NASA Contractor Report 159383



# Fabrication of Titanium Multi-Wall Thermal Protection System (TPS) Test Panel Arrays

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CONTRACT NAS1-15646
DEC 1980



National Aeronautics and
Space Administration

**Langley Research Center**
Hampton, Virginia 23665

# FOREWORD

This is an interim report on work being performed by Rohr Industries - Design and Fabrication of Titanium Multiwall Thermal Protection System (TPS).

This program is administrated by the National Aeronautics Administration Langley Research Center (NASA LaRC). Mr. John Shideler of the Aerothermal Loads Branch, Loads and Aeroelasticity Division, is Technical Monitor for the program.

The following Rohr personnel were the principle contributors to the program during this reporting period: Winn Blair, Program Manager; T. C. Atkinson, Manufacturing Technology; J. E. Meaney, Structures; R. M. Timms, Preliminary Design; and L. A. Wiech, Engineering Laboratory. Overall program responsibility is assigned to the Rohr Aerospace R&D Engineering Organization with U. Bockenhauer, Manager.

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TABLE OF CONTENTS

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## LIST OF FIGURES

## LIST OF FIGURES, Contd



## LIST OF TABLES

# SUMMARY

A titanium multiwall nine panel array was fabricated and delivered to NASA Langley Research Center for testing in the Eight-Foot High Temperature Structures Tunnel. A two-panel array was fabricated and delivered to NASA Langley Research Center for vibrational and acoustical tests. A second two-panel array was fabricated and delivered to NASA Johnson Space Center for radiant heating tests.

# INTRODUCTION

Rohr Industries was awarded a contract by the NASA Langley Research Center January 1979 to design and fabricate titanium multiwall thermal protection system (TPS) panels for testing by NASA. The primary objective of this program was to design and fabricate metallic multiwall sandwich panels (Reference 1) for test and evaluation by NASA. The program consisted of two tasks:

Task I - Design Definition
Task II - Test Model Design and Fabrication

A program schedule and milestones are shown in Figures 1 and 2.

Task I consisted of a preliminary design of panels and tools, fabrication of test panels, and tests in face tension, flexual strength, creep, thermal conductivity and emittance. Results of Task I, which verified the potential of the multiwall concept as a thermally and structurally efficient TPS, are given in Reference 2.

The objective of Task II was to deliver several test panels to NASA for tests, and to further evaluate the fabrication procedure by conducting face sheet tensile tests and flatwise tension tests of panel components, to measure the thermal conductivity of a titanium multiwall panel, to determine the load carrying capability of the attachment clips, and to evaluate the feasibility of fabricating and maintaining a hard vacuum in a panel over a period of time. A nine-panel array was designed, fabricated, and delivered to NASA Langley Research Center for testing in the Eight Foot High Temperature Structures Tunnel. A two-panel array was designed, fabricated and delivered to Langley Research Center for vibrational and acoustical tests. A second two-panel array was fabricated and delivered to Johnson Space Center for radiant heating tests. Only the activities of Task II are described in this report.

Use of commercial products or names of manufacturers in this report does not constitute official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

## FABRICATION

Panel Fabrication - A total of sixteen panels were fabricated using the techniques described in Reference 2. Fourteen of these panels were fabricated per the drawing shown in Figure 3, and two panels were fabricated without attachment clips. These two panels were used to determine the feasibility of producing vacuum tight panels. Of the fourteen panels, one panel was tested to determine the load carrying capability of the attachment clips and tongues. The remaining thirteen panels were arranged into three test panel assemblies. Nine panels were used for the nine-panel array shown in Figure 4, and four panels were used for the two, two-panel arrays shown in Figure 5.

Nine-Panel Array - The backing plate for the nine-panel array shown in Figure 6 had the clips located to a dimensional layout. The panels were gapped 2.54mm (.100") to allow for thermal expansion during test at 811K (1000°F).

The Nomex™ felt shown in Figure 7 was trimmed to size using metal shears, then put into position and bonded using DC1200 primer and DC90-006 cement. The purpose for the Nomex felt was to block gas flow under the panels and to minimize vibration and flutter of the panels. Nomex felt can be used up to 776K (900°F).

To install the panels, the tongues were inserted into the forward most set of clips on the backing plate. To install the second panel, the first panel was held down firmly against the Nomex felt using an aluminum plate 12.7 x 330 x 330mm (1/2" x 13" x 13") on top of the first panel to equally distribute the load. The load required was approximately 356N (80 lbs). While the panel was held tightly against the Nomex felt, the tongues of the second panel were inserted through the clips on the backing plate and into the clips on the back of the first panel. Each subsequent panel was installed in the same manner. Thus the last panel of each row was attached using tongues that were not bonded to a panel, but were bolted to the backing plate. The completed nine-panel array is shown in Figure 8.

Two-Panel Array - Each of the two-panel arrays were assembled in the same manner as the nine-panel array. A photo of the two-panel array is shown in Figure 9.

## INSTRUMENTATION

The nine-panel array that was delivered to Langley Research Center and the two-panel array that was delivered to Johnson Space Center had Type K (chromel alumel) thermocouples installed for the purpose of monitoring the temperature during test. Figures 10a through 10g show thermocouple locations.

## TESTS

The testing in Task II consisted of basic face sheet tension tests, flatwise tension tests, thermal conductivity tests, attachment clip tests and a vacuum-tight panel evaluation. The basic face sheet tension tests were in addition to face sheet tension tests made in Task I and were performed to determine the cause for scatter in the data that was reported in Reference 2. The objective of the flatwise tension tests was to further evaluate the fabrication procedure beyond what was done in Task I. The attachment clip tests were performed to determine the load carrying capabilities of the clips and tongues. Vacuum-tight panel evaluation was performed to determine the feasibility of producing vacuum-tight panels that would remain vacuum-tight for a period of time.

Basic Face Sheet Tension Tests - Specimens for basic face sheet tension tests reported in Reference 2 were taken from a LID (Liquid Interface Diffusion) bonded panel. It is suspected that some of the specimens may have been damaged while cutting them from the panel. To eliminate this possibility, specimens for this test were taken from the 0.038mm (0.015") flat sheets, shown in Figure 11. The flat sheets were plated with LID bonding material and processed through the LID bond cycle. Table 1 shows the test results. The low failing stress of 954.9 Mpa (138.5 KSI) for specimen 1-4 was caused by a micro scratch on the specimen. The data in Table 1 indicate that there was no change in properties caused by the LID process.

Flatwise Tension Test - After additional metallographic examinations, the failed specimens of Task I showed no discrepancies in plating or LID bonding. Additional tests were performed to determine the cause for scatter in data reported in Reference 2. The scatter for a full depth sandwich ranged from a high failing stress of 157 Kpa (20.7 psi) to a low failing stress of 88 Kpa (12.7 psi). Figure 12 shows a typical LID bonded joint for specimens of Tasks I and II in which the LID bonding material is diffused equally across the joint interfaces, creating a good joint between the dimpled sheet and septum sheets.

TABLE 1

BASIC FACE SHEET TENSION TESTS
(ROOM TEMPERATURE)

| | .04 MM (.0015") | | |
|---|---|---|---|
| Configuration | Ftu, Mpa (ksi) | % e | Specimen Number |
| As Received | 1087 (157.7) | 0 | 1-A |
| | 1062 (154.5) | 0.4 | 2-A |
| After LID Bond Cycle | 1090 (158.1) | 0.3 | 1-1 |
| | 1081 (156.8) | 0.2 | 1-2 |
| | 1118 (162.2) | 0.2 | 1-3 |
| | 954.9 (138.5) | 0.2 | 1-4 |
| | 1102 (159.8) | 0.5 | 2-1 |
| | 1047 (151.8) | 0.5 | 2-2 |
| | 1145 (166.0) | 0.5 | 2-3 |
| | 1123 (162.8) | 0.6 | 2-4 |

The specimens for this task were taken from a panel that had been used for thermal conductivity measurements. This panel had been heated to 942K (1200°F) and held for two hours. The maximum design temperature is 811K (1000°F). Five specimens were pulled. Three specimens were 17.4 x 76.2 x 76.2mm (0.68" x 3.0" x 3.0") and two specimens were 17.4 x 50.8 x 50.8mm (0.68" x 2.0" x 2.0"). Table 2 shows failing stress for the large and small specimens. The larger specimen showed twenty-five percent greater failing stress. The lower failing stresses are due to the dimples not being centered about the specimens. The larger specimens have more dimples, and the dimple pattern is symmetric, thus providing a more uniform load distribution which minimized stress concentration.

To obtain more reliable flatwise tension test data, the specimen's size should be increased and the dimples aligned symmetrically about the specimens. Additional tests should be performed at operating temperatures.

## THERMAL CONDUCTIVITY TEST

The thermal conductivity data obtained in Task I (Reference 2) for a 17.4 x 203 x 203mm (0.68" x 8" x 8") panel was higher than had been predicted and was thought to be questionable because of the small panel size. To validate this discrepancy, an additional test was conducted for a larger panel, 17.4 x 305 x 305mm (0.68" x 12" x 12"), with a different test set-up using an insulation, Min-K, TE 1400, as a standard.

This test used the modified guarded hot plate shown in Figures 13 and 14. The quartz lamp arrays are divided into three independent heating zones: central, mid, and edge. Separate automatic controls are used to minimize the temperature gradient between the central test section and the mid guard heater. The edge guard heater, in turn, minimizes the temperature gradient between the mid test section and the edge. In this way, the apparatus is a doubled guarded system. This minimizes any radial heat flow away from the central test section.

TABLE 2

FLATWISE TENSION TEST - FULL DEPTH
SANDWICH OXIDIZED AT 942K (1200°F)

| Specimen Number | Failure Load N, (Lbs) | Failure Stress KPa (ksi) | Specimen Size MM (Inches) |
|---|---|---|---|
| 1 | 672 (151) | 117 (16.9) | 17.4 x 76.2 x 76.2 (.68 x 3 x 3) |
| 2 | 654 (147) | 113 (16.4) | 17.4 x 76.2 x 76.2 (.68 x 3 x 3) |
| 3 | Not Tested | Not Tested | Not Tested |
| 4 | 238 (53.5) | 93 (13.4) | 17.4 x 50.8 x 50.8 (.68 x 2 x 2) |
| 5 | 236 (53) | 93 (13.4) | 17.4 x 50.8 x 50.8 (.68 x 2 x 2) |
| 6 | 178 (40) | 70 (10.1) | 17.4 x 50.8 x 50.8 (.68 x 2 x 2) |

The first step in the additional test was to calibrate the new test apparatus by verifying the thermal conductivity of the Min-K itself. For this first phase of the test, one piece of Min-K was run as the known material and another piece was run as the unknown material. The test data showed that the measured thermal conductivity of the Min-K was the same as shown in the Manufacturer's Technical Data Sheet, Figure 15. These results show that the thermal conductivity test apparatus was functioning properly and capable of maintaining temperature control across the test area.

The test set-up shown in Figure 13b was used for checking thermal conductivity of the titanium multiwall panel. The honeycomb panel was used to provide a uniform temperature to the test panel. The honeycomb panel was instrumented with thermocouples (t/c's) which were fed into the automatic control circuit in order to maintain the desired test temperature. The test panel was instrumented with t/c's that were welded onto both sides of the face sheets at the panel center, midway between the center and edge, and at edge locations. It was placed on top of the honeycomb panel and the instrumented Min-K, with a known thermal conductivity, was placed on top of the test panel. Because of the physical nature of the Min-K, t/c's could not be attached directly to its surface, therefore, t/c's were put on small rectangular tabs which were insulated from the metal surfaces of the test panel and aluminum plate, but were forced onto the Min-K surfaces by the weight of the test set-up. It's t/c locations were the same as for the test panel.

The center measured temperature differences ($\simeq$T) and thickness (>) of the test panel (TS) and Min-K (MK) were used to calculate the thermal conductivity ($\delta$) as follows:

Since

$$QA = \frac{\kappa_{TS}}{\ell_{TS}} \Delta T_{TS} = \frac{\kappa_{MK}}{\ell_{MK}} \Delta T_{MK}$$

$$\kappa_{TS} = \frac{\ell_{TS}}{\ell_{MK}} \frac{\Delta T_{MK}}{\Delta T_{TS}} \kappa_{MK}$$

where $k_M K$ is evaluated at the arithmetic mean temperature,

$$T_{MK} = T_{MK}(\text{HOT SIDE}) - \frac{\Delta T_{MK}}{2}$$

and

$$T_{TS} = T_{TS}(\text{HOT SIDE}) - \frac{\Delta T_{TS}}{2}$$

Figure 16 shows the measured thermal conductivity of the 17.4 x 305 x 305mm (0.68" x 12" x 12") panel and compares this data with predicted values from Reference 1 and the measured data for the smaller panel from Reference 2.

Attachment Clip Tests - A panel, that was LID bonded from detail parts produced in the initial tool proof runs, was tested to evaluate the load carrying capabilities of the clips and tongues. These parts were of marginal quality. Each dimpled sheet was 0.13mm (0.005") less than the 4.27mm (0.168") thickness desired, and the outer sheets were somewhat rough due to stop-off application. Visual examination of the panel after LID bonding indicated the filler sheets had been improperly placed around the clips which caused a disbond between one side of a clip and the bottom sheet. This void was repaired by TIG welding.

For testing, the panel was attached to the two-panel array backing plate, see Figure 17, via the clips and tongues. An aluminum plate 19 x 305 x 305mm (0.75" x 12" x 12") was bonded to the top of the panel. The aluminum plate had a 19mm (3/4") tapped hole located symmetrically about the four clips for attachment to the upper ram of the Instron test apparatus shown in Figure 17. The panel was installed in the Instron test apparatus with the dial indicators, shown in Figure 17, mounted at each corner of the panel to measure movement during the test. The panel was loaded in tension with the full load reacted at the four attachment clips. Figure 18 shows total load vs. movement at each of the four corners. At a load of 1245N (280 lbs), the number 4 clip, which had been repaired by TIG welding, separated from the panel, but the panel continued to carry an increasing load. The panel started to fracture in the top skin at the forward slope adjacent to the bottom skin near clip number 1 at 1428N (321 lbs), shown in Figure 18, and the test was stopped. There was no indication of LID bond failure within the panel. The failure at clip four was attributed to faying surface voids caused by lack of pressure during the LID bonding process caused by improperly placed filler sheets. This condition was corrected by reworking the filler sheets, and the thirteen deliverable panels bonded thereafter were free of this defect.

The results of this test indicate that properly fabricated attachments should sustain more than the 311N (70 lbs) load which was the average carried by each attachment at initiation of failure.

Vacuum-Tight Panel Evaluation - Reference 2 describes the fabrication of a vacuum-tight panel. This panel was damaged when the corner struck a work table which resulted in a leak. In Task II, two additional panels were LID bonded, again with the purpose to evaluate the practicability of fabricating and maintaining a vacuum sealed panel.

The first panel was leak checked twenty-four hours after having been removed from the vacuum furnace. The twenty-four hour delay was induced to permit the panel to fill with gas in the event a leak was present. After the twenty-four hour delay, the panel was immersed into a hot water tank. If a leak were to be present, bubbles formed by the expanded gas escaping from the panel would be observed. The test of the first panel indicated a leak in the top skin near one corner. Examination under a microscope showed a small crater that was caused by a spot weld that had been placed to hold the parts together for LID bonding. An attempt was made to close the hole using a braze repair technique where titanium-copper-nickel braze alloy was applied to the affected area and heated to 1227K (1750°F) for ten minutes in a vacuum furnace. Twelve hours after the panel had been braze repaired, a leak check disclosed no leaks. Twenty-four hours later, a leak was discovered. In this instance, the panel had been damaged by having been bumped on the same corner. No further attempts were made to repair the new hole.

The second panel was LID bonded and leak checked immediately after removal from the vacuum furnace, and no leak was discovered. After one week the panel was leak checked again and no leak was discovered. After two weeks a leak check disclosed a micro leak in the LID bond joint of the outer skins. Further attempts to produce a vacuum-tight panel were discontinued at this time.

This evaluation indicates that thicker outer skins may be required if a reliably vacuum-sealed panel is to be developed.

## CONCLUSIONS

A feasible manufacturing technique has been established for producing multiwall titanium thermal protection system panels. This method was used to produce 13 panels for delivery to NASA for testing. The panels were arranged in a nine-panel array and in two, two-panel arrays.

Additional fabrication development of this LID bond process, perhaps requiring thicker gages, will be necessary to produce and maintain vacuum-tight panels.

The LID bonding process does not significantly reduce the room temperature strength or elongation properties of the TI-6Al-4V sheet used in multiwall TPS panels.

The measured thermal conductivity of a multiwall panel was found to be only 10 percent greater than that predicted by a preliminary thermal analysis.

# REFERENCES

1. Jackson, L. Robert; Multiwall TPS Proceedings of Recent Advances in Structures for Hypersonic Flight, pp 671-706, NASA CP2065, September 1978.

2. Blair, Winford; Meaney Jr., John E; and Rosenthal, Herman A; Design and Fabrication of Titanium Multi-Wall Thermal Protection System (TPS) Test Panels, NASA CR-159241, February 1980.

3. Jackson, L. Robert; and Dixon, Sidney C.; A Design Assessment of Multiwall, Metallic Stand-Off, and RSI Reusable Thermal Protection Systems Including Space Shuttle Applications. NASA TM 81780, April 1980.

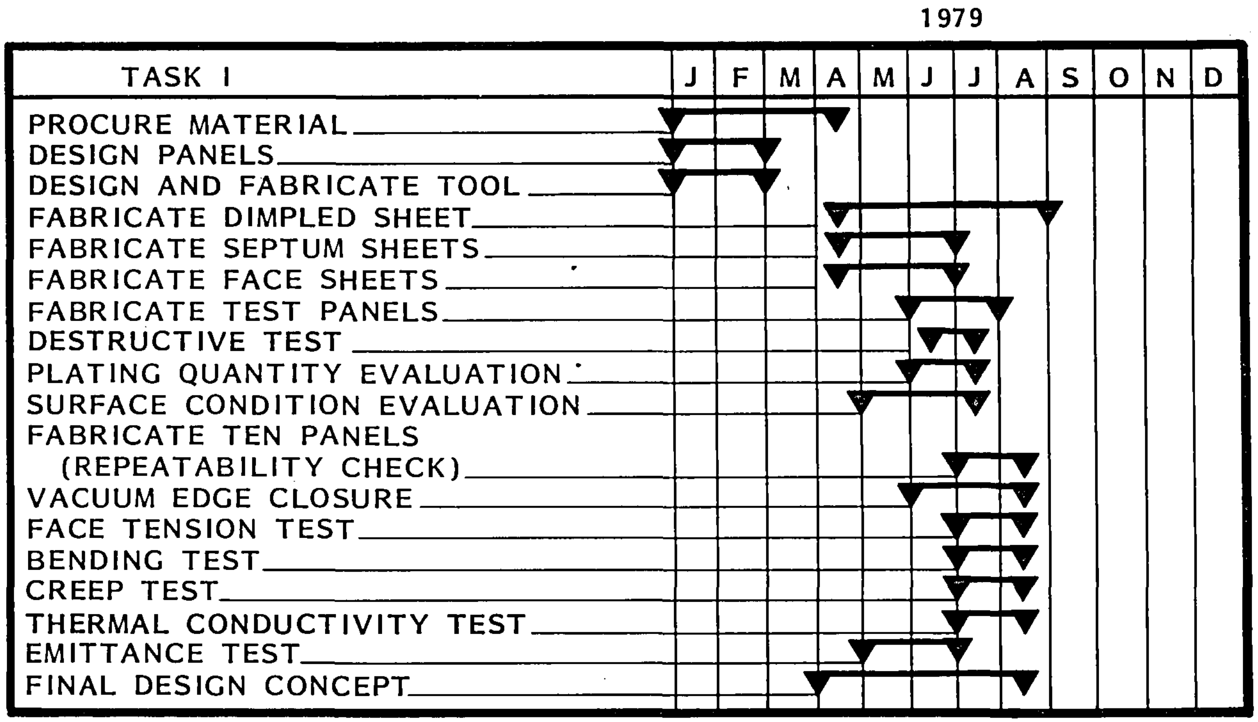



Figure 1. Task 1 Program Schedule

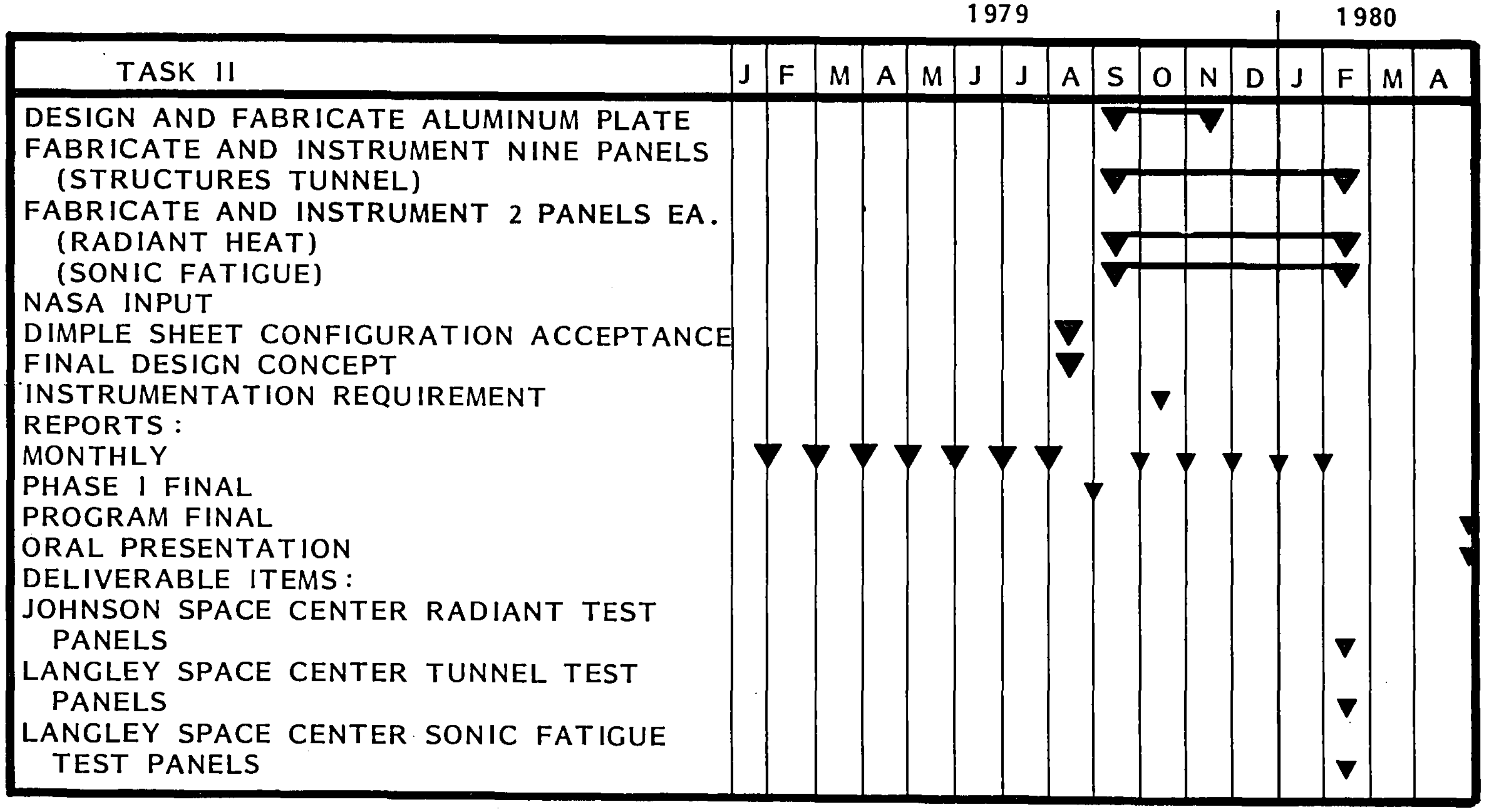



Figure 2. Task 2 Program Schedule

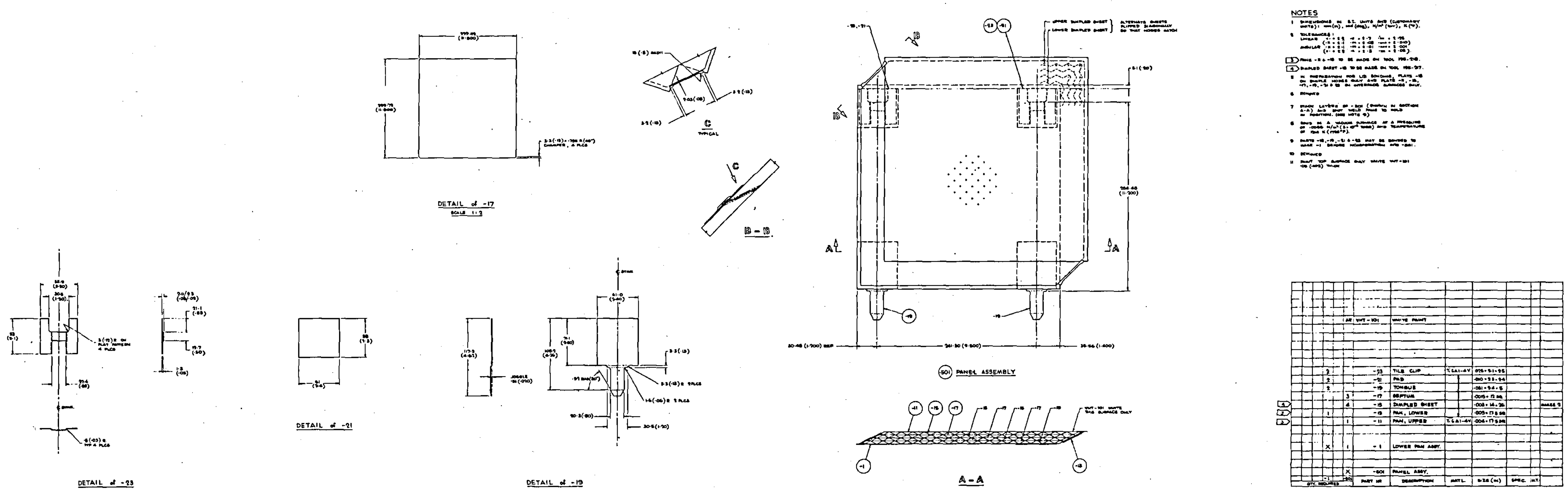



Figure 3. Design, Panel Assembly (Shows Construction Details of Individual Panel)

195-219

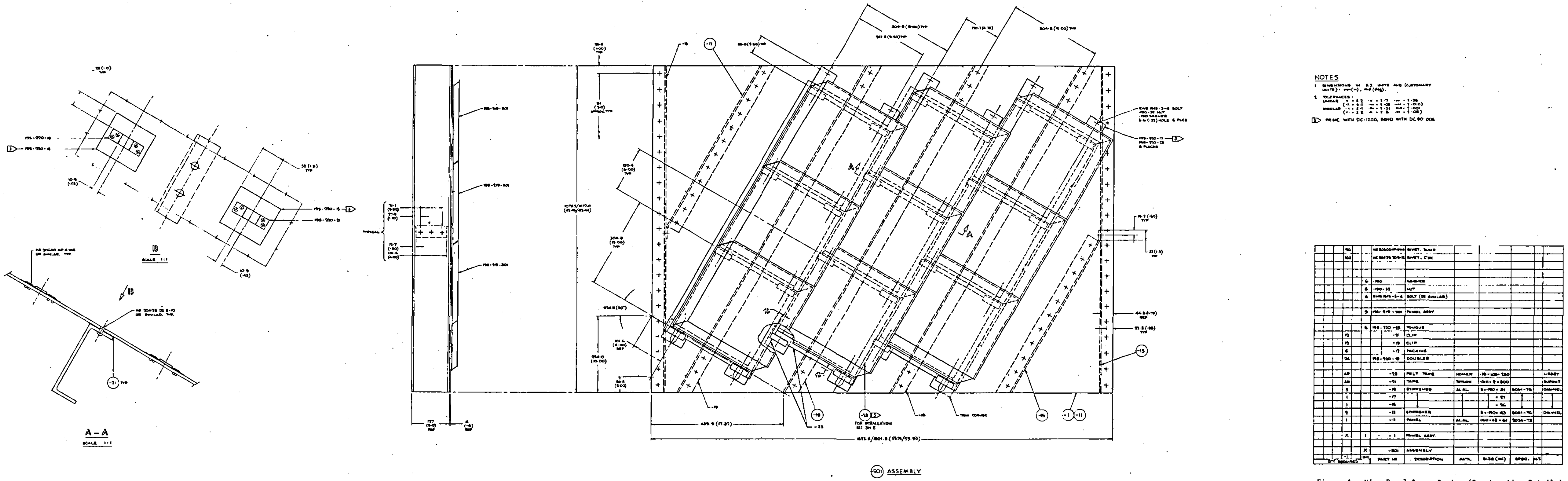



Figure 4. Nine-Panel Array Design (Construction Details), Sheet 1 of 2



195-221

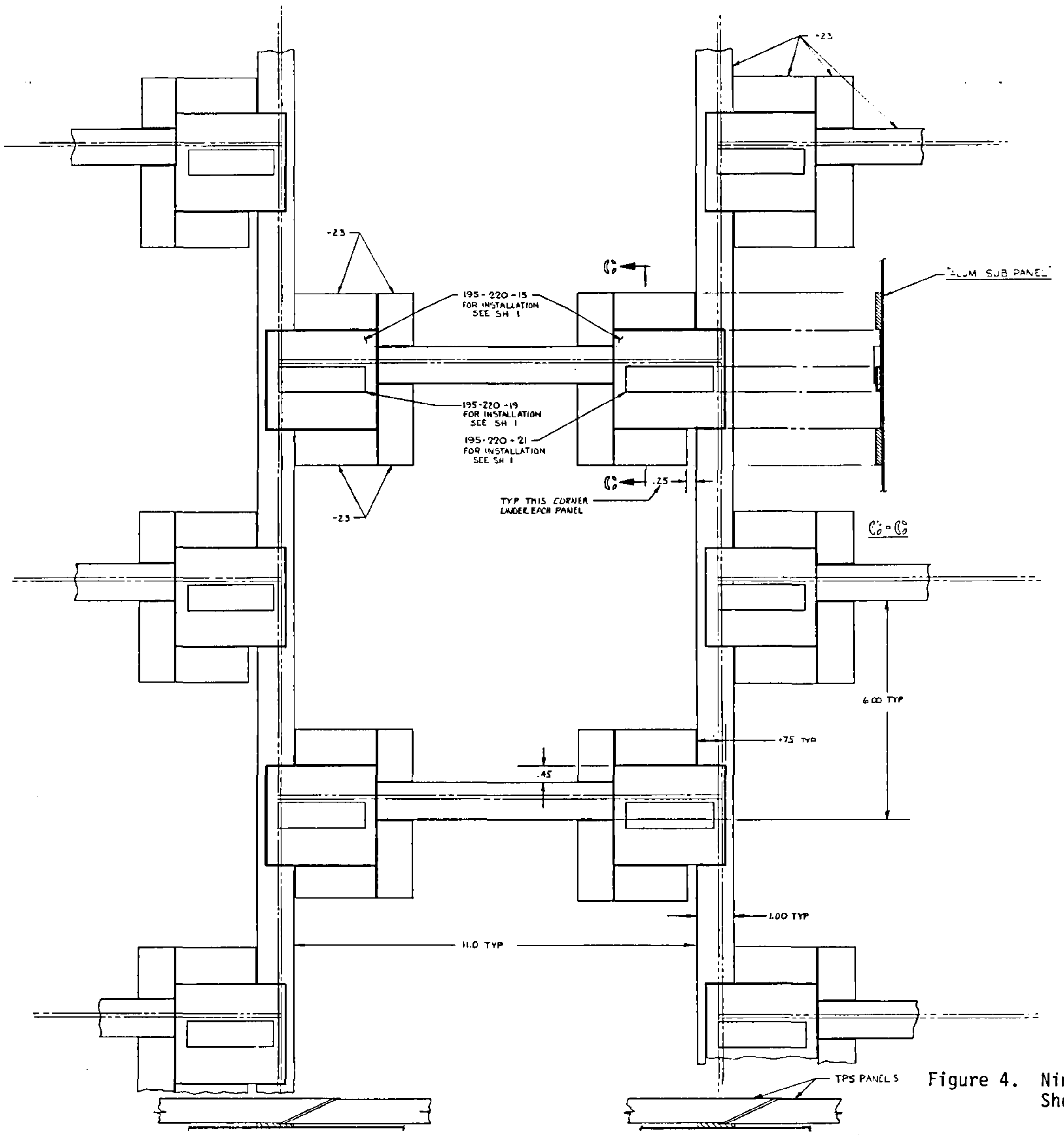
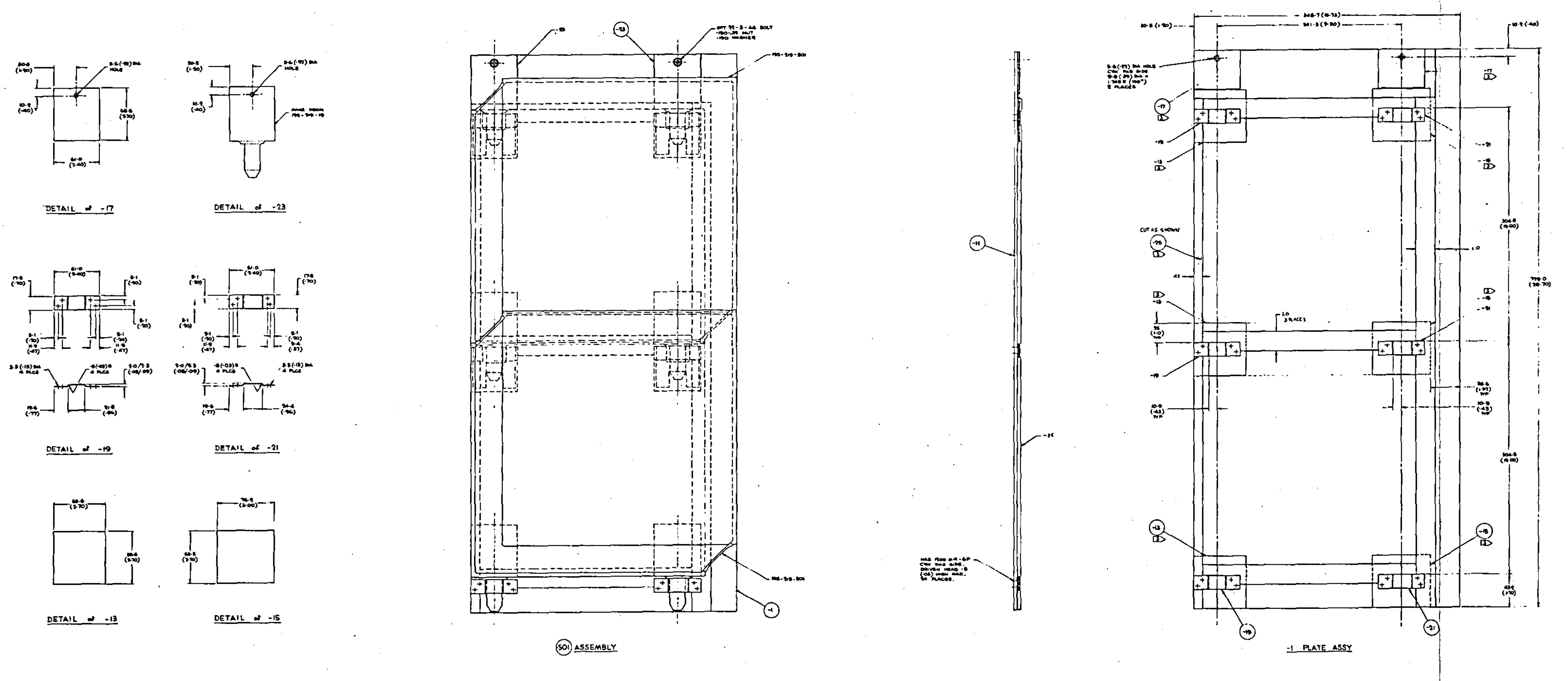



Figure 4. Nine-Panel Array Design (Construction Details), Sheet 2 of 2




NOTES

1 DIMENSIONS IN S.I. UNITS AND (CUSTOMARY UNITS): mm (in), rad (deg).

2 TOLERANCES:
LINEAR [illegible]
ANGULAR [illegible]

3 PRIME WITH DC-1200, BOND WITH DC90-006

| QTY. REQUIRED | | -501 | PART NO | DESCRIPTION | MATL. | SIZE (IN) | SPEC. | WT. | |
|---|---|---|---|---|---|---|---|---|---|
| 24 | | | NAS 1200 MAGR | RIVET | | | | | |
| | | 2 | -190 | WASHER | | | | | |
| | | 2 | -190-32 | NUT | | | | | |
| | | 2 | SPT 22-3-A4 | BOLT (OR SIMILAR) | | | | | SPS |
| | | 2 | 195-219-501 | PANEL ASSY. | | | | | |
| AR | | | -25 | FELT TAPE | NOMEX | [illegible] | | | [illegible] |
| | | 2 | -23 | TONGUE | MAKE FROM 195-219-15 | | | | |
| 3 | | | -21 | CLIP | Ti6Al-4V | .025×.7×2.7 | | | |
| 3 | | | -19 | CLIP | Ti6Al-4V | .025×.7×2.7 | | | |
| 2 | | | -17 | PACKING | AL AL | .071×2.4×2.7 | 2024-T3 | | |
| 3 | | | -15 | DOUBLER | | .020×2.7×3.0 | | | |
| 3 | | | -13 | DOUBLER | | .020×2.7×2.7 | | | |
| 1 | | | -11 | PLATE | AL AL | .160×14×29 | 2024-T3 | | |
| X | | 1 | -1 | PLATE ASSY. | | | | | |
| | | X | -501 | ASSEMBLY | | | | | |

PN 195-220

Figure 5. Two-Panel Array Design (Construction Details)

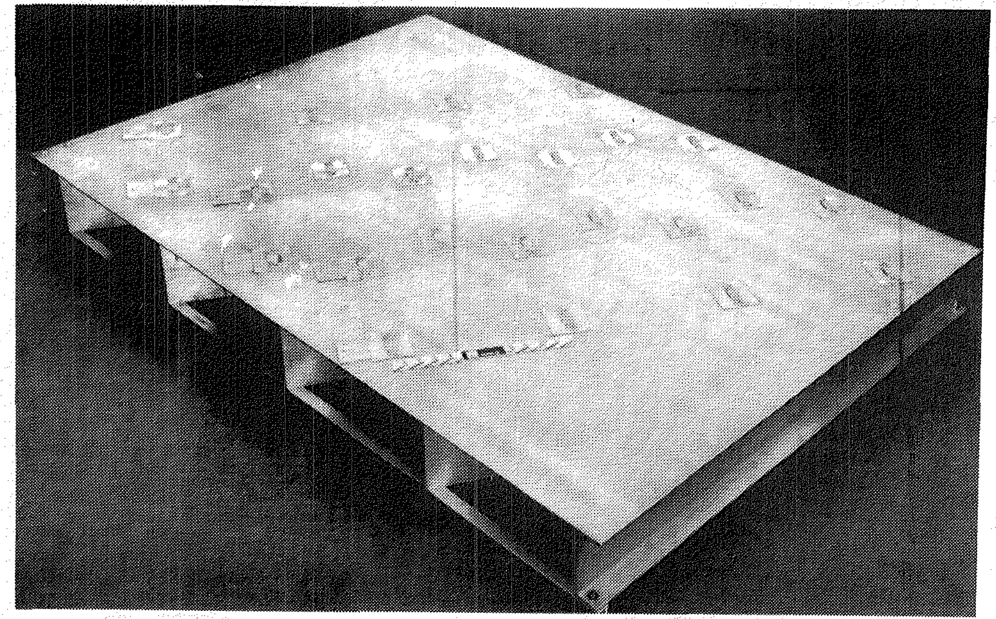


Figure 6. Backing Plate With Clips Installed

Figure 7. Nomex Felt in Position for Bonding to Backing Plate

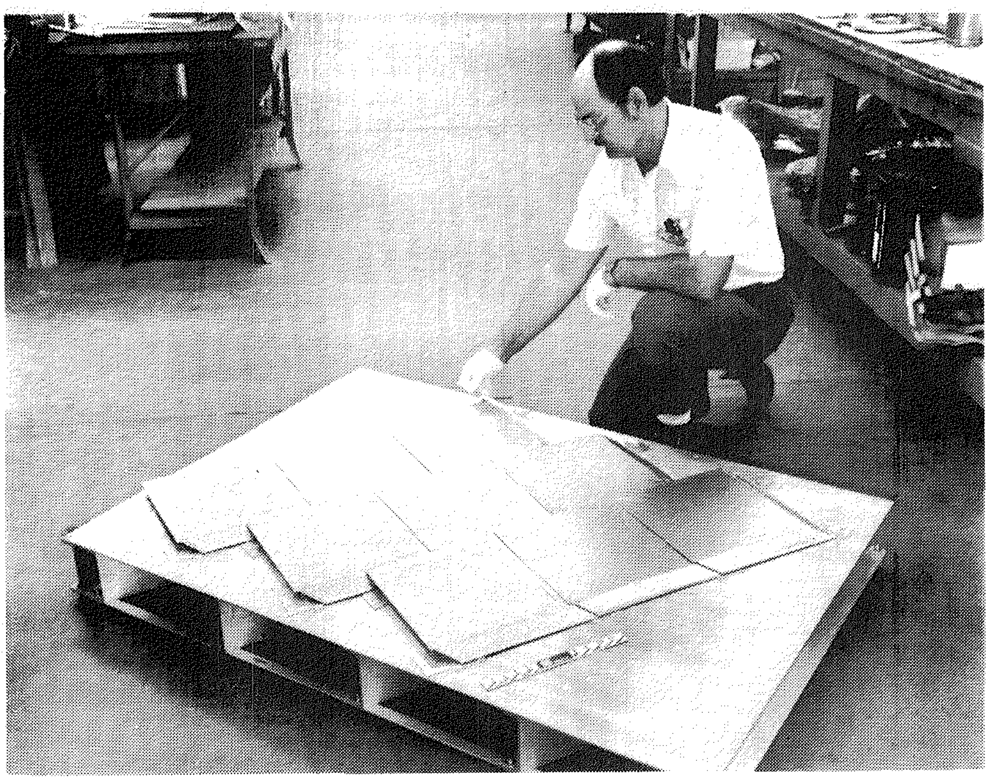


Figure 8. Nine-Panel Array for Testing in 8-Foot High Temperature Structures Tunnel

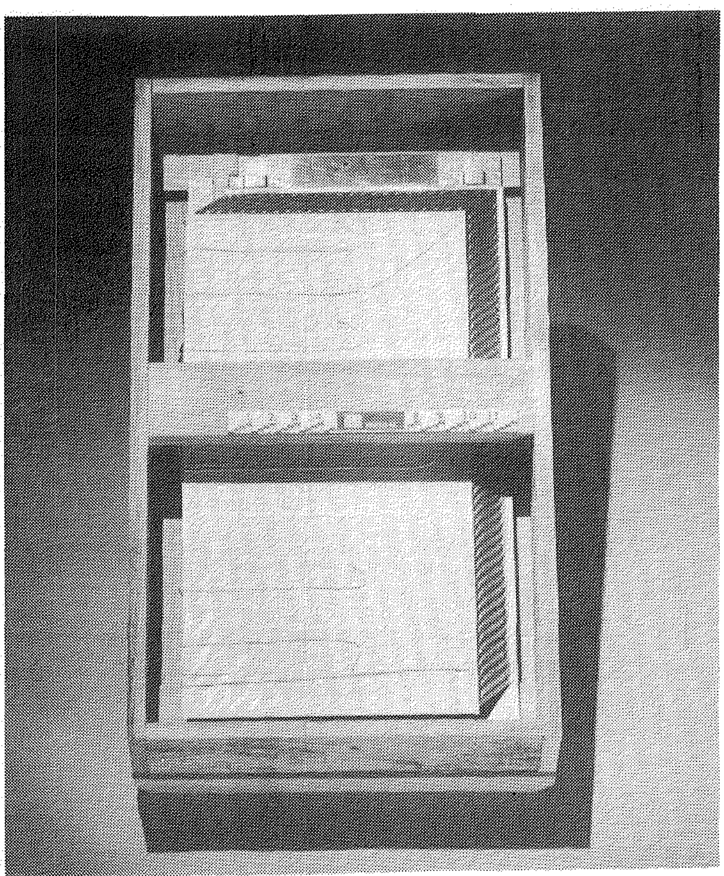


Figure 9. Two-Panel Array for Johnson Space Center Radiant Heating Tests

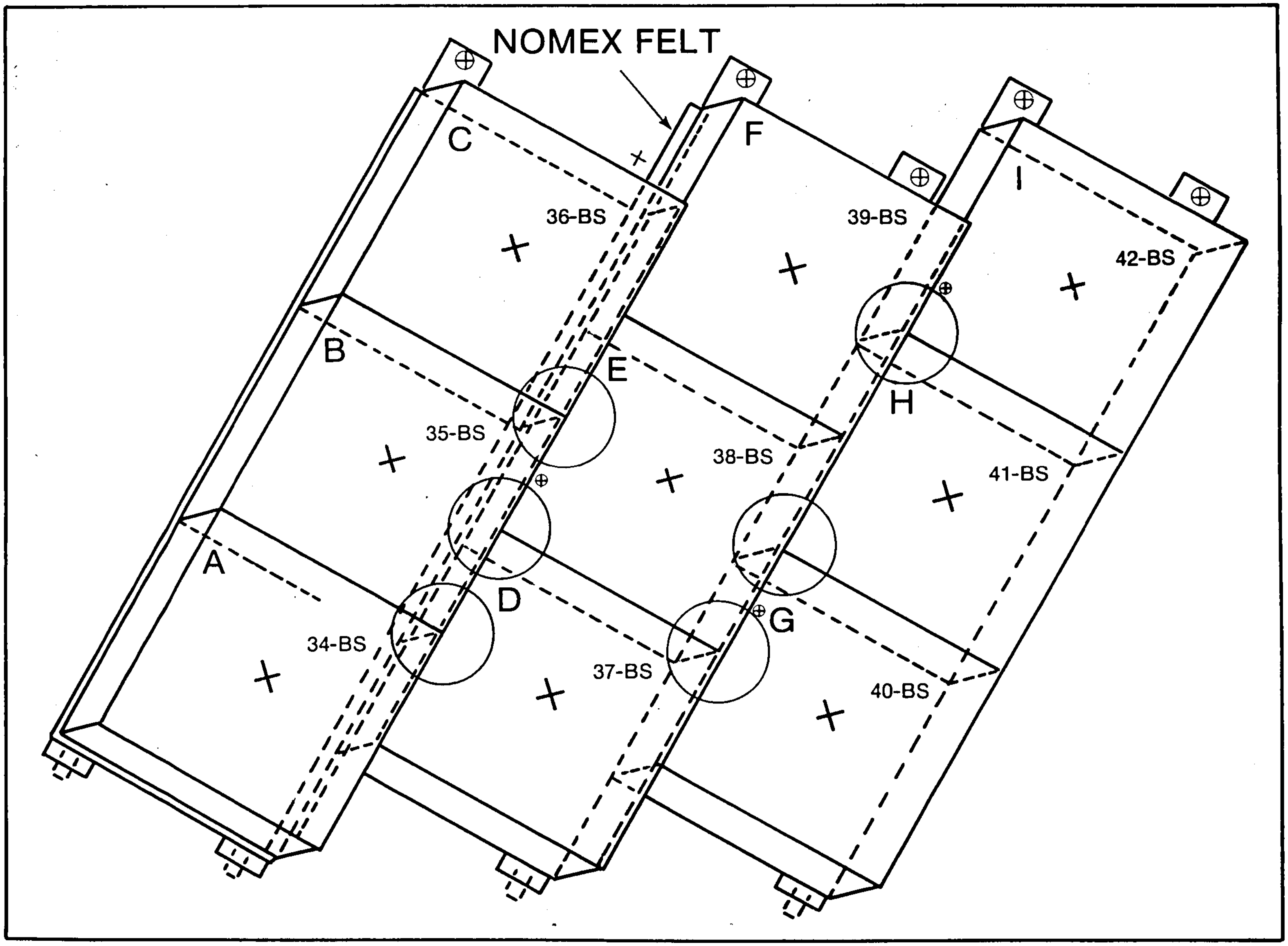



Figure 10a. Shows Panel Layout and Thermocouple Location (+) on Bottom Surface of Panels

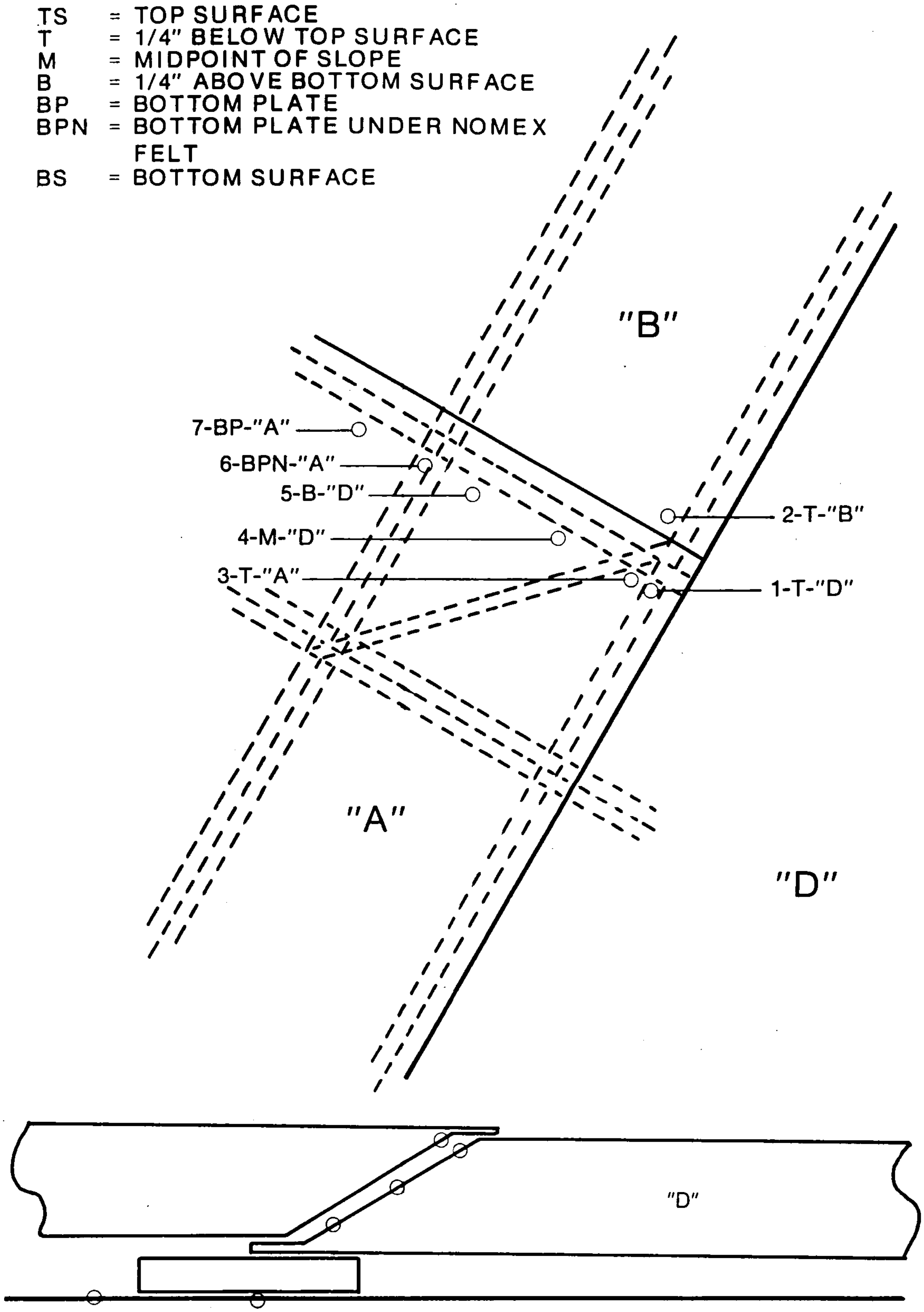



Figure 10b. Shows Thermocouple Locations ( o ) on Panels A, B and D

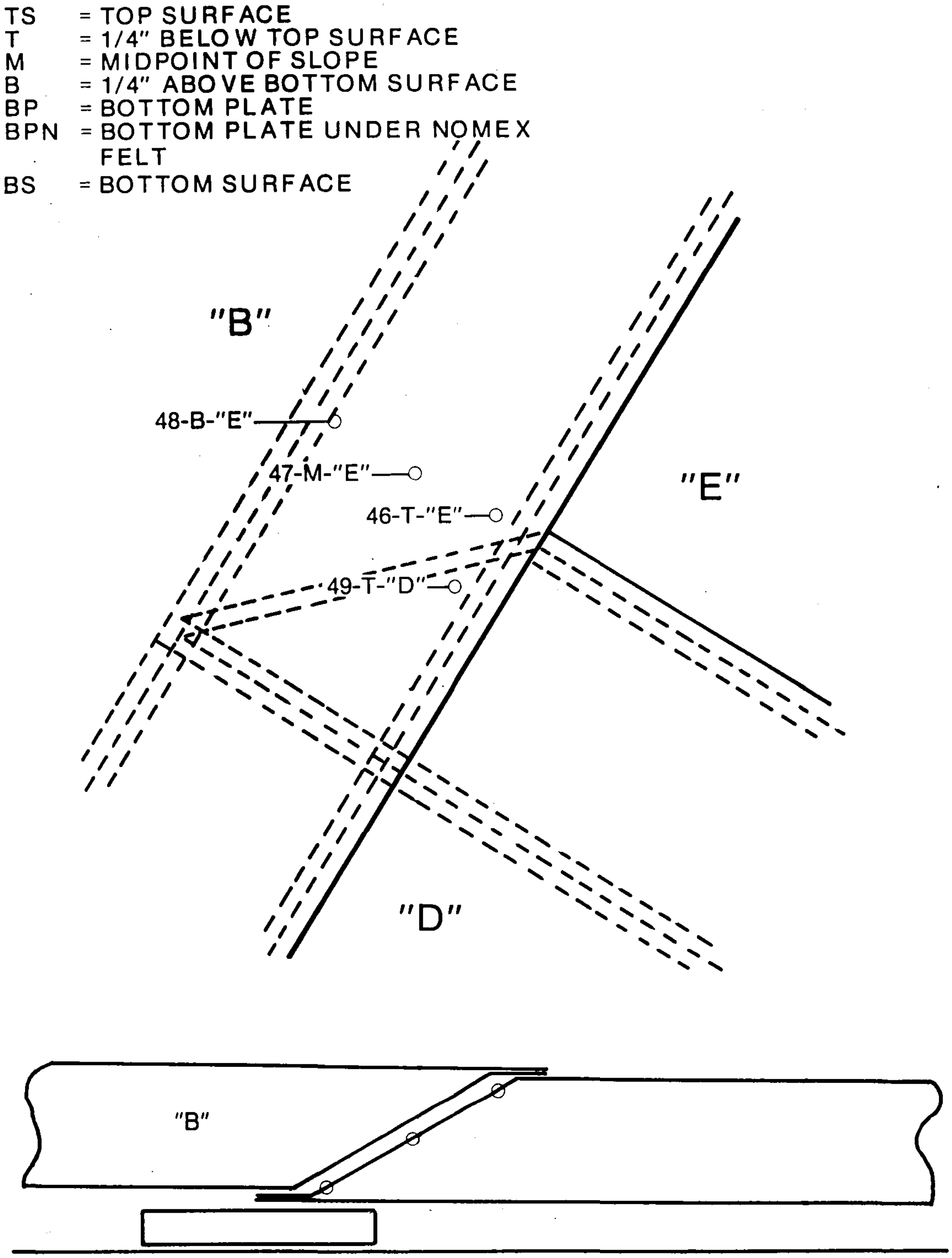



Figure 10c. Shows Thermocouple Locations ( o ) on Panels B, D and E

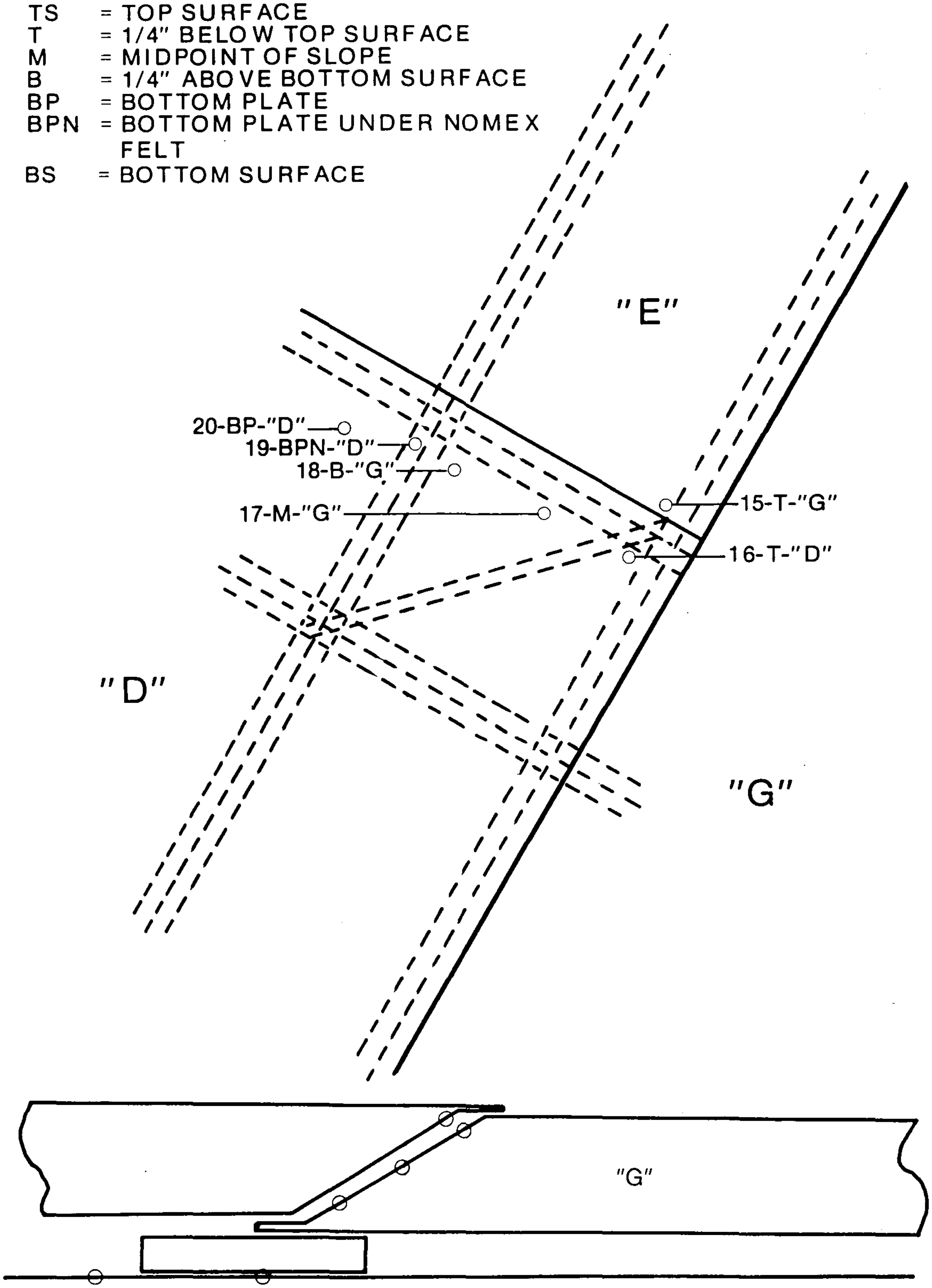



Figure 10d. Shows Thermocouple Locations ( o ) on Panels D and G

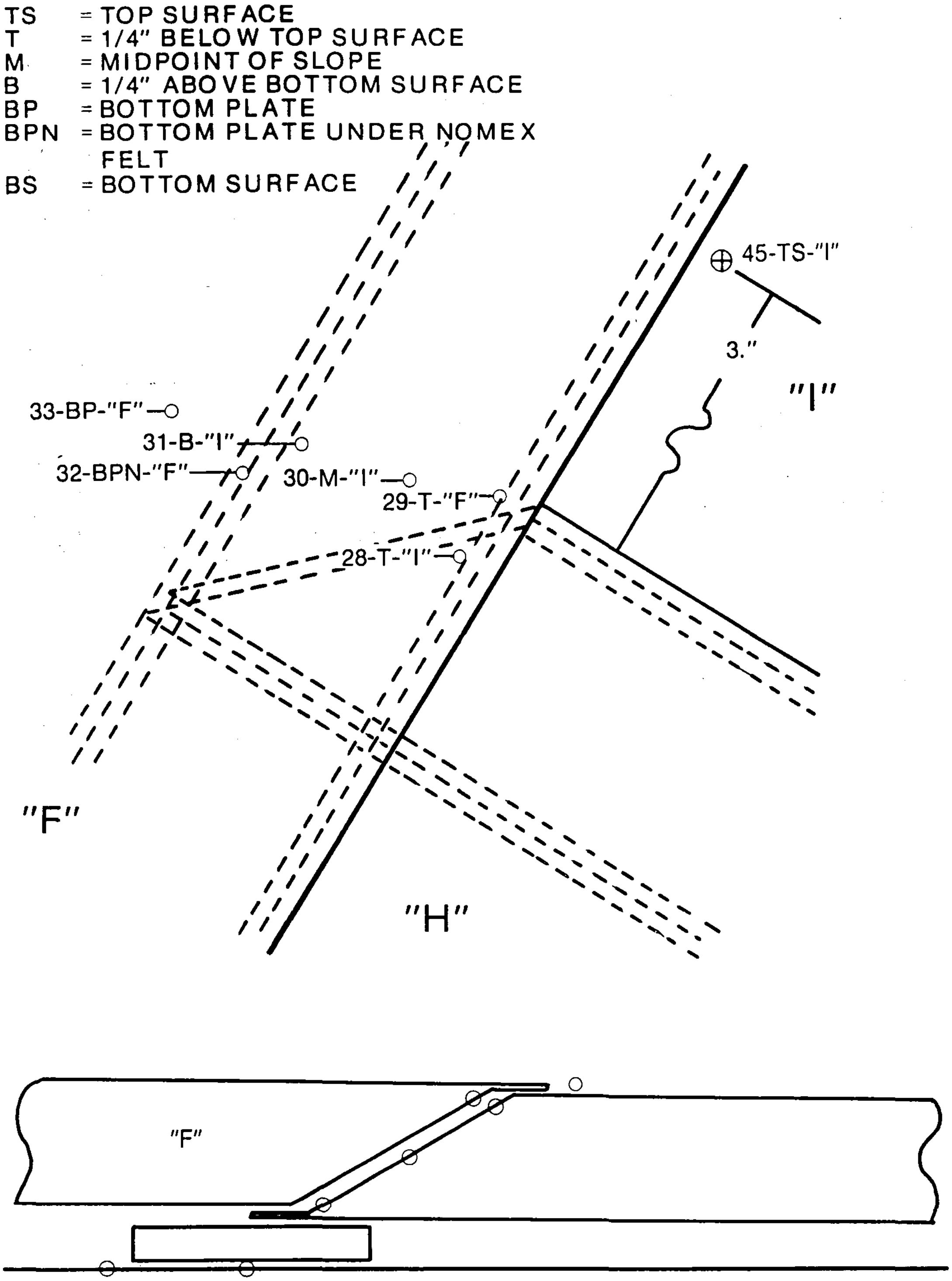



Figure 10e. Shows Thermocouple Locations ( o ) on Panels F and I

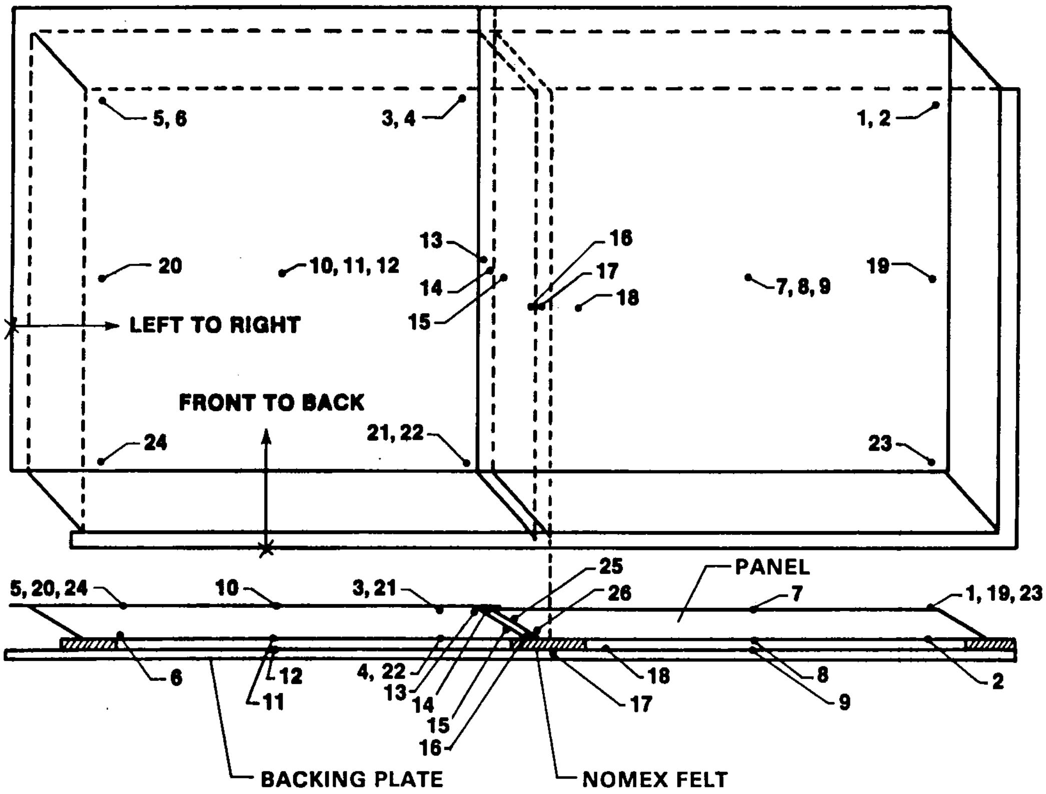



Figure 10f. Thermocouple Layout for Johnson Space Center Two-Panel Array

| Thermocouple Number | Dimension from Front to Back (in.) | Dimension from Left to Right (in.) |
|---|---|---|
| 1 | 1.85 | 24.0 |
| 2 | 1.85 | 24.0 |
| 3 | 2.0 | 11.75 |
| 4 | 2.0 | 11.75 |
| 5 | 2.0 | 2.0 |
| 6 | 2.0 | 1.9 |
| 7 | 7.0 | 18.7 |
| 8 | 7.0 | 18.7 |
| 9 | 7.0 | 18.7 |
| 10 | 7.0 | 7.0 |
| 11 | 7.0 | 7.0 |
| 12 | 7.0 | 7.0 |
| 13 | 7.5 | 13.37 |
| 14 | 7.5 | 13.7 |
| 15 | 7.0 | 12.7 |
| 16 | 5.7 | 13.37 |
| 17 | 5.7 | 13.37 |
| 18 | 5.7 | 14.2 |
| 19 | 7.0 | 23.7 |
| 20 | 7.0 | 2.0 |
| 21 | 1.7 | 11.8 |
| 22 | 1.9 | 11.8 |
| 23 | 2.0 | 23.5 |
| 24 | 2.0 | 2.0 |
| 25 | 6.7 | 13.2 |
| 26 | 5.6 | 13.7 |

Figure 10g. Dimensional Thermocouple Locations From Panel Edge (Johnson Space Center Two-Panel Array)

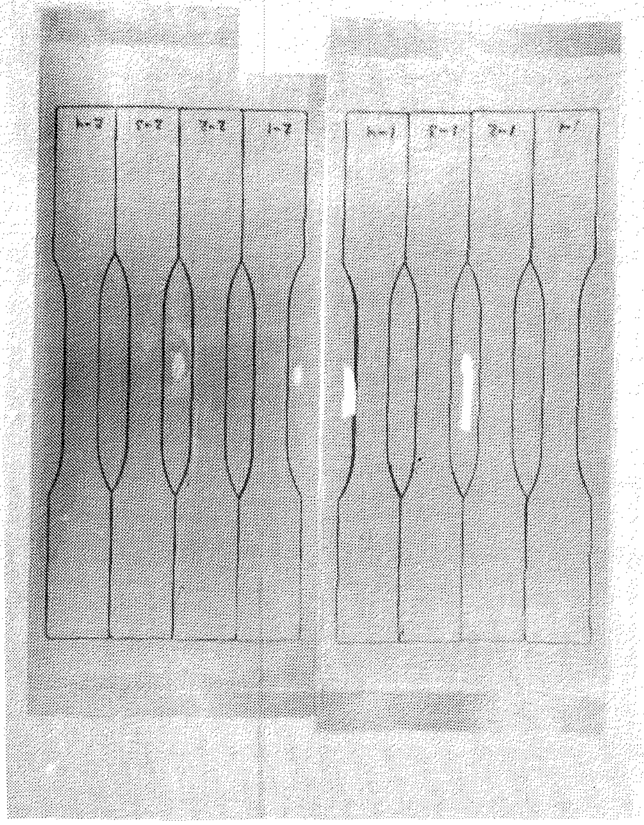


Figure 11. Foil Prior to Specimen Removal

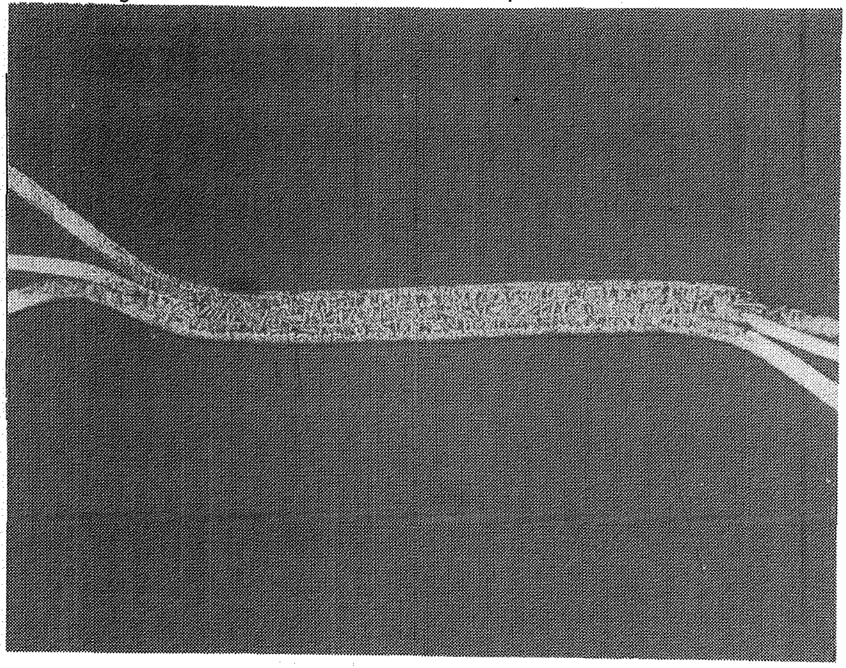


Figure 12. Typical LID-Bonded Joint for Task I and II Panels

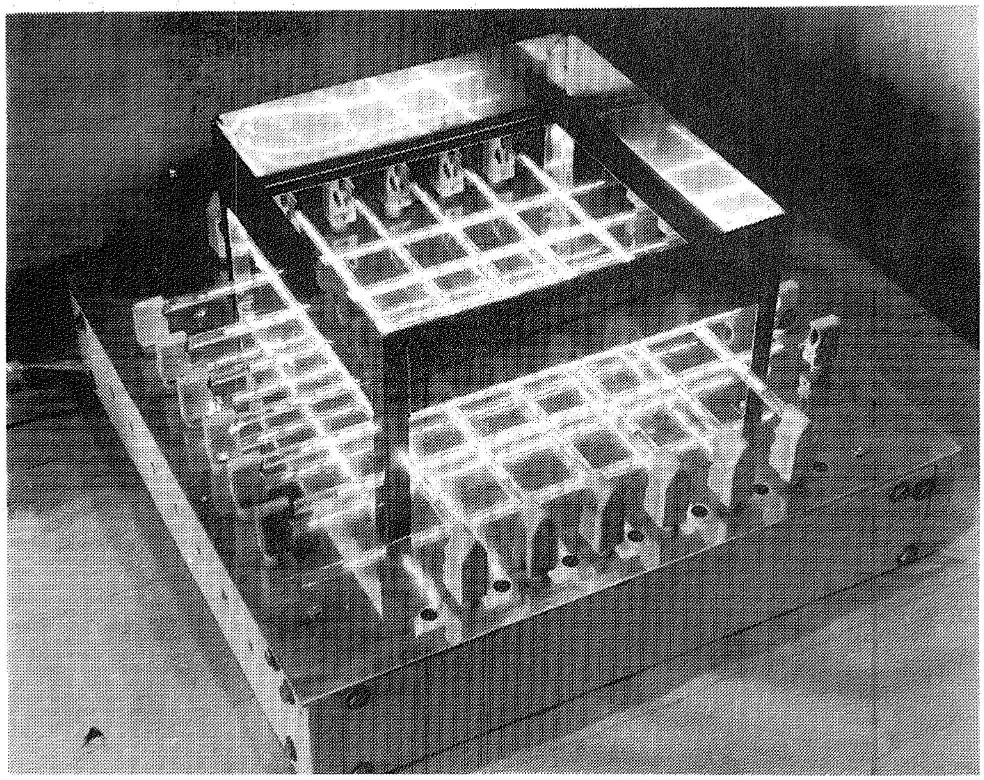


Figure 13a. Zoned Quartz Heating Lamps (Modified Guarded Hot Plate)

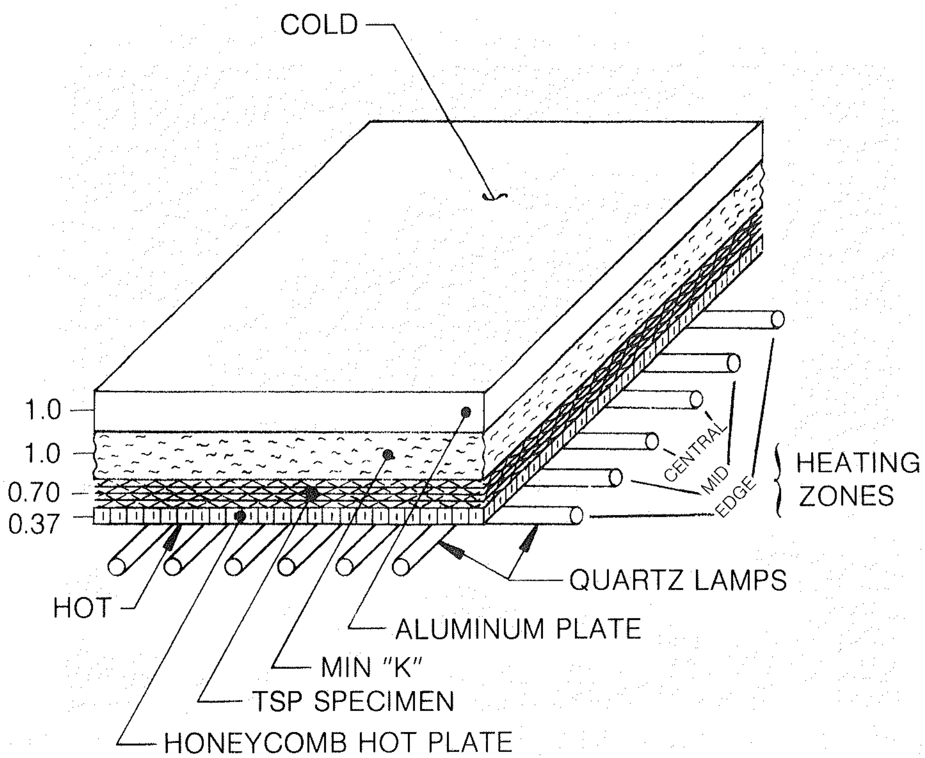



Figure 13b. Layup Used for Checking Thermal Conductivity of Titanium Multiwall Panel

Figure 14. Modified Guarded Hot Plate and Control Apparatus for Measuring Thermal Conductivity

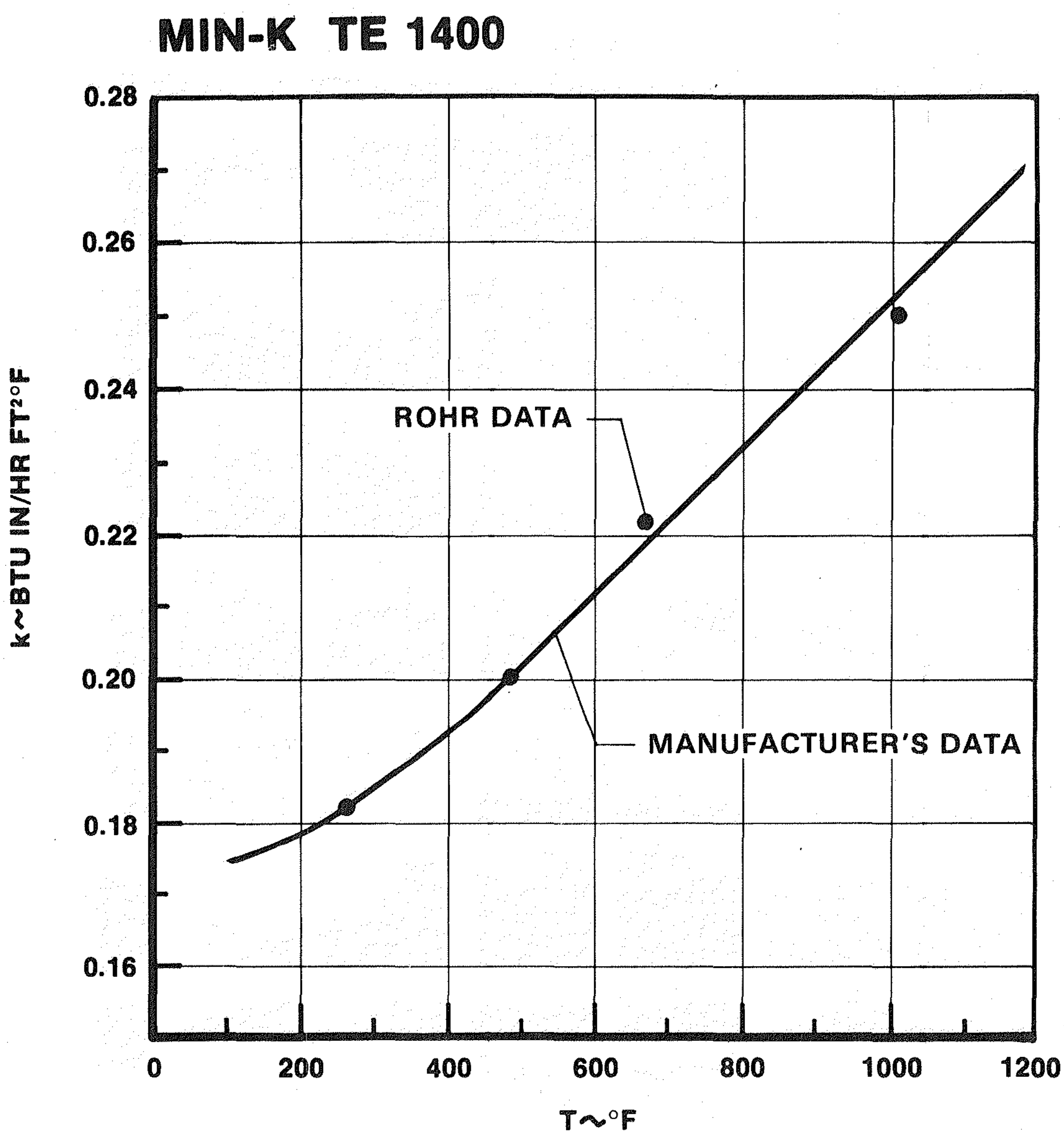



Figure 15. Thermal Conductivity Versus Mean Temperature of MIN-K Compared With Technical Data Sheet of Manufacturer

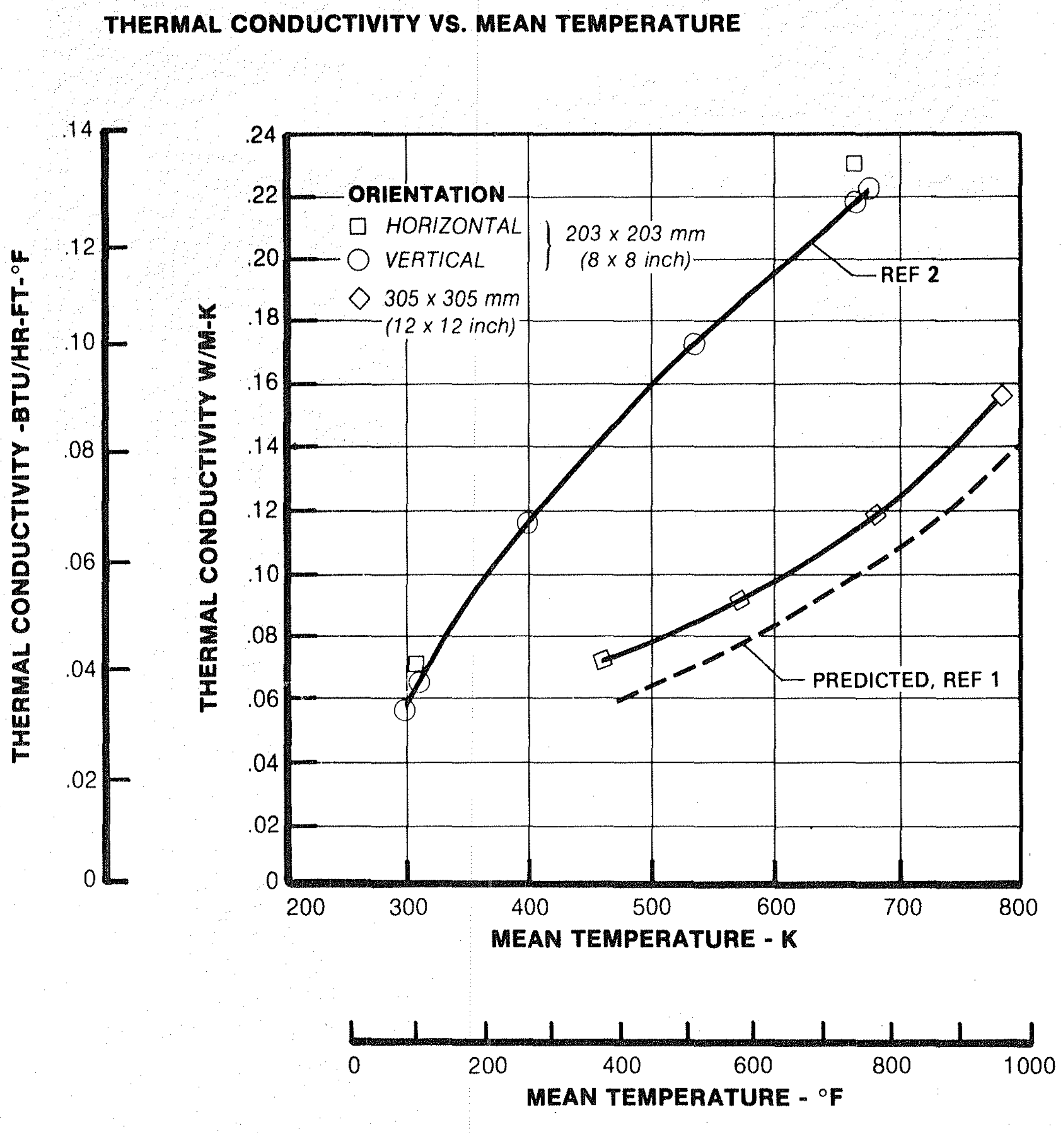



Figure 16. Thermal Conductivity of Titanium Multiwall Panels as Measured and as Predicted

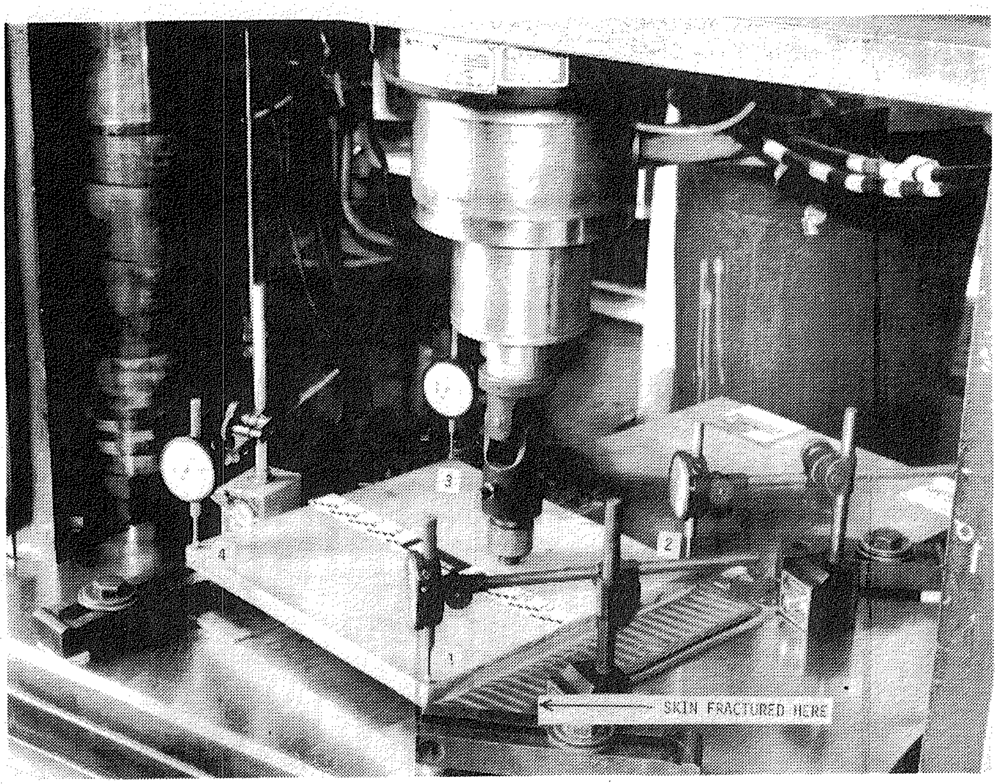



Figure 17. Panel Installed in Instron for Applying Load to Clips and Tongues

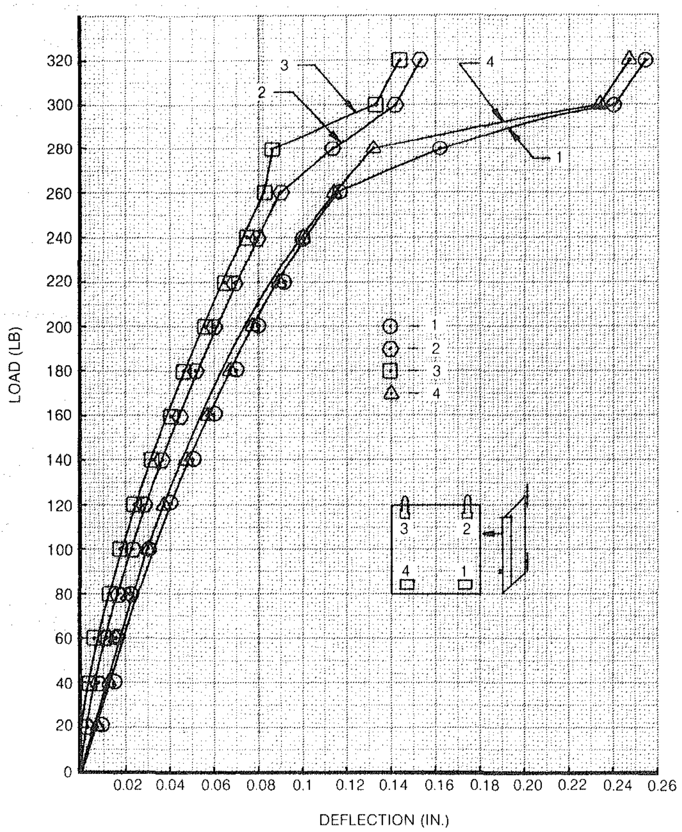



Figure 18. Load Versus Deflection at Each Corner

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| NASA CR-159383 | | |

| 4. Title and Subtitle | 5. Report Date |
|---|---|
| FABRICATION OF TITANIUM MULTI-WALL THERMAL PROTECTION SYSTEM (TPS) TEST PANEL ARRAYS | December 1980 |
| | 6. Performing Organization Code |
| 7. Author(s) | 8. Performing Organization Report No. |
| W. Blair, J.E. Meaney and H.A. Rosenthal | |
| | 10. Work Unit No. |
| 9. Performing Organization Name and Address | 11. Contract or Grant No. |
| Rohr Industries, Inc.<br>P.O. Box 878<br>Chula Vista, CA 92012 | NAS1-15646 |
| | 13. Type of Report and Period Covered |
| 12. Sponsoring Agency Name and Address | Contractor Report |
| National Aeronautics and Space Administration<br>Washington, DC 20546 | 14. Sponsoring Agency Code |

15. Supplementary Notes

Langley technical monitor: John Shideler
Interim Report

16. Abstract

A Titanium Multi-Wall nine panel array was designed, fabricated and delivered to NASA Langley Research Center for testing in the Eight-Foot High Temperature Structures tunnel. A two-panel array was designed, fabricated and delivered to NASA Langley Research Center for vibrational and acoustical tests. A second two-panel array was fabricated and delivered to NASA Johnson Space Center for radiant heating tests. One panel was tested by Rohr Industries for thermal conductivity. A feasible manufacturing technique has been established for producing titanium multi-wall thermal protection system panels. This method was used to produce 13 panels for delivery to NASA for testing.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
|---|---|
| Thermal Protection System Panels<br>Panel fabrication<br>Thermal conductivity | Unclassified - Unlimited<br><br>Subject Category 18 |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of Pages | 22. Price* |
|---|---|---|---|
| Unclassified | Unclassified | 36 | |

**End of Document**