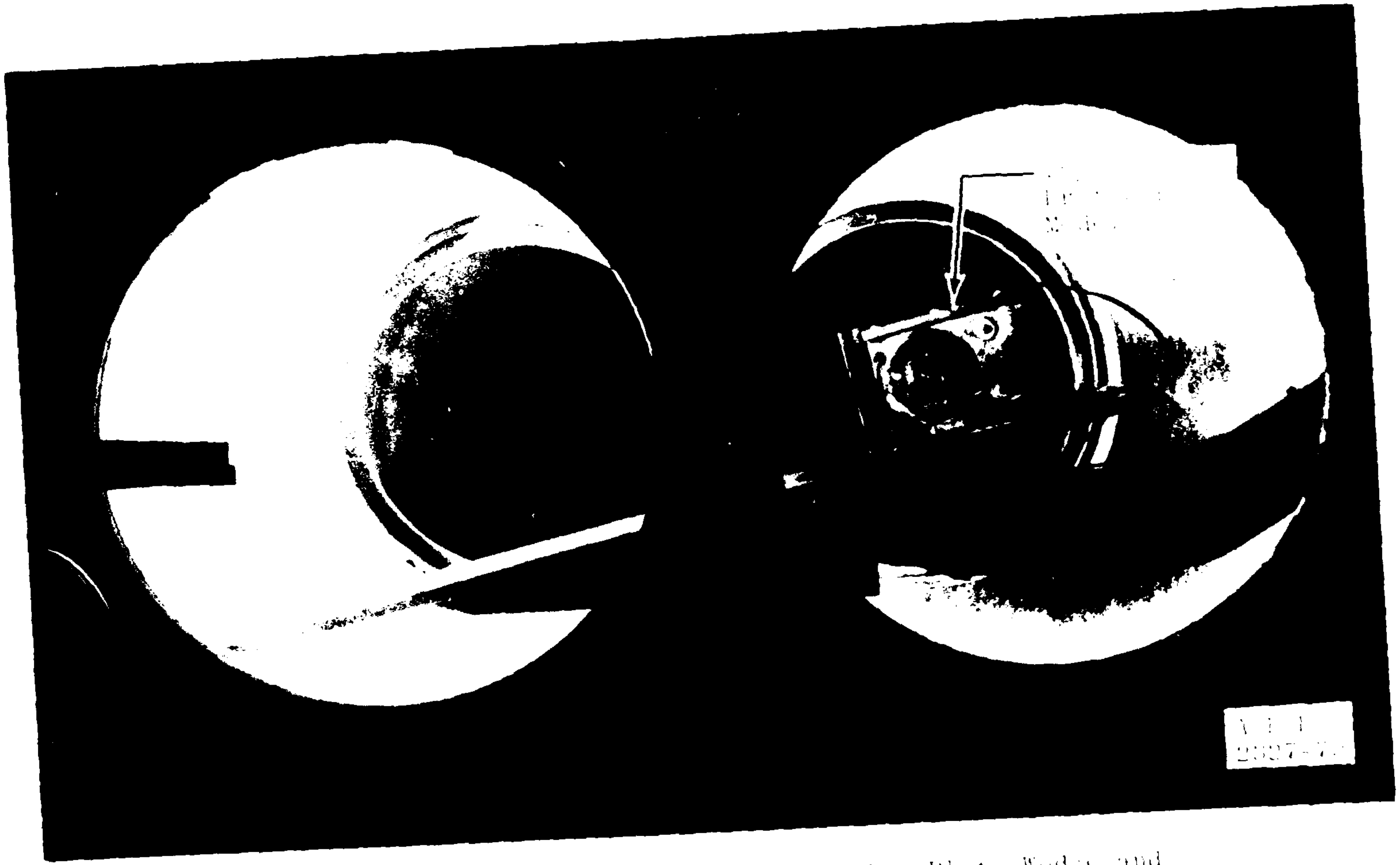
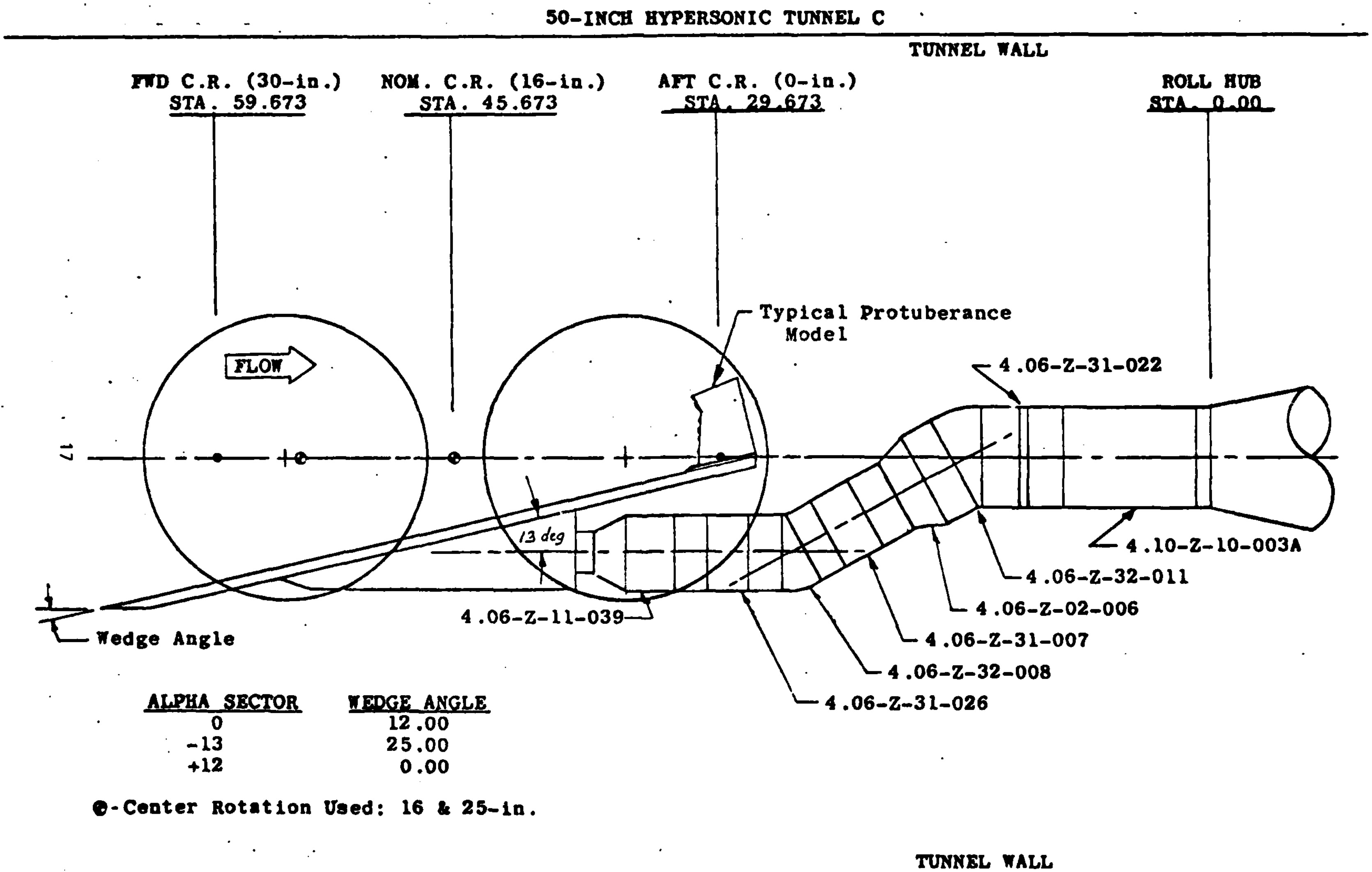


Figure 2. Installation Photograph of Flat-Plate Wedge and Typical Protuberance Model



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

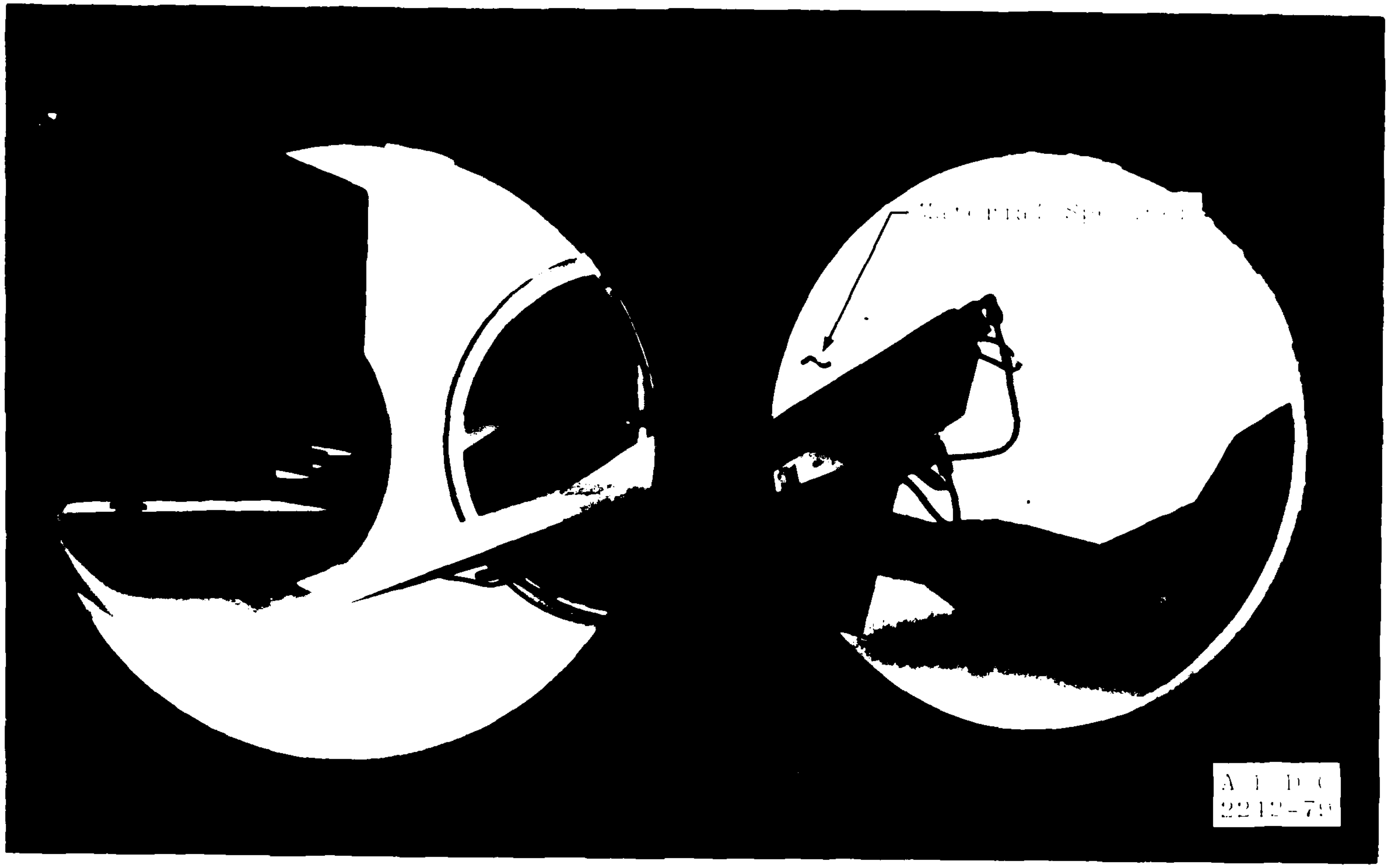
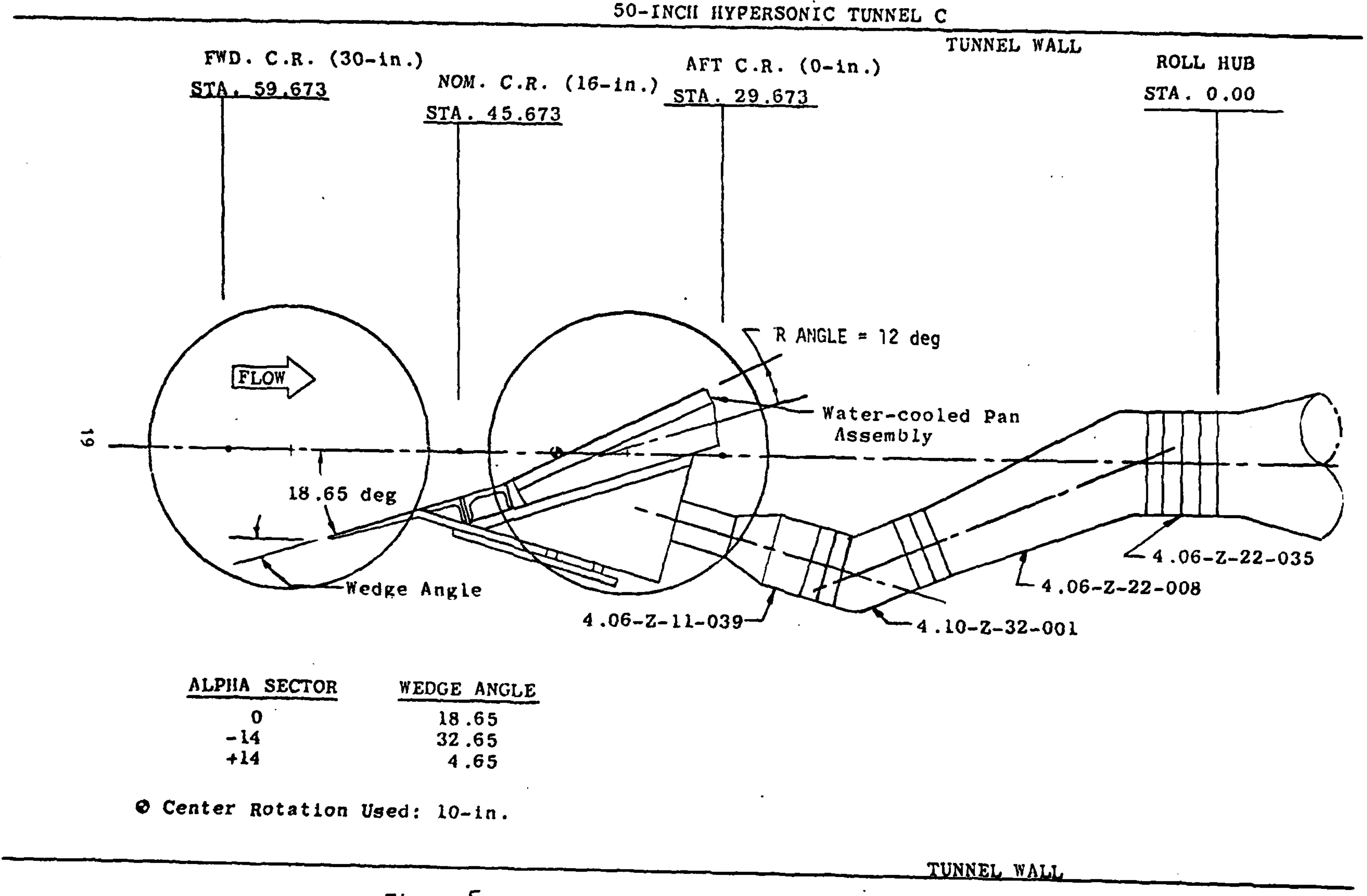


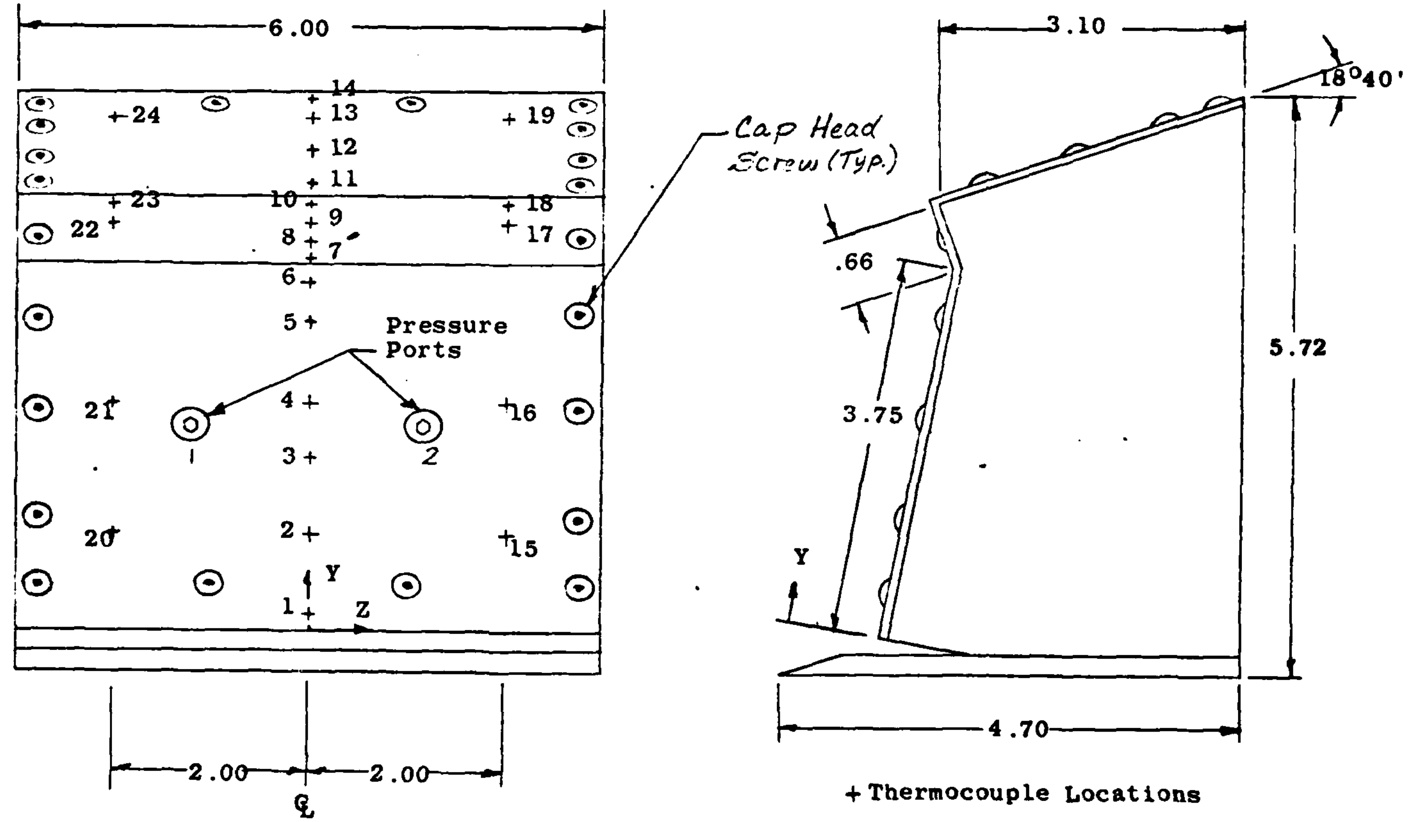
Fig. 1. Photograph of Typical Panel Specimen on Water-Cooled Wedge



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



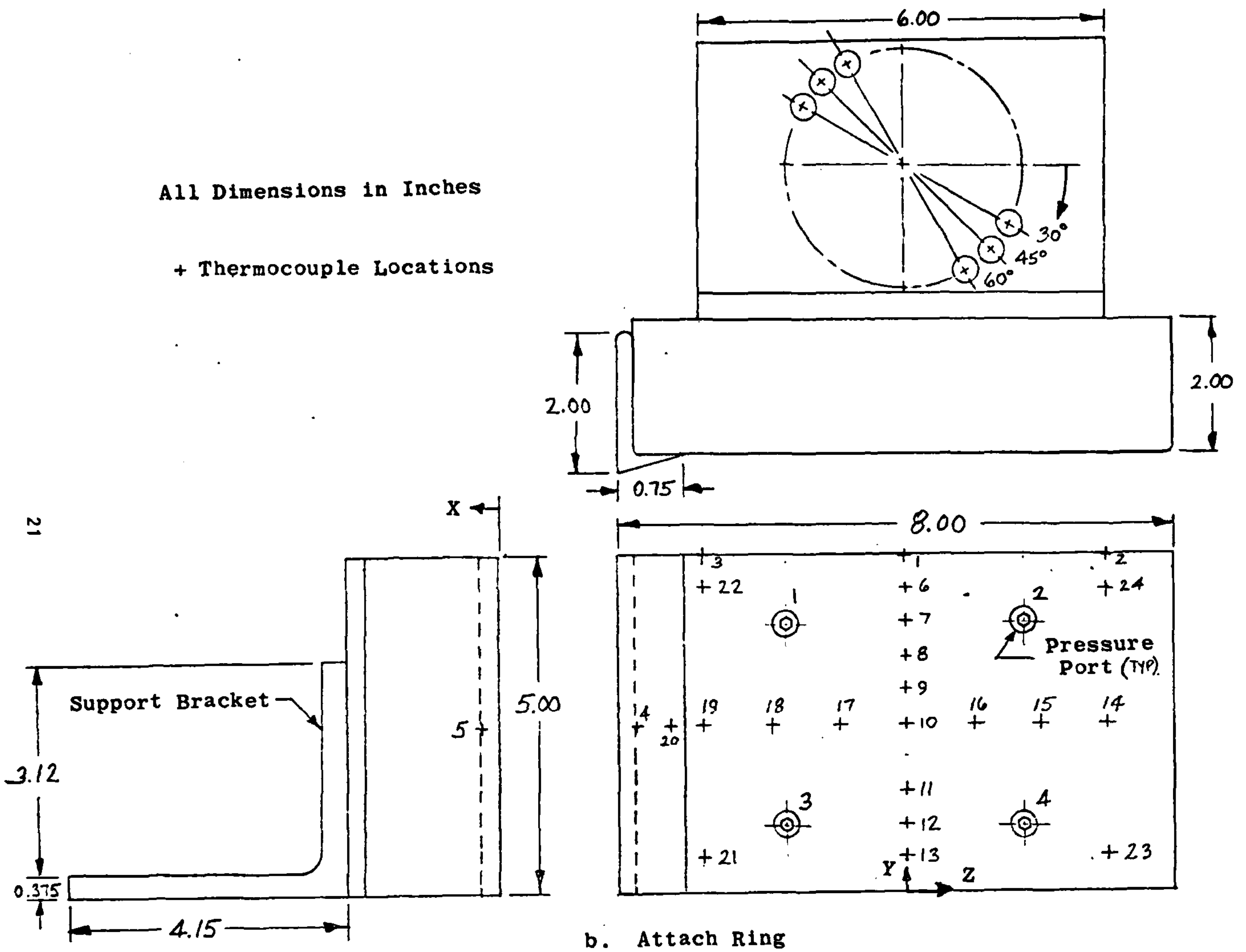
All Dimensions in Inches

+ Thermocouple Locations

Y & Z Dimensions Measured on Skin Surface

a. Kick Ring

Figure 6. Sketches of Thin-Skin Calibration Models

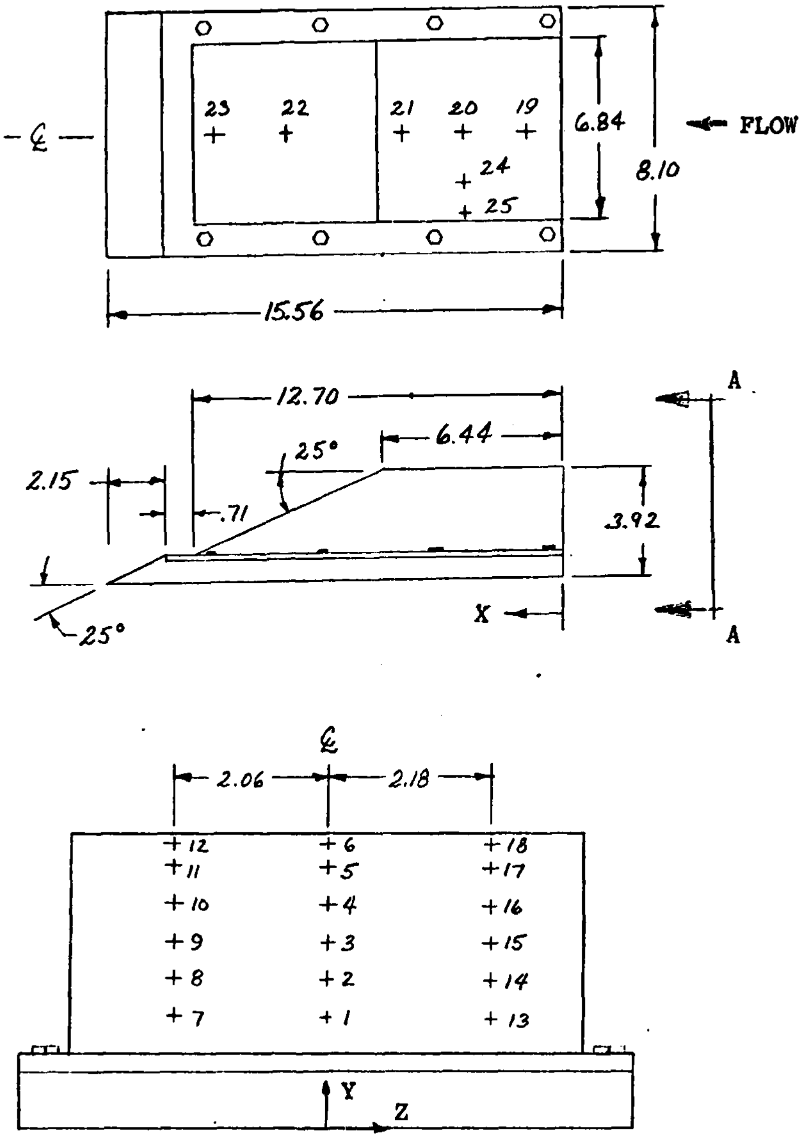


All Dimensions in Inches

+ Thermocouple Locations

b. Attach Ring

Figure 6. Continued



VIEW A-A

All Dimensions in Inches + Thermocouple Locations

c. Range Safety Antenna Cover

Figure 6. Concluded

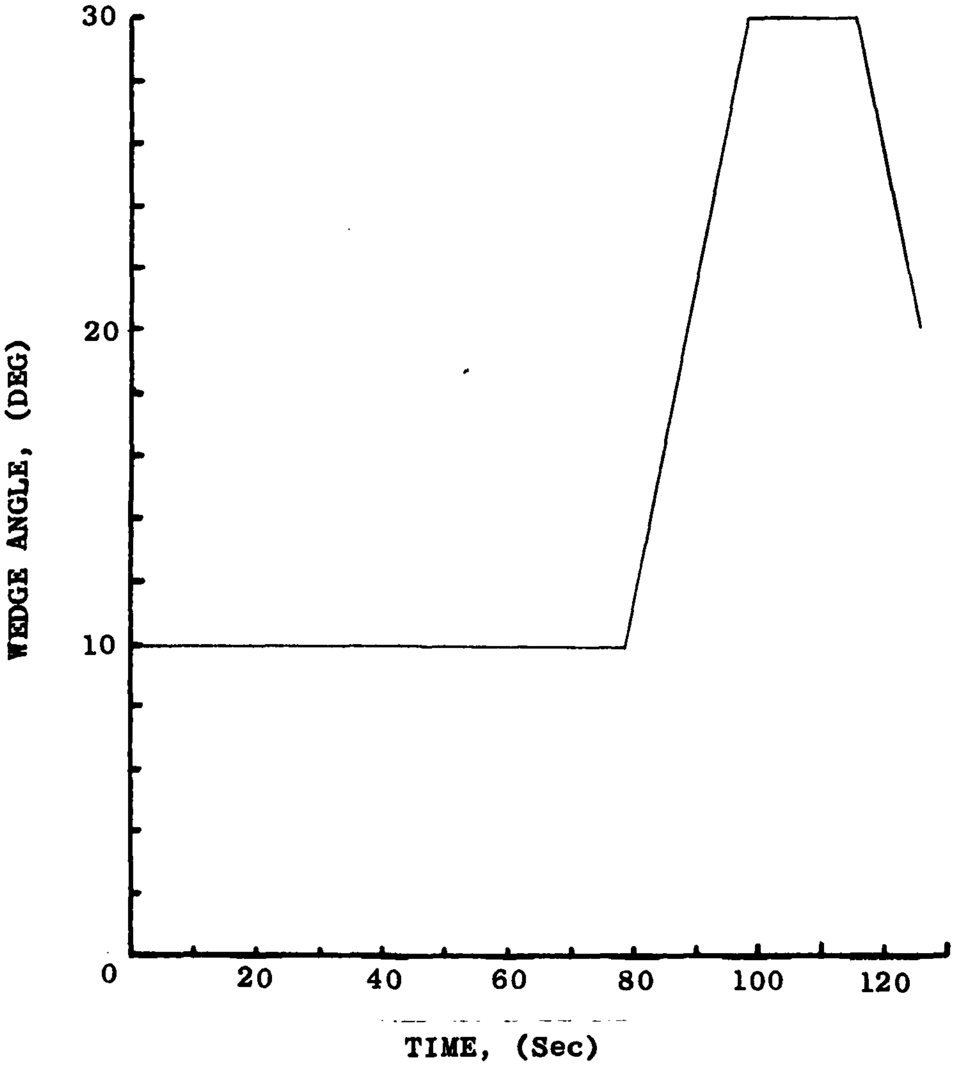


Figure 7. Variable Wedge Angle Trajectory

APPENDIX II

TABLES

TABLE 1. Test Entries

ENTRY NO.	DATE OF TEST	SUMMARY OF PRIMARY TEST CONTENTS
1	Jan. 17, 1979	a. Thin-skin heat transfer calibrations of the SRB Range Safety Antenna Cover (rear face) b. Pressure and heat transfer calibrations of the SRB Attach Ring and Kick Ring protuberances
2	March 7, 1979	a. Characterization and verification testing of B-Stage cork panels b. SRB TPS paint evaluation tests c. Development testing of MSA-2 material panels
3	March 8, 1979	a. Heat transfer calibration tests of Martin-Marietta flight transducer b. Materials evaluation tests of SRM TPS panels and Clevis Joints c. Characterization and verification testing of B-Stage cork panels
4	March 12, 1979	a. Materials evaluation tests of HEXCEL 4S-4120 Phenolic on full scale Attach Ring and Kick Ring protuberances b. Verification tests of SLA-220 and P50 cork on Range Safety Antenna Cover
5	April 2, 1979	a. SRB TPS paint evaluation tests b. Characterization and verification tests of B-Stage cork panels c. Evaluation test of SRM Clevis Joint

TABLE 2. TEST SPECIMENS

ENTRY NO.	CONFIG NUMBER	SAMPLE NUMBER	USER I.D. NUMBER	SPECIMEN DESCRIPTION
1	10	N/A	10	Range Safety Antenna Cover calibration model
	20	N/A	20	Attach Ring calibration model
1	30	N/A	30	Kick Ring calibration model
2	38	3042	OPS-4B	1/8-in. thick MSA-1 panel with To & Tn paint
		3041	OPS-4A	1/8-in. thick MSA-1 panel with To/Tn & Tn paint
		3215	BVP-15	3/8-in. B-Stage cork with To & Tn paint
		3218	BVP-18	1/2-in. B-Stage cork with To/Tn & Tn paint
		3216	BVP-16	3/8-in. B-Stage cork with To & Tn paing
		3209	BVP-9	1/4-in. B-Stage cork with Hyp. & To paint
	38	3220	BVP-20	1/4-in. B-Stage cork with To/Tn & Tn paint
	31	3211	BVP-11	3/8-in. B-Stage cork panel
		3212	BVP-12	
		3213	BVP-13	
		3214	BVP-14	3/8-in. B-Stage cork panel
		3106	MSA2-6	1/2-in. thick panel of MSA
		3143	MSA2-43	
		3141	MSA2-41	
		3111	MSA2-11	
		3107	MSA2-7	
		3146	MSA2-46	
		3121	MSA2-21	
2	31	3145	MSA2-45	1/2-in. thick panel of MSA
3	41	4101	Clevis Joint-No. 2	MSFC Clevis Joint/Pin Retainer
	36	3601	Clevis Joint-.250	Thiokol Clevis Joint with 1/4-in. insulation
	36	3602	Clevis Joint-.125	Thiokol Clevis Joint with 1/8-in. insulation
	36	3603	Clevis Joint-S.C.	Thiokol Clevis Joint with Steel Clip
	51	5101	S/N-1	Thiokol cork panel
	51	5102	S/N-2	
	53	5301	S/N-3	
	53	5302	S/N-4	Thiokol cork panel
	31	3101	BVP-1	1/4-in. B-Stage cork panel
		3110	BVP-10	
		3107	BVP-7	
		3104	BVP-4	1/4-in. B-Stage cork panel
		3119	BVP-19	1/2-in. B-Stage cork panel
		3123	MSA2-23	1/2-in. thick panel of MSA
		3122	MSA2-22	
		3140	MSA2-40	
3	31	3117	MSA2-17	1/2-in. thick panel of MSA
4	11	1102	AF-2	Range Safety Antenna Cover SLA-220 & P50 Cork
	11	1103	AF-3	Range Safety Antenna Cover SLA-220 & P50 Cork
	33	3301	KFC-1	Kick Ring with 1/4-in. phenolic
		3302	KFC-2	Kick Ring with 1/4-in. phenolic
		3303	KFC-3	Kick Ring with 1/4-in. phenolic
	33	3304	KFC-4	Kick Ring with 1/4-in. phenolic
	21	2101	ARF-1	Attach Ring with 1/4-in. phenolic
		2102	ARF-2	Attach Ring with 1/4-in. phenolic
	21	2103	ARF-3	Attach Ring with 1/4-in. phenolic
	52	5201	KJT-1	Kick Ring (Joint) with 1/4-in. phenolic
	61	6101	ISL1-1	Attach Ring Instrument Island with 1/4-in. phenolic
4	61	6102	ISL2-1	Attach Ring Instrument Island with 1/4-in. phenolic
5	41	4103	Clevis Joint No. 3	MSFC Clevis Joint/Pin Retained
	34	3701	C-1	1/4-in. cork panel with Tn & To
		3702	C-2	1/4-in. cork panel with To & Tn
		3703	C-3	9/32-in. cork panel with Hyp & Hyp/Tn
		3704	C-4	3/8-in. cork panel with Hyp & Hyp/Tn
		3705	C-5	3/8-in. cork panel with Hyp/Tn & Hyp
		3706	C-6	1/4-in. cork panel with Hyp/Tn & Hyp
		3707	C-7	1/4-in. cork panel with Wool/Tn & Latex/Tn
		3711	C-11	1/4-in. cork panel with X3-5103/Tn & FRL/Tn
		3713	C-13	1/4-in. cork panel with FL77 & FL77/Tn
		3714	C-14	1/4-in. cork panel with FL77/Tn & FL77
		3801	M-1	1/4-in. MSA panel with Tn & To paint
		3802	M-2	1/4-in. MSA panel with Hyp & Hyp/Tn paint
		3803	M-3	1/8-in. MSA panel with Hyp/Tn & Hyp paint
		3804	M-4	1/4-in. MSA panel with Wool/Tn & Latex/Tn paint
		3806	M-6	1/8-in. MSA panel with X3-5103/Tn & FRL/Tn paint
5	34	3807	M-7	1/4-in. MSA panel with FL77 & FL77/Tn paint

TABLE 2. Continued

ENTRY NO.	CONFIG NUMBER	SAMPLE NUMBER	USER I.D. NUMBER	SPECIMEN DESCRIPTION
5	31	3203	BVP-3	1/4 in.-B-Stage cork panel
		3205	BVP-5	1/4-in. B-Stage cork panel
		3206	BVP-6	1/4-in. B-Stage cork panel
		3208	BVP-8	1/4-in. B-Stage cork panel
		3217	BVP-17	1/2-in. B-Stage cork panel
		3221	BVP-21	3/8-in. B-Stage cork panel
		3222	BVP-22	3/8-in. B-Stage cork panel
5	31	3134	MSA2-34	1/2-in. thick panel of MSA

Notes:

Tn: new Turco paint
To: old Turco paint
Tn/To: new Turco applied over old Turco (/ symbol typical for other paints)
Hyp: Hypalon paint
Wool: Woolsey paint
X3-5103: Dow Corning Silicone Latex
Latex: Exterior Acrylic Latex
FL77: Flame Master Coating

TABLE 3. Thermocouple Locations

a. Kick Ring

TC-NO	X	Y	Z
1	0.00	0.02	0.00
2	↑	1.00	↑
3		1.50	
4		2.00	
5		2.50	
6		3.00	
7		3.50	
8		3.75	
9		4.00	
10		4.25	
11		4.63	
12		5.38	
13		6.38	↓
14		6.88	0.00
15		1.00	2.00
16		2.00	↑
17		4.63	
18		5.38	↓
19		6.38	2.00
20		1.00	-2.00
21		2.00	↑
22		4.63	
23	↓	5.38	↓
24	0.00	6.38	-2.00

PRESSURE PORT	X	Y	Z
1	0.00	1.75	-1.50
2	0.00	1.75	1.50

TABLE 3. Continued

b. Attach Ring

TC-NO	X	Y	Z
1	0.00	5.00	0.00
2	↑	5.00	3.00
3	↓	5.00	-3.00
4	0.00	2.50	-4.00
5	0.25	2.50	-4.00
6	0.00	4.50	0.00
7	↑	4.00	↑
8		3.50	
9		3.00	
10		2.50	
11		1.50	
12		1.00	↓
13		0.50	0.00
14		2.50	3.00
15		↑	2.00
16			1.00
17			-1.00
18			-2.00
19		↓	-3.00
20		2.50	-3.50
21		0.50	-3.00
22		4.50	-3.00
23	↓	0.50	3.00
24	0.00	4.50	3.00

PRESSURE PORT	X	Y	Z
1	0.00	4.00	-1.75
2	↑	4.00	1.75
3	↓	1.00	-1.75
4	0.00	1.00	1.75

TABLE 3. Concluded

c. Range Safety Antenna Cover

TC-NO	X	Y	Z
1	0.00	1.50	0.00
2	↑	2.00	↑
3		2.50	
4		3.00	
5		3.50	↓
6		3.87	0.00
7		1.50	-2.06
8		2.00	↑
9		2.50	
10		3.00	
11		3.50	↓
12		3.87	-2.06
13		1.50	2.18
14		2.00	↑
15		2.50	
16		3.00	
17	↓	3.50	↓
18	0.00	3.87	2.18
19	1.37	3.92	0.00
20	3.37	3.92	↑
21	5.37	3.92	
22	9.54	2.48	↓
23	11.80	1.42	0.00
24	3.37	3.92	-2.00
25	3.37	3.92	-3.38

TABLE 4 . SUMMARY TEST LOG

PAGE 1 OF 2			Sverdrup ARO, Inc.
USER Lockheed Missile & Space Co.	PROJECT TITLE NASA/LMSC SRB TPS Test	PROJECT V41C-80	DATE Jan. 17, 1979
REPRESENTATIVE(S)	MODEL Range Safety Antenna/ Attach Ring/Kick Ring	ARO TEST PERSONNEL J. Ievalts	

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg	C.R. in.	YAW Model deg				Time	Remarks
1	R.S.A. Calib.		10.08	800	1440	0	16	-					
2	↓		↓	↓	↓	7.5	16	-					
3	↓		↓	↓	↓	15	25	-					
4	↓		↓	↓	↓	18	25	-					
5	↓		↓	↓	↓	23	25	-					
6			↓	↓	↓	15	25	-					
7	Attach Ring Calib.		10.17	1800	1440	15	25	30					
8	↓		↓	↓	↓	23	25	30					
9	↓		↓	↓	↓	15	25	45					
10	↓		↓	↓	↓	23	25	45					
11	↓		↓	↓	↓	15	25	60					
12	↓		↓	↓	↓	23	25	60					Tunnel unstarted
13	Kick Ring Calib.		10.17	1800	1440	15	25	30					
14	↓		↓	↓	↓	21	25	30					
15	↓		↓	↓	↓	23	25	30					
16	↓		↓	↓	↓	15	25	30					
17	↓		↓	↓	↓	15	25	45					
18	↓		↓	↓	↓	21	25	45					
19	↓		↓	↓	↓	23	25	45					
20	↓		↓	↓	↓	15	25	60					

NOMENCLATURE

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TABLE 4 . Continued

PAGE 2 OF 2

Sverdrup | ARO, Inc.

USER
Lockheed Missile & Space Co.

REPRESENTATIVE(S)

PROJECT TITLE
NASA/LMSC SRB TPS Test

MODEL
Range Safety Antenna/
Attach Ring/Kick Ring

PROJECT
V41C-80

DATE
Jan. 17, 1979

ARO TEST PERSONNEL
J. Ievalts

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg	C.R. in.	YAW MODEL deg				Time	Remarks
21	Kick Ring Calib.		10.17	1800	1440	21	25	60					
22	↓		↓	↓	↓	23	25	60					
23	↓		↓	↓	↓	23	25	60					

NOMENCLATURE

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TABLE 4 . Continued

PAGE 1 OF 1			Sverdrup | ARO, Inc.
USER Lockheed Missile & Space Co.	PROJECT TITLE NASA/LMSC SRB TPS Test	PROJECT V41C-80	DATE March 7, 1979
REPRESENTATIVE(S)	MODEL B-Stage Cork/ MSA-2/Paint panels	ARO TEST PERSONNEL J. Ievalts	

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg	R ANGLE deg	SAMPLE NUMBER	EXPOSURE TIME sec.	Time	Remarks
1	OPS-4B		10.17	1800	1440	27.5	0	3042	14.3		C.R. is 10 in. for all data groups
2	OPS-4A					18.5	0	3041	33.3		
3	BVP-15					20.0	0	3215	30.9		
4	BVP-18					20.0	0	3218	32.5		
5	BVP-16					25.0	0	3216	21.0		
6	BVP-9					15.0	0	3209	122.8		
7	BVP-9					30.0	0	3209	53.3		
8	BVP-20					Var.*	12	3220	103.1		
9	BVP-11					15.0	12	3211	182.7		
10	BVP-12					15.0	12	3212	355.8		
11	BVP-13					20.0	12	3213	358.7		
12	BVP-14					20.0	12	3214	184.3		
13	MSA2-6					25.0	12	3106	78.3		
14	MSA2-43					25.0	12	3143	103.7		
15	MSA2-41					25.0	12	3141	61.7		
16	MSA2-41					25.0	12	3141	43.5		
17	MSA2-11					25.0	12	3111	51.4		
18	MSA2-7					25.0	12	3107	[illegible]		
19	MSA2-46					25.0	12	3146	210.4		
20	MSA2-21					25.0	12	3121	[illegible]		
21	MSA2-45		▼	▼	▼	25.0	12	3145	302.6		

* Var. - variable wedge angle with time trajectory (see Fig. 7)

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TABLE 4. Continued

PAGE 1 OF 2

Sverdrup | ARO, Inc.

USER Martin-Marietta	PROJECT TITLE NASA/LMSC SRB TPS Test	PROJECT V41C-80	DATE March 8, 1979
REPRESENTATIVE(S) H. Carroll	MODEL Flight Transducer/Flat Plate	ARO TEST PERSONNEL J. Ievalts	

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg					Time	Remarks
1	Cal. Plate		10.11	1200	1440	10.0						C.R. is 10 in. for all data groups
2						15.0						
3			↓	↓	↓	10.0						
4			10.17	1800	1440	10.0						
5						15.0						
6						20.0						
7						25.0						
8						30.0						
9						20.0						
10						10.0						
11	↓		↓	↓	↓	30.0						

NOMENCLATURE

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TABLE 4. Continued

Sverdrup | ARO, Inc.

USER Thiokol/Wasatch Division MSFC-EH41 Lockheed Missile & Space Co.	PROJECT TITLE NASA/LMSC SRB TPS Test	PAGE 2 OF 2 PROJECT V41C-80	DATE March 8, 1979
REPRESENTATIVE(S)	MODEL Clevis Joints/ SRM TPS Panels/B-Stage Cork	ARO TEST PERSONNEL J. Ievalts	

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg	R ANGLE deg	SAMPLE NUMBER		EXPOSURE TIME sec.		Time	Remarks
22	MSFC-Clevis Jnt.		10.17	1800	1440	18.5	0	4101		401.5			C.R. is 10 in. for all data groups
23	0.25"-Clevis Jnt.		10.11	1200	1440	20.0	0	3601		125.1			
24	0.125"-Clevis Jnt.		│	│	│	20.0	0	3602		121.2			
25	Steel Clip-Clevis Jnt.		│	│	│	20.0	0	3603		124.6			
26	Cork Panel S/N-1		│	│	│	12.0	0	5101		[illegible]			
27	Cork Panel S/N-2		│	│	│	23.0	0	5102		401.9			
28	Cork Panel S/N-4		│	│	│	12.0	0	5302		316.1			
29	Cork Panel S/N-3		↓	↓	↓	12.0	0	5301		315.4			
30	BVP-1		10.17	1800	1440	15.0	0	3101		[illegible]			
31	BVP-10		│	│	│	20.0	0	3110		522.2			
32	BVP-7		│	│	│	30.0	0	3107		525.1			
33	BVP-4		│	│	│	25.0	12	3104		227.3			
34	BVP-19		│	│	│	25.0	12	3119		327.6			
35	MSA2-23		│	│	│	25.0	12	3123		117.8			
36	MSA2-22		│	│	│	25.0	12	3122		47.3			
37	MSA2-40		│	│	│	25.0	12	3140		—			No data-computer malfunction
38	MSA2-28		↓	↓	↓	25.0	12	3117		—			No data-computer malfunction

NOMENCLATURE

TABLE 4. Continued

PAGE 1 OF 1			Sverdrup ARO, Inc. AEDC Division
USER Lockheed Missile & Space Co.	PROJECT TITLE NASA/LMSC SRB TPS Test	PROJECT V41C-80	DATE March 12, 1979
REPRESENTATIVE(S)	MODEL Range Safety Antenna/ Attach Ring/Kick Ring	ARO TEST PERSONNEL J. Ievalts	

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg	MODEL YAW deg	C.R. in.	SAMPLE NUMBER		EXPOSURE TIME sec	Time	Remarks
39	R.S.A AF-2		10.08	800	1440	23.0	0	25	1102		[illegible]		Rear face
40	R.S.A AF-3		10.00	225	1440	20.0	0	25	1103		[illegible]		Tunnel unstarted, Front face
41	R.S.A AF-3		10.02	300	1440	5.0	0	16	1103		[illegible]		Front face
42	R.S.A AF-3		10.08	800	1440	0.0	0	16	1103		2.8		Rear face
43	KFC-1		10.17	1800	1440	21.0	30	25	3301		49.1		Rear face with inner tube
44	KFC-2		↓	↓	↓	23.0	30	25	3302		45.5		Front face
45	KFC-3		↓	↓	↓	15.0	60	25	3303		25.9		Front face
46	KFC-2		↓	↓	↓	21.0	30	25	3302		51.3		Rear face
47	ARF-3		↓	↓	↓	15.0	60	25	2103		10.0		Front face with inner tube
48	KFC-4		↓	↓	↓	15.0	60	25	3304		63.4		Rear face
49	KFC-3		↓	↓	↓	15.0	60	25	3303		33.1		Rear face
50	ARF-1		↓	↓	↓	23.0	60	25	2101		—		Tunnel unstarted, front face, no data
51	ARF-1		↓	↓	↓	23.0	30	25	2101		16.3		Front face
52	ARF-2		↓	↓	↓	23.0	30	25	2102		14.6		Front face with inner tube
53	KJT-1		↓	↓	↓	23.0	30	25	5201		—		Front face, no data-computer malfunction
54	ISL2-1		↓	↓	↓	23.0	30	25	6102		52.9		Front face
55	ISL1-1		↓	↓	↓	23.0	30	25	6101		73.8		Front face

NOMENCLATURE

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AFSC Arnold AFSC Tenn

TABLE 4. Continued

USER MSFC-EH41 Lockheed Missile & Space Co.	PROJECT TITLE NASA/LMSC SRB TPS Test	PAGE 1 OF 2 PROJECT V41C-80	Sverdrup ARO, Inc. DATE April 2, 1979
REPRESENTATIVE(S)	MODEL Clevis Joint/ B-Stage Cork/Paint panels	ARO TEST PERSONNEL J. Ievalts	

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg	R ANGLE deg	SAMPLE NUMBER	EXPOSURE TIME sec.		Time	Remarks	
56	MSFC-Clevis Jnt.		10.00	220	1440	18.5	0	4103	20.2			Tunnel unstarted	C.R. is .0 in. for all data groups.
57	MSFC-Clevis Jnt.					14.0	0	4103	[illegible]			Tunnel unstarted	
58	MSFC-Clevis Jnt.					25.0	0	4103	20.1			Tunnel unstarted	
59	MSFC-Clevis Jnt.		↓	↓	↓	18.5	0	4103	[illegible]				
60	C-1		10.17	1800	1440	V-1*	0	3701	62.0				
60	C-1					V-1	0	3701	[illegible]				
61	M-1					V-1	0	3801	127.0				
62	C-3					V-1	0	3703	147.0				
62	C-3					30.0	0	3703	[illegible]				
63	C-4					30.0	0	3704	[illegible]				
64	C-7					V-1	0	3707	[illegible]				
65	C-11					V-1	0	3711	[illegible]				
66	M-2					V-1	0	3802	[illegible]				
66	M-2					30.0	0	3802	[illegible]				
67	M-4					V-1	0	3804	[illegible]				
68	M-6					V-1	0	3806	[illegible]				
69	C-2					V-1	0	3702	[illegible]				
69	C-2					30.0	0	3702	[illegible]				
70	C-5					V-1	0	3705	[illegible]				
70	C-5		↓	↓	↓	30.0	0	3705	[illegible]				

NOMENCLATURE

* V-1: Variable wedge angle trajectory (see Figure 7)

VB-2 (9/77)

AFSC Arnold AFS Tenn

THIS PAGE IS [illegible] QUALITY PRACTICABLE

TABLE 4 . Concluded

PAGE 2 OF 2			**Sverdrup** ARO, Inc. AEDC Division
USER MSFC - EH41 Lockheed Missile & Space Co.	PROJECT TITLE NASA/LMSC SRB TPS Test	PROJECT V41C-80	DATE April 2, 1979
REPRESENTATIVE(S)	MODEL Clevis Joint/ B-Stage cork/Paint panels	ARO TEST PERSONNEL J. Ievalts	

Data Group	Configuration	Config. Confirmed	MACH NO.	PO	TO	WEDGE ANGLE deg	R ANGLE deg	SAMPLE NUMBER		EXPOSURE TIME sec.		Time	Remarks
71	C-6		10.17	1800	1440	V-1	0	3706		57.5			
72	C-13					V-1	0	3713		133.2			
72	C-13					30.0	0	3713		15.4			
73	C-14					V-1	0	3714		[illegible]			
74	M-7					V-1	0	3807		[illegible]			
74	M-7					30.0	0	3807		[illegible]			
75	BVP-3					15.0	0	3203		333.8			
76	BVP-5					20.0	0	3205		50.1			
77	BVP-6					30.0	0	3206		301.1			
78	M-3					30.0	0	3803		67.3			
79	BVP-8					25.0	12.0	3208		105.5			
80	BVP-21					20.0	12.0	3221		389.3			
81	BVP-22					20.0	12.0	3222		174.3			
82	BVP-17					25.0	12.0	3217		165.7			
83	MSA2-34		↓	↓	↓	25.0	12.0	3134		53.5			

NOMENCLATURE

APPENDIX III

SAMPLE TABULATED DATA

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ARO, INC. - AEDC DIVISION                                                                              DATE COMPUTED 16-APR-79
A SVERDRUP CORPORATION COMPANY                                                                         TIME COMPUTED  10:45:30
VON KARMAN GAS DYNAMICS FACILITY                                                                       DATE RECORDED 17-JAN-79
ARNOLD AIR FORCE STATION, TENNESSEE                                                                    TIME RECORDED  20:16:20
NASA/LMSC RRA TPS                                                                                      PROJECT NUMBER V41C-80

GROUP   CONFIG   MACH     PO       TO         ALPHA SECTOR  WEDGE ANGLE  ROLL SECTOR  YAW MODEL     CENTERLINE
        NUMBER   NUMBER   (PSIA)   (DEGR)        (DEG)         (DEG)        (DEG)       (DEG)    (HOUR MIN SEC MSEC)
  8       20     10.17    1799.    1897.        -11.22         23.22        0.00        30.00      20  16   26  326

T-INF    P-INF     Q-INF      V-INF     RHO-INF       MU-INF        RE/FT        HO         INJECT TIME   EXPOSURE TIME   C.R.
(DEGR)   (PSIA)    (PSIA)   (FT-SEC)    (LB/FT3)    (LB-SEC/FT2)   (FT-1)     (BTU/LBM)       (SEC)          (SEC)        (IN)
  92.1   0.037      2.689    4785.     1.088E-03     7.414E-08    2.183E+06  4.77E+02        5.14           4.71        25.00

                                                      THIN-SKIN CALIBRATION
TC-NO     X         Y         Z          TH          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    0.000      5.00      0.00      913.78        71.48            9.51          0.964E-02               13.89
   2    0.000      5.00      3.00      797.89        59.15            7.87          0.714E-02               10.29
   3    0.000      5.00     -3.00      829.03        58.21            7.75          0.723E-02               10.42
   4    0.000      2.50     -4.00      576.65        23.84            3.17          0.240E-02                3.45
   5    0.250      2.50     -4.00      672.67        43.62            5.81          0.473E-02                6.81
   6    0.000      4.50      0.00      863.03        58.00            7.72          0.744E-02               10.72
   7    0.000      4.00      0.00      827.41        66.83            8.89          0.829E-02               11.94
   8    0.000      3.50      0.00      893.66        79.72           10.61          0.105E-01               15.18
   9    0.000      3.00      0.00      950.64        82.09           10.93          0.115E-01               16.57
  10    0.000      2.50      0.00      928.47        66.63            8.87          0.912E-02               13.14
  11    0.000      1.50      0.00     1045.39        91.43           12.17          0.142E-01               20.50
  12    0.000      1.00      0.00     1044.94        97.03           12.91          0.151E-01               21.74
  13    0.000      0.50      0.00     1057.34        98.40           13.10          0.155E-01               22.37
  14   DELETE
  15    0.000      2.50      2.00     1014.60       102.69           13.67          0.154E-01               22.22
  16    0.000      2.50      1.00     1118.02       118.78           15.81          0.202E-01               29.10
  17    0.000      2.50     -1.00     1105.17       110.73           14.74          0.185E-01               26.69
  18    0.000      2.50     -2.00     1082.95       112.07           14.92          0.182E-01               26.28
  19    0.000      2.50     -3.00     1262.39        93.38           12.43          0.195E-01               28.05
  20    0.000      2.50     -3.50      668.18        69.53            9.25          0.751E-02               10.82
  21    0.000      0.50     -3.00     1084.45        79.70           10.54          0.129E-01               18.60
  22    0.000      4.50     -1.00      939.14        85.29           11.35          0.118E-01               17.01
  23    0.000      0.50      1.00     1041.23       100.31           13.35          0.155E-01               22.38
  24    0.000      4.50      3.00      921.61        85.32           11.36          0.116E-01               16.71


    PORT     PRESSURE
   NUMBER     (PSIA)
      1        4.33
      2        7.20
      3        6.51
      4        4.95
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1. Sample Tabulated Protuberance Calibration Data

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ARO, INC. - AEDC DIVISION                                                                                 DATE COMPUTED 12-APR-79
A SVERDRUP CORPORATION COMPANY                                                                            TIME COMPUTED  07:12:43
VON KARMAN GAS DYNAMICS FACILITY                                                                          DATE RECORDED  8-MAR-79
ARNOLD AIR FORCE STATION, TENNESSEE                                                                       TIME RECORDED   4:25:20
NASA/LMSC SRB TPS MATERIALS TEST                                                                          PROJECT NUMBER  V41C-80
                                                   50 INCH HYPERSONIC TUNNEL C

GROUP  CONFIG   SAMPLE    MACH      PO       TO      ALPHA-SECTOR  WEDGE ANGLE  ROLL-MODEL  CENTER-ROTATION  R.ANGLE   PAGE  1
       NUMBER   NUMBER   NUMBER   (PSIA)  (DEG R)       (DEG)         (DEG)       (DEG)        (INCHES)       (DEG)
 16      31     3141     10.17    1796.    1897.        -6.43         25.08        0.00         10.00          12.00

 T-INF   P-INF   O-INF     V-INF    RHO-INF       MU-INF        RE/FT       HO      INJECT TIME      CENTERLINE         EXPOSURE TIME
(DEG R) (PSIA)  (PSIA)   (FT/SEC)   (LB/FT3)   (LB-SEC/FT2)    (FT-1)   (BTU/LBM)     (SEC)    (HOUR MIN SEC MSEC)       (SEC)
 92.1    0.037   2.685    4785.    1.087E-03   7.414E-08   2.180E+06  4.773E+02     4.01        4   25  45  340         43.51

                                          WEDGE ATTITUDE AND TEMPERATURE HISTORY

 TIME   WEDGE     TC1      TC2      TC3      TC4      TC5      TC6      TC7      TC8      TC9      TC10     TC11     TC12
        ANGLE
(SEC)   (DEG)   (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)  (DEG F)
  1.0   25.08     87.      83.      85.      83.
  3.0   25.07     87.      83.      86.      84.
                SHADOWGRAPH TAKEN AT   4.5 SECONDS.
  5.0   25.08     87.      83.      86.      85.
  7.0   25.07     87.      83.      87.      86.
  9.0   25.07     87.      83.      86.      86.
 11.0   25.07     87.      84.      86.      86.
 13.0   25.07     87.      85.      86.      86.
 15.0   25.06     87.      87.      87.      86.
 17.0   25.07     89.      89.      87.      86.
 19.0   25.06     90.      91.      88.      86.
 21.0   25.06     93.      95.      88.      86.
 23.0   25.06     96.      99.      88.      86.
 25.0   25.06    100.     107.      89.      86.
 27.0   25.06    106.     117.      89.      86.
 29.0   25.05    115.     126.      89.      86.
 31.0   25.06    127.     136.      90.      87.
 33.0   25.05    141.     146.      91.      87.
 35.0   25.05    157.     158.      92.      89.
 37.0   25.05    173.     169.      94.      90.
                SHADOWGRAPH TAKEN AT  39.4 SECONDS.
 39.0   25.05    198.     189.     100.      95.
 41.0   25.14    208.     197.     101.      95.
                SHADOWGRAPH TAKEN AT  42.7 SECONDS.
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2. Sample Tabulated Material Specimen Data