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WIND TUNNEL TESTS OF THE SPACE SHUTTLE EXTERNAL TANK INSULATION MATERIAL AT ELEVATED HEAT FLUX CONDITIONS

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Calspan Field Services, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER
ARNOLD AIR FORCE STATION, TENNESSEE
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NOTICES

APPROVAL STATEMENT

This report has been reviewed and approved.

RUSSELL B. SORRELLS
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FOR THE COMMANDER

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Wind tunnel tests of the space shuttle External Tank Foam Insulation were conducted in the von Karman Gas Dynamics Facility Tunnel C. The tests were conducted in two entries. On the first entry Tunnel C was run at Mach 4 with a total temperature of 1030-1150°F and a total pressure which varied from 30-180 psia. Cold wall heating rates were changed by varying the wedge angle and by adding and removing a shock generator or a cylindrical protuberance. The second entry was conducted at Mach 10 with a total temperature of 1140°F and a total

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20. ABSTRACT, Concluded.

pressure of 1750 psia. Selected results from both entries are presented to illustrate the test techniques and typical data obtained.

CONTENTS

APPENDIXES

NOMENCLATURE

ALPHI	Indicated pitch angle, deg
b	Model skin thickness, in.
c	Model material specific heat, Btu/lbm-°R
C1	Laboratory gage calibration factor, BTU/ft^2-sec-mv
C2	Temperature corrected gage calibration factor, BTU/ft^2-sec-mv
CAL	Calibration
CAMERA	Denotes camera locations: TOP - top of tunnel, OS - operating side of tunnel (right side looking downstream)
CR	Center of rotation, axial station along the tunnel centerline about which the model rotates in pitch, in.
DTW/DT	Derivative of the model wall temperature with respect to time, °R/sec
E	Gardon gage output, mv
fps	Frames per sec
H(TT)	Heat transfer coefficient based on TT, QDOT/(TT-TW) Btu/ft^2-sec-°F
ITT	Enthalpy based on TT, Btu/lbm
KG	Gardon gage temperature calibration factor, °R/mv
M	Free-stream Mach number
MU	Dynamic viscosity based on free-stream temperature, lbf-sec/ft^2
P	Free-stream static pressure, psia
PIC NO	Picture number, corresponds to number on each frame of contact print

XXXX - XXX

RUN NUMBER   FRAME NUMBER

PT	Tunnel stilling chamber pressure, psia
Q	Free-stream dynamic pressure, psia
QDOT	Heat flux, Btu/ft^2-sec
QDOT-O	Cold wall (i.e. 0°F) heat flux calculated from QDOT = H(TT)(TT-460) Btu/ft^2-sec
RE	Free-stream Reynolds number, ft^{-1}
RHO, ρ	Free-stream density, lbm/ft^3
ROLL NO	Identification number for each roll of film
RUN	Data set identification number
T	Free-stream static temperature, °R
TC/NO	Thermocouple identification number
TGE	Gardon gage edge temperature, °R
TGDEL	Temperature differential from the center to the edge of Gardon gage disc, °R
THETA	Angular measurement on the model, deg (see Fig. 6b)
TI	Initial wall temperature
TIME	Elapsed time from lift-off, sec
TIMECL	Time at which the model reached tunnel centerline, Central Standard Time
TIMEEXP	Time of exposure to the tunnel flow when the data were recorded, [TIME - $\left(\frac{32}{57}\right)$ (TIMEINJ)], sec
TIMEEXPT	Total exposure time for a RUN, sec
TIMEINJ	Elapsed time from lift-off to arrival at tunnel centerline, sec
TT	Tunnel stilling chamber temperature, °R

TW	Model surface temperature, °R
V	Free-stream velocity, ft/sec
WA	Wedge angle, deg (see Fig. 2)
X, Y, Z	Orthogonal body axis system directions (see Fig. 2)
X1	Specially defined heat transfer data axis system for plotting (see Fig. 6c)

1.0 INTRODUCTION

The work reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 921E02, Control Number 9E02, at the request of the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), Huntsville, Alabama for the Martin-Marietta Corporation (Michoud Operations), New Orleans, Louisiana. The Martin-Marietta Corporation project manager was Mr. S. Copsey and the NASA/MSFC project managers were Mr. J. Warmbrod and Mr. F. D. Bachtel. The results were obtained by Calspan Field Services, Inc./AEDC Division, operating contractor for the Aerospace Flight Dynamics testing effort at the AEDC, AFSC, Arnold Air Force Station, Tennessee. The tests were conducted under AEDC Project No. C594VC (Calspan No. V41C-35).

The objective of this test was to measure the response to interference heating of the material used on the space shuttle's External Tank Thermal Protection System (ET-TPS). The wedge technique with a cylindrical protuberance or shock generator was used to produce an augmented local heating rate. Data from this test will be used to evaluate a possible reduction in weight of the space shuttle external tank by reducing the amount of insulative material or replacing it with a lighter material.

The first entry was performed in the Hypersonic Wind Tunnel (C) on October 7 and 9, 1981. Data were recorded at Mach number 4 with tunnel stilling chamber pressures ranging from 30-180 psia and temperatures from 1030-1150°F. The cold wall heating rates of 0.3 to 60 Btu/ft^2-sec were obtained by varying the nominal wedge angle (WA) and by adding or removing a shock generator or a cylindrical protuberance.

The second entry was performed on November 11, 1981. Data were recorded at Mach number 10 with a stilling chamber pressure of 1750 psia and temperature of 1440°F.

All test data including detailed logs and other information required to use the data have been transmitted to the user and sponsor as described in Table 1. Inquiries to obtain copies of the test data should be directed to NASA/MSFC/ED33, Marshall Space Flight Center, 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 which can be operated continuously using air supplied by the VKF main compressor plant. A natural gas fired combustion heater can be operated either in series or in parallel with an electric resistance heater to provide the required stagnation temperatures. Two interchangeable axisymmetric contoured nozzles produced either a Mach 10 flow in a 50-in. diam test section or a Mach 4 flow in a 25-in. diam free jet test region. For

Mach 10 operation tunnel stilling chamber pressure can be varied from 300 to 2000 psia and the maximum stilling chamber temperature is 2260°R. During Mach 4 operation the corresponding values are 20 to 180 psia and 1660°R. A comparison between Figs. 1a-d shows that converting from one configuration to the other involves replacing the Mach 10 nozzle with the Mach 4 stilling chamber and nozzle. All other components are common to both Mach 4 and Mach 10 operation. 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. 1.

2.2 TEST ARTICLE

This test was conducted in two entries. Two different wedges were used and the specimens varied in size to fit the different wedges. For the Mach 4 entry, a 12-in. x 34-in. wedge supplied by Martin-Marietta and shown in Fig. 2a was used. The 12-in. wedge could also be used with a shock generator to provide augmented heating rates on the specimen area (see Fig. 2b). The shock generator angle (shock angle) could be varied from 0 to 25°, in increments of 5°, to change the position of the interference region. For the Mach 10 entry the 15-in. x 41.5-in. wedge shown in Fig. 2c was used. The smaller wedge was used at Mach 4 due to the smaller test rhombus size in this nozzle . Both wedges used boundary-layer trips to ensure turbulent flow.

A photograph of a typical test specimen run on Entry 1 is shown in Fig. 3. The specimens were basically flat (12.0 x 20.0 in.) panels consisting of a 0.125-in. aluminum support plate covered with a 1.0 ± 0.25-in. layer of Spray on Foam Insulator (SOFI) (see Fig. 4a). Some panels had holes in the SOFI to allow the mounting of a 5.0-in. diam, 3-in. high protuberance as shown in Fig. 4b. Other panels had a 14-in. x 4-in. area of SOFI removed and replaced with a repair patch as seen in Fig. 4c. Three panels also had a 2-in. plug in addition to the repair patch as seen in Fig. 4d. One sample had a protective top coat on half of the sample as seen in Fig. 4e. On the second entry, the specimens consisted of a 15.0- x 24.0- x 0.125-in. aluminum support plate covered with a 1.0- ± 0.25-in. layer of SLA-561 (see Fig. 5). Four areas were covered with a deicing compound.

For a complete list of materials tested see Table 2.

Two thin skin calibration models (Fig. 6) instrumented with thermocouples were also provided by Martin-Marietta for the Mach 4 entry. One was a flat plate (Fig. 6a) to be used with or without the shock generator. A second model (see Fig. 6b-d) was used to calibrate the heating levels around a protuberance and had a 5.0-in. diam, 3-in. high stainless steel cylinder mounted to it.

The specimen samples from Entry 1 were attached to the 12-in. material wedge as shown in Fig. 2a. A photograph is shown in Fig. 7. Installation of the 12-in. wedge in Tunnel C, is shown in Fig. 8a and b.

The insulation panels from Entry 2 were attached to the 15-in. VKF material wedge shown in Fig. 2c. An installation sketch of this wedge is shown in Fig. 9.

2.3 TEST INSTRUMENTATION

The instrumentation, recording devices, and calibration methods used to measure the primary tunnel and test data parameters are listed in Table 3a along with the estimated measurement uncertainties. The range and estimated uncertainties for primary parameters that were calculated from the measured parameters are listed in Table 3b.

A variety of cameras was used to record the test results. Color motion pictures (2 cameras) and 70-mm sequence color stills recorded any changes in the samples as they were tested. The movie cameras were operated at frame rates of 24 fps (see Table 4). A shadowgraph still or high speed shadowgraph movie was taken for each run to aid in visualizing the shock wave patterns about the protuberances. A black and white video tape was also made for general coverage during the test. All photographic data taken during the test are identified in Table 4.

During both entries Gardon gages were used to define the heating levels upstream of the test samples. For the 12-in. wide wedge (Entry 1) eleven gages were installed (see Fig. 2a) and for the 15-in. wide wedge (Entry 2) nine gages were used (see Fig. 2c). The coordinate locations of the Gardon gages are listed in Tables 5a and b.

The Gardon gages used in the wedge were a special high temperature type, 0.25-in. in diam, with a 0.010-in. thick sensing disk. Each gage had a Chromel®-Alumel® thermocouple to provide the gage edge temperature. These temperatures, together with the gage output, were used to determine the gage surface temperatures and corresponding heat transfer rate, which was then used to calculate the local heat transfer coefficient.

The calibration model temperatures were measured with FE-CN thermocouples. The thermocouple locations are shown in Fig. 6 and their coordinates and corresponding skin thickness are listed in Tables 5c and 5d.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS

A summary of the nominal test condition is given below:

	M	PT, psia	TT, °R
Entry 1	4.0	30-180	1470-1600
Entry 2	10.10	1750	1900

A test summary showing the configurations tested and the variables for each is presented in Table 6.

3.2 TEST PROCEDURES

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, the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

The required local flow conditions over the test specimen are produced by attaching the panel to a large wedge. The oblique shock wave generated by the wedge reduces the free-stream Mach number to the desired local Mach number. Since the free-stream Mach number is fixed, the local Mach number is varied by pitching the wedge. With the free-stream Mach number and the wedge angle defined, the pressure and temperature ratios across the shock wave are established. The pressure and temperature along the wedge surface can then be set as desired by adjusting the tunnel stilling chamber pressure and temperature. A complete description of this technique as used in Tunnel C is given in Ref. 2.

3.3 DATA REDUCTION

Measured stilling chamber pressure and temperature and the calibrated test section Mach number are used to compute the free-stream parameters. The equations for a perfect gas isentropic expansion from stilling chamber to test section are modified to account for real gas effects.

Data measurements obtained from the Gardon gages are gage output (E) and gage edge temperature (TGE). The gages are direct reading heat flux transducers and the gage output is converted to heating rate by means of a laboratory calibrated gage scale factor (C1). The scale factor has been found to be a function of gage temperature and therefore must be corrected for gage temperature changes,

$$C2 = C1\ f(TGE) \tag{1}$$

Heat flux to the gage is then calculated for each data point by the following equation:

$$QDOT = (E)(C2) \tag{2}$$

The gage wall temperature used in computing the gage heat transfer coefficient is obtained from two measurements - the output of the gage edge thermocouple (TGE) and the temperature difference (TGDEL) from the gage center to its edge. TGDEL is proportional to the gage output, E, and is calculated by:

$$TGDEL = (KG)(E) \tag{3}$$

The gage wall temperature is then computed as

$$TW = TGE + 0.75\ TGDEL \tag{4}$$

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

The VKF standard Gardon gage data reduction procedure was used to compute model local heat-transfer coefficients. The procedure averages five consecutive samples of gage output, (E) commencing with the data loop recorded at approximately one second after the model arrives at tunnel centerline. The average output is then compared to each individual reading used in the average to check for outliers. If the individual readings differ from the calculated average by more than ±2 percent or ±15 counts, whichever is larger, an asterisk (*) is printed next to the tabulated value of QDOT. The gage edge temperature (TGE) was averaged in the same manner with ±5 deg allowable deviation from the average.

The heat-transfer coefficient for each gage was computed using the following equation,

$$H(TT) = \frac{QDOT}{(TT-TW)} \tag{5}$$

QDOT-0 is the heat flux calculated when the gage wall temperature (TW) is assumed to be 460°R (0°F). It is computed using the following equation,

$$QDOT\text{-}0 = H(TT)(TT-460) \tag{6}$$

The reduction of thin skin temperature data to coefficient form normally involves only the calorimeter heat balance for the thin skin as follows:

$$QDOT = \rho bc\ DTW/DT \tag{7}$$

$$H(TT) = \frac{QDOT}{TT-TW} = \frac{\rho bc\ DTW/DT}{TT-TW} \tag{8}$$

Thermal radiation and heat conduction effects on the thin-skin element are neglected in the above relationship and the skin temperature response is assumed to be due to convective heating only. It can be shown that for constant TR, the following relationship is true:

$$\frac{d}{dt}\left[\ln\left(\frac{TT-TI}{TT-TW}\right)\right] = \frac{DTW/DT}{TT-TW} \tag{9}$$

Substituting Eq. (9) in Eq. (8) and rearranging terms yields:

$$\frac{H(TT)}{\rho bc} = \frac{d}{dt}\left[\ln\left(\frac{TT-TI}{TT-TW}\right)\right] \quad (10)$$

By assuming that the value of H(TT)/ρbc is a constant, it can be seen that the derivative (or slope) must also be constant. Hence, the term

$$\ln\left(\frac{TT-TI}{TT-TW}\right)$$

is linear with time. This linearity assumes the validity of Eq. (8) which applies for convective heating only. The evaluation of conduction effects will be discussed later.

The assumption that H(TT) and c are constant is reasonable for this test although small variations do occur in these parameters. The variations of H(TT) caused by changing wall temperature and by transition movement with wall temperature are trivial for the small wall temperature changes that occur during data reduction. The value of the model material specific heat, c, was computed by the relation

$$c = 8.86196 \times 10^{-2} + 3.98668 \times 10^{-5}(TW), \text{ (316 stainless steel)} \quad (11)$$

The maximum variation of c over any curve fit was less than 1.5 percent. Thus, the assumption of constant c used to derive Equation 10 was reasonable. The value of density used for the 316 stainless steel skin was, $\rho = 501\ lbm/ft^3$, and the skin thickness, b, for each thermocouple is listed in Table 5.

The right side of Equation 10 was evaluated using a linear least squares curve fit of 15 consecutive data points to determine the slope. The curve fit was started at approximately the time the model arrived on the tunnel centerline. For each thermocouple the tabulated value of H(TT) was calculated from the slope and the appropriate values of ρbc; i.e.,

$$H(TT) = \rho bc \frac{d}{dt}\left[\ln\left(\frac{TT-TI}{TT-TW}\right)\right] \quad (12)$$

To investigate conduction effects a second value of H(TT) was calculated at a time one second later. A comparison of these two values was used to identify those thermocouples that were influenced by significant conduction (or system noise). The data for a given thermocouple were deleted* if the values of H(TT) differed by more than 35 percent. In general, conduction and/or noise effects were found to be negligible.

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*The word DELETE is used on the tabulated data to identify these thermocouples.

3.4 UNCERTAINTY OF MEASUREMENTS

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

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

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

Estimates of the measured data uncertainties for this test are given in Table 3a. The data uncertainties for the measurements are determined from in-place calibrations through the data recording system and data reduction program.

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

4.0 DATA PACKAGE PRESENTATION

A complete set of all photographic data and tabulated data for this test has been provided to Martin-Marietta Corporation. Photographic data which showed significant testing results and a complete set of tabulated data have been provided to NASA/Marshall Space Flight Center/ED33, Huntsville, Alabama. All test specimens for this test have been returned to the Martin-Marietta Corporation.

A representative posttest photograph is shown in Fig. 10. This is the same test panel shown in the pretest photograph in Fig. 3.

Samples of the tabulated and plotted data from the calibration and materials specimen runs are presented in Appendix C. A copy of all tabulated data has been retained on microfilm in the VKF. The photographs and movies generated during this test will be retained for one year and then they will be discarded.

Agreement of the test data to the VKF flat plate solution was good and an example can be seen in Fig. 11. The test data were taken from Runs 3 through 7 at a distance of 24 in. from the leading edge of the wedge. Data repeatability from run to run was excellent and an example can be seen in Fig. 12.

REFERENCES

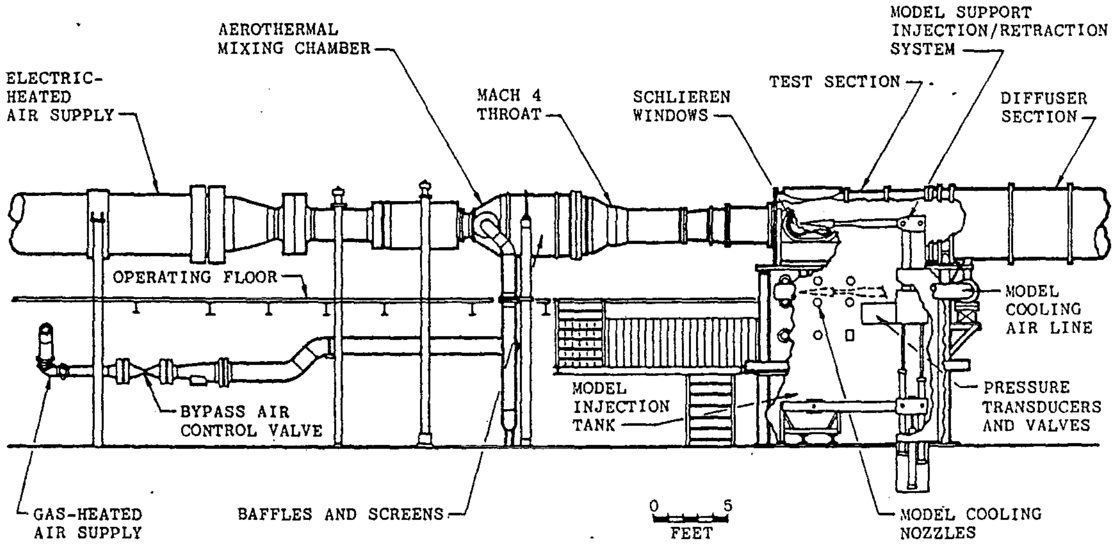
1. Test Facilities Handbook (Eleventh Edition). "von Karman Gas Dynamics Facility, Vol. 3." Arnold Engineering Development Center, April 1981.

2. Matthews, R. K. and Stallings, D. W. "Materials Testing in the VKF Continuous Flow Wind Tunnels," Presented at AIAA 9th Aerodynamic Testing Conference, Arlington, TX, June 7-9, 1976.

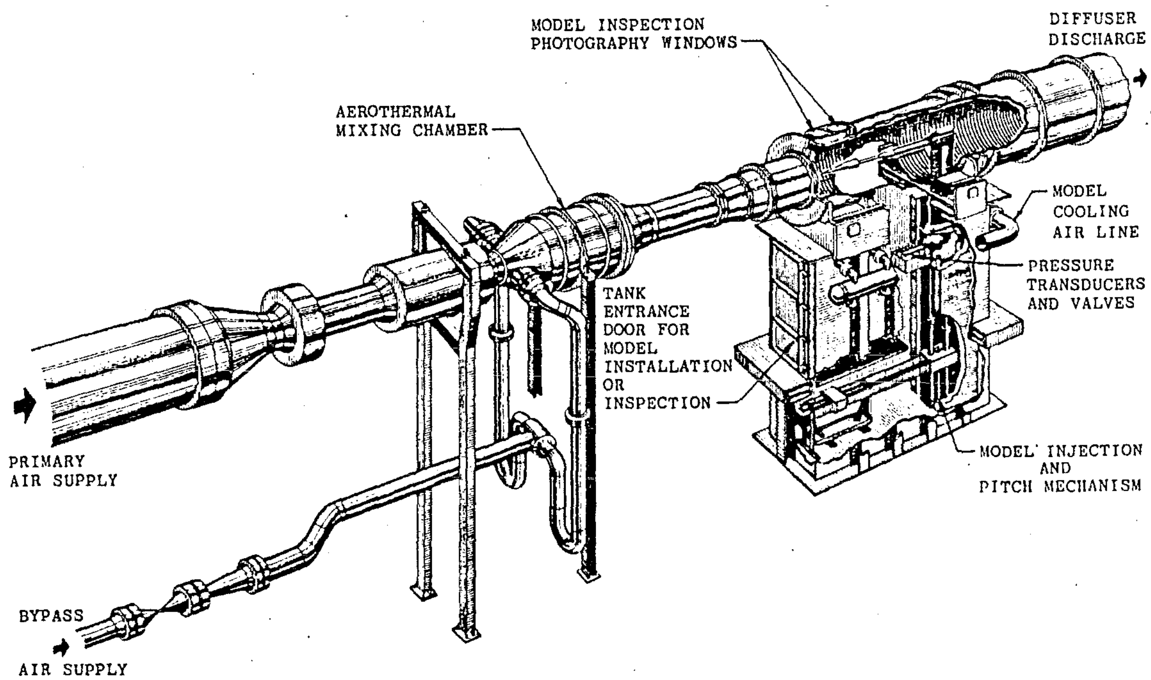
3. Thompson, J. W. and Abernethy, R. B. et. al., "Handbook Uncertainty in Gas Turbine Measurements," AEDC-TR-73-5 (AD-755356) February 1973.

APPENDIX A.

ILLUSTRATIONS

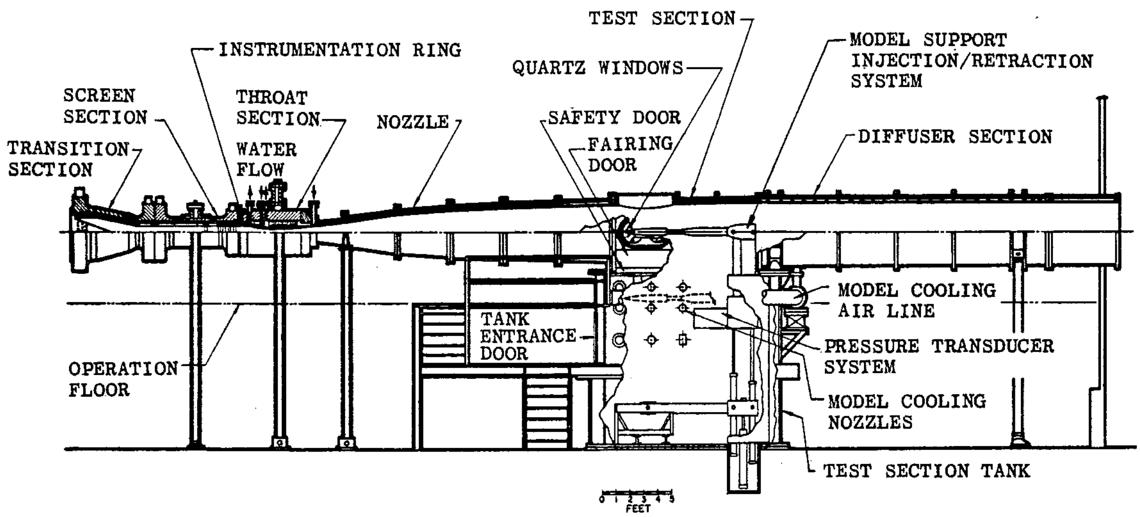


a. Tunnel Assembly, Mach 4 Configuration

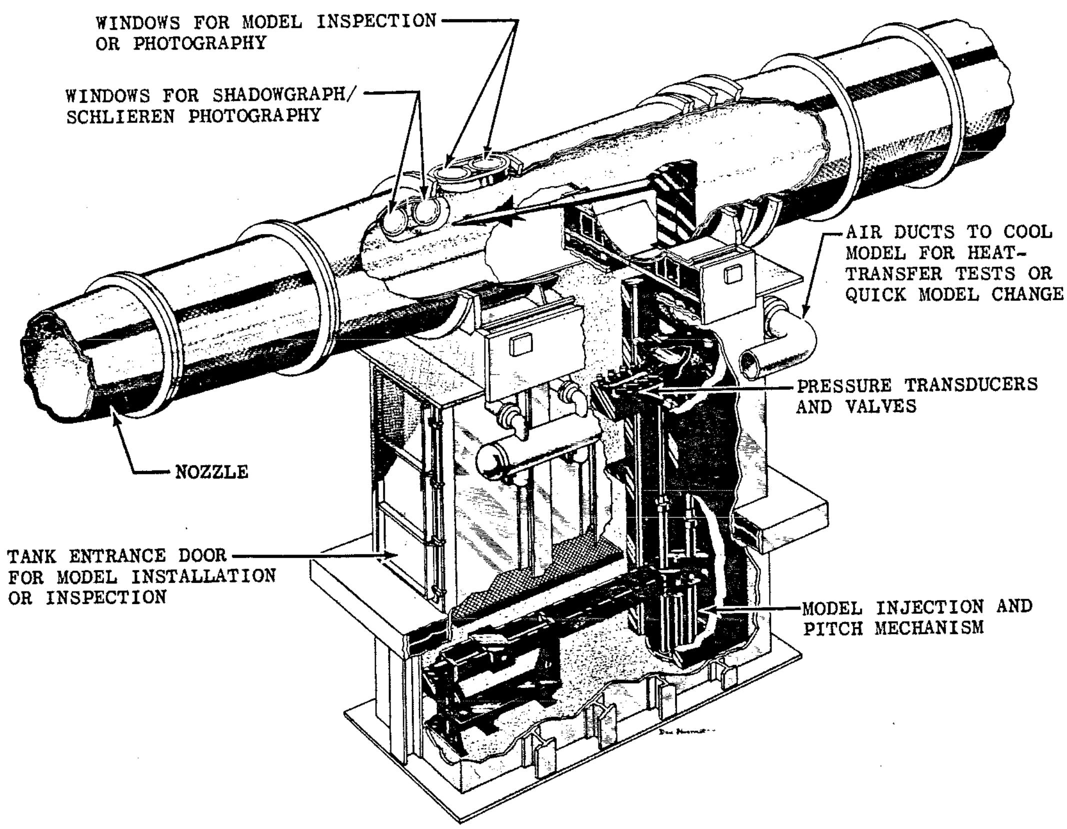


b. Perspective of Tunnel Test Section Area, Mach 4 Configuration

Figure 1. Tunnel C

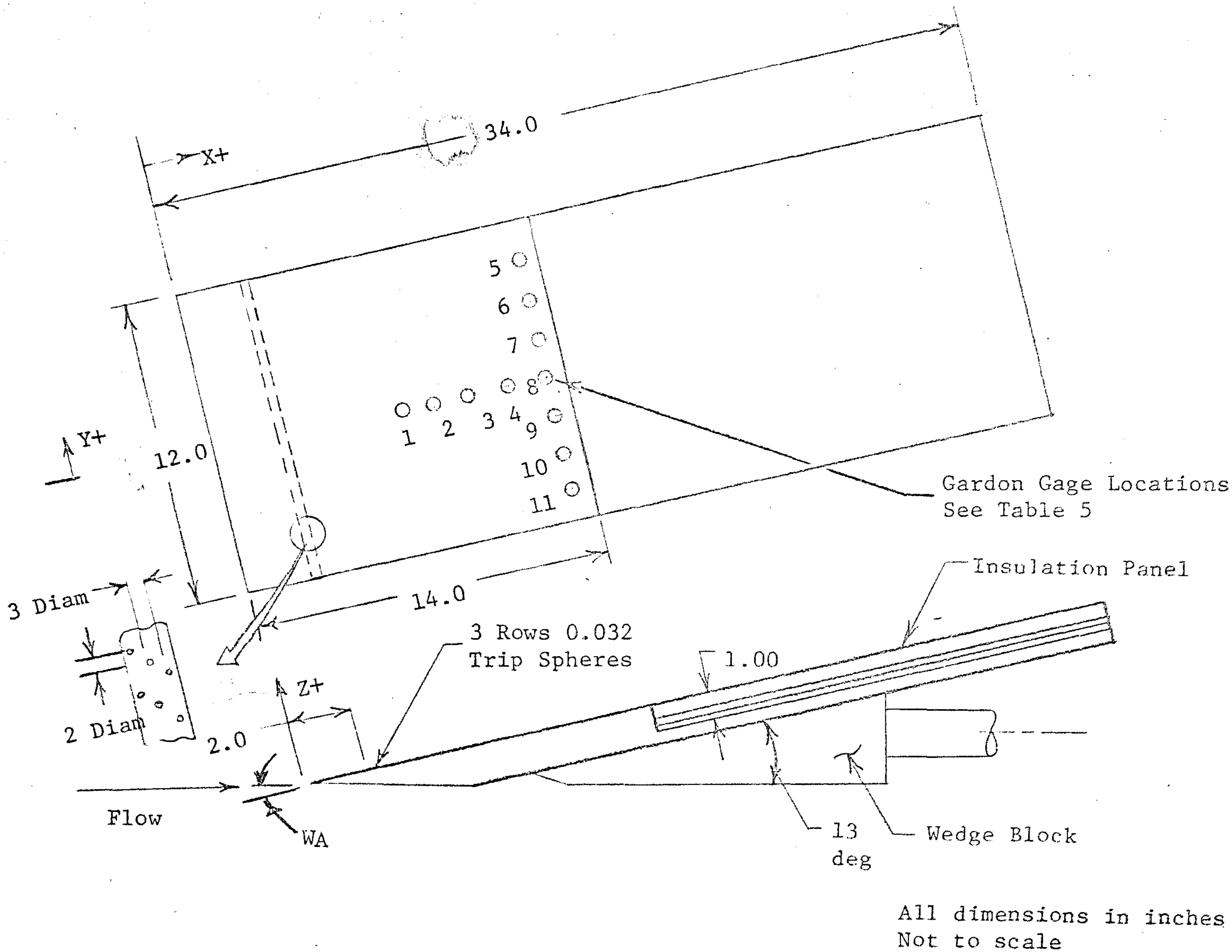


c. Tunnel Assembly, Mach 10 Configuration



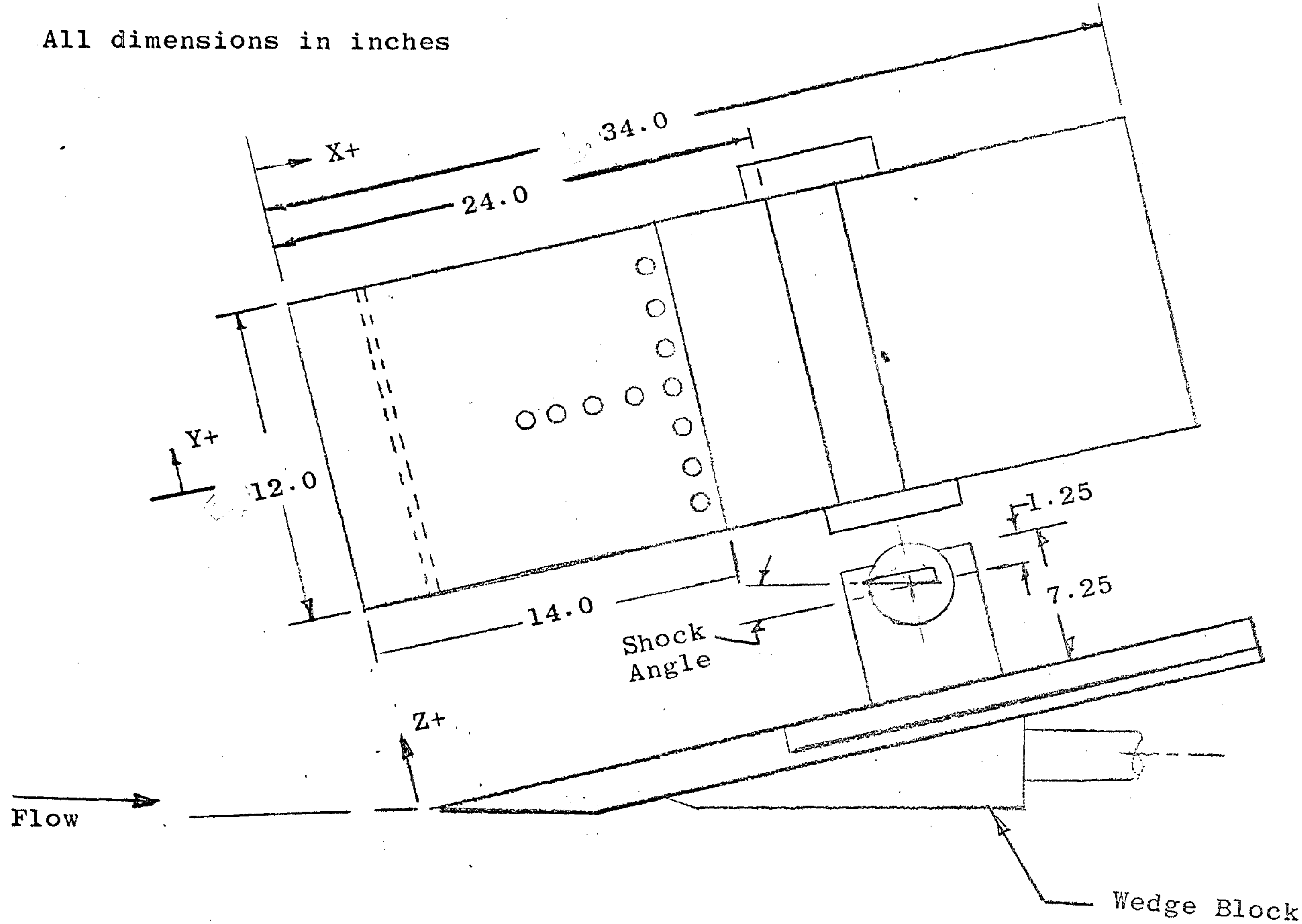
d. Tunnel Test Section, Mach 10 Configuration

Figure 1. Concluded



a. Sketch of 12-in. Wide Materials Testing Wedge

Figure 2. Material Testing Wedge



b. Sketch of 12-in. Wedge with Shock Generator

Figure 2. Continued

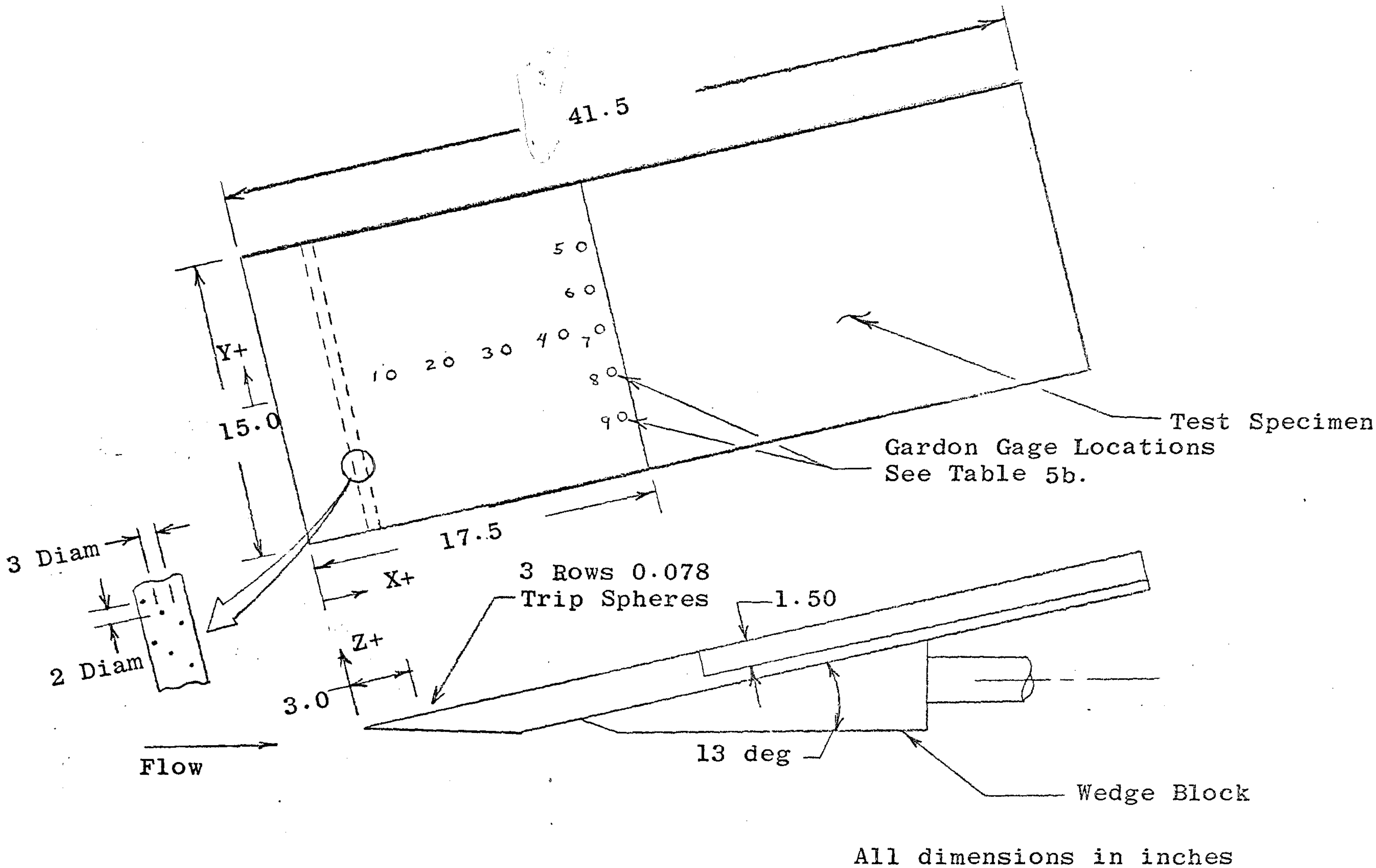


Fig.

c. Sketch of VKF 15-in. Wide Wedge

Figure 2. Concluded

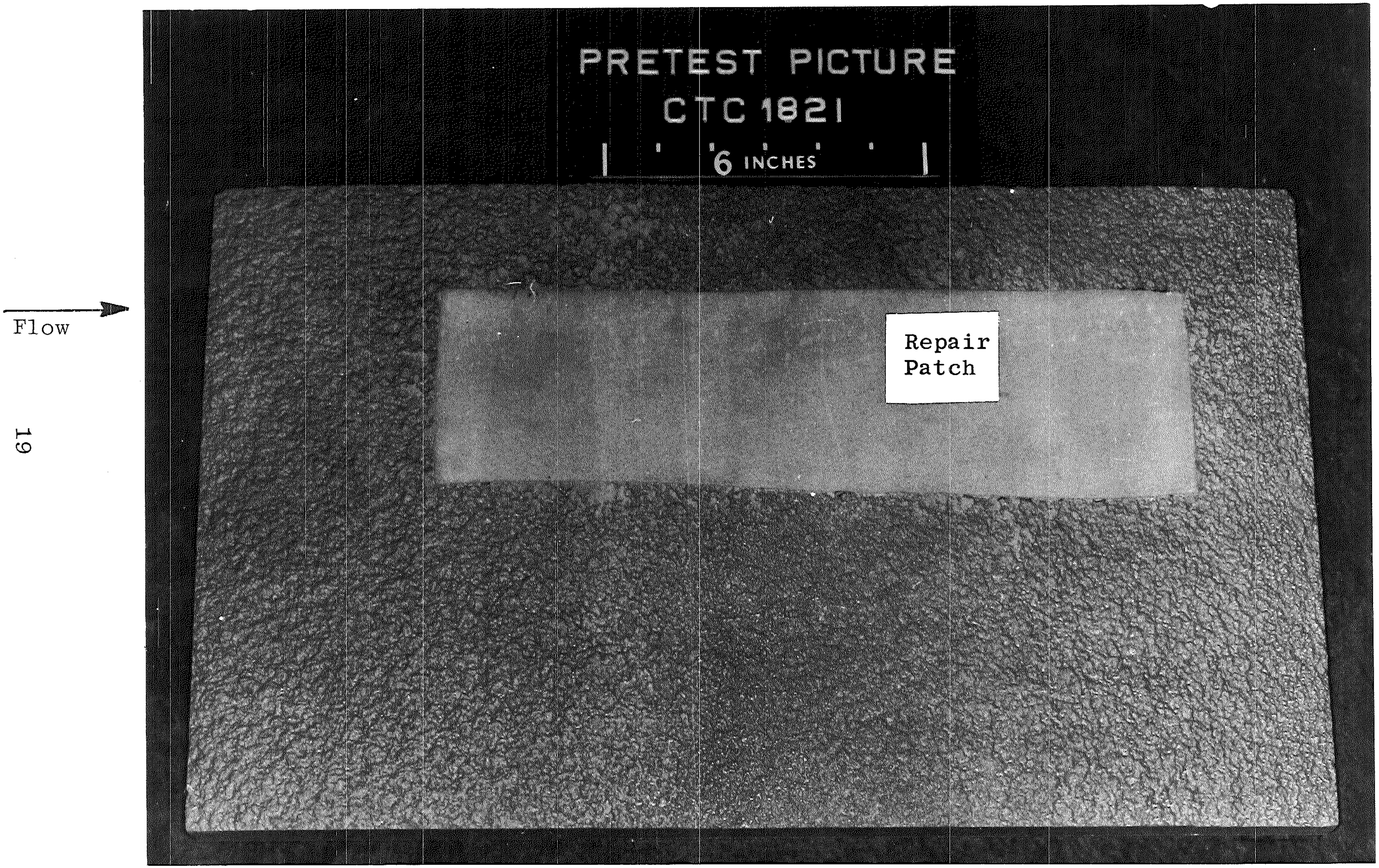
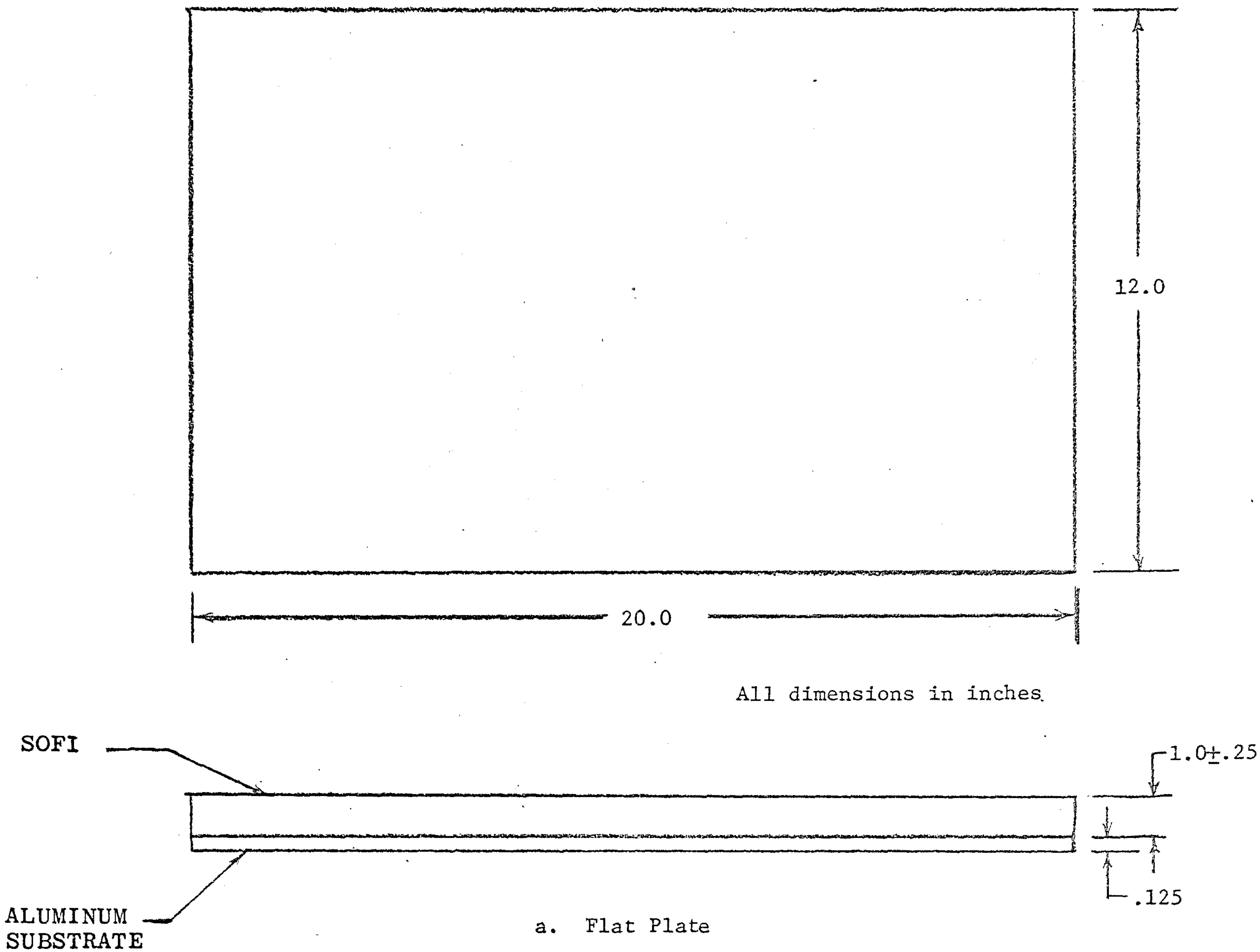
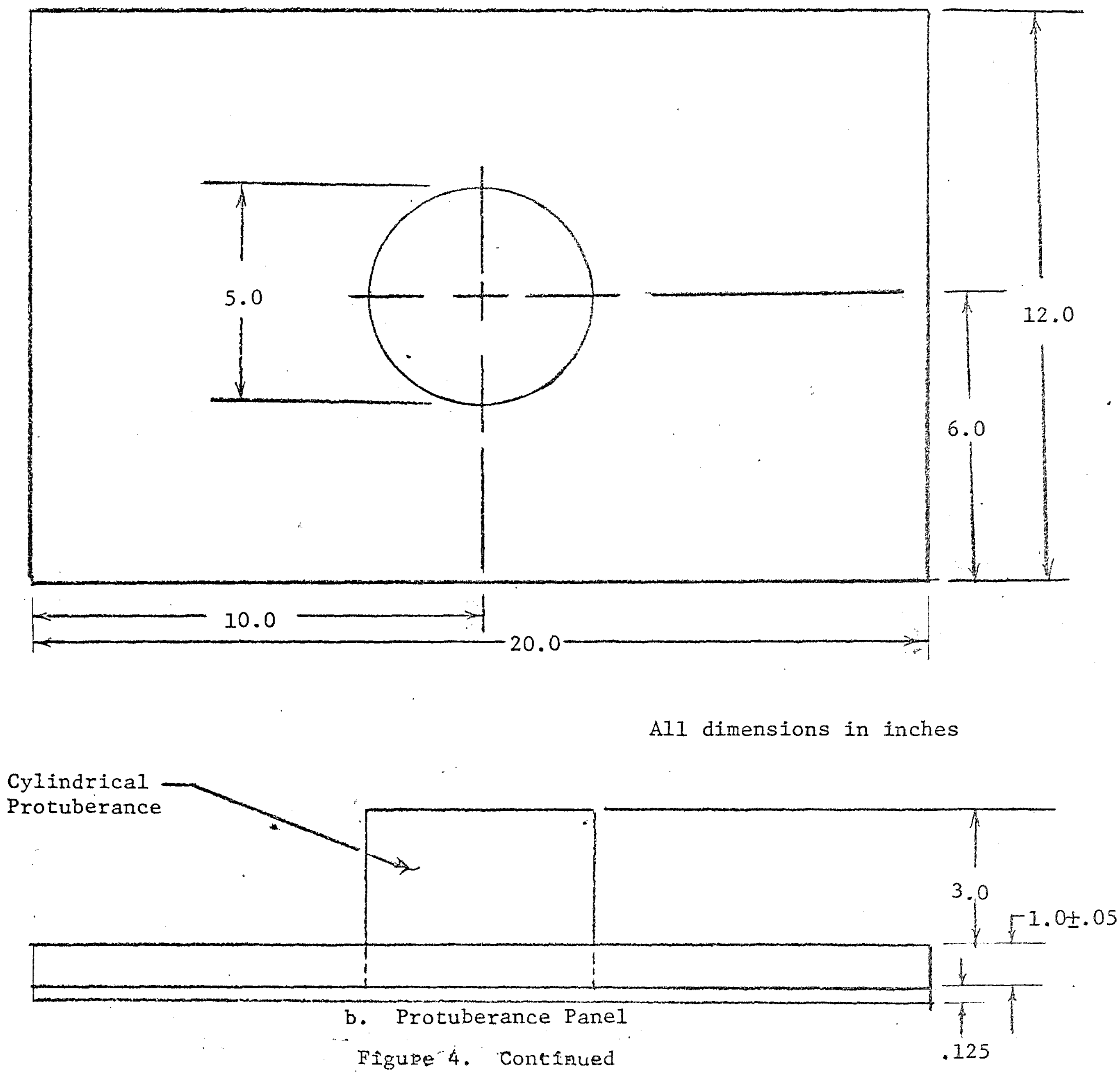


Figure 3. Typical Specimen Pretest Photograph



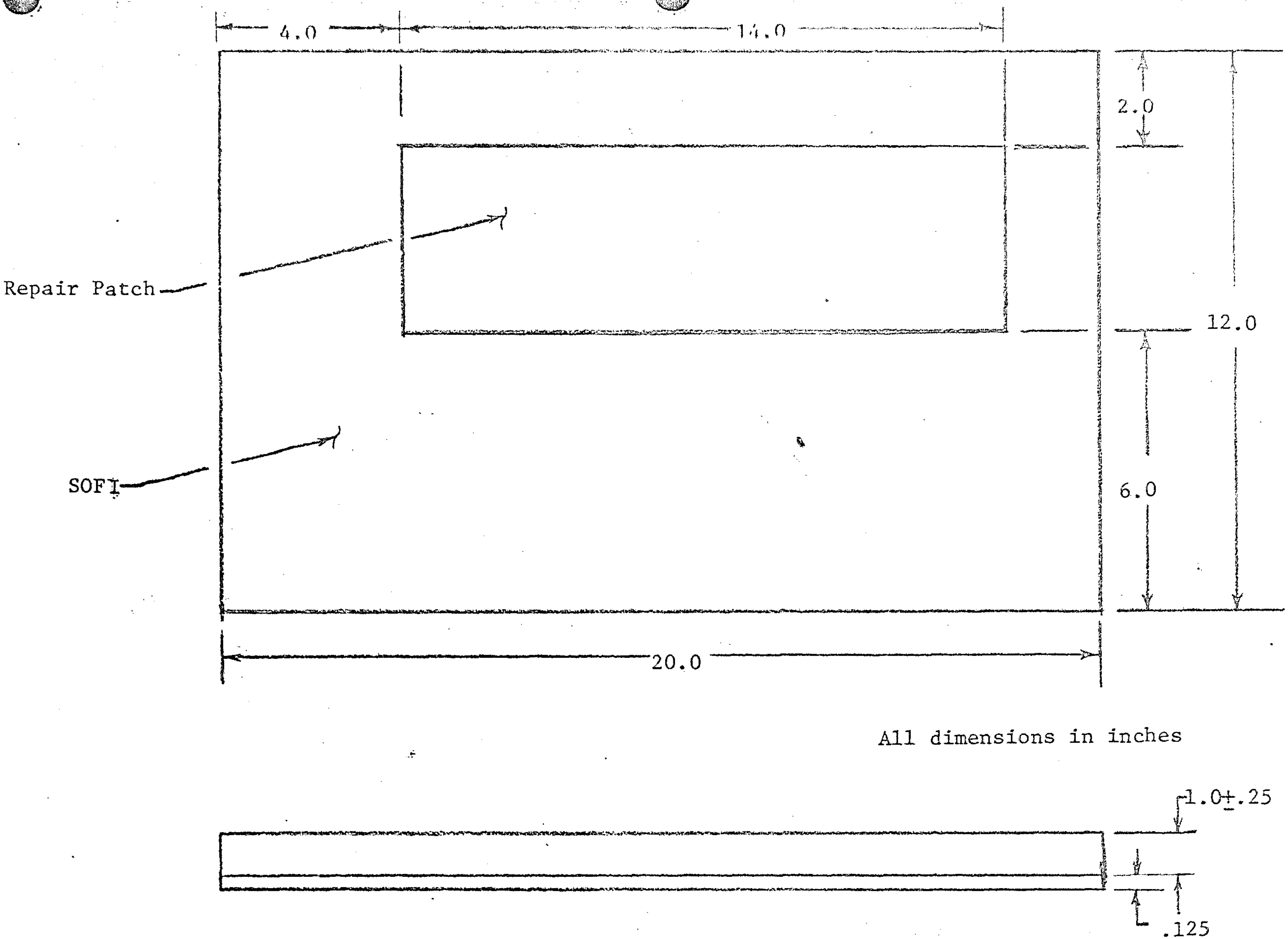
a. Flat Plate

Figure 4. Specimen Configuration, Mach 4 Entry

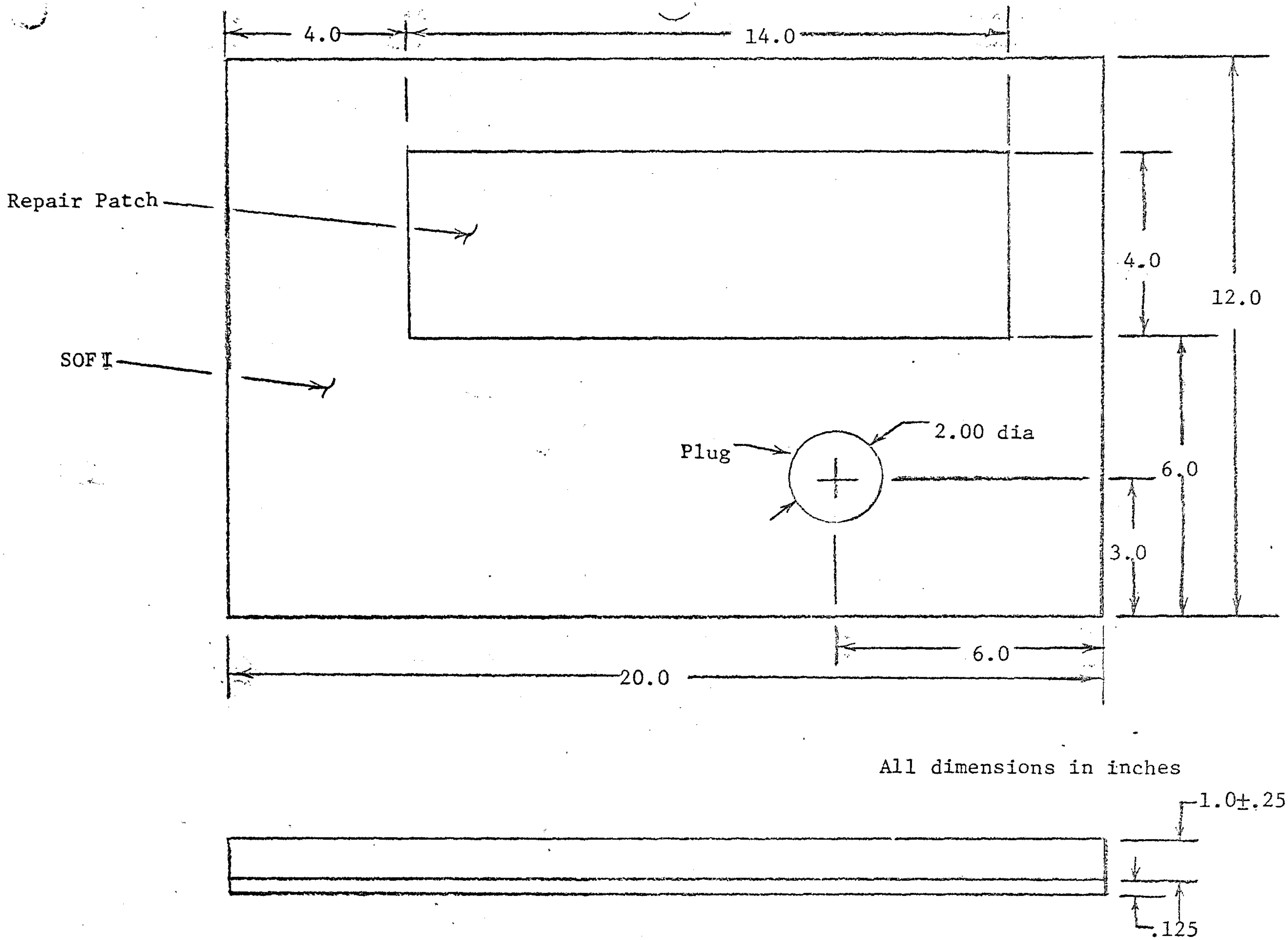


b. Protuberance Panel

Figure 4. Continued

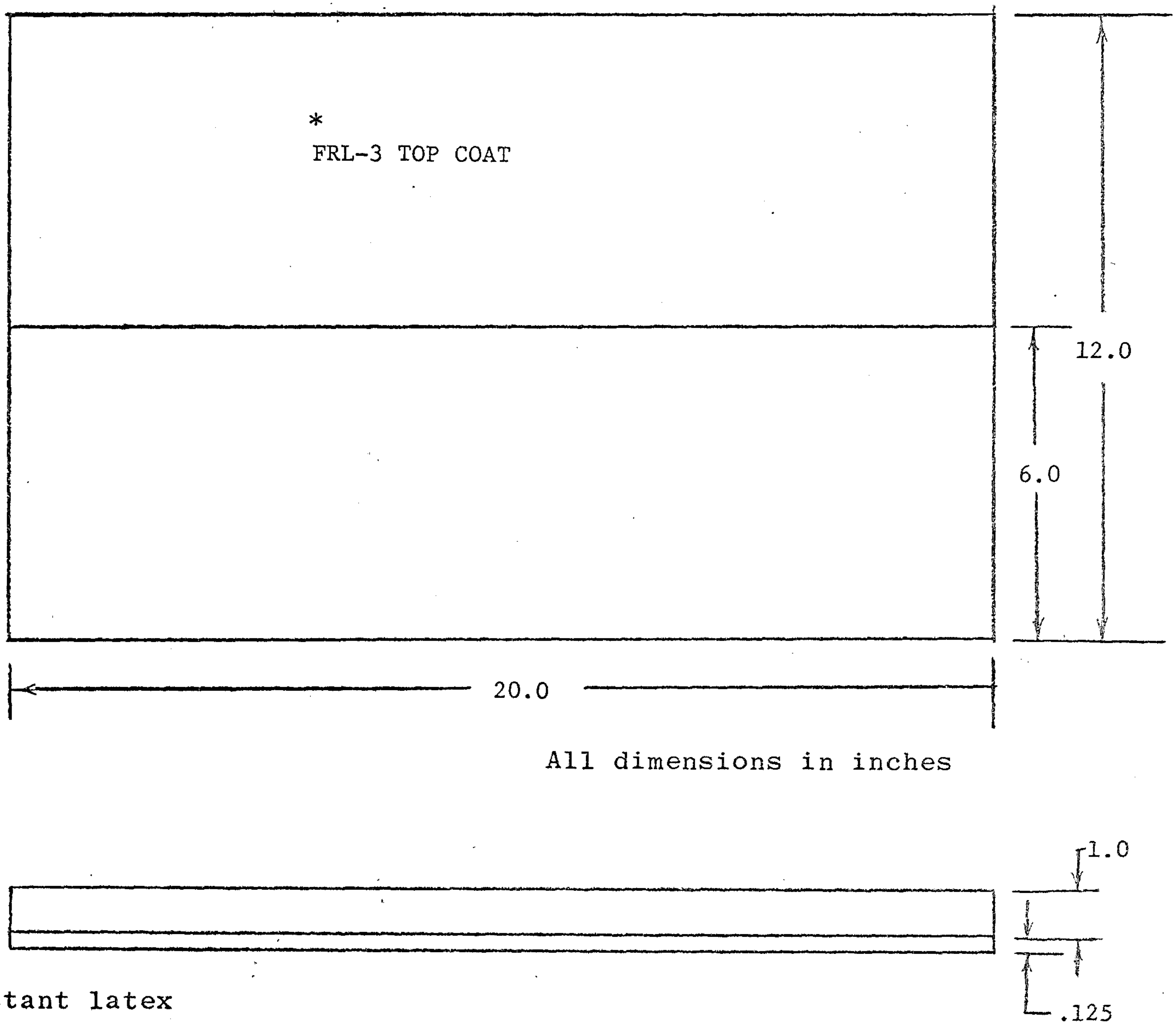


c. Repair Panel
Figure 4. Continued



d. Repair Panel and Plug

Figure 4. Continued



*Fire resistant latex

e. Panel with Topcoat

Figure 4. Concluded

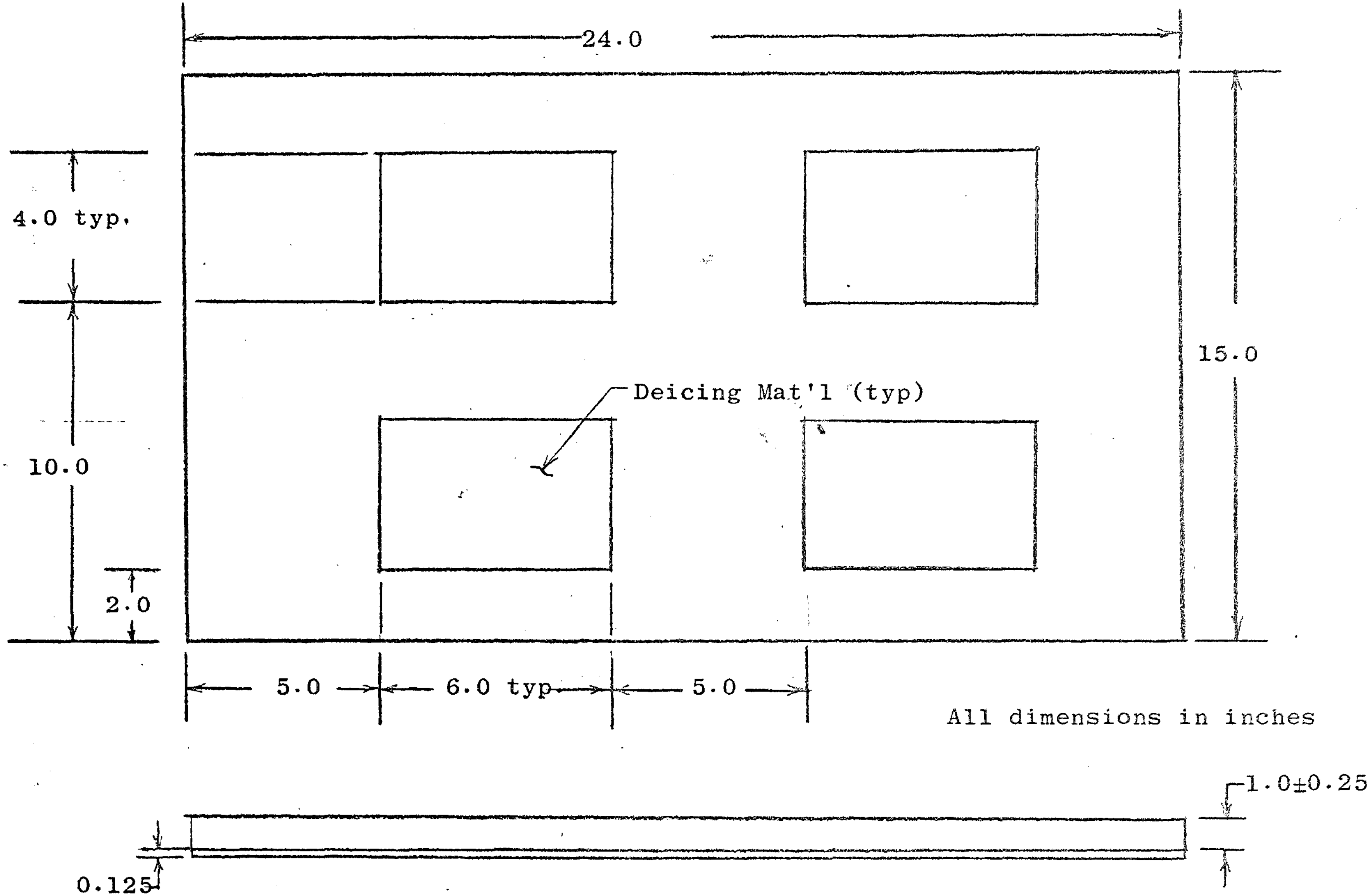
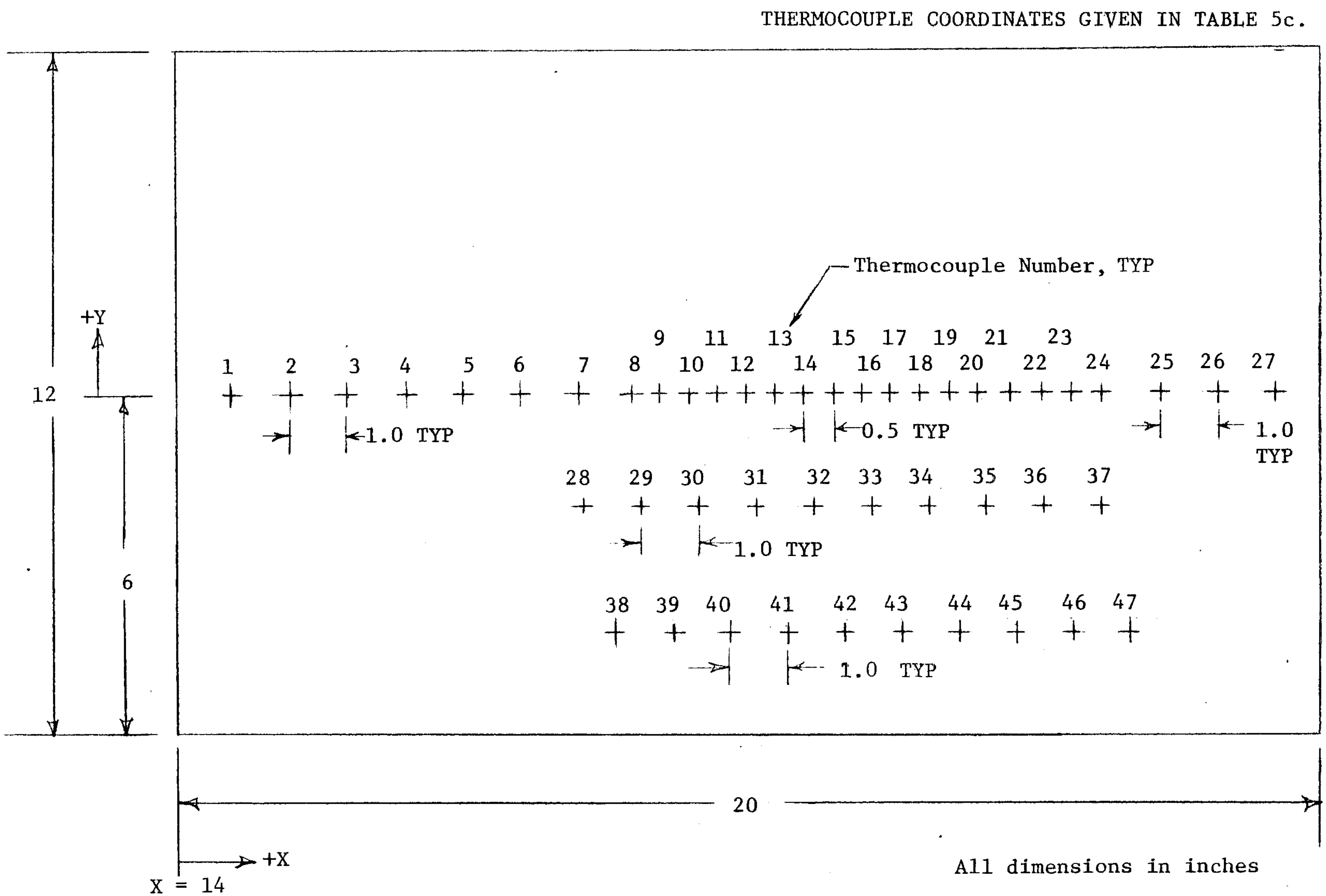
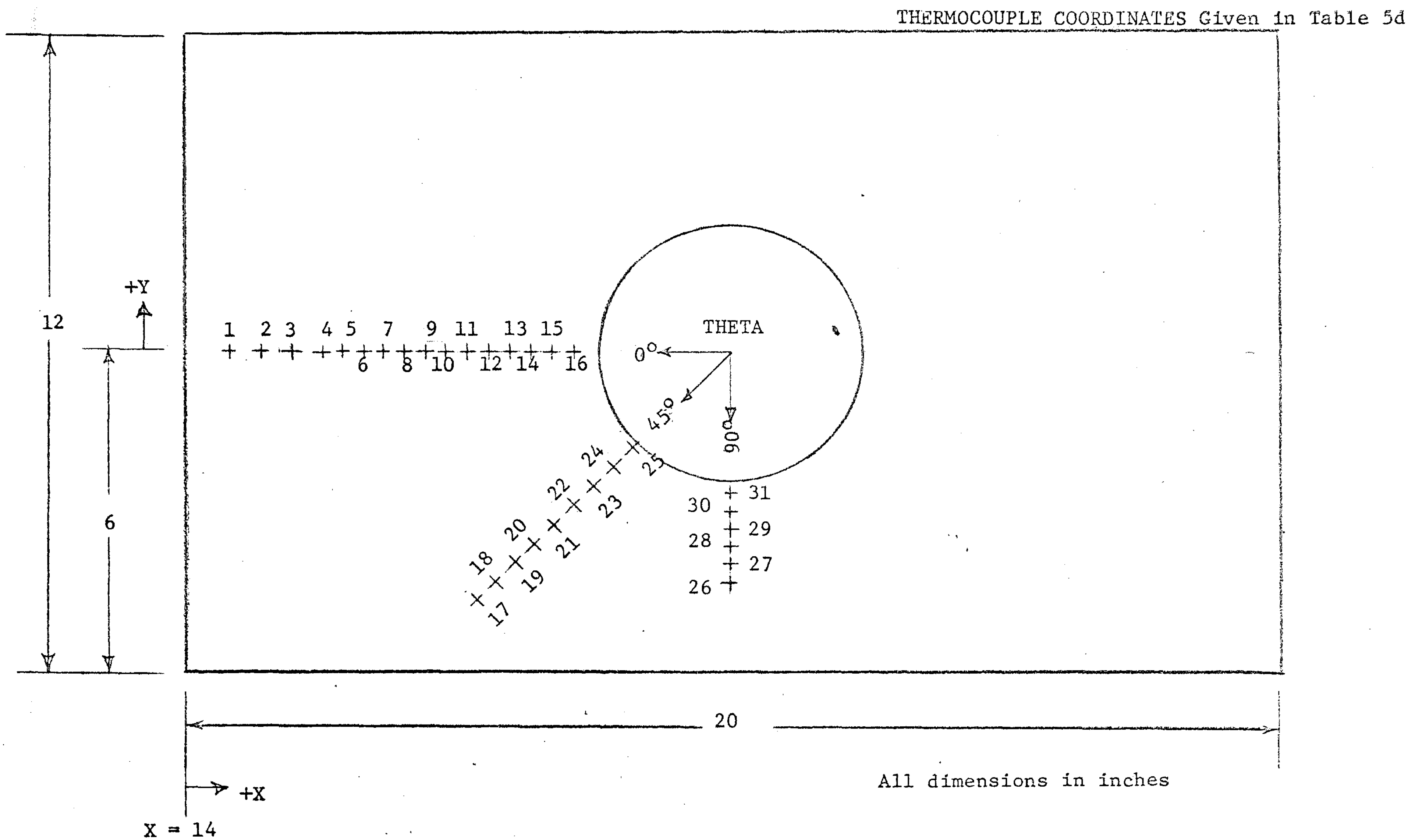


Figure 5. Specimen Configuration Mach 10 Entry



a. Flat Plate Calibration Model, Top View

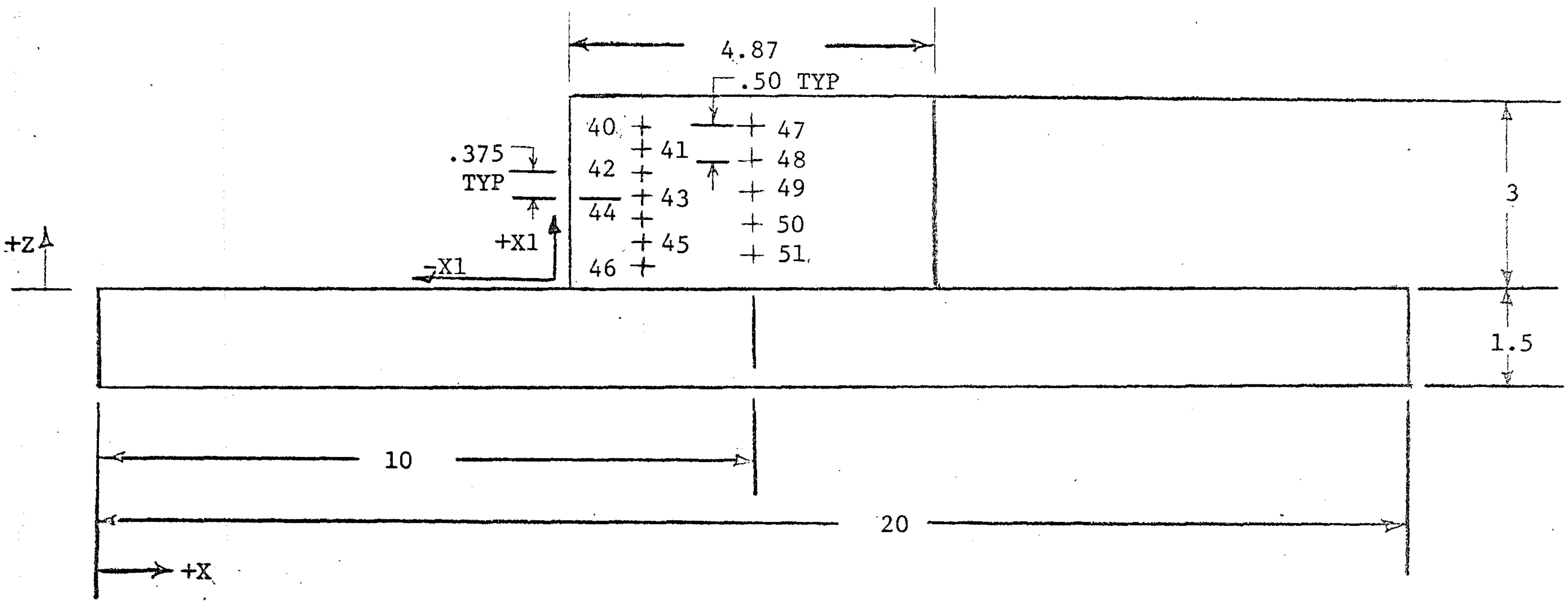
Figure 6. Calibration Panel Thermocouple Locations



b. Protuberance Calibration Model, Top View

Figure 6. Continued

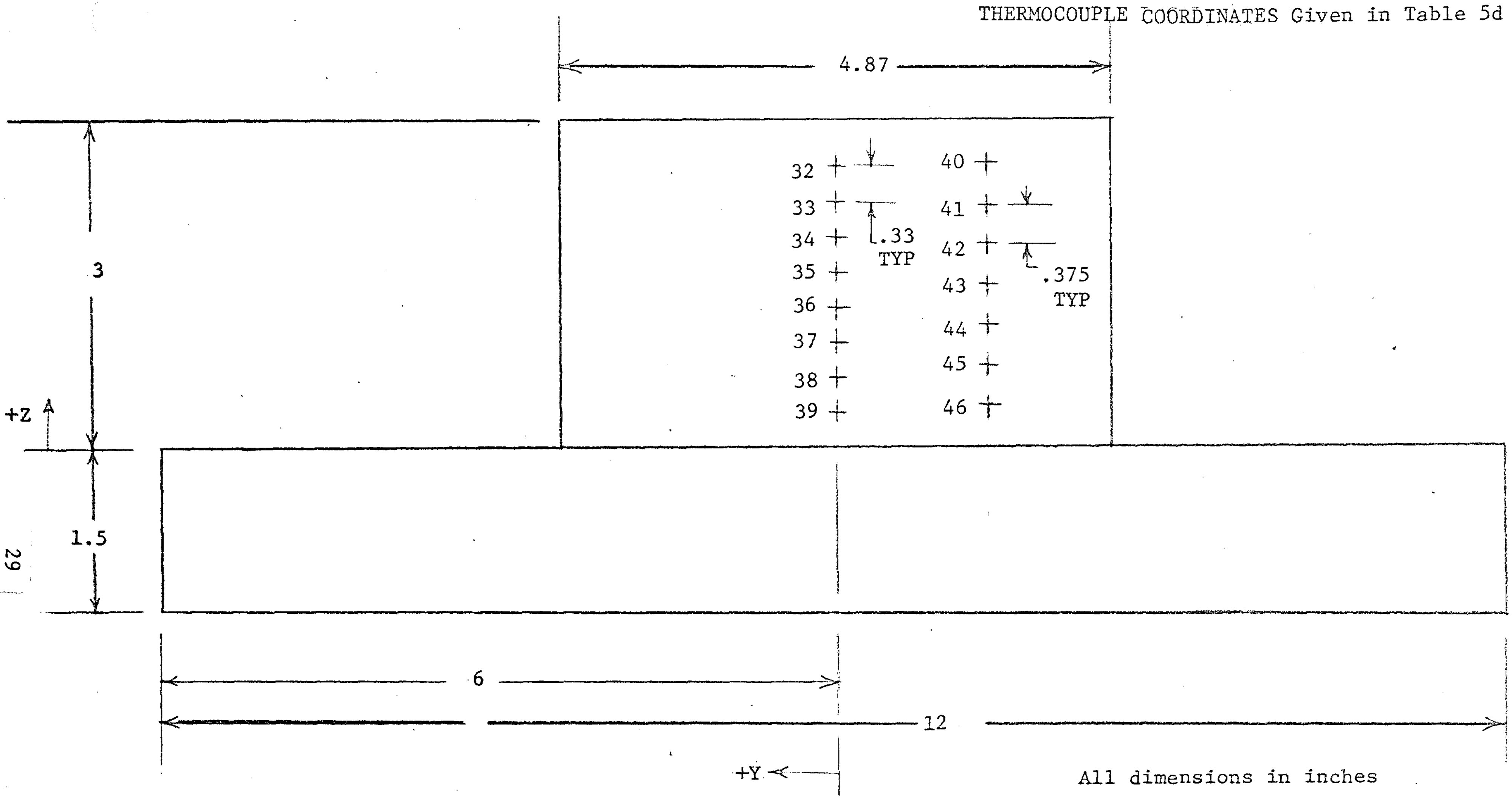
THERMOCOUPLE COORDINATES Given in Table 5d



All dimensions in inches

c. Protuberance Calibration Model, Side View

Figure 6. Continued



d. Protuberance Calibration Model, Front View

Figure 6. Concluded

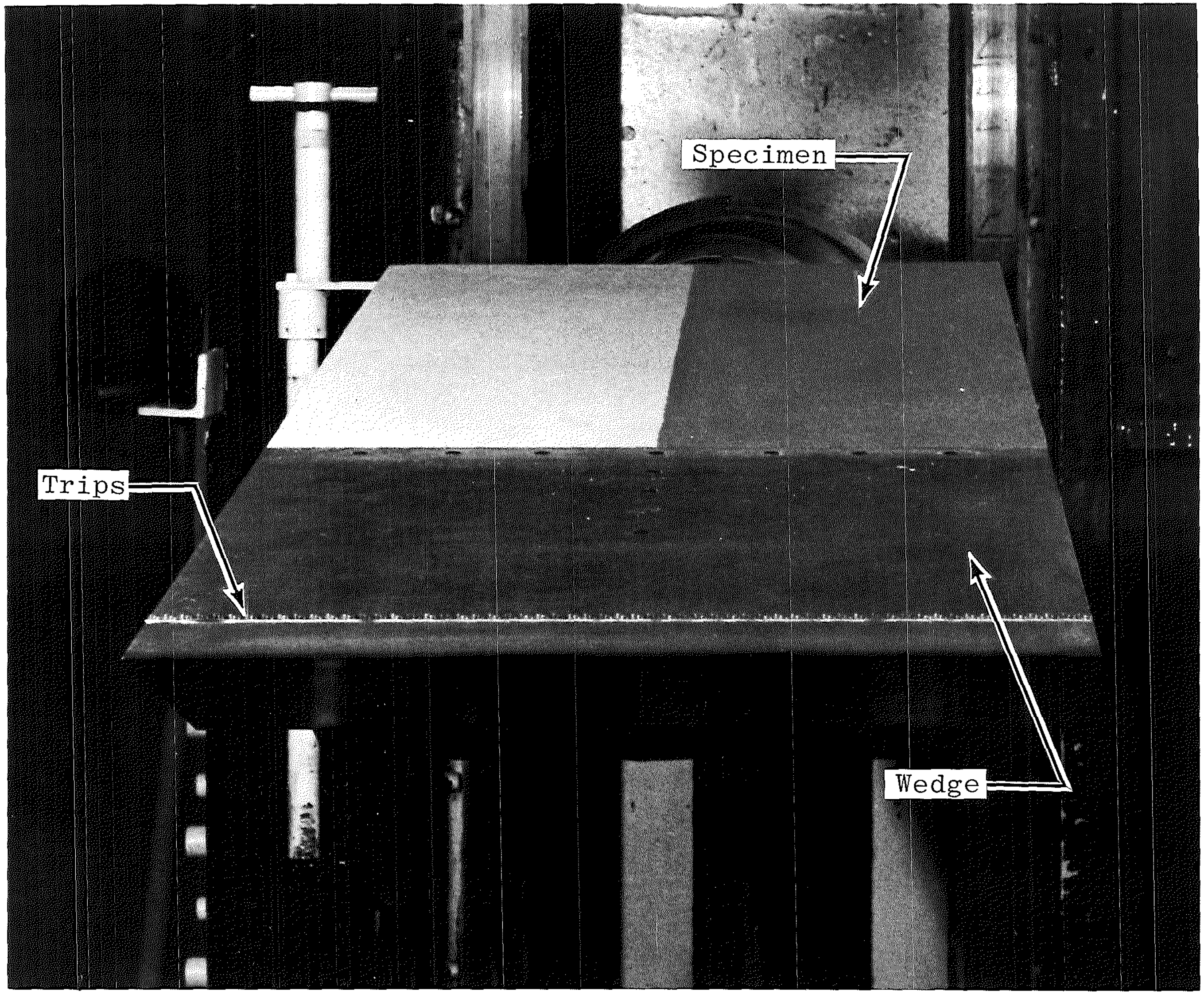
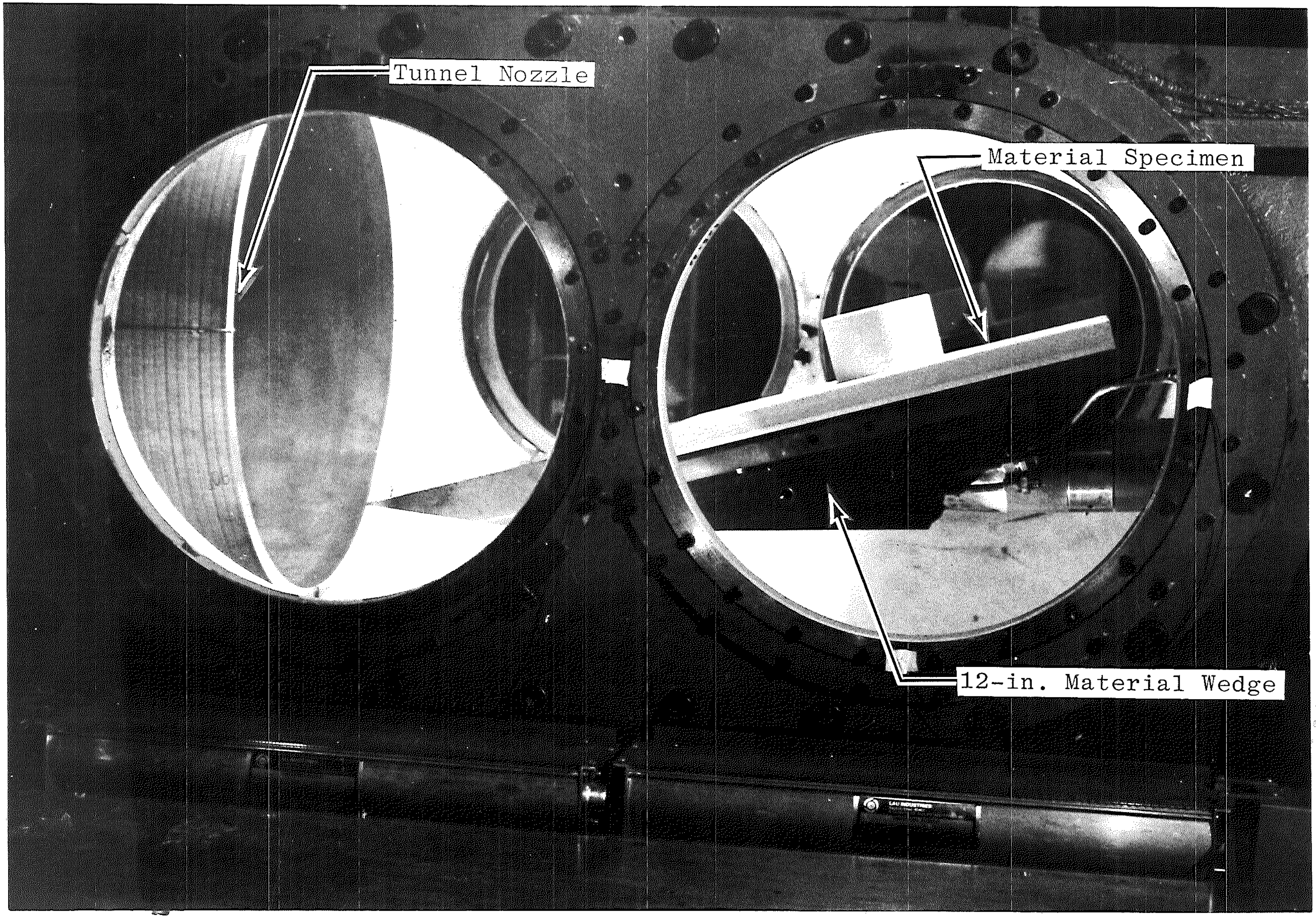
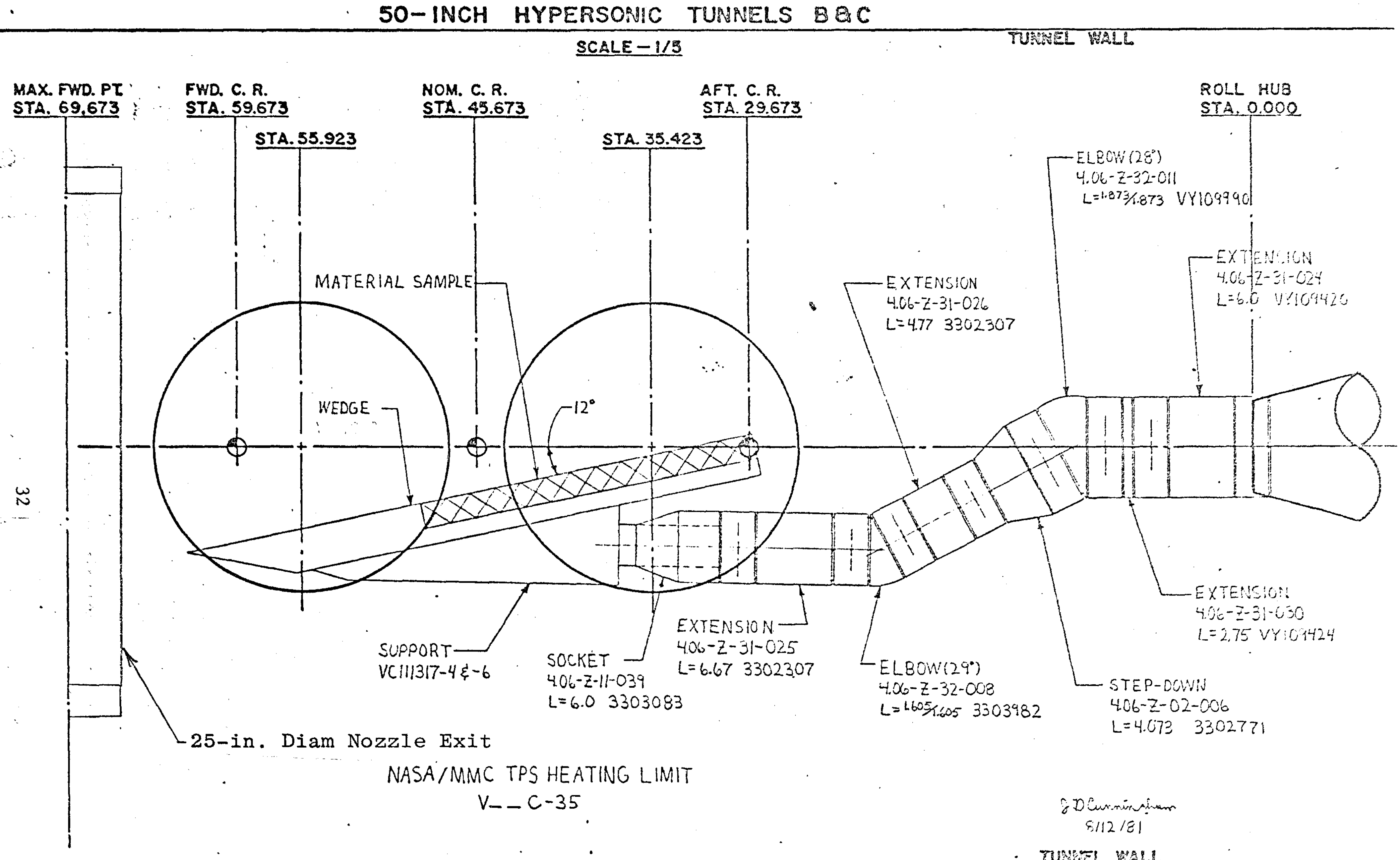


Figure 7. Model Installation



a. Installation Photograph

Figure 8. Installation in Tunnel C Mach 4



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b. Installation Sketch for Mach 4 Entry
Figure 8. Continued

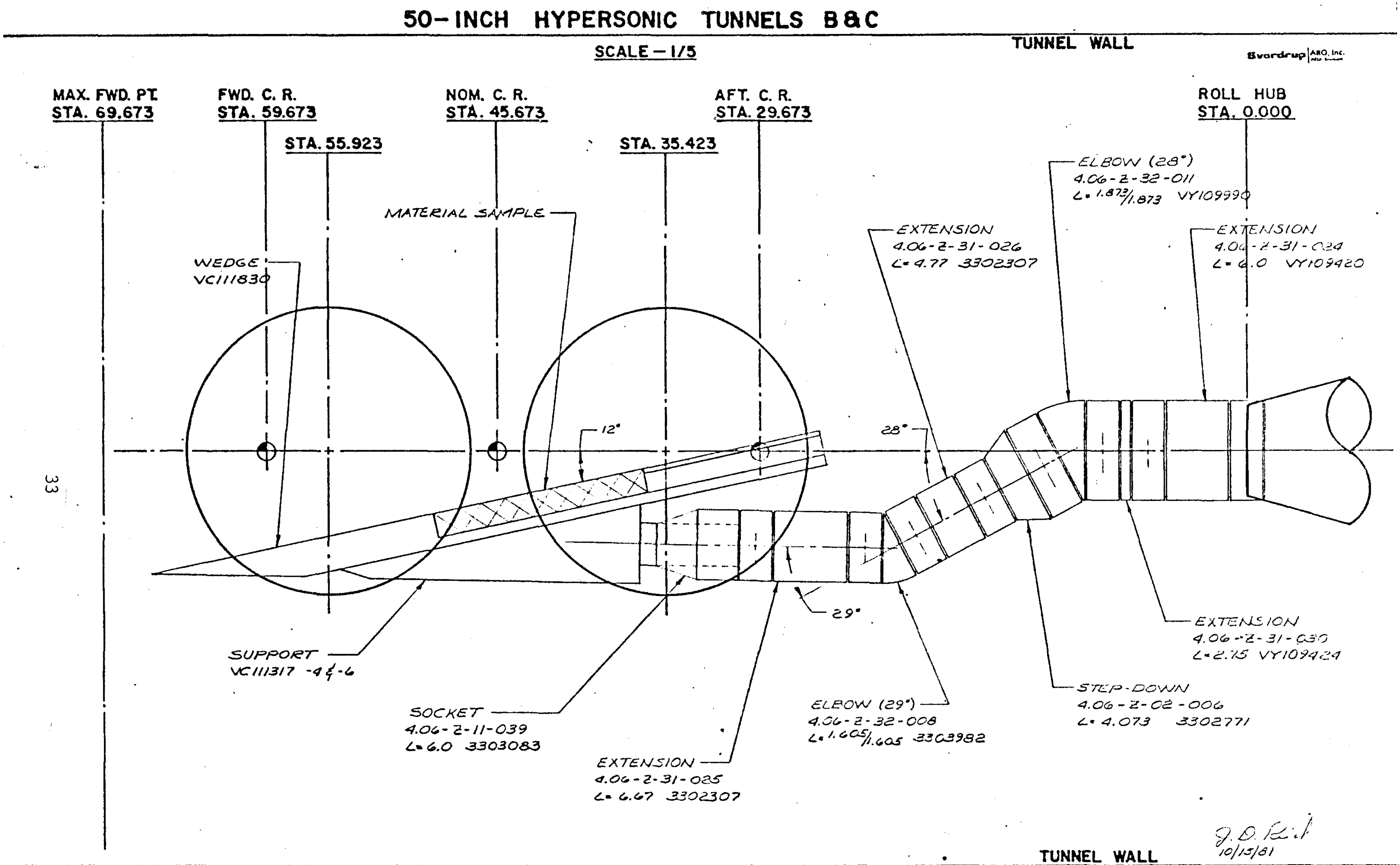

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Figure 9. Installation Sketch for Mach 10 Entry

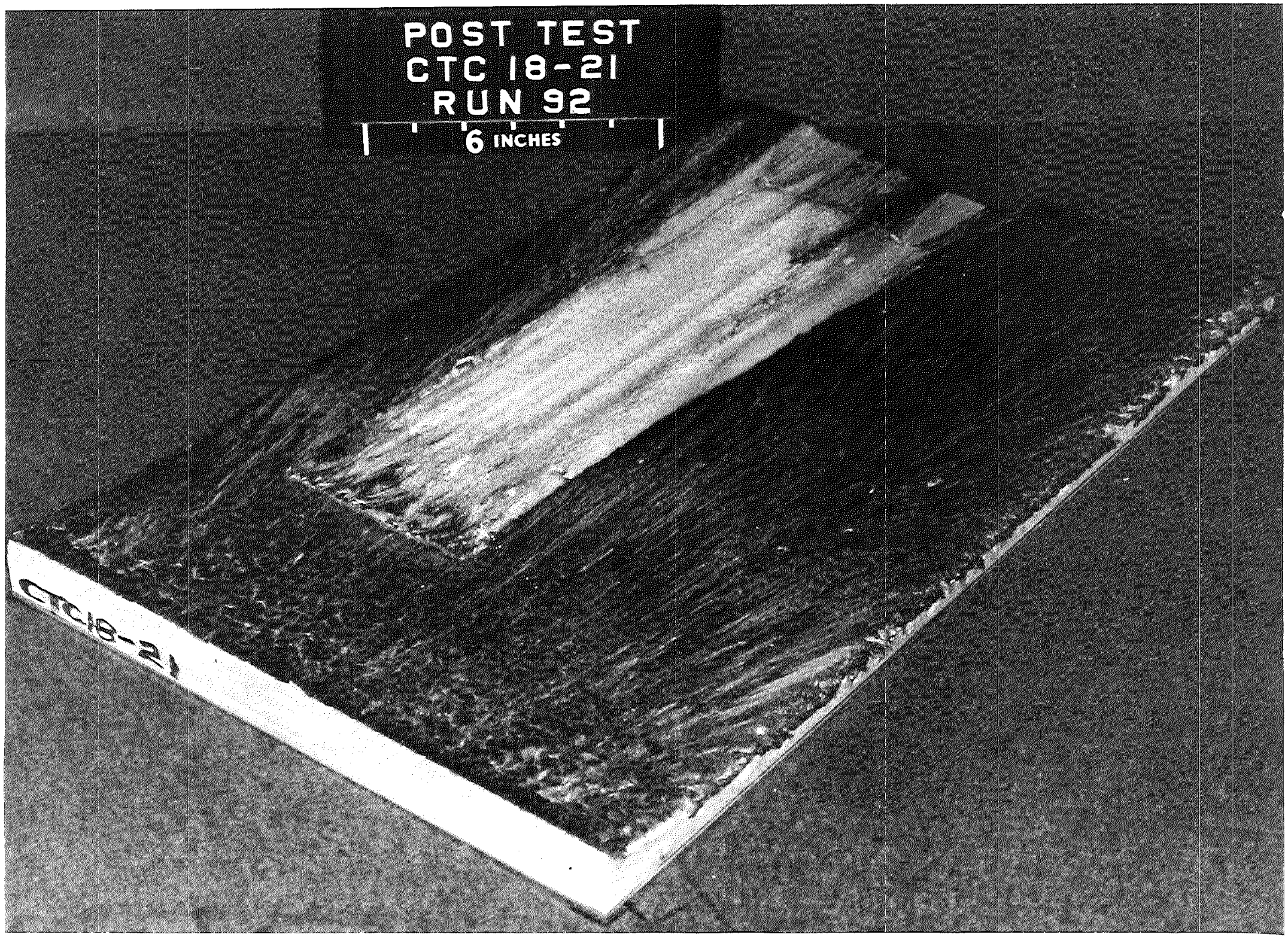
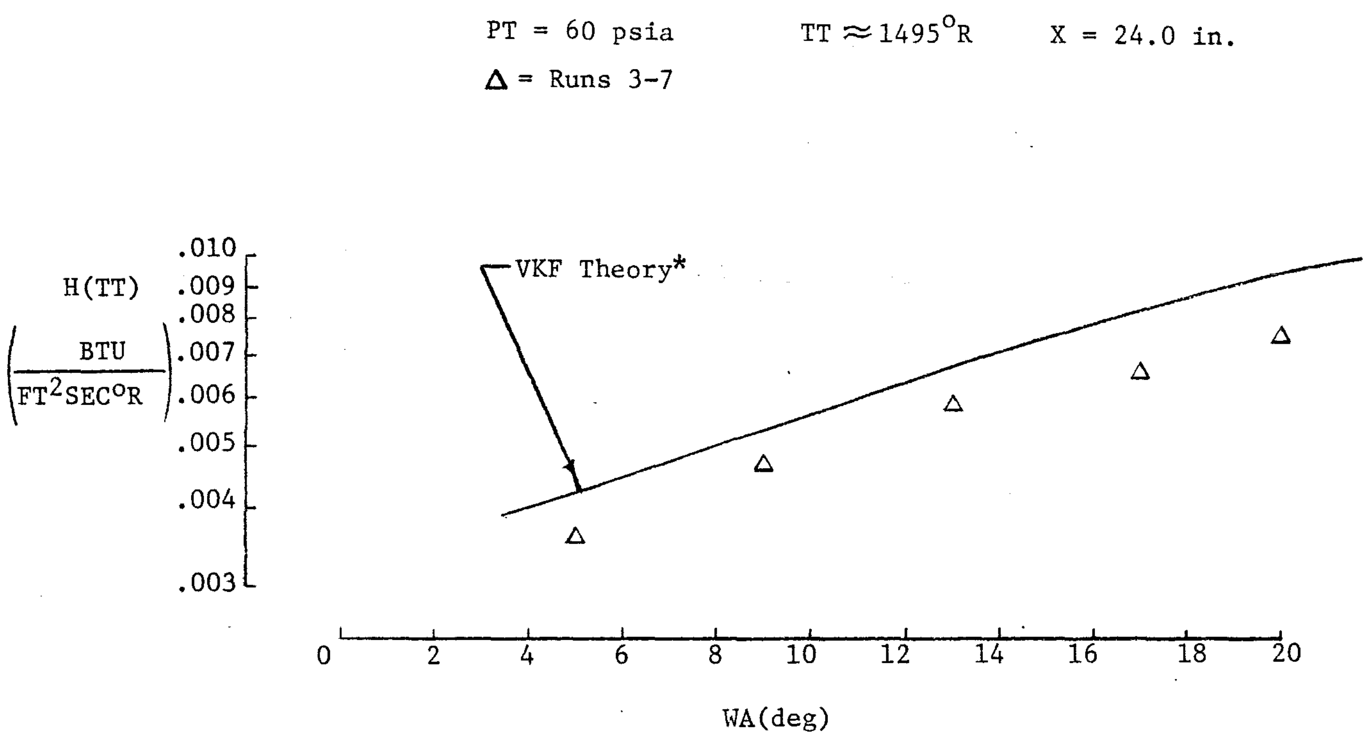


Figure 10. Typical Posttest Picture



* Theory based on Eckert reference method assuming oblique shock.

Figure 11. Comparison of Tunnel Data with Analytical Calculations

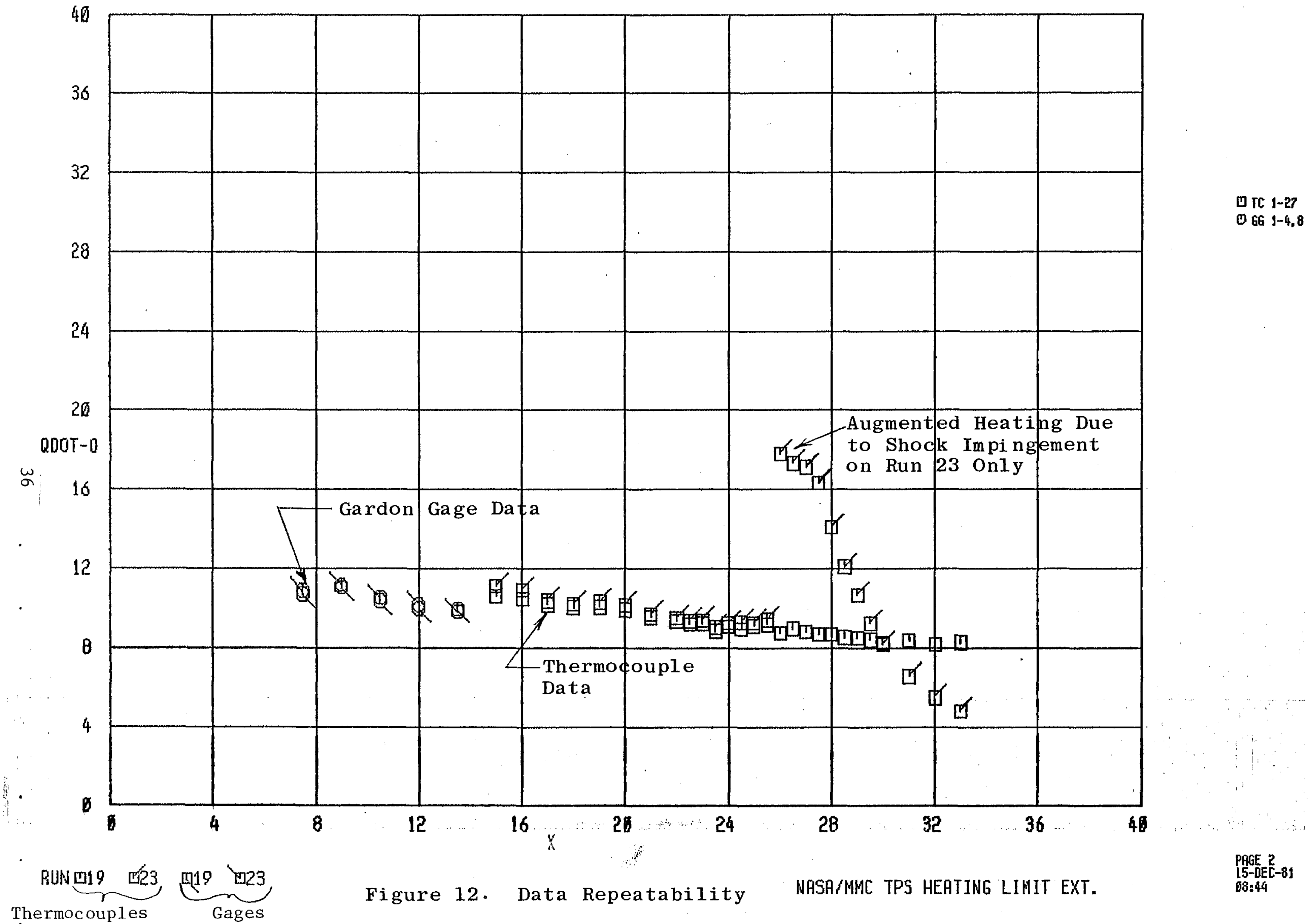


Figure 12. Data Repeatability

NASA/MMC TPS HEATING LIMIT EXT.

APPENDIX B.

TABLES

TABLE 1. Data Transmittal Summary

The following items were transmitted to the User and Sponsor:

	User	Sponsor
	Mr. Steve Copsey Martin-Marietta Michoud Operations P.O. Box 29340 New Orleans, LA 70189	Mr. Lee Foster ED/33 MSFC Marshall Space Flight Center Huntsville, AL 35812
Item	No. of Copies	No. of Copies
Final Data Package Vols. 1, 2 and 3 of 3	3	2
Installation Photos Nos. 7760-7764,1846	2 each 8x10 prints	1 each 8x10 prints
Specimen Pretest Photos Nos. 1A,1B,2	1 each 8x10 prints	1 each 8x10 prints
Specimen Posttest Photos Nos. Runs 1A 38-44,56-97 1B 98-100 2 56-63 3 63-97	1 each 8x10 prints	1 each 8x10 prints
70-mm Sequence Nos. Runs 23 38-44 32 38-44 29 56-71 30 56-71 35 72-90 33 72-90 42 92-97 76 92-97 42B 98-100 76B 98-100	1 contact print 1 duplicate negative	1 contact print
70-mm Shadowgraph Stills Nos. Runs 24 1-44 26 1-44 10 56-97 16 56-97 614 98-100	1 contact print 1 duplicate negative	1 contact print
16-mm Direct Movie ID Nos. Runs 4428 38-44 4429 38-44 4554 56-69 4556 56-69 4555 70-79	1 work print	1 work print

TABLE 1. Concluded

Item		No. of Copies	No. of Copies
ID Nos.	Runs		
4557	70-79	1 work print	1 work print
4452	80-90		
4546	80-90		
4450	92-97		
4451	92-97		
4581	98-100		
16-mm High Speed Shadowgraph Movies		1 work print	1 work print
ID Nos.	Runs		
4434	48		
4435	48		
4436	50		
4437	50		
4438	52		
4439	52		
4440	53		
4441	53		
4442	55		
4443	55		
4444	58		
4445	58		
4446	60		
4447	60		
4448	61		
4449	61		

TABLE 2. Material Summary

Sample No.	RUN NO.	Panel Mat'l	Protub. No.	Protub. Mat'l	Patch Mat'l	Plug Mat'l	Plug Depth	Deicing Mat'l	Fig. No.
CTC18-01	65	CPR-488	–	–	PDL-4034	PDL-4034	0.50	–	4d
02	96	↓	–	–	PDL-4034	–	–	–	4c
03	42	↓	–	–	PDL-4034	PDL-4034	0.25	–	4d
04	43	↓	–	–	PDL-4034	–	–	–	4c
05	82	↓	–	–	PDL-4034	PDL-4034	0.75	–	4d
06	73	↓	–	–	PDL-4034	–	–	–	4c
07	80	↓	–	–	↓	–	–	–	4c
08	95	↓	–	–	↓	–	–	–	4c
09	88	↓	–	–	↓	–	–	–	4c
10	89	↓	–	–	↓	–	–	–	4c
11	68	↓	–	–	↓	–	–	–	4c
12	84	↓	–	–	↓	–	–	–	4c
13	38	↓	–	–	↓	–	–	–	4c
14	56	↓	–	–	↓	–	–	–	4c
15	39	↓	–	–	PDL-4034	–	–	–	4c
16	93	↓	–	–	↓	–	–	–	4c
17	81	↓	–	–	↓	–	–	–	4c
18	72	↓	–	–	↓	–	–	–	4c
19	83	↓	–	–	↓	–	–	–	4c
20	44	↓	–	–	PDL-4034	–	–	–	4c
21	92	↓	–	–	↓	–	–	–	4c
22	87	↓	–	–	↓	–	–	–	4c
23	85	↓	–	–	↓	–	–	–	4c
24	90	↓	–	–	↓	–	–	–	4c
25	67	↓	–	–	↓	–	–	–	4c
26	71	↓	–	–	↓	–	–	–	4c
27	94	↓	–	–	PDL-4034	–	–	–	4c
28	69	↓	–	–	↓	–	–	–	4c
29	74	↓	–	–	↓	–	–	–	4c
30	86	↓	–	–	↓	–	–	–	4c
31	97	↓	–	–	↓	–	–	–	4c
32	57	↓	–	–	↓	–	–	–	4c
33	41	↓	–	–	BX-250	–	–	–	4c
34	40	↓	–	–	BX-250	–	–	–	4c

TABLE 2. Concluded

Sample No.	RUN NO.	Panel Mat'l	Protub. No.	Protub. Mat'l	Patch Mat'l	Plug Mat'l	Plug Depth	Deicing Mat'l	Fig. No.
CTC18-37	66	PDL-4034	–	–	–	–	–	–	4a
38	70	PDL-4034	–	–	–	–	–	–	4a
39	75	PDL-4034	–	–	–	–	–	–	4a
49	63	CPR-488	SN-22	CPR-488	–	–	–	–	4b
53	58	CPR-488	SN-19	SLA-561	–	–	–	–	4b
54	59	CPR-488	SN-20	SLA-561	–	–	–	–	4b
55	60	CPR-488	SN-16	CPR-488	–	–	–	–	4b
56	61	PDL-4034	SN-21	CPR-488	–	–	–	–	4b
57	62	PDL-4034	SN-14	CPR-488	–	–	–	–	4b
77	77	NCF1-2513	–	–	–	–	–	–	4a
80	76	TU-2008	–	–	–	–	–	–	4a
81	78	CPR-402	–	–	–	–	–	–	4a
82	79	2PCF Foam w/ D3 Top coat	–	–	–	–	–	–	4e
117-1	99	SLA561	– –	– –	– –	–	–	Ethylene Glycol + Water	5
117-2	98, 100	SLA561	–	–	–	–	–	DMSO + Water	5

TABLE 3. ESTIMATED UNCERTAINTIES

a. Basic Measurements

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT* Precision Index (S) Percent of Reading	Precision Index (S) Unit of Measurement	Precision Index (S) Degree of Freedom	Bias (B) Percent of Reading	Bias (B) Unit of Measurement	Uncertainty ±(B + t_{95}S) Percent of Reading	Uncertainty ±(B + t_{95}S) Unit of Measurement	Range	Type of Measuring Device	Type of Recording Device	Method of System Calibration
STILLING CHAMBER, PRESSURE, PT, psia		0.002 0.002 0.007 0.62 0.62	>30 >30 >30 >30 >30	0.16	0.011 0.8	0.015 (0.2% + 0.004) (0.2% + 0.014) (0.8psi+ 1.24psi) 2.04 (0.15% + 1.24psi)		<5.5 <15 <60 >156.2% < 500 >500 < 2500	Bell & Howell force balance pressure transducer Wiancko variable reluctance pressure transducer	Digital data acquisition system analog-to-digital converter	In-place application of multiple pressure levels measured with a pressure measuring device calibrated in the standards laboratory
TOTAL TEMPERATURE, TT, °F		1 1	>30 >30	0.375	2		4 ±(.375% +2°F)	32 to 530 530 to 2300	Chromel®-Alumel® thermocouple	Doric temperature instrument digital multiplexer	Thermocouple verification of NBS conformity/voltage substitution calibration
PITCH ANGLE, ALPHI		0.025	>30				0.05	15	Potentiometer		Heidenhain rotary encoder ROD700 Resolution: 0.0006° Overall accuracy: 0.001°
TIME		$5x10^{-4}$	>30	Runtime(sec)x5x 10^{-6}		Runtime(sec)x5x 10^{-6})+10^{-3}		ms to 365 days	Systron Donner time code generator	Digital data acquisition system	Instrument lab calibration against Bureau of Standards
HEAT TRANSFER, QDOT, BTU/ft²-sec	1.5	0.015	>30 >30	2 2		(0.03 + 2%) 5%		<1 1 to 10	Gardon gage	Digital data acquisition system analog-to-digital converter	Radiant heat source and secondary standard
E_{mv}	0.1		>30	0.01		(0.2% + 0.01)		10 TO 20	DEC-10/Multiverter Preston amplifier		Millivolt standard, referenced to lab standard
TEMPERATURE, TGE, °F		1 1	>30 >30	3/8%	2	4 (3/8% + 2°F)		32 to 530 530 to 2300	CrAl thermocouple		

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

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TABLE 3. Concluded

b. Calculated Parameters

Parameter Designation	STEADY-STATE ESTIMATED MEASUREMENT*							Range
	Precision Index (S)			Bias (B)		Uncertainty $\pm(B + t_{95}S)$		
	Percent of Reading	Unit of Measurement	Degree of Freedom	Percent of Reading	Unit of Measurement	Percent of Reading	Unit of Measurement	
H(TT), BTU/ft^2-sec-^oR GARDON GAGE	2.0		>30	2.0		6.0		10^{-1} TO 10^{-4}
M		0.008 0.007 0.006 0.004	>30 >30 >30 >30		0+ 0+ 0+ 0+		0.016 0.014 0.012 0.008	2.0 10.02 10.05 10.11
QDOT-0, BTU/ft^2-sec GARDON GAGE	2.0		>30	2.0		6.0		0 TO 100
TW, ^oR	0.2		>30	0.4		0.8		All
WA, deg		0.05	>30		0+		0.10	All
RE ft^{-1}	0.70 0.36		>30 >30	0.56 0.45		1.96 1.17		$0.5x10^6 ft^{-1}$ $3.7x10^6 ft^{-1}$
H(TT), BTU/ft^2-sec-^oR Thin Skin Thermocouple	1.0 4.0 7.0		>30 >30 >30	6.0 6.0 6.0		8.0 14.0 20.0		$1x10^{-3}$ $1x10^{-4}$ → $1x10^{-3}$ $< 1x10^{-4}$

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

TABLE 4. Photographic Data Summary

	Camera Type	Frame Rate	Camera Location	Sample View	Film Roll No.	RUN No.
Shadowgraph Camera 1	Varitron 70 mm Shadowgraph still	1 per 15 sec	Operating side upstream window	left side view of forward portion of sample on ℄	0024 0010	1-44 56-97
Shadowgraph Camera 2	Varitron 70 mm Shadowgraph still	1 per 15 sec	Operating side downstream window	left side view of sample and wedge on centerline	0026 0016 614	1-44 56-97 98-100
Camera 1	Varitron 70 mm still	1 per 2 sec	Top upstream window	top view of sample on center-line with projected grid lines	0023 0029 0033 0042A 0042B	38-44 56-71 72-90 92-97 98-100
Camera 2	DBM-SS 16mm motion pictures	24 frames per sec	Top upstream window		4428 4554 4555 4452 4450	38-44 56-69 70-78 80-90 92-97
Camera 3	Varitron 70 mm still	1 per 2 sec	Operating side upstream window	left side view of forward portion of sample on ℄	0032 0030 0035 0076A 0076B	38-44 56-71 72-90 92-97 98-100
Camera 4	DBM-SS 16 mm movie	24 frames per sec	Operating side upstream window		4429 4556 4557 4546 4451 4581	38-44 56-69 70-78 80-90 92-97 98-100
Shadowgraph Camera 5	Hycam 16 mm shadowgraph movies	1000 frames per sec	Operating side upstream window		4434 4436 4438 4440 4442 4444 4446 4448	48 50 52 53 54 55 56 57
Shadowgraph Camera 6	Hycam 16 mm shadowgraph movies	1000 frames per sec	Operating side downstream window	left side view of sample and wedge on centerline	4435 4437 4439 4441 4443 4445 4447 4449	48 50 52 53 55 58 60 61

TABLE 5. Instrumentation Locations

a. Gardon Gages, Entry 1, the 12-in. Wedge

Gardon Gage No.	X, In.	Y, In.
1	7.5	0
2	9.0	0
3	10.5	0
4	12.0	0
5	13.5	4.5
6	13.5	3.1
7	13.5	1.75
8	13.5	0
9	13.5	-1.75
10	13.5	-3.1
11	13.5	-4.5

b. Gardon Gages Entry 2, the 15-in. Wedge

Gardon Gage No.	X, In.	Y, In.
1	5.81	0
2	9.13	0
3	12.04	0
4	14.94	0
5	17.02	4.50
6	17.02	2.25
7	17.02	0
8	17.02	− 2.25
9	17.02	− 4.50

TABLE 5. Continued

c. Flat Plate Calibration Model Thermocouple

TC/No.	X, in.	Y, in.	Skin Thickness, in.
1	15	0	0.062
2	16	↓	↓
3	17		
4	18		
5	19		
6	20		
7	21		
8	22		
9	22.5		
10	23.0		
11	23.5		
12	24		
13	24.5		
14	25		
15	25.5		
16	26		
17	26.5		
18	27		
19	27.5		
20	28		
21	28.5		
22	29		
23	29.5		
24	30		
25	31		
26	32		
27	33		
28	9.2	-2	
29	10.2	↓	
30	11.2		
31	12.2		
32	13.2		
33	14.2		
34	15.2		
35	16.2		
36	17.2		
37	18.2		
38	9.7	-4.2	0.063
39	10.7	↓	↓
40	11.7		
41	12.7		
42	13.7		
43	14.7		
44	15.7		
45	16.7		
46	17.7		
47	18.7		

TABLE 5. Concluded

d. Protuberance Calibration Model Thermocouples

TC/No.	X, in.	Y, in.	Z, in.	Theta, deg	Skin Thickness, in.	X_1, in.
1	14.8	0	0	0	0.054	-6.70
2	15.41	↓	↓	↓	↓	-6.09
3	16.03	↓	↓	↓	↓	-5.47
4	16.64	↓	↓	↓	↓	-4.86
5	17.043	↓	↓	↓	↓	-4.457
6	17.445	↓	↓	↓	↓	-4.055
7	17.848	↓	↓	↓	↓	-3.652
8	18.250	↓	↓	↓	↓	-3.250
9	18.653	↓	↓	↓	↓	-2.847
10	19.055	↓	↓	↓	↓	-2.445
11	19.458	↓	↓	↓	↓	-2.042
12	19.860	↓	↓	↓	↓	-1.640
13	20.263	↓	↓	↓	↓	-1.237
14	20.665	↓	↓	↓	↓	-0.835
15	21.068	↓	↓	↓	↓	-0.432
16	21.470	↓	↓	↓	↓	-0.030
17	19.162	-5.162	↓	45	0.054	–
18	19.582	-4.742	↓	↓	↓	–
19	20.002	-4.322	↓	↓	↓	–
20	20.421	-3.902	↓	↓	↓	–
21	20.841	-3.483	↓	↓	↓	–
22	21.261	-3.063	↓	↓	↓	–
23	21.681	-2.643	↓	↓	↓	–
24	22.101	-2.223	↓	↓	↓	–
25	22.521	-1.803	↓	↓	↓	–
26	24.0	-4.30	↓	90	0.047	–
27	24.0	-3.95	↓	↓	↓	
28	24.0	-3.60	↓	↓	↓	
29	24.0	-3.25	↓	↓	↓	
30	24.0	-2.90	↓	↓	↓	
31	24.0	-2.55	↓	↓	↓	
32	21.5	0	2.664	0	0.050	2.664
33	21.5	↓	2.331	↓	↓	2.664
34	21.5	↓	1.998	↓	↓	1.998
35	21.5	↓	1.665	↓	↓	1.665
36	21.5	↓	1.332	↓	↓	1.332
37	21.5	↓	0.999	↓	↓	0.999
38	21.5	↓	0.666	↓	↓	0.666
39	21.5	↓	0.333	↓	↓	0.333
40	22.232	-1.768	2.625	45	↓	–
41	22.232	↓	2.250	↓	↓	–
42	22.232	↓	1.875	↓	↓	–
43	22.232	↓	1.50	↓	↓	–
44	22.232	↓	1.125	↓	↓	–
45	22.232	↓	0.750	↓	↓	–
46	22.232	↓	0.375	↓	↓	–
47	24.0	-2.50	2.50	90	↓	–
48	24.0	↓	2.00	↓	↓	–
49	24.0	↓	1.50	↓	↓	–
50	24.0	↓	1.00	↓	↓	–
51	24.0	↓	0.50	↓	↓	–

TABLE 6. Run Summary

Tunnel C Entry One M = 4

RUN	PLATE NUMBER	PROTUB. NUMBER	PT, psia	TT, °R	WEDGE ANGLE, deg	SHOCK WEDGE ANGLE, deg	TIME EXPT, sec
2	clean cal.	-	59.67	1487.7	0.92	-	2.51
3	clean cal.	-	59.56	1492.7	4.98	-	2.56
4		-	59.63	1495.7	9.01	-	2.53
5		-	59.63	1506.7	13.05	-	2.53
6		-	59.48	1516.7	17.10	-	2.53
7		-	59.10	1514.7	20.11	-	2.53
8	shock cal.	-	59.78	1521.7	17.12	5	5.30
9		-	59.60	1521.7	9.03	5	3.35
10		-	59.48	1515.7	0.92	5	3.51
11		-	59.19	1515.7	0.89	10	3.41
12		-	59.36	1521.7	9.03	10	3.41
13		-	59.27	1513.7	17.10	10	3.43
14		-	59.22	1514.7	17.12	15	3.41
15		-	59.54	1521.7	9.02	15	3.46
16		-	59.81	1522.7	0.88	15	3.41
17	clean cal.	-	118.31	1510.7	0.84	-	3.44
18		-	119.56	1528.7	4.99	-	3.41
19		-	119.65	1553.7	9.07	-	3.41
20		-	119.50	1559.7	13.09	-	3.40
21		-	119.40	1556.7	17.18	-	3.37
22	shock cal.	-	118.94	1558.7	17.21	5	3.40
23	shock cal.	-	118.83	1558.7	9.05	5	3.43
24	shock cal.	-	118.90	1558.7	0.83	5	3.49
25	clean cal.	-	158.34	1541.7	17.23	-	3.40
26		-	158.62	1556.7	13.15	-	3.43
27		-	158.75	1560.7	9.06	-	3.43
28		-	158.32	1561.7	4.96	-	3.46
29		-	158.77	1561.7	0.75	-	3.58
30		-	178.78	1552.7	17.24	-	3.46
31		-	179.15	1554.7	13.16	-	3.40
32		-	178.90	1558.7	9.08	-	3.41
33		-	178.91	1562.7	4.93	-	3.49
34		-	179.04	1562.7	0.72	-	3.61
35	shock cal.	-	29.64	1501.7	0.95	5	3.44
36		-	29.06	1502.7	9.02	5	3.46
37		-	29.17	1501.7	17.09	5	3.43
38	CTC18-13	-	59.25	1496.7	9.09	--	49.98
39	-15	-	59.29	1504.7	20.15	-	30.66
40	-34	-	59.15	1511.7	20.16	-	31.23
41	-33	-	59.26	1513.7	20.09	-	31.24
42	-03	-	59.31	1514.7	11.08	5.0	31.04
43	-04	-	59.49	1513.7	1.00	5.0	31.64
44	-20	-	60.0	1500	9.07	10.0	21.23
45	protub.cal	calib.	59.16	1506.7	0.95	-	3.46

TABLE 6. Continued

RUN	PLATE NUMBER	PROTUB. NUMBER	PT, psia	TT, °R	WEDGE ANGLE, deg	SHOCK WEDGE ANGLE, deg	TIME EXPT, sec
46	protub.	calib.	59.04	1512.7	4.99	-	3.64
47			59.02	1517.7	9.05	-	3.46
48			59.23	1521.7	13.09	-	3.58
49			59.07	1526.7	17.15	-	3.64
50			29.09	1513.7	0.94	-	3.59
51			29.98	1510.7	5.02	-	3.58
52			29.68	1513.7	9.05	-	3.61
53			29.80	1516.7	13.08	-	3.61
54			29.39	1517.7	17.11	-	3.60
55			29.48	1515.7	20.11	-	3.65
56	CTC18-14	-	29.65	1507.7	0.93	5.0	61.99
57	-32	-	29.60	1503.7	0.92	5.0	61.59
58	-53	SN-19	29.34	1499.7	0.96	-	12,26
59	-54	SN-20	29.64	1495.7	13.05	-	8.36
60	-55	SN-16	29.39	1492.7	0.98	-	10.18
61	-56	SN-21	29.47	1490.7	0.97	-	6.37
62	-57	SN-14	29.36	1487,7	0.97	-	3.83
63	-49	SN-22	29.38	1487.7	0.91	-	12.08
65	-01	-	59.34	1499.7	20.16	-	46.44
66	-37	-	59.11	1502.7	20.15	-	46.32
67	-25	-	59.45	1511.7	20.15	-	46.72
68	-11	-	59.36	1524.7	0.93	5.0	46.37
69	-28	-	59.17	1533.7	0.92	5.0	46.67
70	-38	-	59.17	1538.7	0.92	5.0	46.38
71	-26	-	59.23	1544.7	0.91	5.0	46.62
72	-18	-	59.22	1547.7	17.14	5.0	31.46
73	-06	-	59.08	1549.7	17.14	5.0	31.69
74	-29	-	59.31	1552.7	17.15	5.0	21.49
75	-39	-	59.02	1553.7	17.14	5.0	21.50
76	-80	-	59.15	1554.7	20.14	-	62.21
77	-77	-	59.32	1554.7	20.14	-	54.97
78	-81	-	59.27	1554.7	20.14	-	39.01
79	-82	-	59.30	1551.7	20.15	-	3.92
80	-07	-	119.28	1546.7	7.54	-	46.61
81	-17	-	118.89	1562.7	15.17	-	31.38
82	-05	-	118.97	1572.7	15.17	-	31.38
83	-19	-	118.83	1572.7	17.20	-	31.59
84	-12	-	118.79	1571.7	9.12	5.0	21.95
85	-23	-	118.75	1577.7	9.12	5.0	21.35
86	-30	-	118.93	1583.7	9.12	5.0	16.71
87	-22	-	118.86	1586.7	17.21	5.0	16.26
88	-09	-	118.95	1586.7	17.21	5.0	20.42
89	-10	-	119.11	1585.7	17.21	5.0	13.77
90	-24	-	118.91	1581.7	17.19	-	26.28
92	-21	-	158.90	1590.7	17.25	-	21.58

TABLE 6. Concluded

RUN	PLATE NUMBER	PROTUB. NUMBER	PT, psia	TT, °R	WEDGE ANGLE, deg	SHOCK WEDGE ANGLE, deg	TIME EXPT, sec
94	CTC18-27	-	158.66	1603.7	17.25	-	21.36
95	-08	-	158.80	1607.7	17.24	-	21.27
96	-02	-	158.47	1609.7	17.24	-	31.78
97	-31	-	158.67	1609.7	17.24	-	16.56
Tunnel C Entry Two M = 10							
98	117-2	-	1748.57	1896.7	24.18	-	30.60
99	117-1	-	1750.83	1898.7	24.17	-	92.82
100	117-2	-	1750.38	1900.7	24.18	-	62.13

RUNS 1, 64, and 91 were system calibration and have been deleted from the final data package.

APPENDIX C.

SAMPLE TABULATED AND PLOTTED DATA

RUN	SAMPLE	PROTUB.	ALPHI DEG	WA DEG	CR IN	TIMEINJ SEC	TIMECL HOUR	MIN	SEC	MSEC	TIMEEXPT SEC
22	SHOCK CAL	NONE	-5.21	17.21	25.00	2.416	4	32	37	941	3.40

M	PT PSIA	TT DEG R	T DEG R	P PSIA	Q PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	ITT BTU/LBM
4.00	118.94	1558.7	382.2	7.606E-01	8.52	3833.8	5.371E-03	2.921E-07	2.191E+06	3.860E+02

WEDGE GARDON GAGE DATA

GAGE	X	Y	TGE (DEG R)	TW (DEG R)	QDOT (BTU/FT2-SEC)	H(TT) (BTU/FT2-SEC-R)	QDOT-O (BTU/FT2-SEC)
1	7.50	0.00	569.6	635.0	13.37	1.447E-02	1.591E+01
2	9.00	0.00	567.5	634.2	14.13	1.529E-02	1.680E+01
3	10.50	0.00	563.1	625.2	13.27	1.422E-02	1.563E+01
4	12.00	0.00	561.7	617.9	13.14	1.396E-02	1.535E+01
5	13.50	4.50	558.7	622.9	12.65	1.352E-02	1.486E+01
6	13.50	3.10	562.6	622.4	11.49	1.228E-02	1.349E+01
7	13.50	1.75	559.5	637.2	13.34	1.448E-02	1.592E+01
8	13.50	0.00	561.3	617.8	13.37	1.421E-02	1.562E+01
9	13.50	-1.75	560.9	609.7	12.21	1.287E-02	1.415E+01
10	13.50	-3.10	558.8	637.6	12.11	1.315E-02	1.445E+01
11	13.50	-4.50	560.7	610.5	11.14	1.175E-02	1.291E+01

a. Gardon Gage Data

Sample 1. Heat-Transfer Data

RUN 22

ARVIN/CALSPAN FIELD SERVICES, INC.
AEDC DIVIS.
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/MMC HEATING LIMIT EXT.

DATE COMPUTED [illegible]-DEC-81
TIME COMPUTED [illegible]2:09:25
DATE RECORDED 9-OCT-81
TIME RECORDED 1:57:54
PROJECT NUMBER V C 35

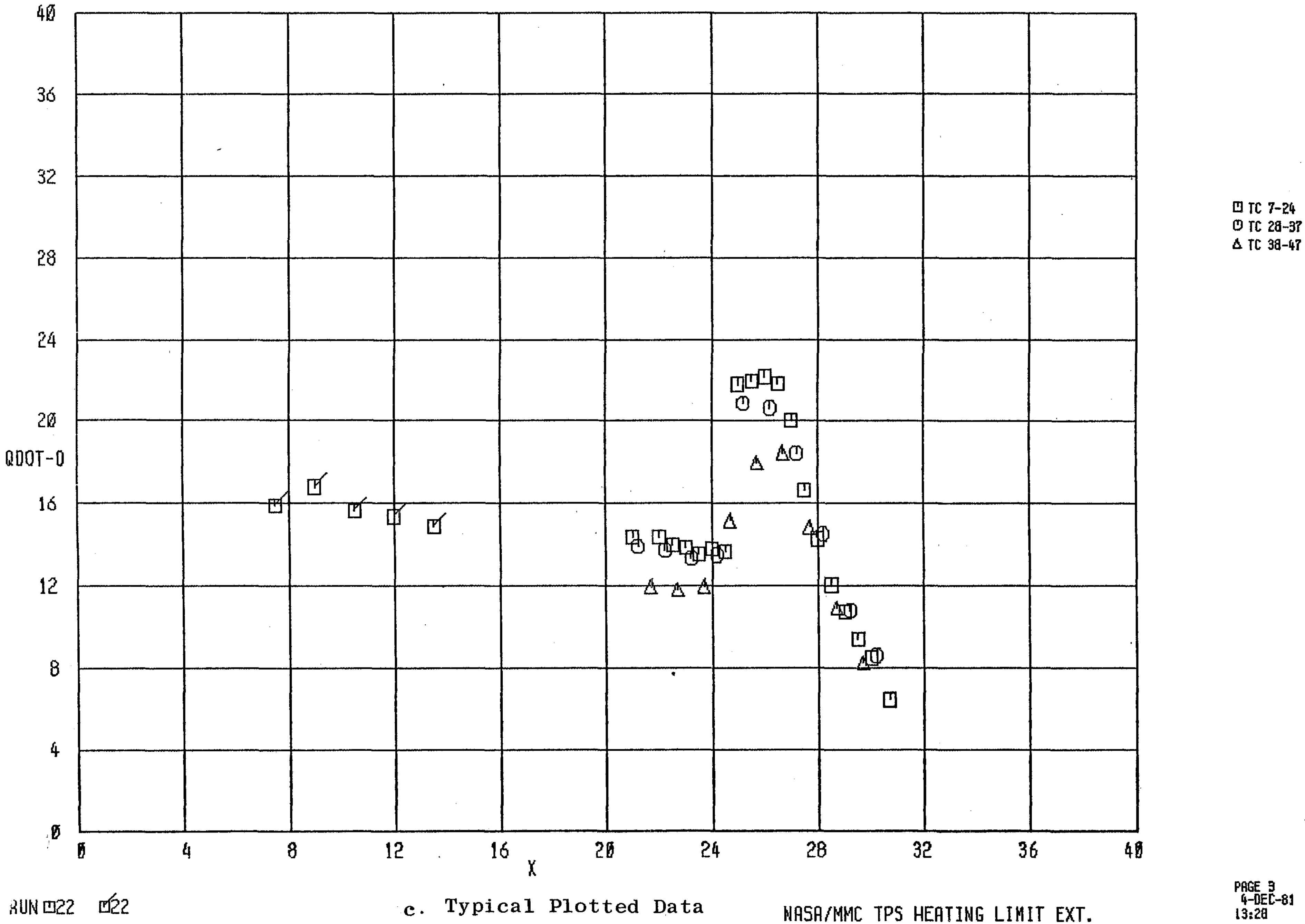
RUN	SAMPLE	PROTUB	ALPHI DEG	WA DEG	CR IN
48	PROTUB CAL.M	CAL.	-1.09	13.09	25.00

M	PT PSIA	TT DEG R	T DEG R	P PSIA	Q PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	ITT BTU/LBM
4.00	59.22	1523.7	373.0	3.790E-01	4.24	3786.9	2.743E-03	2.861E-07	1.129E+06	3.768E+02

TC/No.	X	Y	Z	THETA	TW (DEG R)	QDOT (BTU/FT2-SEC)	H(TT) (BTU/FT2-SEC-R)	QDOT-0 (BTU/FT2-SEC)	THICK
1	14.800	0.000	0.000	0.	570.8	6.7128	7.045E-03	7.4935	0.054
2	15.410	0.000	0.000	0.	566.4	4.1340	4.318E-03	4.5934	0.054
3	16.030	0.000	0.000	0.	562.4	2.3511	2.446E-03	2.6015	0.054
4	16.640	0.000	0.000	0.	539.1	1.1276	1.145E-03	1.2181	0.054
5	17.043	0.000	0.000	0.	539.0	1.1574	1.175E-03	1.2502	0.054
6	17.445	0.000	0.000	0.	594.2	13.1300	1.413E-02	15.0254	0.054
7	17.848	0.000	0.000	0.	596.1	13.6739	1.474E-02	15.6794	0.054
8	18.250	0.000	0.000	0.	597.7	13.6648	1.476E-02	15.6971	0.054
9	18.653	0.000	0.000	0.	598.3	13.2559	1.433E-02	15.2371	0.054
10	19.055	0.000	0.000	0.	599.7	13.3467	1.444E-02	15.3642	0.054
11	19.458	0.000	0.000	0.	602.2	14.5914	1.583E-02	16.8426	0.054
12	19.860	0.000	0.000	0.	595.2	10.9801	1.183E-02	12.5789	0.054
13	20.263	0.000	0.000	0.	594.0	9.1350	9.826E-03	10.4520	0.054
14	20.665	0.000	0.000	0.	621.2	19.6969	2.183E-02	23.2151	0.054
15	21.068	0.000	0.000	0.	698.9	49.9155	6.052E-02	64.3727	0.054
16	21.470	0.000	0.000	0.	633.6	26.2240	2.946E-02	31.3389	0.054
17	19.162	-5.162	0.000	45.	579.7	8.5206	9.026E-03	9.6009	0.054
18	19.582	-4.742	0.000	45.	583.7	9.8989	1.053E-02	11.2019	0.054
19	20.002	-4.322	0.000	45.	584.8	10.0772	1.073E-02	11.4167	0.054
20	20.421	-3.902	0.000	45.	586.7	10.1135	1.079E-02	11.4813	0.054
21	20.841	-3.483	0.000	45.	590.7	11.9432	1.290E-02	13.6162	0.054
22	21.261	-3.063	0.000	45.	582.8	7.9260	8.424E-03	8.9602	0.054
23	21.681	-2.643	0.000	45.	592.6	10.4628	1.124E-02	11.9527	0.054
24	22.101	-2.223	0.000	45.	658.9	35.7991	4.140E-02	44.0327	0.054
25	22.521	-1.803	0.000	45.	613.8	18.6937	2.055E-02	21.8543	0.054
26	24.000	-4.300	0.000	90.	591.0	11.9580	1.282E-02	13.6370	0.047
27	24.000	-3.950	0.000	90.	600.6	16.3135	1.767E-02	18.7974	0.047
28	24.000	-3.600	0.000	90.	612.5	20.0078	2.196E-02	23.3557	0.047
29	24.000	-3.250	0.000	90.	614.8	19.4167	2.136E-02	22.7227	0.047
30	24.000	-2.900	0.000	90.	595.8	12.5490	1.352E-02	14.3857	0.047
31	24.000	-2.550	0.000	90.	575.9	7.1201	7.512E-03	7.9905	0.047
32	21.565	0.000	2.664	0.	648.9	27.6016	3.155E-02	33.5619	0.050
33	21.565	0.000	2.331	0.	657.6	31.2624	3.610E-02	38.3972	0.050
34	21.565	0.000	1.998	0.	657.8	29.2389	3.377E-02	35.9191	0.050
35	21.565	0.000	1.665	0.	651.6	28.7897	3.301E-02	35.1160	0.050
36	21.565	0.000	1.332	0.	651.6	33.5485	3.847E-02	40.9174	0.050
37	21.565	0.000	0.999	0.	634.3	30.3980	3.418E-02	36.3572	0.050
38	21.565	0.000	0.666	0.	607.9	19.4954	2.129E-02	22.6433	0.050

b. Thin-Skin Thermocouple Data

Sample 1 Continued



c. Typical Plotted Data
Sample 1 Concluded

NASA/MMC TPS HEATING LIMIT EXT.

PAGE 3
4-DEC-81
13:28

ARVIN/CALSPAN FIELD SERVICES, INC.
AEDC DIVISION
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
NASA/MMC TPS HEATING LIMIT MATERIAL
PAGE 1

DATE COMPUTED 4-DEC-81
TIME COMPUTED 12:21:48
DATE RECORDED 9-OCT-81
TIME RECORDED 3:46:33
PROJECT NUMBER V--C-35

RUN	SAMPLE	PROTUB.	ALPHI DEG	WA DEG	CR IN	TIMEINJ SEC	TIMECL HOUR	MIN	SEC	MSEC	TIMEEXPT SEC
65	CTC18- 1	NONE	-8.16	20.16	25.00	3.173	3	46	52	152	46.44

M	PT PSIA	TT DEG R	T DEG R	P PSIA	Q PSIA	V FT/SEC	RHO LBM/FT3	MU LBF-SEC/FT2	RE FT-1	ITT BTU/LBM
4.00	59.34	1499.7	366.7	3.804E-01	4.26	3754.9	2.800E-03	2.820E-07	1.159E+06	3.704E+02

CAMERA	PIC NO.	TIME SEC	TIMEEXP SEC
TOP	1	0.20	MODEL HAS NOT REACHED CENTERLINE
OS	1	0.20	MODEL HAS NOT REACHED CENTERLINE
TOP	2	2.18	MODEL HAS NOT REACHED CENTERLINE
OS	2	2.18	MODEL HAS NOT REACHED CENTERLINE
TOP	3	4.24	2.45
OS	3	4.24	2.45
	SHADOWGRAPH TAKEN AT 4.4 SECONDS.		
TOP	4	6.30	4.52
OS	4	6.30	4.52
TOP	5	8.37	6.59
OS	5	8.37	6.59
TOP	6	10.45	8.67
OS	6	10.45	8.67
TOP	7	12.50	10.72
OS	7	12.51	10.73
TOP	8	14.58	12.80
OS	8	14.58	12.80
TOP	9	16.67	14.88
OS	9	16.67	14.88
TOP	10	18.75	16.97
OS	10	18.75	16.97
	SHADOWGRAPH TAKEN AT 19.7 SECONDS.		
TOP	11	20.82	19.04
OS	11	20.82	19.04
TOP	12	22.89	21.11
OS	12	22.89	21.11
TOP	13	24.98	23.20
OS	13	24.98	23.20
TOP	14	27.06	25.28
OS	14	27.07	25.29
TOP	15	29.14	27.36
OS	15	29.14	27.36
TOP	16	31.21	29.43
OS	16	31.22	29.44
TOP	17	33.30	31.51
OS	17	33.30	31.51
	SHADOWGRAPH TAKEN AT 35.0 SECONDS.		
TOP	18	35.36	33.58
OS	18	35.37	33.59
TOP	19	37.45	35.66
OS	19	37.45	35.66
TOP	20	39.50	37.72
OS	20	39.51	37.73

Sample 2. Photographic Data