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Fabrication of Prepackaged Superalloy Honeycomb Thermal Protection System (TPS) Panels

W. Blair, J. E. Meaney,
and H. A. Rosenthal
Rohr Industries, Inc.
Chula Vista, California

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FOREWORD

This is an interim report on work being performed by Rohr Industries, Inc., - Design and Fabrication of Titanium Multiwall Thermal Protection System (TPS) - describing the Task V activities. Task V, Concept Development of prepackaged Superalloy Honeycomb Sandwich panels consisted of:

a. A material survey and preliminary design;

b. Fabrication of component and full sized panels for structural and thermal tests;

c. Thermal analysis;

d. Structural analysis;

e. Thermal and structural tests to verify the design analysis; and

f. Fabrication of 25 panels for delivery to NASA Langley Research Center for additional testing.

This program is administrated by the National Aeronautics and Space Administration Langley Research Center (NASA LaRC). Mr. John Shideler of the Thermal Structures Branch, Loads and Aeroelasticity Division, is the technical monitor.

The following Rohr personnel were the principal contributors to the program during this reporting period: Winn Blair, Program Manager; J. Burton, Structures R&D; Dale Jennings, Manufacturing Technology; J. E. Meaney, Structures R&D; Brian Norris, Metals R&D; H. A. Rosenthal, Thermal R&D; D. Timms, Preliminary Design; and L. A. Wiech, Engineering Laboratory. Overall responsibility is assigned to the Rohr Aerospace R&D Engineering organization with U. Bockenhauer, Manager.

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SUMMARY

A material survey was conducted to find suitable materials that could be used as a Thermal Protection System (TPS) for one hundred missions on entry vehicles where the temperature range is 810° to 1,366°K (1,000° to 2,000°F) and pressure loads do not exceed 13.8 kiloPascals (kPa) (2 PSI). A combination of INCONEL 617, TI-6Al-4V and silica fiber materials were selected to be used as a sandwich. A TPS panel was designed using the thermal requirements for Space Shuttle Body Point 1300 as representative design criteria. Thermal and structural analyses were performed. Component specimens and full size panels were fabricated and tested to verify the design. Comparison of analytical and test data substantiate the analysis methods and verify the thermal and structural performance of the panels.

After design verification tests, one array of twenty panels, an array of two panels, and three single panels were fabricated and delivered to NASA Langley Research Center for additional testing.

1/ INTRODUCTION

As part of a program to develop lightweight durable Thermal Protection Systems (TPS) for future space transportation systems, titanium TPS panels have been studied for application where surface temperatures do not exceed 1000°F (References 1 through 5). This report describes an extension of the program to develop TPS for the temperature range from 1000°F to 2000°F. The objective of the work reported herein (Task V, Contract NASI-15646) was to survey high temperature materials and select a TPS material/configuration based on prepackaged superalloy concepts identified in References 5, 6 and 7, to analyze the selected design both thermally and structurally, and to fabricate and test specimens to obtain data for correlation with analysis. Finally, upon verification of the design, full-sized panels and arrays of panels were fabricated for delivery to NASA for additional testing.

2/ DESCRIPTION OF CONFIGURATION

The design configuration is the result of various trade off studies performed on the original design supplied by NASA-Langley (see References 5-7). The trade offs involved the structural and thermal performance of the panel. The resultant design is shown in Figure 1-A.

The inner and outer layers of the panel are honeycomb sandwich. The original configuration called for dimpled core as used in the titanium multiwall concept. However, the use of honeycomb core was shown to be more efficient structurally and to be equivalent in thermal performance even though the honeycomb has a higher thermal conductivity. This is because the honeycomb core sandwich does not structurally require as much thickness as the dimpled core sandwich, and consequently there can be more fibrous insulation for a given panel thickness.

The side walls of the original design were slanted at 0.524 Radians (30 degrees) in an attempt to optimize thermal performance. Detailed investigation into this concept produced several objectionable features. First, since the center of pressure of the top layer of the panel did not line up with the centroid of the attachment clips, there was significant nonuniformity in the internal loading. Secondly, the sloped side walls were heavier and did not have the strength or stability of vertical sidewalls. Thirdly, finite element model studies revealed a thermal kinematics problem between adjacent panels. With the sloped arrangement, adjacent panel sidewalls thermally grow and rotate into each other. Finally, a detailed thermal analysis showed the vertical sidewalls to have adequate thermal performance. As a result, the design configuration has vertical sidewalls which have corrugated flutes to provide stability and impede the flow of gases through the gap between panels during service.

The detail design Figure 1-A, employs a titanium 6Al-4V 4.32 mm (0.170 inch) thick honeycomb inner panel, a 7.11 mm (0.280 inch) thick Inconel 617 honeycomb outer panel with 12.7 mm (0.50 inch) thick Dynaflex and 35.31 mm (1.39 inches) thick Q Fiber Felt sandwiched between the two panels. The Inconel 617 honeycomb panel which was brazed includes two 0.13 mm (0.005 inch) thick skins, honeycomb core, and four side closures. The titanium 6Al-4V honeycomb panel which was Liquid Interface Diffusion (LID) bonded includes two 0.15 mm (0.006 inch) thick skins and honeycomb core.

The honeycomb core for the Inconel sandwich is 1/4 inch cell fabricated from 0.05 mm (0.002 inch thick) Inconel 617 foil. This foil thickness is the thinnest that can be brazed with the very aggressive braze alloy that was used. The cell size and face sheet thicknesses were determined by trade off studies which calculated the minimum weight of the sandwich system for the required strength. The critical strength parameter is intracell buckling. The core height is the minimum required to react the bending moment created by the pressure loads.

The honeycomb core for the titanium sandwich is 3/16 inch cell fabricated from 0.05 mm (0.002 inch) Ti-3Al-2.5V foil. This is the thinnest foil that can practically be LID bonded. The cell size, core height, and face

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LID bonding is a Rohr Proprietary process in which the part interfaces are plated with one or more element which when heated to the proper temperature will melt, creating a short time eutectic melt with the titanium causing a bond to occur across the interface.

sheet thicknesses were determined by the same methods as those for the Inconel sandwich. The results of all stress analyses are discussed in Section 7.3 "Structural Analysis of Full Sized Panel."

The Q-Fiber Felt and Dynaflex were sized based on the predicted temperature range between the honeycomb panels. The Inconel 617 honeycomb panel was sized based on an entry temperature of 1,366°K (2,000°F) and 2 psi external pressure load. The Titanium 6Al-4V honeycomb panel was sized based on the same entry conditions plus the concentrated load near each of the four corner attachment points.

The panels are normally attached to a vehicle by means of a bayonet and clip arrangement (see Figure 2). As shown, the bayonet goes into a clip on an adjacent panel and also through a vehicle clip. Thus each bayonet secures the forward edge of its panel, and the aft edge of the panel in front of it. The panel bayonets and clips are attached to the panels by diffusion bonding and the vehicle clips are mechanically fastened to the vehicle. The panels are installed in shingle fashion. Therefore, if a panel were damaged near the front of the vehicle, it would be necessary to start panel removal from the rear of the vehicle and remove an entire row to reach the damaged panel.

To have more flexibility in removal and replacement of panels on a vehicle, an alternate attachment concept was designed. It is a through-panel fastener concept and is used on a panel at the end of a row of panels. The through-panel fastener allows this end panel to be removed and access to be gained to the adjacent panels. As shown in Figures 1-A and 3, a sleeve structure with a removable cap is internally brazed to the panel and a bolt connects it to the vehicle substructure. The through-panel fastener was designed to transfer loads between the upper and lower panels and at the same time limit the through-panel thermal conductance. The conductance path is limited by the use of a plastic washer under the bolt head and by the small contact area between the bolt and lower panel. In addition, the fastener cavity is filled with fibrous insulation to limit direct radiation.

3/ DESIGN CONDITIONS

A Space Shuttle environment for body point 1300 was used as typical design criteria for this panel. The design point is located on the bottom centerline just aft of the cockpit. The design criteria for this panel included temperature and aerodynamic pressure environments for an ascent and a descent condition. These pressure loads and thermal gradients are tabulated in Table 1.

The ascent condition provided the maximum pressure load (ΔP) on the panel. This load was contractually set at 14 KPa (2.0 psi) ultimate. Accurate determination of a typical pressure load for the panel is difficult because such loads can be associated with complex surface pressure gradients which occur due to shock waves on the vehicle surface. However the 14.0 KPa (2.0 psi) agrees well with that derived during the Reference 7 study. This study included two areas which are also on the underbody of the shuttle and have temperature environments similar to BP 1300. One is designated Area II and is located on the lower aft fuselage. The other is designated Area III and is located on the main landing gear door. The associated surface temperature gradients for the 14.0 KPa (2 psi) design load was conservatively assumed to be the maximum one of either Area II or Area III. This turned out to be Area II and is shown on Page 2-9 of Reference 7 and Table 1 of this report.

The descent condition provided the maximum thermal environment and thermal gradient. The temperature and pressure data tabulated in Tables 2 and 3 were used to calculate the temperature distributions shown in Figure 4. The critical thermal gradient occurred at time = 500 seconds where the outer surface reaches its maximum temperature value of 1900°F. At this time, the inner surface is still relatively cool at 208°F so the maximum temperature gradient exists on the panel. Reference 7 study showed that there are not any pressure loads on the Area II and Area III panels during these elevated temperature exposures. The shock pressures are exerted after the panels have cooled down to near ambient temperature. These two conditions, providing separately the maximum pressure and thermal gradients on the panel, are used in the Section 7.3 structural analysis.

The effects of time at temperature were also considered during the test program and during the stress analysis. Basically, this consideration is that the panels during entry are exposed to 1256° to 1366°K (1800° to 2,000°F) environment for approximately 300 seconds during every flight or approximately 8 hours for 100 flights.

4/ MATERIAL SURVEY

Literature was searched to locate a suitable metal that would retain adequate strength at temperatures up to 1,366°K (2,000°F) for 100 hours. This selection was based on the fact that a 100-mission reuse requirement for TPS for a shuttle type vehicle represents a total life requirement on the order of 10 to 100 hours at elevated temperature.

At elevated temperatures, the short time mechanical properties (F_{tu}, F_{ty}) are still of importance in design, but time-dependent properties become the governing design consideration. Creep strength, metallurgical stability, and oxidation resistance are included in this category. The creep strength of an alloy will determine its high temperature load-carrying ability while oxidation will have to be accounted for by an increase in thickness to maintain the required load carrying capability for the total life. In addition to the above criteria, availability, cost and fabricability have to be taken into account in determining the most suitable alloy. Material in the following gauges were required for this task:

a. 0.051 mm by 102 mm wide (0.002 inch by 4 inches wide)
b. 0.076 mm by 330 mm wide (0.003 inch by 13 inches wide)
c. 0.127 mm by 330 mm wide (0.005 inch by 13 inches wide)

Four alloy families were considered. They are:

a. Precipitation strengthened (PH) super alloys
b. Oxide dispersed alloys
c. Refractory alloys
d. Solid solution strengthened alloys

4.1 PRECIPITATION STRENGTHENED (PH) SUPERALLOYS

Gamma prime, the main strengthening precipitate of Precipation Strengthened Superalloys, starts to become metallurgically unstable after short exposures to temperatures at or around 1,366°K (2,000°F). This instability (overaging or solutioning) is reflected in the degradation of high temperature mechanical properties. This family of alloys must therefore be excluded from consideration. Rene 41 (see Table 4), for example, has been considered in previous studies (Reference 5) as a potential TPS material. The solutioning temperature of Rene 41, however, is 1,338°K (1,950°F). Exposure of this material to 1,366°K (2,000°F) would thus result in a material with extremely low creep strength that would be totally unsuitable.

4.2 OXIDE DISPERSED (OD) ALLOYS

The OD alloys such as thoria dispered (TD) nickel, TD nickel-chromium, and MA 956 [Yttria (Y_2O_3) dispersed] have adequate 1,366°K (2,000°F) yield and creep strengths (see Table 4). However, use of these alloys may result in fabrication and availability problems. MA 956, for example, has only been rolled to 0.012 inch. The TD nickel alloys have over 12-month lead times and cannot be rolled down to the required dimensions indicated in Reference 3 at this time.

4.3 REFRACTORY ALLOYS

Refractory materials such as columbium, molybdenum, and tungsten alloys have more than adequate 1,366°K (2,000°F) yield and creep strengths. However, they are inherently difficult to use in fabrication processes, require a coating to protect them from oxidation at high temperature, and they become brittle at room temperature. Due to the encountered difficulties, this family of alloys is usually considered as TPS material for temperatures above 1,366°K (2,000°F) only.

4.4 SOLID SOLUTION STRENGTHENED SUPERALLOYS

Solid solution strengthened alloys, as the name implies, receive much of their high temperature strength from solute refractory (chromium, molybdenum, tungsten) and cobalt atoms. These atoms strengthen by acting to retard dislocation movement. In addition, these alloys are also strengthened through carbide precipitation.

In selecting a suitable candidate TPS material, one of the most useful sets of data for comparison purposes is the 1,366°K (2,000°F) 100 hour 0.2 percent specific creep strength, which may be derived from the 100 hour 0.2 percent creep strength. Unfortunately, this data is not as readily available for all the potential solid solution strengthened superalloys as is the 1,366°K (2,000°F) 100 hour creep rupture data. The main set of data used in comparing the creep behavior of the differing alloys was therefore the creep rupture data.

A list of candidate solid solution strengthened superalloys is shown in Table 4. As creep strength to weight ratios are important for any high temperature aerospace component, the alloys in Table 4 are listed 1 to 10 in order of their 1,366°K (2,000°F) 100 hour creep rupture specific strength. 1,366°K (2,000°F) and 1,255°K (1,800°F) creep rupture (100 hour) and short time Ultimate Tensile Strength (UTS) results are also shown for comparison.

As can be seen in Table 4, the three alloys that stand out as having exceptional 1,366°K (2,000°F)/100 hour creep rupture specific strength are INCOLOY® 802, INCONEL® 617 and L605. The 1,366°K (2,000°F)/100 hour

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creep rupture strengths of approximately 20 MegaPascals (MPa) (3.0 kilopounds per square inch (ksi)) of these alloys are from 30 percent to over 200 percent greater than the creep rupture strengths of the rest of the solid solution strengthened alloys listed in Table 4. Approximately the same ratios also hold true for the creep rupture specific strengths.

Although INCOLOY 802 can be rolled down to sheet, it is not available commercially in the thin gauges required. Likewise, L605 is unsuitable because:

a. It has poor oxidation resistance [1,255°K (1,800°F)/ 100 hour oxidation loss of 0.0889 mm (0.0035 inch)] (Reference 8), and

b. It contains 53 percent Cobalt which increases costs and lead times.

INCONEL 617 is available in the required gauges and has excellent oxidation resistance. INCONEL 617 was therefore selected as the candidate material.

4.5 INCONEL 617

INCONEL 617 is a solid-solution, Ni-Cr-Co-Mo alloy with an exceptional combination of high temperature strength [100 hour, 1,366°K (2,000°F) 0.2 percent creep strength of 10.3 MPa (1.5 ksi)] and resistance to 1,366°K (2,000°F) cyclic oxidation (References 7, 9, 10, 11, and 12). Due to its exceptional properties, it is currently used in the combustion section of gas turbines. Strengthening of the alloy during exposure to temperature originates primarily from discrete $M_{23}C_6$ precipitates. This phase was found to remain stable at temperatures up to 1,366°K (2,000°F).

INCONEL 617 has good fabricability and formability. Machining and welding are carried out using standard procedures for nickel alloys.

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5/ FABRICATION

5.1 FABRICATION OF HONEYCOMB SANDWICH COUPON TEST SPECIMENS

Specimens of INCONEL 617 were fabricated for testing in:

a. Face sheet tension
b. Creep
c. Edgewise compression
d. Flatwise tension
e. Pressure/Thermal Gradients
f. Thermal conductivity.

All honeycomb sandwich panels were fabricated 7.1 mm by 304.8 mm by 304.8 mm (0.280 inch by 12 inches by 12 inches) and subdivided into the appropriate test specimen sizes. A modified brazing/diffusion bonding process was used for joining the INCONEL 617 honeycomb panels. The process consisted of applying braze alloy (1.97B-0.02C-13.13Cr-3.4Fe-Ni Balance) approximately 40 grams per square foot to one side of each face sheet, and installing 6.35 mm (0.250 inch) cell honeycomb core between the face sheets for joining.

The layup was placed on a flat reference in a vacuum furnace where 0.14 kilograms (0.3 pounds) per square inch of tungsten pellets were added on top of the panels to provide pressure for brazing and diffusion bonding. The furnace was then evacuated to 1 X 10^{-4} torr and heated to 1,450°K (2,150°F), held for three minutes, then cooled to 1,311°K (1,900°F) and held for one hour before cooling to 431°K (300°F) and removing from the furnace. After bonding, all honeycomb specimens were evaluated using the ultrasonic through-transmission C-scan method.

5.2 FABRICATION OF FULL SIZE PANELS FOR PRESSURE AND THERMAL CONDUCTIVITY TESTS

INCONEL 617 subassemblies and titanium subassemblies were fabricated separately and then joined in a third assembly process.

5.2.1 FABRICATING THE INCONEL 617 SUBASSEMBLY -- The 0.13 mm by 313.30 mm by 313.30 mm (0.005-inch by 12.334-inch by 12.334-inch) skins were square sheared. The honeycomb core 6.35 mm (0.25 inch) cell by 0.08 mm (0.002 inch) thick foil by 304.8 mm by 304.8 mm by 101.6 mm (12 inches by 12 inches by 4 inches) was fabricated using a Rohr Coremaster machine. The 101.6 mm (4-inch) log was subdivided into 304.8 mm by 304.8 mm by 7.11 mm (12-inch by 12-inch by 0.280-inch) pieces using an electric discharge saw and a conventional mill and belt sander.

The side closures were formed on the 195-255 form tool as shown in Figure 5 and then hand trimmed. Since INCONEL 617 is relatively easy to form at room temperature, the form tool was made of 6061 aluminum. This form tool was machined using the numerical control machining process and then hand sanded to a smooth finish. The parts were formed in an ASEA hydropress. The side closures were formed in two stages. In the first stage, the corrugations were formed in the 195-256-9, -11, -13, and -15 side closures. (See Figure 1B for part numbers.) In the final stage, one insert was removed from each end of the form tool and one insert was added to each side of the form tool for forming the end flanges on the -13 and -15 side closures. Figure 6 shows the finished form tool and tool proof parts.

All parts were process cleaned in a pickling solution of nitric/hydrofluoric acid before assembly. The parts were assembled with braze alloy (1.97B-.020C-13.13CR-3.45Fe-Ni Balance) applied at all interfaces as shown in Figure 7. All components were resistance spot tack welded together at each joint. This made the assembly shown in Figure 8 self supporting for brazing/diffusion bonding. Brazing/diffusion bonding was accomplished in a vacuum furnace at a pressure of 1 X 10^{-4} torr and temperatures of 1,450°K (2,150°F) for three minutes, then cooled to 1,311°K (1,900°F) and held for one hour. After bonding, all honeycomb-core-to-skin joints were evaluated using the ultrasonic through-transmission C-scan method.

5.2.2 FABRICATING THE Ti-6Al-4V SUBASSEMBLY -- The Ti-6Al-4V skins were designed with flanges on two sides of each skin which close out the sides of the Ti-6Al-4V subassembly. Due to this configuration and the thin gage 0.15 mm (0.006 inch) material, a superplastic forming process was selected. The superplastic forming tool shown in Figure 9 was designed to form the outer and inner skins simultaneously. Forming was accomplished in a vacuum furnace where a protective environment could be provided while forming the thin gage titanium.

C1020 steel was selected as the tooling material based on the coefficient of thermal expansion and the small number, approximately 25 each, of parts required for this program. Figure 9 shows tool proof parts being removed from the tool.

The honeycomb core was fabricated in a log of 304.8 mm by 304.8 mm by 101.6 mm (12 inches by 12 inches by 4 inches) by 4.7 mm (0.18 inch) cell size by 0.05 mm (0.002 inch) foil gage, using the Rohr Coremaster machine. The core log was then subdivided into 4.3 mm (0.17 inch) thick pieces. The core was plated for LID bonding using a Rohr proprietary process.

Final cleaning was accomplished by immersion in a vapor degreaser. LID bonding was accomplished in a vacuum furnace that was evacuated to 1 X 10^{-5} torr. The part was heated to 1,213°K (1,725°F) and held for a period of time while LID material was being diffused into base material to make the joints. After bonding, all honeycomb core to skin joints were evaluated using the ultrasonic C-scan method. Figures 10 and 11 show the completed titanium subassembly.

5.2.3 JOINING THE SUBASSEMBLIES -- The flanges of both subassemblies were prepared for LID bonding of the bi-metal joint using a Rohr proprietary process. After preparation for LID bonding, the INCONEL 617 subassembly was filled with 12.7 mm (0.5 inch) of precut DYNAFLEX and 35.3 mm (1.39 inch) of precut Q-FIBER FELT, as shown in Figures 12 and 13. After the DYNAFLEX and Q-FIBER FELT had been installed, the titanium subassembly shown in Figure 10 was installed over the Q-FIBER FELT. The flanged areas of both subassemblies were then resistance spot tack welded to each other for LID bonding. Since the subassemblies were resistance spot tack welded to each other, the assembly was somewhat self-fixturing. Only a flat reference surface was required to support the panel for LID bonding. Figure 14 shows the assembly being laid up for LID bonding the bi-metal joint. Figures 15 and 16 show a completed bi-metal panel with bayonet/clip attachments.

The 59.7 mm by 304.8 mm by 304.8 mm (2.35-inch by 12-inch by 12-inch) panel with clips and tongues weighed 0.926 kilograms (2.04 pounds). The same size panel with only through-panel fasteners weighed 0.898 kilograms (1.98 pounds). All panels were checked dimensionally and visually for defects.

The 195-254 through-panel fastener (Figure 3) is fabricated as a braze/diffusion bonded assembly. The base, flange and housing are fabricated using a standard production type blank die. The threaded insert and cap are machined using a hand screw machine (turret lathe). The parts are cleaned for brazing using a degrease solution. These parts are then assembled and resistance spot tack welded into position. Braze alloy (1.97B-0.02C-13.13Cr-3.4Fe) is applied at each joint and the assembly is placed in a vacuum furnace with the flange side down for braze/diffusion bonding at 1,450°K (2,150°F). Only a visual inspection is required to determine quality.

5.2.4 FABRICATION OF PANEL ARRAYS -- A twenty-panel array, a two-panel array, and three separate panels were fabricated and delivered to NASA Langley Research Center for further testing.

5.2.4.1 Twenty-Panel Array -- The twenty-panel array was designed to fit an existing 1078.5 mm by 1523.0 mm (42.46-inch by 59.96-inch) opening in the test apparatus for the 8-foot High Temperature Structures Tunnel. The basic panel size is 304.8 mm by 304.8 mm (12.0 inches by 12.0 inches). Therefore, three panels of 284.2 mm by 304.8 mm (11.19 inches by 12.0 inches), one panel of 284.2 mm by 149.4 mm (11.19 inches by 5.88 inches) and four panels of 304.8 mm by 149.4 mm (12.0 inches by 5.88 inches) in addition to twelve basic panels were required to fill the test fixture. An individual panel is shown in Figure 16 and the twenty-panel array is shown in Figure 17.

The panel joints were aligned with the flow so that gas flow in the joints could be studied during tunnel tests. The array of panels were attached to a 4.8 mm (0.190 inch) thick plate, shown in Figure 18, which represents the mass of the shuttle fuselage structure at the design location, body point 1300.

Panel fabrication was accomplished using the process parameters described in Section 6. The panels were processed six at a time, as shown in Figure 19. The quantity was governed only by the available furnace size.

All honeycomb subassemblies were evaluated using the ultrasonic through-transmission C-scan method. All subassemblies and final assemblies were checked dimensionally for conformance to the drawing. The final assemblies, such as that shown in Figure 15, were pressure checked in an unrestrained position to 14 KPa (2 psi) internal pressure.

To pressure check the panels a Meriam manometer using Meriam 295 Red Fluid (2.95 specific gravity), shown in Figure 20, was used. A regulator in the airline was used to prevent the panel from being over-pressurized when the flexible tygon line was placed over the vent hole in the lower panel.

Evaluation showed some panels to have intracell dimpling of the face sheets. This was not considered to be a structural problem since some of the specimens tested and reported in Section 7 had intracell dimpling and had acceptable test results.

5.2.5 INSTRUMENTATION -- The 20-panel array and the 2-panel array were instrumented with Type K thermocouples. INCONEL sheath was used where the temperature was expected to be above 1,255°K (1,800°F) and 30 gage fiberglass sheath couples were used in areas where the temperature was expected to be below 1,255°K (1,800°F). Five INCONEL sheath type couples were installed inside an INCONEL 617 subassembly before final assembly. This panel was installed at the 2-C location in the 20-panel array. Figures 21 and 22 show the thermocouple layout for both arrays.

5.2.6 INSTALLATION -- The panels having clips and tongues as means of attachment were somewhat more difficult to install on the aluminum plate than the panels having through-panel fasteners. This was due to having to compress the NOMEX felt, which was coated with RTV rubber, while sliding the tongue into the clips. The 20-panel array had pressure probe connections installed in seven places, as shown in Figure 21. The pressure probes were located to detect pressure buildup between the aluminum plate and the bottom side of the panels during tunnel tests.

Three additional panels were mounted on individual 4.8 mm (0.19 inch) thick plates. These plates each had NOMEX felt installed between the panel and the plate, but had no instrumentation. These panels were interchangeable with other panels in the 20-panel array.

6/ THERMAL PERFORMANCE

The procedure followed for the thermal analysis was:

a. Entry conditions were used for shuttle body point 1300 and a transient thermal analysis was run to size insulation thickness, (i.e., design of overall tile thickness).

b. Steady-state temperatures were measured across manufactured tiles. Measured hot and cold face surface temperatures were used and a steady-state thermal analysis was performed to predict temperatures and effective conductivity, and to correlate them with test values.

6.1 TRANSIENT ANALYSIS TO DETERMINE PANEL THICKNESS

Figure 23 represents the thermal math model used in the MITAS lumped parameter thermal analysis computer program (Reference 13) to size the insulation thickness of the tile. The temperature and pressure histories shown in Tables 2 and 3 for shuttle body point 1300, trajectory 14414.1C were supplied by Langley Research Center as a starting point for the thermal analysis. Thermophysical properties of the INCONEL 617 honeycomb, DYNAFLEX®, Q-FIBER FELT®, titanium honeycomb, and aluminum used in the analysis are provided in Tables 5-8, respectively.

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Q-FIBER FELT is a registered trademark of Johns-Manville Corp., Denver, Colorado.

Because the external pressure varies with time, the insulation thermal conductivity was allowed to vary with pressure in addition to the usual temperature variation. The resulting maximum temperature of the aluminum plate was determined from a transient analysis for various cases, with a different, arbitrarily selected, thickness of insulation. To ensure that stored energy at the end of entry does not continue to heat the aluminum structure, the given temperature and pressure histories were extended to 2,000 seconds. Because the Q-FIBER FELT has a temperature limit of 1,255°K (1,800°F), care was taken in the analysis to ensure that this limit would not be exceeded.

During the early computer runs, the temperature at point 28 of the math model was monitored and evaluated as a function of DYNAFLEX and Q-FIBER FELT thicknesses. From this it was determined that a 12.7 mm (0.5 inch) thickness of DYNAFLEX would keep the insulation interface below 1,255°K (1,800°F). The remaining analyses, therefore, had the DYNAFLEX thickness fixed at 0.5 inch, but used various Q-FIBER FELT thicknesses.

Typical results of the transient analysis are shown in Figure 23, where temperature responses are shown for the case where the total thickness of the tile is 55.9 mm (2.35 inches). For this case the insulation interface was 1,117°K (1,550°F) and the maximum temperatures of the aluminum was 439°K (330°F). The maximum temperature of the aluminum for three insulation thicknesses is shown in Figure 24. Extrapolation of this data to 454°K (350°F) establishes a required thickness of 58.4 mm (2.3 inches). Because the TPS thickness was selected at an early stage in the program, the tile design thickness of 59.7 mm (2.35 inches) was not changed.

6.2 STEADY-STATE ANALYTICAL PREDICTION AND CORRELATION OF TEMPERATURE DISTRIBUTION AND EFFECTIVE CONDUCTIVITY WITH THE TEST RESULTS FOR THE BI-METAL THERMAL PROTECTION SYSTEM

6.2.1 TESTS -- Thermal conductivity tests were performed using a modified guarded hot plate shown in Figures 25 and 26. The hot plate has quartz lamps that are divided into three independent heating zones;

control, 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 double guarded system. This minimizes any radial heat flow away from the central test section. Min-K, having a known thermal conductivity, was used as a test standard to calibrate the test apparatus and run thermal conductivity tests.

The test panels are shown in Figures 27 and 28. The test setup shown in Figure 29 was used for checking thermal conductivity of the superalloy panel. The test panel was placed on top of a honeycomb panel and the known thermal conductivity instrumented Min-K was placed on top of the test panel. The honeycomb panel was used as the "Hot Plate" to provide a more uniform heating of the test specimen. The honeycomb panel was instrumented with thermocouples, the outputs of which were fed into the automatic control circuit in order to maintain the test temperature. The test panel was instrumented with thermocouples that were welded onto both sides of the panel surface at the center, midway between the center and edge, and at edge locations. Because of the physical nature of the Min-K, thermocouples could not be attached directly to its surface. Therefore, thermocouples were put on small INCONEL 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 setup. Thermocouple plan-form locations on the Min-K were the same as for the test panel.

6.2.2 ANALYSES

-- Measured boundary temperatures obtained from the steady-state thermal conductivity tests were used as boundary conditions in thermal analyses to predict the temperature distribution of a 304.8 mm by 304.8 mm (12- inch by 12-inch) bi-metal TPS tile.

Figure 30 represents the thermal math model used for the analysis. The model differs from the transient model in that it includes a cold face boundary, Min K insulation, no primary structure, and no gap radiation.

The thermophysical properties used for the analysis are presented in Tables 5 through 9. Since the test was conducted at sea level pressures, only the 2,116 pounds per square foot (1 atmosphere) were used.

Results

Steady-state computer runs were performed using, as boundary temperatures, the measured temperatures of the hot face (node 1) and cold face (node 17). The analytical temperature of node 13 (cold side of the titanium honeycomb) was compared with the measured temperature. Two sets of computer runs were performed, one without sidewall to predict the temperature in the center of the tile, and another with a sidewall to predict the temperature adjacent to the sidewall. The transient model and the original steady state model had the sidewall conducting directly from node 1 to node 13. It was necessary to change the model only for one steady state solution. That is, measurements along a line directed from hot face to cold face and through the tile center could be correlated without sidewall conduction in the thermal model. Measurements near the sidewall needed the addition of sidewall conduction retained in the thermal model to obtain a close correlation. Table 10 presents the boundary temperatures used and a comparison of the predicted and measured temperatures for node 13.

Figure 31 presents the percent error of the predicted temperatures versus measured temperatures. For the area above the zero percent line, the analytical model predicts higher temperatures and is, therefore, conservative. Based on that error, a 452°K (350°F) analytical predicted temperature for the cold face of the titanium honeycomb will have an actual temperature of 447°K (344.8°F). Based on the sidewall error curve, the cold face of the titaninum honeycomb will be 422°K (335.7°F). In the actual case, the aluminum structure diffuses the temperature so that actual temperature will be somewhere between the two.

Figure 32 presents the effective thermal conductivities (calculated from temperatures obtained from the test data and from temperatures obtained from the thermal math model) as a function of mean temperature at the center of the panel.

The center measured temperature differences (ΔT) and thickness (ℓ) of the test specimen (TS) and Min-K (MK) were used to calculate the effective thermal conductivity (k) as follows:

Since

$$Q/A = \frac{k_{TS}}{\ell_{TS}} \Delta T_{TS} = \frac{k_{MK}}{\ell_{MK}} \Delta T_{MK}$$

Then

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

The conductivities k_{MK} and k_{TS} are evaluated at the arithmetic mean temperatures,

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

and

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

It is noted there is very little difference between analytical and measured K's thereby indicating that the analytical model is very good.

The through panel fastener, Figure 3, was designed for low heat transfer by ensuring that the three modes of heat transfer were minimized. To block radiation and restrict air convection, fibrous insulation, DYNAFLEX®, was placed within the cavity of the fastener. In that way DYNAFLEX's very low thermal conductivity is substituted for those two terms. Therefore, the heat transfer becomes primarily a conduction problem. Metal conduction was minimized by keeping the cross-sectional area (the conducting area) normal to the panel axis small, i.e., fastener conduction area/panel total area is a small value. The maximum number of fasteners per panel is four. So, for a panel that is 304.8 mm by 304.88 mm, the conduction area ratio is four times each fastener conduction area/(304.8 by 304.8). This is (4Π) (14.478) (0.127)/(304.8 by 304.8) = 0.00025. The effective thermal conductivity of a panel with fasteners, k_{TWP}, may be approximated by $k_{TWP} = 0.00025\ k_p + (1 - 0.00025)k_T$ where k_p is fastener material conductivity and k_T is panel thermal conductivity.

The CERACHROME® contribution is not included because its conductivity is nearly the same as k_T.

This equation may be rewritten as

$$(k_{TWP}/k_T) = 0.00025\ (k_p/k_T) + 1 - 0.00025$$

At 900F (482.2C), k_p = 11.92 Btu/hr ft f(20.6228 w/mk)
and from Figure 32 k_T = 0.07 Btu/hr ft F (0.1211 w/mk)

Thus

$$(k_{TWP}/k_T) = 0.00025\ (11.92/0.07) + 1 - 0.00025$$

$$(k_{TWP}/k_T) = 1.04$$

i.e., a maximum increase of 4.0 percent would be expected for the panels' k.

Based on these test results, the thermal conductivities used in the thermal math model are considered acceptable for future thermal analyses.

7/ STRUCTURAL PERFORMANCE

7.1 GENERAL

The purpose of the structural evaluation program was twofold:

a. To provide basic mechanical properties of the brazed INCONEL 617 sandwich.

b. To predict and verify the structural performance of the panel design and manufacturing processes.

7.2 MECHANICAL PROPERTIES OF INCONEL 617 HONEYCOMB SANDWICH

The basic mechanical property testing was performed on coupon size specimens while the structural and thermal performance verification was performed on a full size panel. The full size panel tests verify that the panel is able to withstand a realistic simultaneous pressure load and temperature environment. The coupon test quantifies the strength properties of the material system and verifies that the panel met all of the design requirements. An outline of the test program with the number of specimens involved is provided in Table 11.

During the coupon testing, face sheets and sandwich structures with various gages (including the final design configuration) were tested. Specimens were ultrasonically C-scanned prior to testing. Specimen locations were marked on the C-scans and the panels. Photographs were taken of the panels for a permanent record of their location. Each specimen was identified by a number/letter combination that related it to the panel from which it came and to the type of test that was performed on it.

The remainder of this section provides details of all of the testing. These details include a description of:

a. Test specimen configuration
b. Test apparatus and procedures
c. Test results.

7.2.1 FACE SHEET TENSION TESTS -- Tests were conducted to determine the basic mechanical properties of INCONEL 617 foil material as received and after being subjected to various conditions. These conditions included:

a. Processed/brazed to honeycomb core
b. Pretest exposure to 1,366°K (2,000°F) for either 5 or 25 hours.

Test temperatures varied from room temperature to 1,366°K (2,000°F). The following mechanical properties were determined:

a. Yield (Fty) and ultimate (Ftu) stress
b. Percentage elongation (e)
c. Modulus of elasticity (E).

The modulus of elasticity values were measured from load - deflection curves that were plotted in conjunction with a linear variable differential transformer (LVDT) and with the Instron test machine.

The specimens, except for the as-received specimens, were cut from brazed INCONEL 617 honeycomb sandwich panels. The honeycomb core was removed from the face sheets with a high speed grinder. The overall specimen size was 2 inches by 10 inches with a 1-inch wide test section. Two thicknesses were tested: 0.076 mm (0.003 inch) and 0.127 mm (0.005 inch).

The test program and results are summarized in Figure 33 and in Tables 12, 13, and 14. The groupings are by duration of pretest 1,366°K (2,000°F) exposure. These are respectively: none, 5 hours and 25 hours. The pretest thermal exposure was performed to determine the degradation of material properties over the life of a panel. It has been estimated that these panels would be exposed to 1,256° to 1,366°K (1,800° to 2,000°F) environment for approximately 300 seconds during every flight or approximately 8 hours for 100 flights. This duration was conservatively bracketed by the 5 and 25 hour exposure times and using the upper temperature value of 1,366°K (2,000°F). The atmosphere used for this exposure was sea level air -- a conservative condition since most entry heating occurs at a high altitude.

The test specimens were separated from the core prior to exposure. The effects of this pretest exposure are discussed in subsequent paragraphs and are also illustrated metallographically in Figures 34 through 36. Figure 35 shows the typical microstructure of the INCONEL 617 alloy in the solution-annealed condition. Figure 35 shows the foil after being brazed to honeycomb core and being exposed for 5 hours at 1,366°K (2,000°F). The rough upper surface is braze alloy. A very thin gray layer on the surfaces indicates an oxidation film. Dark lines and spots indicate the beginnings of intergranular oxidation. Figure 36 is the same except the exposure duration of 1,366°K (2,000°F) temperature has been increased to 25 hours. The oxidation film has increased in thickness and the intergranular oxidation is significantly greater.

Table 12 summarizes the testing on specimens that had not been subjected to pretest thermal exposure. The yield and ultimate strength values are comparable to, or slightly higher than, published data. The percent elongation of the as-received material is considerably lower (12 percent versus 31 percent) than the values on the material certification sheets that were produced by the material vendor. Subsequent investigations showed that if the test specimens are more carefully prepared (to ensure failures in the two-inch test area) and load rates are reduced to 0.51 mm (0.02 inch) per minute crosshead speed, elongation values increase from 12 percent to 34 percent.

Tables 13 and 14 summarize the testing on specimens with 5 and 25 hours of 1,366°K (2,000°F) pretest thermal exposure, respectively. These exposures have only a moderate impact on the yield strength values. However, the ultimate strength and the percent elongation values continue to decrease with the duration of pretest exposure. The reduction stabilizes at 1,366°K (2,000°F) and the number of hours of exposure does not affect these test values. Therefore, the pretest exposure durations are most critical for room temperature mechanical properties. Figures 37 and 38 display this point graphically. Percent elongation values show the same trend.

7.2.2 CREEP TESTS -- Tests were conducted to determine the long term strength of INCONEL 617 foil material when exposed to elevated temperature and sustained stress levels. The test matrix is shown in Table 15. As shown, the testing included temperatures from 1,089° to 1,366°K (1,500° to 2,000°F) and foil conditions of as-received and processed/brazed-to-honeycomb core.

The initial test specimen configuration was 6.4 mm (1/4 inch) wide by 51 mm (2 inches) long by 0.08 mm (0.003 inch) thick. This specimen proved to be adequate at the 1,089°K (1,500°F) test temperature condition; however at 1,366°K (2,000°F) it produced widely scattered results which are not reported. The reason for the scatter is believed to be related to the small size of the test specimen and the resulting small load requirements. The specimen size was then substantially increased to 19 mm by 76 mm by 0.08 mm (3/4 inch by 3 inches by 0.003 inch) for all 1,255°K and 1,366°K (1,800°F and 2,000°F) testing. The test setup is shown schematically in Figure 39 with an overall photograph in Figure 40. Note that specimens are dead weight loaded and that creep deflections are automatically plotted as a function of time. The larger creep specimen, along with three thermocouple probes, is shown in Figure 41.

The test data is tabulated in Table 16 and is shown in the Larson-Miller plots in Figure 42. The total elevated temperature life of the structure is estimated to be 8 hours for 100 missions (See Section 7.2.1) with a maximum temperature of 1,311°K (1,900°F). For the purpose of comparing this test data with actual stress-temperature conditions, specific stress and temperature points are provided. This comparison conservatively treats the total eight hours as occurring at each temperature point examined.

7.2.3 EDGEWISE COMPRESSION TESTS

These tests were conducted to evaluate the ability of thin foil gages to carry significant compressive loads. These thin gages, when bonded into sandwich structure, do have some initial waviness. Therefore, it had been theorized that these sheets were already in a buckled condition and as such would be unable to carry any significant compressive loads. The tests completely disproved this theory because ultimate compressive stresses of considerable magnitude were measured.

The test specimens were brazed INCONEL sandwich with a square cell core that had a height of approximately 7.1 mm (0.280 inch). The specimens were 76 mm (3 inches) wide and 89 mm (3.5 inches) long in the direction of the applied load. The ends of the specimens were potted with an acrylic compound to provide local support and uniform load application. The specimens with 0.08 mm (0.003-inch) thick face sheets had considerably more initial face sheet waviness than those with 0.13 mm (0.005 inch) face sheets.

The test program and results are tabulated in Table 17. The specimens were tested in accordance with ASTM C364. The failure mode for all specimens was intracell buckling, which is to be expected for a sandwich with thin face sheets and large ratios of cell size to face sheet thickness. Figure 43 plots the test results versus analytical results. This figure shows that there is close agreement for the 0.13 mm (0.005-inch) face sheets. However, the test results for the 0.08 mm (0.003-inch) face sheets are approximately 30 to 75 percent higher than the analytical results.

The analytical results are from an intracell buckling equation (See equation C12.5.1 of Reference 18) which was developed from tests of standard sandwich specimens and almost certainly never involved these foil type gages. Therefore, the discrepancy between analytical and test results is attributable to inaccuracy in the analytical method when dealing with large ratios of cell size to face sheet thickness and large ratios of braze alloy to face sheet thickness. Consequently, the analysis conservatively underestimated the specimen load carrying capability.

7.2.4 FLATWISE TENSION TESTS

Flatwise tension testing is a standard method of assessing the process procedures of the bonding operation. The results are not directly used in the stress analysis but they do provide a means of comparing the strength of various bonded joints. The data presented includes room and elevated temperature data on both environmentally exposed and unexposed specimens. The environmental exposure was in a 1,366°K (2,000°F) air furnace for either 5 or 25 hours. The test setup for room temperature testing is shown in Figure 44. The test setup for elevated temperature testing is shown in Figure 45.

The test plan is shown in Tables 18A and 18B. As shown, some of the E panel specimens received a pretest thermal exposure. As in the case of the face sheet tension tests, this exposure was performed to determine the degradation of material properties over the life of a panel. It has been estimated that these panels would be exposed to 1,256° to 1,366°K (1,800° to 2,000°F) environment for approximately 300 seconds during every flight or a total of approximately 8 hours for the 100-flight design life. This duration was conservatively bracketed by the 5 and 25 hour exposure times at 2000°F. There were several conservative procedures used during this pretest exposure. They include:

a. A 1,366°K (2,000°F) exposure (the upper temperature limit)
b. A test atmosphere of sea level air (actual exposure will be at elevations where there is rarefied atmosphere)
c. Exposing the separate 76 mm by 76 mm (3-inch by 3-inch) specimens rather than an entire panel with edge closures which would protect the interior part of the panel.

Another feature of the test program was room temperature and elevated temperature testing. The room temperature specimens had loading blocks adhesively bonded to them. The elevated temperature specimens had the loading blocks brazed to them using 1.97B-0.02C -13.13Cr -3.4 Fe braze alloy at 2175°F. This process did not interfere with the sandwich brazed joints.

The first panels that were fabricated for these tests were designated AFT and GFT. As defined in Tables 18A and 18B, they had 0.08 mm (0.003 inch) face sheets and 4.6 mm (0.1875 inch) cell core. C-scans of these panels showed varying degrees of bond quality. In order to correlate C-scan readings with joint strength, the panels were cut into specimens and tested. Test specimen numbers and results were recorded on the C-scans. As a result, a high degree of correlation was identified between the C-scans and the flatwise tension strengths. Those specimens that showed low quality bonds in the C-scans had considerably less strength (on an average of 1/3 to 1/2) than those without disbonds. The disbonds in these panels were attributed to early development problems in the manufacturing process. The test results for these panels are not included in this report. The E panel, which was fabricated subsequent to the A and G panels, had ideal C-scans. The configuration of the E panel is identical to the production panel design (0.005 each face sheets and 0.25 inch cell core). Only the results of E panel flatwise tension tests are reported here.

The room temperature test results for the E panel specimens are tabulated in Table 19 and plotted graphically in Figure 46. The reduction in strength after exposure to 1,366°K (2,000°F) is attributed to oxidation of the core and not to oxidation of the braze joint. This conclusion is supported by the failure modes and photomicrographs of the joints. In fact, some of the 25 hour exposed core had failed locally prior to loading due to the exposure. The failure mode for the unexposed specimens was 100 percent in the brazed joint while the exposed specimens had large areas of core failure. Figures 47 through 49 show the brazed joint of a core cell wall and a face sheet after various amounts of 1,366°K (2,000°F) exposure. It is evident that the cell wall is being attacked much more severely than the braze joint. It should be noted that even the core in the center of the specimens was oxidized. The air passageways are through the cell nodes which are spotwelded together.

The elevated temperature results of testing specimens from the E panel require a special explanation. The low results shown in Table 19 are the result of extenuating circumstances. After 25 hours at 1,366°K (2,000°F), the 76.2 mm by 76.2 mm (3-inch by 3-inch) specimens were severely warped as well as oxidized. This warpage could have been alleviated by subjecting a large panel to the exposure instead of the small 76.2 mm by 76.2 mm (3-inch by 3-inch) specimens. For room temperature tests, this warpage does not cause any great problems because additional adhesive can be added to fill gaps between the loading blocks and face sheet. However, the elevated temperature specimens require that loading blocks be attached by brazing alloy, which can not fill large gaps like the adhesive. Consequently, during the test, there was uneven loading and local separation of the face sheets from the loading blocks. These test conditions and results must be considered unrealistic to any actual service operation.

As stated previously, flatwise tension results by themselves are not a normal part of the stress analysis. However, they provide a means to evaluate the effects of other parameters on joint integrity. In this test it has been shown that a 1,366°K (2,000°F) exposure in an oxygen rich atmosphere over a period of time has a significantly deleterious effect on the sandwich structure. However, the conservative nature of the testing has measured reductions that far exceed those which would result from the flight design life.

7.3 STRUCTURAL ANALYSIS OF FULL-SIZE PANEL

7.3.1 FINITE ELEMENT MODEL -- A finite element model of the entire panel was constructed in order to determine the internal stresses and external deflections for the design conditions discussed in Section 3.0. The model, shown in Figure 50, has approximately 390 nodes. The coded model input sample is shown in the appendix. The computer program selected for the analysis was NASTRAN. The selection was based on the fact that this program has industry wide acceptance and use, and Rohr has extensive experience with it. The upper INCONEL sandwich and the lower titanium sandwich panels were modeled using one inch by one inch panel elements which are defined as CQUAD4. CQUAD4 panel elements are special plate members that represent sandwich structure. The sidewalls were modeled as a combination of two different elements. These elements are CSHEAR, to represent the sidewalls capability to react shear loads, and pinned CBAR members, to represent the beam-column load capability of the corrugated flutes. The clip and bayonet attach fittings are modeled as rod members as shown in Section A-A and B-B in Figure 50. Rods were selected so there would not be any bending capability in these supports. In addition, the rods were given an axial stiffness which was determined from a full panel pull test. Subsequently, the pressure and thermal gradients described in Section 3.0 were applied to the model. The stress levels are discussed below and the deflection values are discussed in Section 7.4 of this report.

7.3.2 STATIC STRESS ANALYSIS -- The calculated stresses, for the two ascent conditions and the one descent condition, are shown on Figures 51-A through 51-F. These stresses are superimposed on finite element models in order to provide a representation of the stress distributions within the panels. The panels have two center lines of symmetry, therefore only a quarter of the panel is required to define the internal stress distributions. The stresses shown on the INCONEL and titanium honeycomb are principal major or minor stresses with (+) representing tension and (-) compression. The stresses shown on the sidewalls in parentheses are shear stresses and the other sidewall stresses are axial loads in the bars representing the corrugations.

The all positive margins of safety for the critical stresses from these conditions are tabulated in Tables 21A and 21B. Included in these tables are allowables for the INCONEL and titanium honeycomb, INCONEL sidewalls and the titanium bayonet attach fittings. The critical failure mode for the honeycomb structure is intracell buckling. The allowable curve for the INCONEL is shown in Figure 52. It is based on room temperature test data from edgewise compression tests (Table 17), and temperature reduction factors based on modulus of elasticity (E). The E values were generated during the mechanical property testing and are averages of specimens pretest exposed to 5 hours of 2000°F and those exposed to 25 hours of 2000°F (see Figure 38). The titanium honeycomb allowable, shown in Figure 53, is based on equations in Reference 17. The INCONEL sidewall, which was found not to be stability critical, has allowables based on F_{ty} shown in Figure 37 . The value used is an average between the curves for 5-hour and 25-hour pretest exposure of 2000°F. The titanium bayonet fittings have allowables based on MIL-HDBK-5D values for Ti-6Al-4V.

In conclusion, the successful structural panel testing verifies the analysis and the integrity of the panel.

7.4 THERMAL/PRESSURE TESTS ON FULL-SIZE PANEL

7.4.1 GENERAL -- In order to verify the structural integrity of a total panel assembly, a series of thermal and pressure gradient tests were conducted. A panel assembly, which was fabricated to Rohr Engineering Drawing 195-256, was installed in a test fixture in a manner which accurately simulated installation to a vehicle surface. The test panel, which was instrumented with thermocouples and dial indicators, is shown in Figure 28.

7.4.2 TEST FIXTURE AND INSTRUMENTATION - The test fixture (Rohr Drawing 501-560) is shown schematically in Figure 54. Photographs of the test fixture and instrumentation are shown in Figures 55 through 59. In the schematic, starting at the bottom, there are dial indicators with ceramic dowels which penetrate through the quartz lamps. The quartz lamp bank array is shown in Figure 56. The ceramic dowels, shown protruding through the lamps, must penetrate a water chamber which circulates water to cool and protect the aluminum support plate. Surrounding the lamp bank (not shown in Figure 54 but shown in Figure 55) is a rectangular, gold-plated reflecting shield which keeps the heat in and on the panel.

A completely independent and separate assembly is suspended above the lamp assembly. This assembly contains:

a. The test panel
b. Mounting clips
c. Seals
d. A pressure chamber to load the panel.

The test panel has its exterior surface exposed directly to the lamp array. The panel is clipped into the base of the pressure chamber. Figure 57 shows this chamber in an inverted position and without the cover plate. Note that the clips and bayonet fittings for the normal mating structure are included.

Also shown in this figure and in the schematic of Figure 54 are two different seals. The design and function of these silicone seals is very important. The seal on the outer perimeter simulates the NOMEX® pad that would be installed on the shuttle vehicle. This pad is compressed during panel installation and provides a tight fit for the panel. It also reacts crushing pressure loads that push the panel against the vehicle. The test seal is purposely not bonded to the panel so that it will not inadvertently react blowoff pressure loads that pull the panel away from the vehicle.

The inner seal is referred to as the flap seal. It provides the seal to the pressure chamber. As such it must be bonded to the panel but also must not react any blowoff loads. This is possible because of the seal design. The seal is L-shaped and, since it is made from silicone rubber, does not have any bending stiffness. Consequently, the seal is incapable of reacting load and therefore all loads go through the clips as they should. Figures 58 and 59 show views of this seal as it attaches to the bottom of the panel. Also note the holes in the panel. The holes assure that all pressure gradients will be across the outer INCONEL sandwich structure. These holes are not part of the panel design but are incorporated in the test to accommodate rapid pressure changes that could take place during the test but not during actual flight conditions. The final part of the fixture is a cover plate which is bolted on. A vacuum pump provides crush pressure and an external air supply provides blowoff pressure. Both are monitored by a pressure gage.

Figure 55 shows, on the far left, a Thermac Controller (Research Incorporated) which regulates power to the quartz lamps. To the right of this is a Fluke Data Logger which records the temperatures from the thermocouples.

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7.4.3 TEST PROGRAM AND RESULTS -- The testing was performed according to the six conditions outlined in Table 22. The intent of the program was to cover as many possible design conditions as practical and to do so in a conservative manner. Note that the critical design conditions described in Section 3.0 are met or exceeded by these test conditions. The ascent design conditions listed in Table 1 is exceeded by test conditions V and VI and the descent design condition is approximated by test Condition IV. At the time of the test, the precise temperature gradient had not been calculated. In this test program, the design ultimate burst and crush pressures were initially applied at room temperature. Subsequently the panel was subjected to the maximum 1,366°K/477°K (2,000°F/400°F) temperature gradient without pressure loads. Next, the design ultimate burst pressure load was applied in combination with a conservative temperature gradient (a higher temperature gradient than that expected in combination with pressure) of 812°K/311°K (1,000°F/100°F). After successfully passing this severe condition, the loading was increased to determine the margin of safety. At 25 KPa (3.6 psi) an air leak occurred at two of the corners of the panel and the testing was terminated. Other than these small holes at the two corners there was no discernible damage to the panel.

The panel was repaired by placing a 0.08 mm (0.003 inch) thick piece of INCONEL 617 foil over the holes. Resistance spot welds were then made between the foil and the panel to close the holes. The panel was re-installed in the test fixture, heated to the 812°K (1,000°F)/311°K (100°F) temperature gradient, and pressurized to 25 KPa (3.6 psi) at which time a pressure drop was again noted. The panel was removed and evaluated. A failure in the INCONEL 617 side closures at the titanium 6Al-4V intersection as shown in Figures 60 and 61 was noted. Tack welds used to stabilize the panel during LID bonding held when the bonded area between tack welds separated causing small tears in the side wall. Since the failure was primarily in the base material, no other attempt was made to repair the panel.

The heat-up rates on the test panel were controlled and were those calculated for an entry condition for body point 1300. These temperatures were monitored during heat-up and during load application. Table 23 shows the temperatures for various burst pressure loads. The results verify the consistent and uniform temperature gradients that were established throughout the panel.

Figure 62 plots the deflections at the center of the top surface of the panel versus applied pressure loads. For the severe test condition of 14 KPa (2 psi) burst pressure plus 811°K/311°K (1,000°F/100°F) temperature gradient, the deflection at the center of the panel was 4.0 mm (0.156 inch): 1.5 mm (0.060 inch) due to thermal and 2.4 mm (0.096 inch) due to pressure. In order to relate this to panel bow, Figure 63 was plotted. The plot shows deflection values at all 4 corners of the panel, the middle of one side and the center of the panel for the severe condition. The plotted deflections are those due to pressure only and the thermal deflections are presented in tabular form. In order to calculate maximum panel bow (an aerodynamics performance concern), the value of the corner with the smallest deflection is subtracted from the panel center deflection. For the 14 KPa (2 psi) plus 811°K/311°K (1,000°F/100°F) condition, corner number one had the smallest deflection. This value was 1.3 mm (0.051 inch): 0.3 mm (0.011 inch) due to thermal and 1.0 mm (0.040 inch) due to pressure. Therefore, the maximum panel bow for the ultimate design condition was 2.7 mm (0.105 inch). The nonlinearity in the deflection curves above the 14 KPa (2 psi) load is attributed to bending in the clips.

Table 20 presents a comparison of deflections obtained from the test versus those calculated by the NASTRAN finite element model described in Section 7.3. As shown, the analytical procedure underestimated the test results except for the 2 psi room temperature blowoff condition. These higher analytical results are surmised to be from an under prediction of the stiffness of the bayonet support fittings.

In conclusion, the panel design and manufacturing processes were demonstrated by full scale tests to be completely adequate to withstand the design criteria defined in Table 1. Consideration should be given as to whether protective coatings are necessary for the exterior of these panels in order to reduce the oxidation effects of elevated temperatures.

8/ CONCLUSIONS

A metallic reusable Thermal Protection System (TPS) panel with the potential for withstanding 1,366°K (2,000°F) was designed to protect areas of space reentry vehicles where the temperature does not exceed 1,311°K (1,900°F) and the pressure load is no greater than 14 KPa (2 PSI).

Test panels were fabricated using existing production facilities and processes. It was demonstrated that the panels can be mass produced by processing large quantities of parts simultaneously. One array of twenty panels and five extra panels were fabricated and delivered to NASA Langley Research Center for additional Testing. A TPS panel was designed using the thermal requirements for Space Shuttle body point 1300 as representative design criteria. Thermal and structural analyses were performed. Component specimens and full size panels were fabricated and tested to verify the design. Comparison of analytical and test data substantiate the analysis methods and verify the thermal and structural performance of the panels.

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Table 1. Design Criteria - Body Point 1300

LOAD CONDITION	OUTER PANEL			INNER PANEL		
	ΔP (PSI) ULTIMATE	T OUTER SURFACE °F	ΔT °F	ΔP (PSI) ULTIMATE	T INSIDE SURFACE °F	ΔT °F
Ascent	± 2.0[a]	650[b]	50[c]	0.0[d]	100[c]	0[c]
Descent	0.0[e]	1900[f]	31[f]	0.0[c]	208[f]	24[f]

a) This value is a contractual requirement and can be either a blowoff or crush pressure.

b) Reference 7, Pages 2-9.

c) Assumes same heating rates for ascent as descent. See Figure 4.

d) Panel has vent holes through inner sandwich layer.

e) Reference 7 reports that descent shock pressures occur only after panel has cooled down to nearly ambient temperature.

f) Maximum temperature and thermal gradient for BP/1300. See Figure 4.

Table 2. Trajectory 14414.1C

TIME SECONDS	BODY POINT 1300 SURFACE T °F
0	250
100	650
200	1,100
300	1,700
400	1,800
450	1,900
500	1,900
600	1,870
700	1,800
800	1,630
900	1,530
1,000	1,420
1,100	1,280
1,200	1,120
1,300	1,000
1,400	1,050
1,500	650
1,600	280
1,700	120
2,000*	120

The typical surface temperature history for body point 1300 of space shuttle trajectory 14414.1C (once around).

* Extended time to ensure no continued temperature rise of the aluminum structure.

Table 3. Typical Time Pressure History for Shuttle Body Point 1300

TIME SECONDS	BODY POINT 1300 PRESSURE LBF/SQ FT
0	0.01087
100	0.08373
200	1.01035
350	17.69237
450	26.51259
550	32.69217
600	37.28221
650	40.55208
700	44.23282
750	43.79233
800	42.45522
850	43.84506
1,050	59.55977
1,150	69.60561
1,200	74.90744
1,250	69.32410
1,300	68.84630
1,350	61.44383
1,400	71.89258
1,450	66.87845
1,500	76.15733
1,550	91.65157
1,600	115.08743
1,650	171.99934
1,750	2116.217
2,000*	2116.217

* Extended time to ensure no continued temperature rise of the aluminum structure.

Table 4. Candidate Materials for Thermal Protection System
(1 to 10 listed in order of 1,366°K (2,000°F) 100 hour Creep Rupture Specific Strengths)

	MATERIAL	100 HR CREEP RUPTURE STRENGTH Mpa (ksi)		SHORT TIME U.T.S. Mpa (ksi)		DENSITY g/cm^3 (lb/in^3)	1,366°K (2,000°F)/100 HR CREEP RUPTURE SPECIFIC STRENGTH MPa/gcm^{-3} ksi/lb in^{-3}	MAIN ALLOY CONSTITUENT
		1,366°K (2,000°F)	1,255°K (1,800°F)	1,366°K (2,000°F)	1,255°K (1,800°F)			
A	Rene 41	N.A.	69 (10.0)	N.A.	276 (40)	8.25 (0.298)	N.A.	Nickel
B	T.D. Ni	48 (7)	66 (9.5)	90 (13)	110 (16)	8.86 (0.320)	5.46 (21.9)	Nickel
C	T.D. Ni-Cr	55 (8)	72 (10.5)	131 (19)	179 (26)	8.47 (0.306)	6.51 (26.1)	Nickel
1	INCOLOY 802	21 (3.0)	48 (7.0)	83 (12)	115 (17)	7.83 (0.283)	2.64 (10.6)	Iron
2	INCONEL 617	19 (2.7)	41 (6.0)	83 (12)	150 (22)	8.36 (0.302)	2.22 (8.9)	Nickel
3	L605 (= Haynes 25)	19 (2.8)	48 (7.0)	131 (19)	235 (34)	9.13 (0.330)	2.12 (8.5)	Cobalt
4	Haynes 188	15 (2.2)	41 (6.0)	131 (19)	255 (37)	9.13 (0.330)	1.67 (6.7)	Cobalt
5	INCONEL 625	12 (1.8)	32 (4.6)	76 (11)	140 (20)	8.44 (0.305)	1.47 (5.9)	Nickel
6	Nimonic 86	12 (1.7)	31 (4.5)	97 (14)a	237 (34)b	8.53 (0.308)	1.37 (5.5)	Nickel
7	INCONEL 601	11 (1.6)	23 (3.4)	34 (5)	62 (9)	8.05 (0.291)	1.37 (5.5)	Nickel
8	Haynes 556	11 (1.6)	32 (4.7)	97 (14)	185 (27)	8.22 (0.297)	1.35 (5.4)	Iron
9	INCONEL 600	10 (1.4)	19 (2.8)	N.A.	76 (11)	8.41 (0.304)	1.15 (4.6)	Nickel
10	HASTELLOY X	8 (1.2)	26 (3.8)	90 (13)	150 (22)	8.22 (0.297)	0.9 (4.0)	Nickel

a - 1,323°K (1,922°F)
b - 1,173°K (1,652°F)

N.A. - Not Available
A - Precipitation Hardened Superalloy
B-C - Oxide Dispersed Alloys
1-10 - Solid Solution Strengthened Superalloys

Table 5. Thermophysical Properties of INCONEL 617 Honeycomb (4-20 Core) Thickness 0.293 Inch

T (°F)	Cp (BTU/LB-°F)
78.	0.100
200.	0.104
400.	0.111
600.	0.117
800.	0.124
1000.	0.131
1200.	0.137
1400.	0.144
1600.	0.150
2000.	0.163

T °F	k* (BTU/FT-HR-°F)
100.	0.1482
200.	0.1666
400.	0.2041
600.	0.2512
800.	0.3107
1000.	0.3846
1200.	0.4755
1400.	0.5858
1600.	0.7178
1800.	0.8738
2000.	1.0565

* Effective Thermal Conductivity calculated by standard methods (see Reference 15)

INCONEL Density = 521.0 $\mathrm{lbs/ft^3}$

ε external = 0.80 ε internal = 0.60

Table 6. Thermophysical Properties of DYNAFLEX

T (°F)	Cp (BTU/LB-°F)
240	0.202
440	0.233
640	0.252
840	0.267
1040	0.274
1240	0.280
1640	0.284

T	P	k (BTU/HR-FT-°F)						
°F	PSF	0.0278	0.2785	2.785	27.85	139.2	278.4	2116
200		0.0043	0.0048	0.0088	0.0178	0.0206	0.0211	0.0215
400		0.0106	0.0111	0.0150	0.0261	0.0306	0.0313	0.0320
600		0.0173	0.0177	0.0214	0.0342	0.0403	0.0414	0.0425
800		0.0255	0.0259	0.0294	0.0433	0.0512	0.0327	0.0542
1000		0.0369	0.0373	0.0406	0.0553	0.0649	0.0669	0.0688
1200		0.0530	0.0534	0.0566	0.0718	0.0830	0.0854	0.0879
1400		0.0706	0.0710	0.0740	0.0896	0.1023	0.1052	0.1083
1600		0.0930	0.0933	0.0962	0.1119	0.1262	0.1296	0.1333
1800		0.1156	0.1159	0.1187	0.1345	0.1501	0.1540	0.1583
2000		0.1466	0.1469	0.1496	0.1654	0.1823	0.1867	0.1917
2200		0.1827	0.1829	0.1855	0.2013	0.2193	0.2243	0.2300
2400		0.2173	0.2175	0.2200	0.2358	o.2549	0.2606	0.2670

Density = 6.0 lbs/ft^3

Reference: Manufacturer Brochure for 2116 PSF Values. The k values at other pressures are estimated by methods of References 16 and 17.

Table 7. Thermophysical Properties of Q FIBER FELT

T (°F)	Cp (BTU/LB-°F)
240	0.202
440	0.233
840	0.267
1040	0.274
1240	0.280
1640	0.2845

T	P	k (BTU/HR-FT-°F)						
°F	PSF	0.0278	0.2785	2.785	27.85	139.2	278.4	2116
100		0.0020	0.0030	0.0085	0.0155	0.0168	0.0170	0.0172
200		0.0050	0.0059	0.0116	0.0201	0.0220	0.0223	0.0225
300		0.0078	0.0087	0.0145	0.0244	0.0268	0.0272	0.0275
400		0.0107	0.0116	0.0174	0.0285	0.0316	0.0321	0.0325
600		0.0181	0.0188	0.0246	0.0380	0.0425	0.0432	0.0438
800		0.0267	0.0274	0.0330	0.0483	0.0541	0.0551	0.0560
1000		0.0364	0.0370	0.0425	0.0592	0.0665	0.0678	0.0690
1200		0.0476	0.0483	0.0534	0.0713	0.0802	0.0818	0.0833
1400		0.0624	0.0635	0.0685	0.0876	0.0981	0.1001	0.1020
1500		0.0765	0.0770	0.0820	0.1015	0.1127	0.1149	0.1170

Density = 3.5 lb/ft^3

Reference: Manufacturer Brochure for 2116 PSF Values. The k values at other pressures are estimated by methods of References 16 and 17.

Table 8. Thermophysical Properties of Titanium Honeycomb (3-20 Core) Thickness 0.185 Inch

T (°F)	Cp (BTU/LB-°F)
0.	0.140
200.	0.140
400.	0.145
600.	0.148
800.	0.155
1000.	0.166

T °F	k* (BTU/FT-HR-°F)
0.	0.0651
100.	0.0764
200.	0.0883
400.	0.1133
600.	0.1413
800.	0.1754
1000.	0.2149

* Effective Thermal Conductivity calculated by standard methods (see Reference 15)

Titanium Density = 281.5 lb/ft^3

ε external = 0.80 ε internal = 0.18

**Aluminum properties used were:

density = 169 lb/ft^3
C_p = 0.229 BTU/lb - °F

Table 9. Thermophysical Properties of MIN-K

T °F	k (BTU/FT-HR-°F)
100.	0.0145
200.	0.0148
300.	0.0153
400.	0.0159
500.	0.0166
1200.	0.0225

Reference: Manufacturers Brochure

Table 10. Boundary Temperatures Used and Comparison of Predicted and Measured Steady State Temperatures

MEASURED BOUNDARY TEMPERATURES		$T13_T$	$T13_A$	PERCENT ERROR	Q_A *	Q_T **
T_1	T_{17}	MEASURED	ANALYTICAL PREDICTION	$\frac{(T13_A-T13_T)}{T13_T}$ x 100	BTU/HR ANALYTICAL PREDICTION	BTU/HR TEST
CENTER OF TILE						
305.5	90.3	190.7	189.2	-0.78	17.38	17.61
605.8	123.6	385.2	391.7	1.68	48.6	47.31
896.2	154.9	610.0	618.2	1.34	88.65	86.25
1189.2	201.8	866.2	871.8	0.65	137.2	134.58
1474.9	265.9	1139.8	1136.3	-0.31	191.88	192.00
1799.4	354.5	1461.5	1445.9	-1.07	258.91	266.18
ADJACENT TO SIDEWALL						
305.5	90.3	198.8	203.7	2.46	19.93	19.05
605.8	123.6	397.6	416.5	4.75	53.44	49.65
896.2	154.9	615.1	647.5	5.27	94.89	87.31
1189.2	201.8	877.0	902.0	2.85	144.38	137.17
1474.9	265.9	1155.5	1165.5	0.86	199.61	196.16
1799.4	354.5	1476.0	1472.3	-0.25	266.10	270.50

* Based on predicted temperature at T_{13}

** Based on measured temperature at T_{13}

Table 11. Structural Test Summary

TEST TYPE	PRETEST ELEVATED TEMP. EXPOSURE	ELEVATED TEMP. TESTS	NUMBER OF SPECIMENS
Face Sheet Tension[1]	Yes	Yes	61
Face Sheet Creep[1]	No	Yes	16
Edgewise Compression[2]	No	No	35
Flatwise Tension[2]	Yes	Yes	30
Full Panel Pressure/Temperature Gradient	No	Yes	1

[1] Test specimens are INCONEL foil material both as-received and after process/brazing

[2] Test specimens are INCONEL brazed sandwich

Table 12. INCONEL 617 Face Sheet Tension Tests - No Pretest Environmental Exposure - Average Values

SPECIMEN CONFIGURATION	SPECIMEN THICKNESS mm (inch)	NUMBER OF SPECIMENS	TEST TEMPERATURE K (°F)	Fty[1] MPA (KSI)	Ftu[1] MPA (KSI)	e[1] %	E[1] GPA (KSI x 10^3)
A-1 As-Received	0.076 (0.003)	5	Room Temp.	582 (84.4)	889 (129.0)	12.1	221. (32.0)
A-2 As Received[2]	0.076 (0.003)	5	Room Temp	583 (84.5)	1007 (146.1)	34.3	195.5 (28.3)
B. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	Room Temp.	478 (69.3)	836 (121.3)	2.7	184 (26.7)
C. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1089 (1500)	226 (32.8)	468 (67.9)	5.5	98.6 (14.3)
D. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1255 (1800)	118 (17.1)	219 (31.7)	10.7	77.2 (11.2)
E. Processed/Brazed to Honeycomb Core	0.127 (0.005)	4	1255 (1800)	139 (20.1)	219 (31.7)	22.3	110.0 (16.1)
F. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1366 (2000)	45 (6.5)	62 (9.0)	3.0	21.0 (3.05)

[1] Average values.

[2] This is a repeat of A-1 tests with specimens more carefully prepared and load rates reduced to 0.51 mm (0.02 inches) per minute crosshead speed.

Table 13. INCONEL 617 Face Sheet Tension Tests - 5 Hours of 2,000°F Pretest Exposure - Average Values

SPECIMEN CONFIGURATION	SPECIMEN THICKNESS mm (inch)	NUMBER OF SPECIMENS	TEST TEMPERATURE K (°F)	Fty MPA (KSI)	Ftu MPA (KSI)	e %	E GPA (KSI x 10^3)
E. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	Room Temp.	412. (59.8)	585. (84.9)	1.6	219. (31.7)
H. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1255 (1800)	127. (18.4)	148. (21.5)	2.3	72.4 (10.5)
I. Processed/Brazed to Honeycomb Core	0.127 (0.005)	5	1255 (1800)	137. (19.8)	174. (25.3)	8.3	77.9 (11.3)
F. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1366 (2000)	37. (5.3)	39. (5.7)	1.5	19.2 (2.78)

Table 14. INCONEL 617 Face Sheet Tension Tests - 25 Hours of 2,000°F Pretest Exposure Average Values

SPECIMEN CONFIGURATION	SPECIMEN THICKNESS mm (inch)	NUMBER OF SPECIMENS	TEST TEMPERATURE K (°F)	Fty MPA (KSI)	Ftu MPA (KSI)	e %	E GPA (KSI x 10^3)
K. Processed/Brazed to Honeycomb Core	0.076 (0.003)	2	Room Temp.	388.0 (56.2)	404.0 (58.6)	0.6	216.0 (31.4)
L. Processed/Brazed to Honeycomb Core	0.076 (0.003)	5	1366 (2000)	41.0 (6.0)	46.0 (6.7)	1.2	32.0 (4.64)

Table 15. Creep Tests - INCONEL 617 (0.003 Inch Foil)

SPECIMEN CONFIGURATION	SPECIMEN SIZE (inch)	TEST TEMPERATURE	NUMBER OF SPECIMENS
Sheet Material As-Received	1/4 x 2 x 0.003	1500°F	6
Processed/Brazed to Honeycomb Core	1/4 x 2 x 0.003	1500°F	5
Processed/Brazed to Honeycomb Core	3/4 x 3 x 0.003	1800°F	2
Processed/Brazed to Honeycomb Core	3/4 x 3 x 0.003	2000°F	3(a)
TOTAL			16

(a) Some other tests were conducted at this temperature with the smaller (1/4 inch x 2 inch) test specimens. However, the test results were considered invalid and are not reported.

Table 16. INCONEL 617 Creep Rupture Test Results

	SPECIMEN NO.	STRESS (KSI)	TEMPERATURE (°F)	TIME (HRS.)	P = (460 + T) (20 + log t)10^{-3}
AS REC'D MATERIAL	1A	20.0	1500	20.0	41.8
	2A	20.0	1500	19.5	41.7
	3A	17.0	1500	29.9	42.1
	4A	13.0	1500	167.3[2]	43.6
	5A	15.0	1500	107.1	43.2
	6A	17.0	1500	44.5	42.4
BRAZED SANDWICH FACE SHEET	1C	17.0	1500	116.2[2]	43.2
	2C	21.0	1500	32.0	42.2
	3C	21.0	1500	63.6	42.7
	4C	21.0	1500	69.8	42.8
	5C	20.0	1500	98.3	43.1
	N1 [1]	1.0	2000	90.0	54.0
	N2 [1]	1.0	2000	330.4	55.4
	N4 [1]	6.0	1800	46.8	49.7
	N5 [1]	6.0	1800	53.7	49.1
	N6 [1]	2.0	2000	92.3	54.0

1 These specimens have 3/4 inch wide test area while others have 1/4 inch wide test area.

2 No Failure

P = Larson-Miller Parameter

T = Temperature, °F

t = Time, hrs.

Table 17. Edgewise Compression - INCONEL 617 Sandwich (See Figure 43)

SPECIMEN CONFIGURATION	NUMBER OF SPECIMENS	Fcu[1] (KSI)
0.003 inch Face Sheet, 3/16 inch with 0.002 inch Core	5	57.0
0.003 inch Face Sheet, 1/4 inch with 0.002 inch Core	5	43.8
0.003 inch Face Sheet, 3/8 inch with 0.002 inch Core	5	28.3
0.003 inch Face Sheet, 3/16 inch with 0.0015 inch Core	5	53.0
0.005 inch Face Sheet, 3/16 inch with 0.002 inch Core	5	60.1
0.005 inch Face Sheet, 1/4 inch with 0.002 inch Core	5	52.5
0.005 inch Face Sheet, 3/8 inch with 0.002 inch Core	5	39.3
TOTAL	35	

[1] These are average values

[2] Testing was performed at room temperature

Table 18A. Explanation of Panel Identification Number

XFT-Y

X - Panel Configuration

FT - Type of Test - Flatwise Tension

Y - Test Conditions

TEST CONDITIONS

Y	Pre-Test Environment	Test Temperature	Material Processing Status
A	None	Room Temperature	As Received
B	None	Room Temperature	Brazed
C	None	1500°F	Brazed
D	None	2000°F	Brazed
E	5 Hours @ 2000°F air furnace	Room Temperature	Brazed
F	5 Hours @ 2000°F air furnace	2000°F	Brazed
G	25 Hours @ 2000°F air furnace	Room Temperature	Brazed
H	25 Hours @ 2000°F air furnace	2000°F	Brazed

Table 18B

PANEL CONFIGURATION

X	Face Sheet Thickness (Inches)	Core Cell Size (Inches)	Core Foil Thickness (Inches)
A*	0.003	3/16	0.002
B	0.003	1/4	0.002
C	0.003	3/8	0.002
D	0.005	3/16	0.002
E*	0.005	1/4	0.002
F	0.005	3/8	0.002
G*	0.003	3/16	0.0015

* Only these configurations were selected for flatwise tension testing

Table 19. Flatwise Tension Tests
(3-Inch by 3-Inch One-Layer INCONEL 617 Honeycomb Core Sandwich)

PANEL IDENTIFICATION [1]	PRE-TEST ENVIRONMENT	TEST TEMPERATURE	NUMBER OF SPECIMENS	AVERAGE FLATWISE TENSION STRENGTH (PSI
AFT - B	None	Room Temperature	10	Note: C-Scans of many of the specimens from panels AFT and GFT indicated defective braze joints. Test results are not reported.
GFT - B	None	Room Temperature	10	
GFT - C	None	1,500°F	5	
GFT - D	None	2,000°F	5	
EFT - B	None	Room Temperature	10	1682
EFT - E	5 Hours @ 2,000°F Air Furnace	Room Temperature	5	799
EFT - G	25 Hours @ 2,000°F Air Furnace	Room Temperature	10	213
EFT - H	25 Hours @ 2,000°F Air Furnace	2,000°F	5	18 [2]
TOTAL			60	

PANEL CONFIGURATION	FACE SHEET THICKNESS (INCHES)	CORE CELL SIZE (INCHES)	CORE FOIL THICKNESS (INCHES)
A	0.003	3/16	0.002
G	0.003	3/16	0.0015
E	0.005	1/4	0.002

[1] See Table 18A for explanation.

[2] These specimens were severely warped by the 25-hour furnace exposure and consequently the brazed loading blocks cause highly concentrated loads.

Table 20. Panel Deflections - Analytical versus Test

LOADING CONDITION	LOCATION		
	CENTER OF PANEL[1]	MIDDLE OF EDGE OF PANEL[2]	CORNER OF PANEL[3]
A. 2 psi Blowoff - Room Temperature			
Analytical	0.147 Inch	0.117 Inch	0.120 Inch
Test	0.098 Inch	0.078 Inch	0.044 Inch
B. 2 psi Crush Room Temperature			
Analytical	-0.032 Inch	0.001 Inch	0.005 Inch
Test	-0.039 Inch	0.017 Inch	0.008 Inch
C. Max. Thermal Gradient			
Analytical (1900°F)(203°F)	0.093 Inch	0.055 Inch	0.016 Inch
Test (2000°F)(400°F)	0.138 Inch	0.067 Inch	0.049 Inch

1) Grid #1120 (see Figure 50); Dial Indicator #3 (see Figure 65)

2) Grid #1126 (see Figure 50); Dial Indicator #5 (see Figure 65)

3) Grid #616 (see Figure 50); Dial Indicator #1 (see Figure 65)

Table 21A. Ascent Conditions (Ref. Table 1)
Stress Levels and Margins of Safety

COMPONENT	ASCENT CONDITION		ASCENT ALLOWABLE (PSI)	FAILURE MODE	MINIMUM MARGIN OF SAFETY
	STRESS (CRUSH) (PSI)	STRESS (BLOWOFF) (PSI)			
INCONEL Sandwich	-9,700[a]	-11,500[a]	41,000[b]	Intracell Buckling	+2.57
INCONEL Sidewall	-7,690[c]	5,540[c]	48,700[d]	Axial and Shear	+5.33
Titanium Sandwich	-2,900[e]	-14,900[f]	24,000[g]	Intracell Buckling	+0.61
Titanium Clip	0	180,500[h]	183,300[i]	Bending	+0.02
Titanium Clip	0	120,300[j]	140,400[k]	Bending	+0.17

(+) Tension

(-) Compression

a) QUAD4 Element ID 1021, principal stress

b) Intracell Buckling Allowable @ T = 600°F Ref. Figure 52

c) Shear 103, Bars 103 and 104 (shear stress and average stress in two adjacent bars), principal stress

d) Not critical in stability, use F_{ty} at T = 400°F.
Reference Figure 37 (average of 5-hour and 25-hour data.

e) QUAD4 109 (t = 0.006 inch) principal stress

f) QUAD4 210 (t = 0.003 inch) principal stress

g) Intracell Buckling Allowable @ T = 100°F. Reference Figure 53.

h) 2.0 PSI ultimate + temperature environment

i) Ultimate plastic bending allowable + temperature

j) 1.33 psi limit + temperature environment

k) Limit plastic bending allowables + temperature environment.

Table 21B. Descent Conditions (Ref. Table 1)
Stress Levels and Margins of Safety

COMPONENT	DESCENT CONDITION STRESS	DESCENT ALLOWABLE	FAILURE MODE	MINIMUM MARGIN OF SAFETY
INCONEL Sandwich	-9,100[a]	14,500[b]	Intracell Buckling	+0.59
INCONEL Sidewall	-5,200[c]	33,500[d]	Axial and Shear	+5.44
Titanium Sandwich	-9,100[e]	23,200[f]	Intracell Buckling	+1.55
Titanium Clip	0	111,400[g]		High

(+) Tension

(-) Compression

a) Intracell Buckling Allowable @ T = 1869°F (Maximum stress is on inner surface of INCO Honeycomb). Reference Figure 52.

b) Shear Panel 12, Bar 324 and Rod 325 (shear stress and average axial stresses in bar and rod), principal stress.

c) Not critical in stability, use F_{ty} @ T = 1050°F. Reference Figure 37 (average of 5-hour and 25-hour data.

d) QUAD4 210 (t = 0.003 inch).

e) Intracell Buckling Allowable @ T = 200°F Reference Figure 53.

f) Ultimate Plastic Bending Allowable + Temperature.

Table 22. INCONEL Bi-Metal Panel Pressure-Thermal Gradient Test

Condition I	Room Temperature	2 psi (crush)
Condition II	1,000°F/100°F	2 psi (crush)
Condition III	Room Temperature	2 psi (burst)
Condition IV	2,000°F/400°F	-0- psi
Condition V	1,000°F/100°F	2 psi (burst)
Condition VI	1,000°F/100°F	3.6 psi (burst) Panel Air Leak

8 Thermocouples
6 Dial Indicators
Controlled Heatup Rates

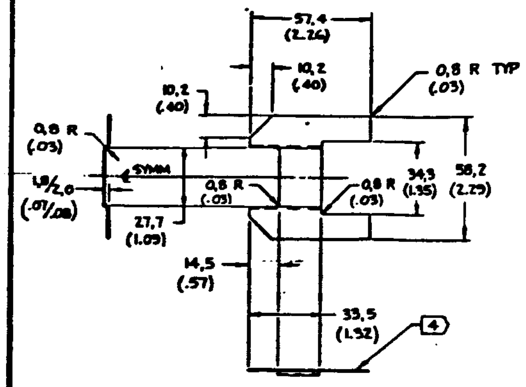
Table 23. Test Panel Temperature Profile During Burst Pressure Test

APPLIED PRESSURE LOAD KPa (PSI)	THERMOCOUPLE READING °K (°F)							
	1	2	3	4	5	6	7	8
6.89 (+1.00)	814.8 (1007)	815.9 (1009)	413 (283)	332 (137)	336 (145)	814.8 (1007)	816.5 (1010)	811.5 (1001)
13.8 (+2.00)	812.6 (1003)	814.8 (1007)	414 (285)	328 (131)	333 (139)	812.6 (1003)	813.7 (1005)	808 (995)
17.2 (+2.50)	813.2 (1004)	822.0 (1020)	416 (289)	323 (121)	330 (134)	813.7 (1005)	818.2 (1013)	817.6 (1012)
20.7 (+3.00)	793 (967)	805 (989)	435 (323)	319 (114)	333 (139)	793 (968)	800 (980)	813.2 (1004)
24.1 (+3.50)	785 (949)	796 (974)	452 (354)	312 (101)	323 (122)	784 (952)	780 (945)	810 (998)
24.8 (+3.60)	834.3 (1043)	855.9 (1081)	435 (324)	310 (93)	312 (102)	837.0 (1047)	855.4 (1080)	820.9 (1018)

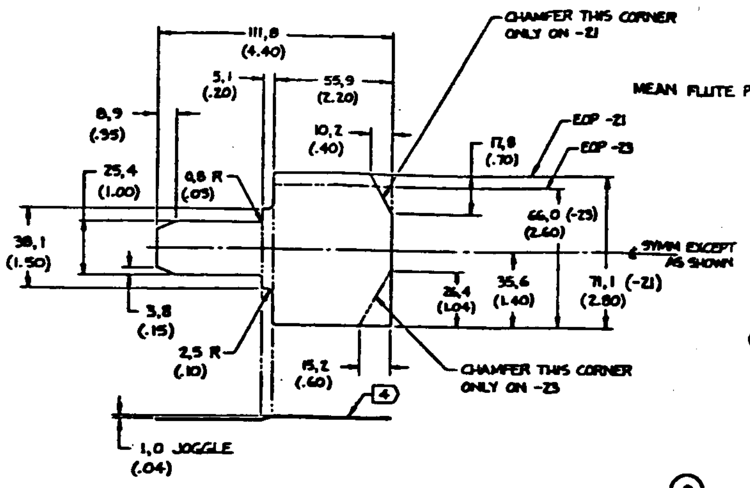
Thermocouples 1,2, 6, 7 and 8 are on the hot outer surface of the panel.

Thermocouple 3 is on the side of the panel.

Thermocouples 4 and 5 are on the panel inner surface.

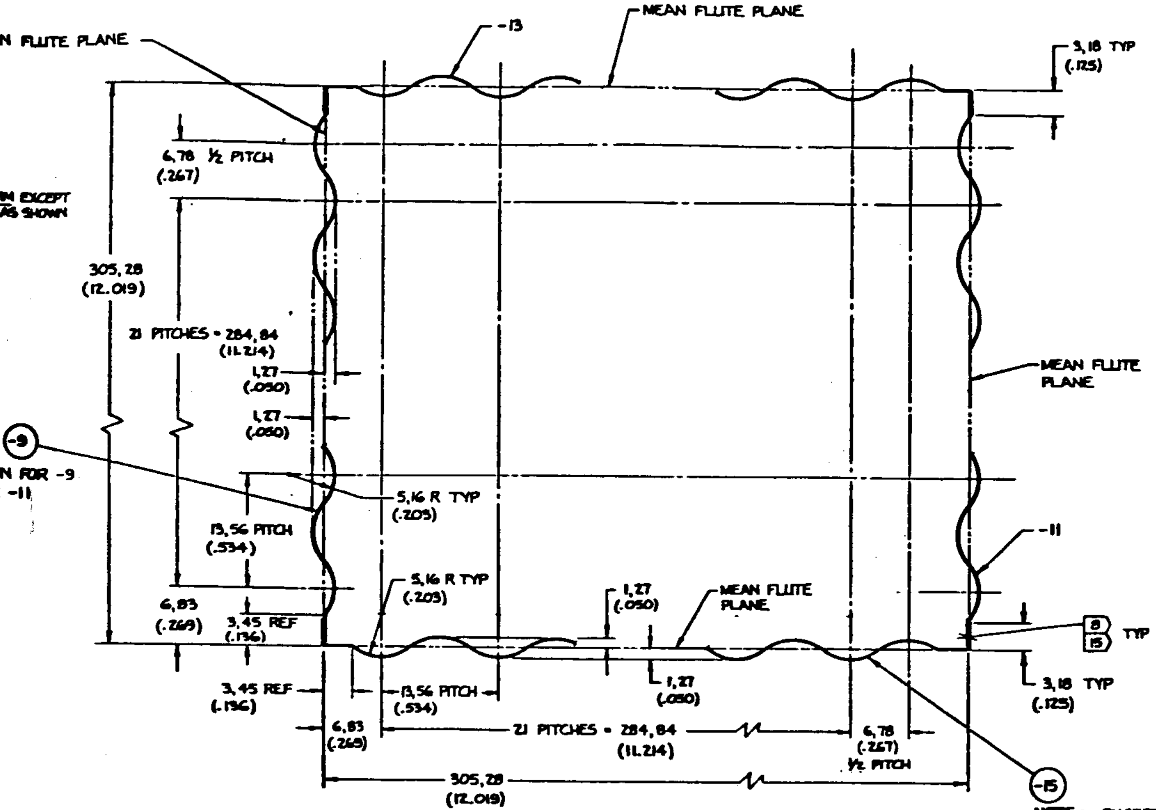


DETAIL (-25)



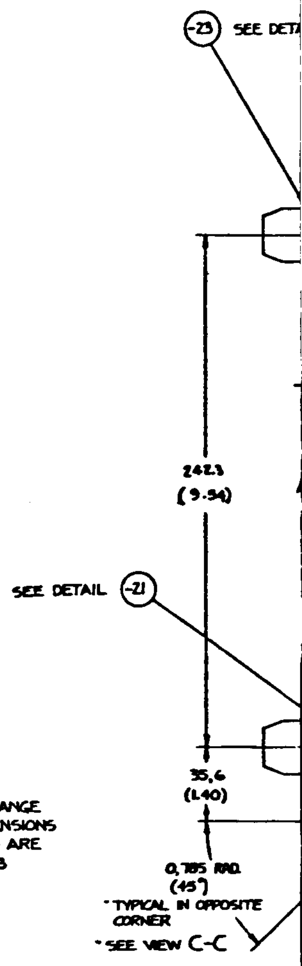
DETAIL (-21) & (-23)

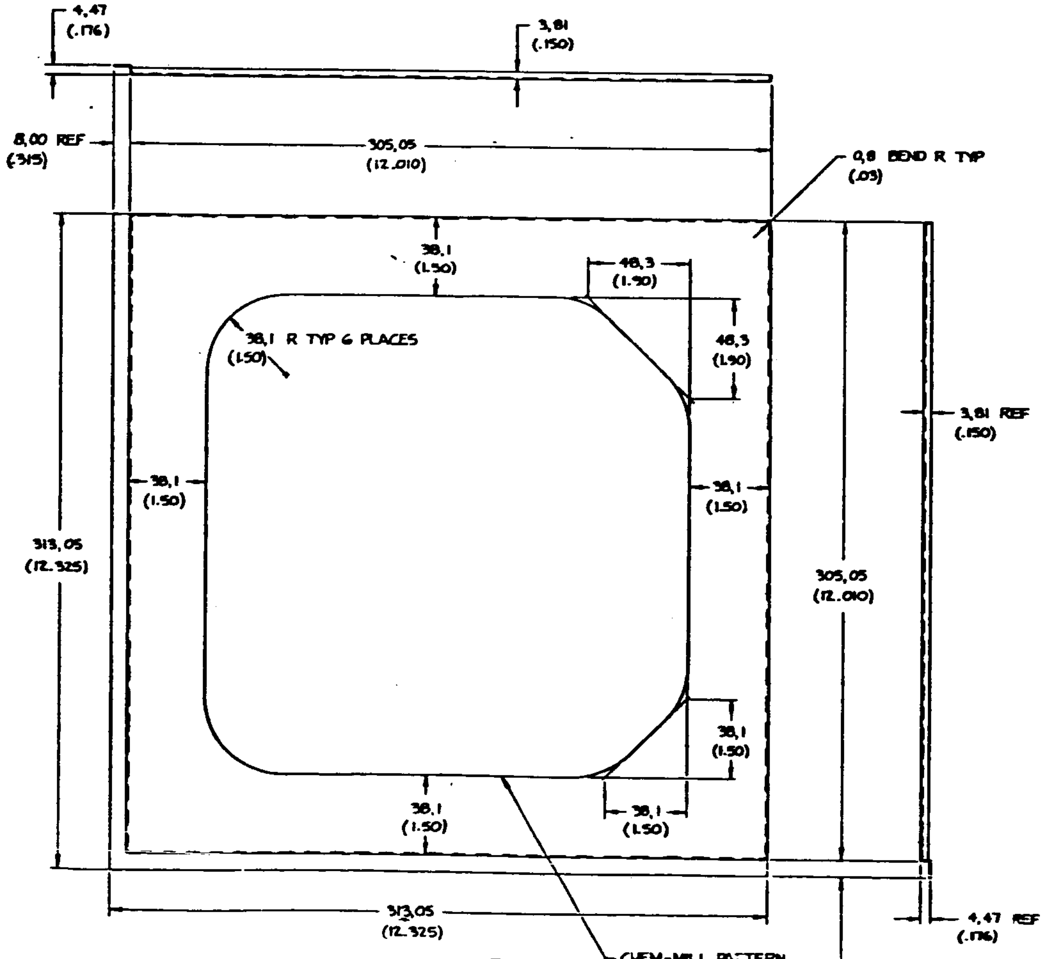
NOTE:
DIMENSIONS SHOWN FOR -9
ARE TYPICAL FOR -11



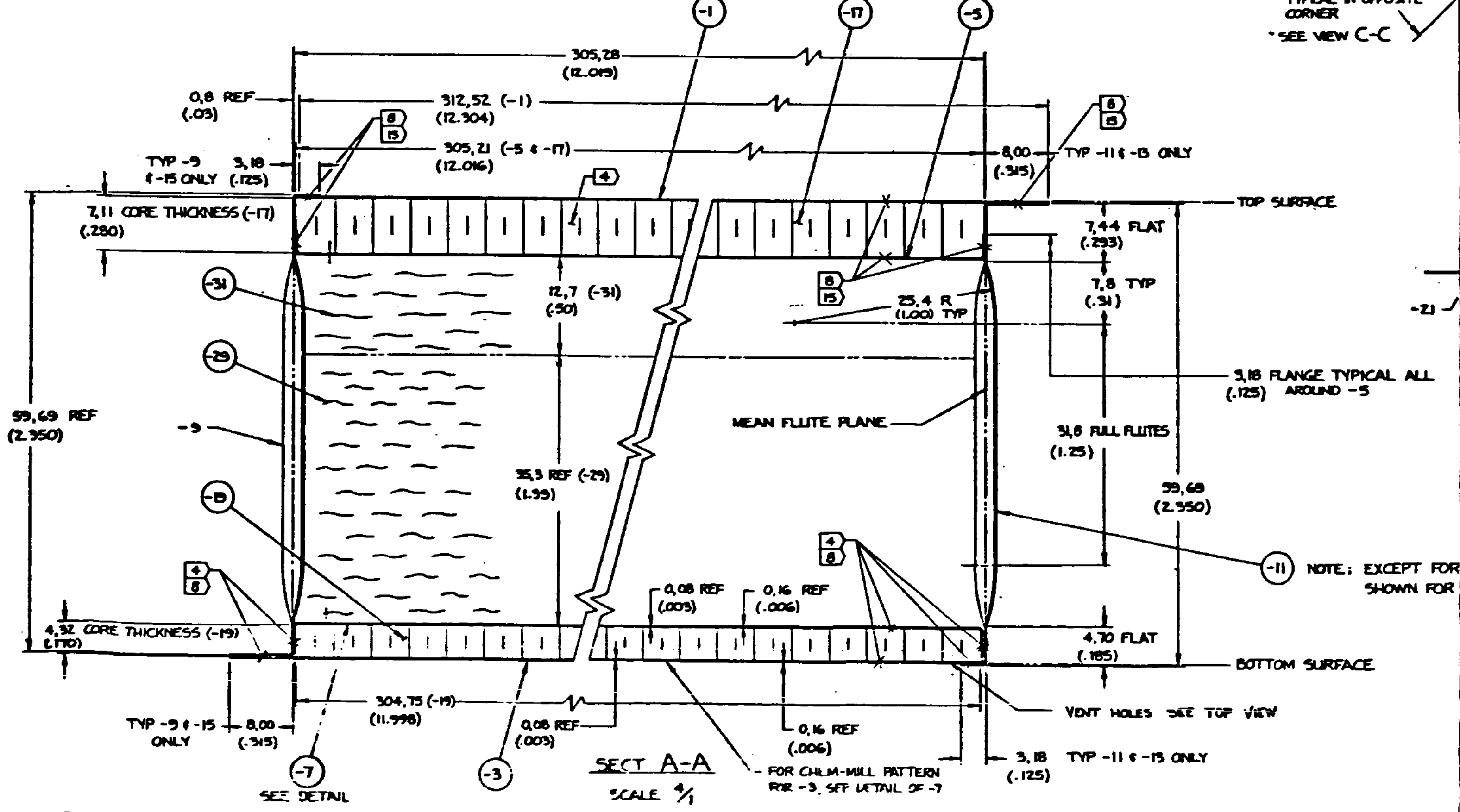
SECT B-B
SCALE 4/1

NOTE: EXCEPT FOR FLANGE DIRECTION, DIMENSIONS SHOWN FOR -15 ARE TYPICAL FOR -13

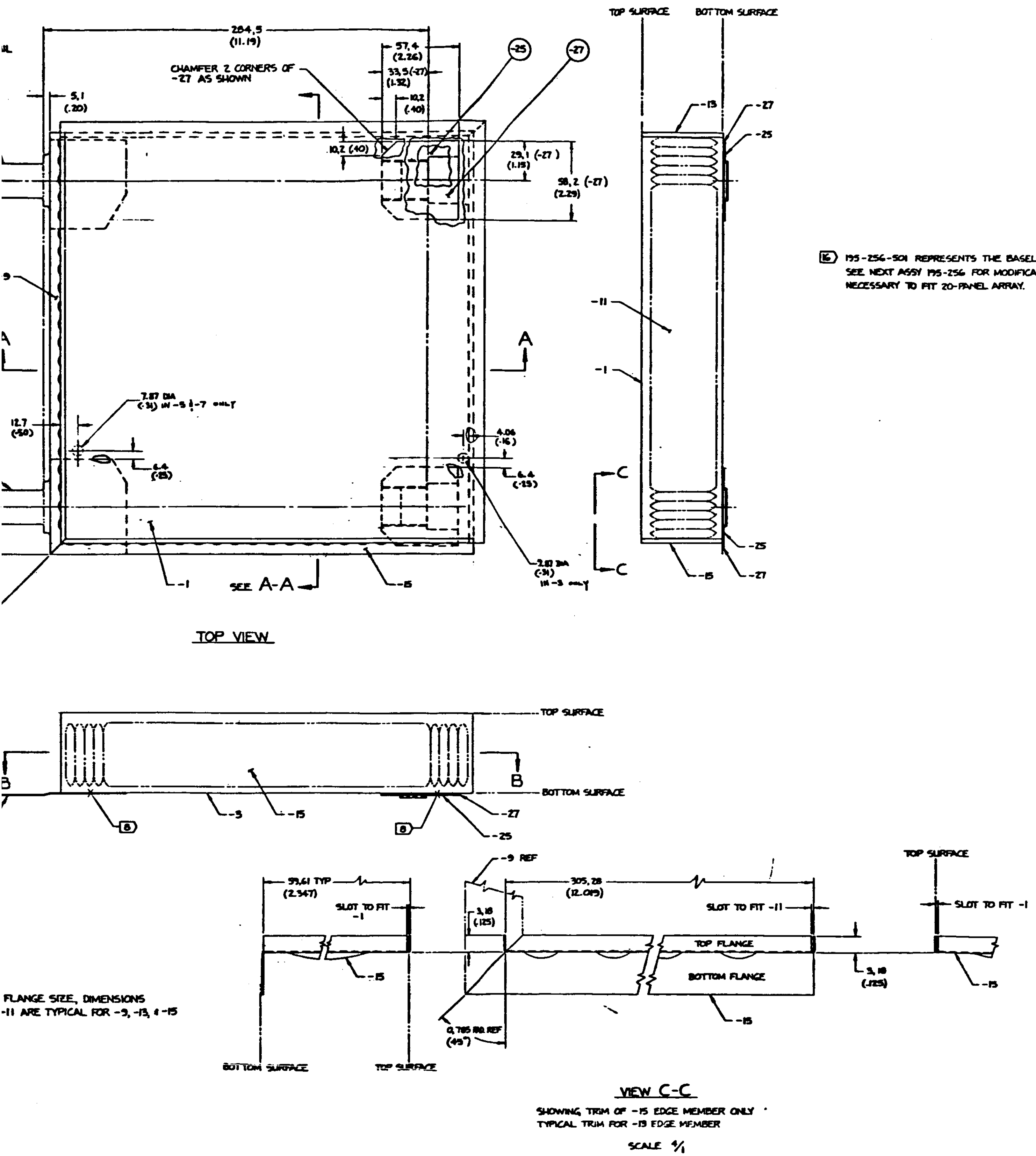




DETAIL (-7)



SECT A-A
SCALE 4/1



16) 195-256-501 REPRESENTS THE BASELINE PANEL.
SEE NEXT ASSY 195-256 FOR MODIFICATIONS TO PANELS, NECESSARY TO FIT 20-PANEL ARRAY.

GENERAL NOTES
UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS IN S.I. UNITS & (CUSTOMARY UNITS); mm (in.), rad (deg), N/m² (torr), K (°F)
2. TOLERANCES:

LINEAR	X. = ±2	.X = ±.7	.XX = ±.25
	(.X = ±.1	.XX = ±.03	.XXX = ±.010)
ANGULAR	.X = ±.1	.XX = ±.01	.XXX = ±.001
	(X = ±2	.X = ±.5	.XX = ±.05)

3. SEE 195-255 FOR TOOL TO MAKE CLOSURES, -9, -11, -13, & -15
4) LID PLATE THESE SURFACES, & ENTIRE H/C CORE PER RPS 11.89, TYPE B IN PREPARATION FOR BONDING
5. FORM TITANIUM PARTS PER RPS 14.02
6. PROCESS -17 & -19 CORES PER RPS 11.88-9
7. CHEM-MILL TITANIUM PER RPS 14.10. TOLERANCES ± 0,03 (±.001). VACUUM DEGASSING MANDATORY
8) SPOTWELD COMPONENTS IN POSITION IN PREPARATION FOR BONDING
9. IDENTIFY ALL PARTS & ASSY'S PER RPS 13.99. RUBBER STAMP LOCATION OPTIONAL. IMPRESSION STAMPING NOT PERMITTED.
10. PROCESS BOND ASSY PER RPS 11.88
11. BOND IN A VACUUM FURNACE AT A PRESSURE OF .0066 N/m² (5×10^{-6} torr) & TEMPERATURE OF 1214 K (1725°F).
12) OXIDIZE THIS SURFACE ONLY E-8
13. PERMISSIBLE WAVINESS ± 0,81 (±.032)
14) CORE MATERIAL PER RMS 110
15) SUPERALLOY L.I.D. BOND PER RPS (TBD)

QTY REQD			-501	PART NO.	DESCRIPTION	MATERIAL	SIZE (in.)	SPEC	HT	
			A/R	-31	CERACHROME 36.12 Kg/m³ (6.0 LB/FT³)					
			A/R	-29	Q-FIBER FELT 56.07 Kg/m³ (3.5 LB/FT³)					
			2	-27	DOUBLER	TI-6AL-4V	.020 × 3 × 3	AMS 4911		
			2	-25	CLIP	↕	.020 × 3 × 3	↕		
			1	-23	TONGUE	↕	.032 × 3 × 5	↕		
			1	-21	TONGUE	TI-6AL-4V	.032 × 3 × 5	AMS 4911		
			1	-19	CORE 3-20-RCB	TI-3AL-2.5V	.170 × 13 × 13	14)		
			1	-17	CORE 4-20-RB-P	INCO 617	.280 × 13 × 13	14)		
			1	-15	CLOSURE	↕	.003 × 4 × 14			
			1	-13	↕	↕	↕			
			1	-11	↕	↕	↕			
			1	-9	CLOSURE	INCO 617	.003 × 4 × 14			
			1	-7	SEPTUM - LOWER	TI-6AL-4V	.006 × 14 × 14	AMS 4911		
			1	-5	SEPTUM - UPPER	INCO 617	.005 × 13 × 13			
			1	-3	SKIN - LOWER	TI-6AL-4V	.006 × 13 × 13	AMS 4911		
			1	-1	SKIN - UPPER	INCO 617	.005 × 13 × 13			
			X	-501	PANEL ASSY 16)					

INDUSTRIES, INC.
PANEL ASSY-
NASA T.P.S.
J 51553 195-256

Figure 1-A. Panel Assembly

2

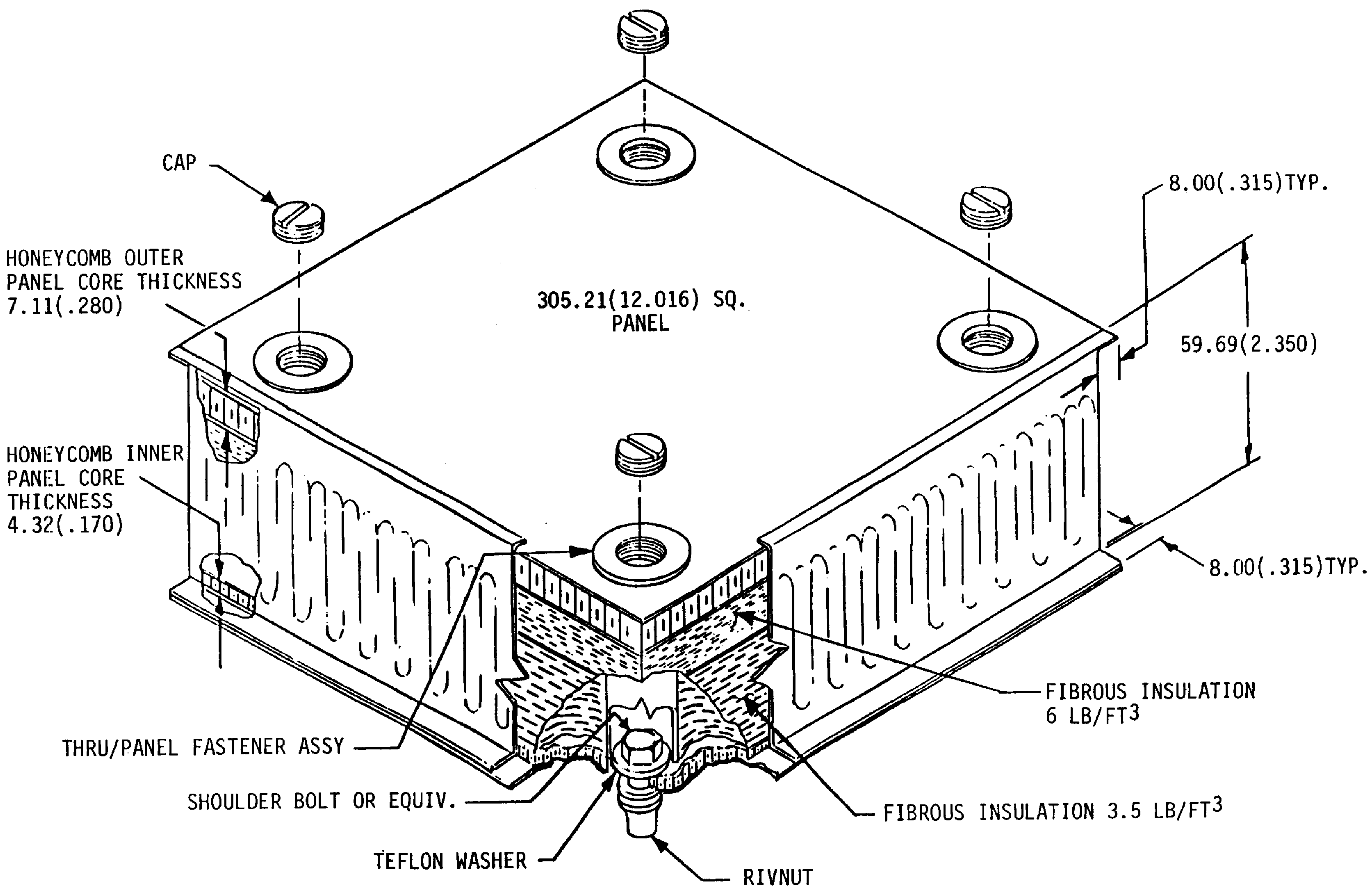


Figure 1-B. Schematic of Bi-Metal Silica Sandwich Panel

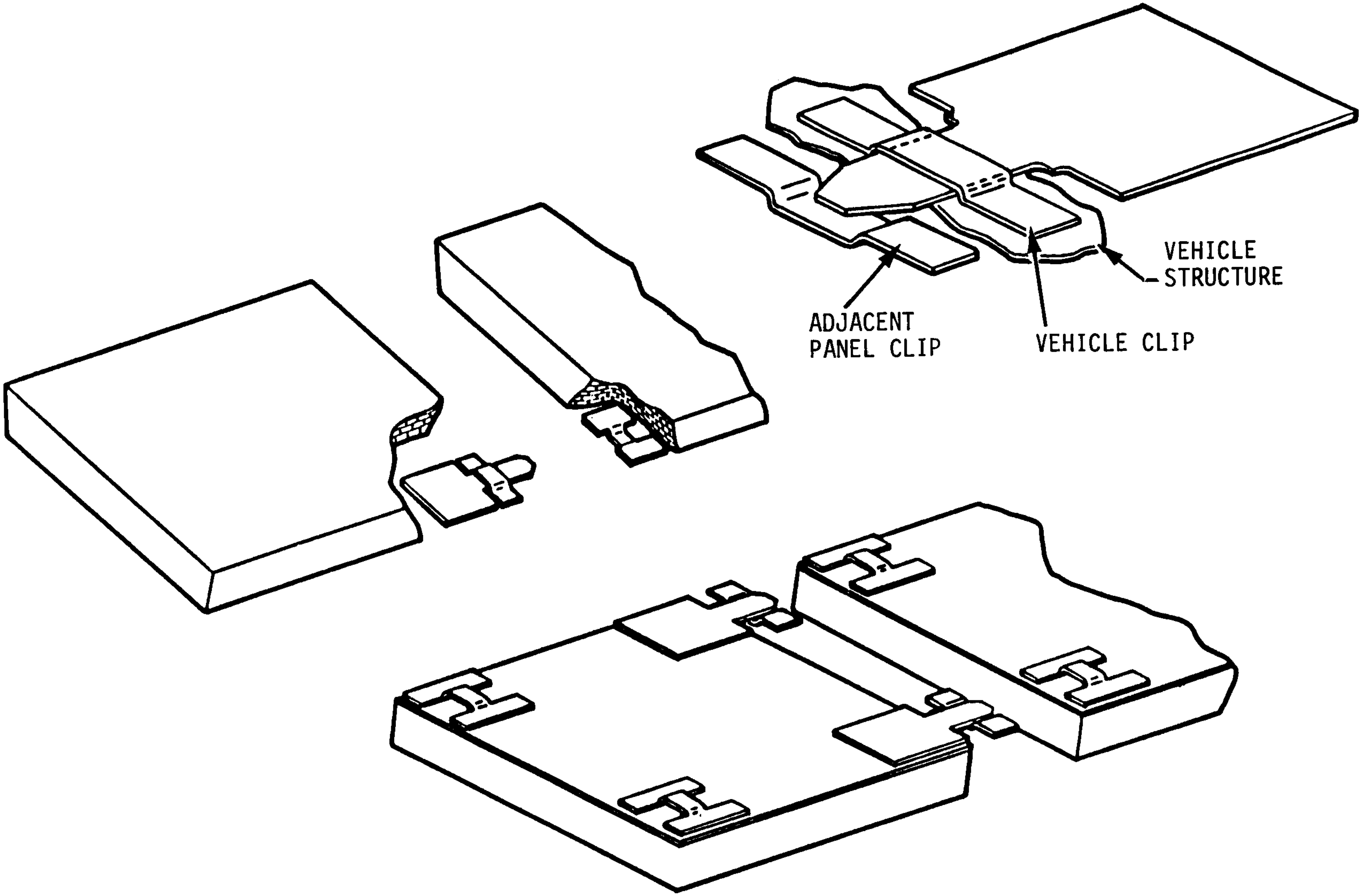
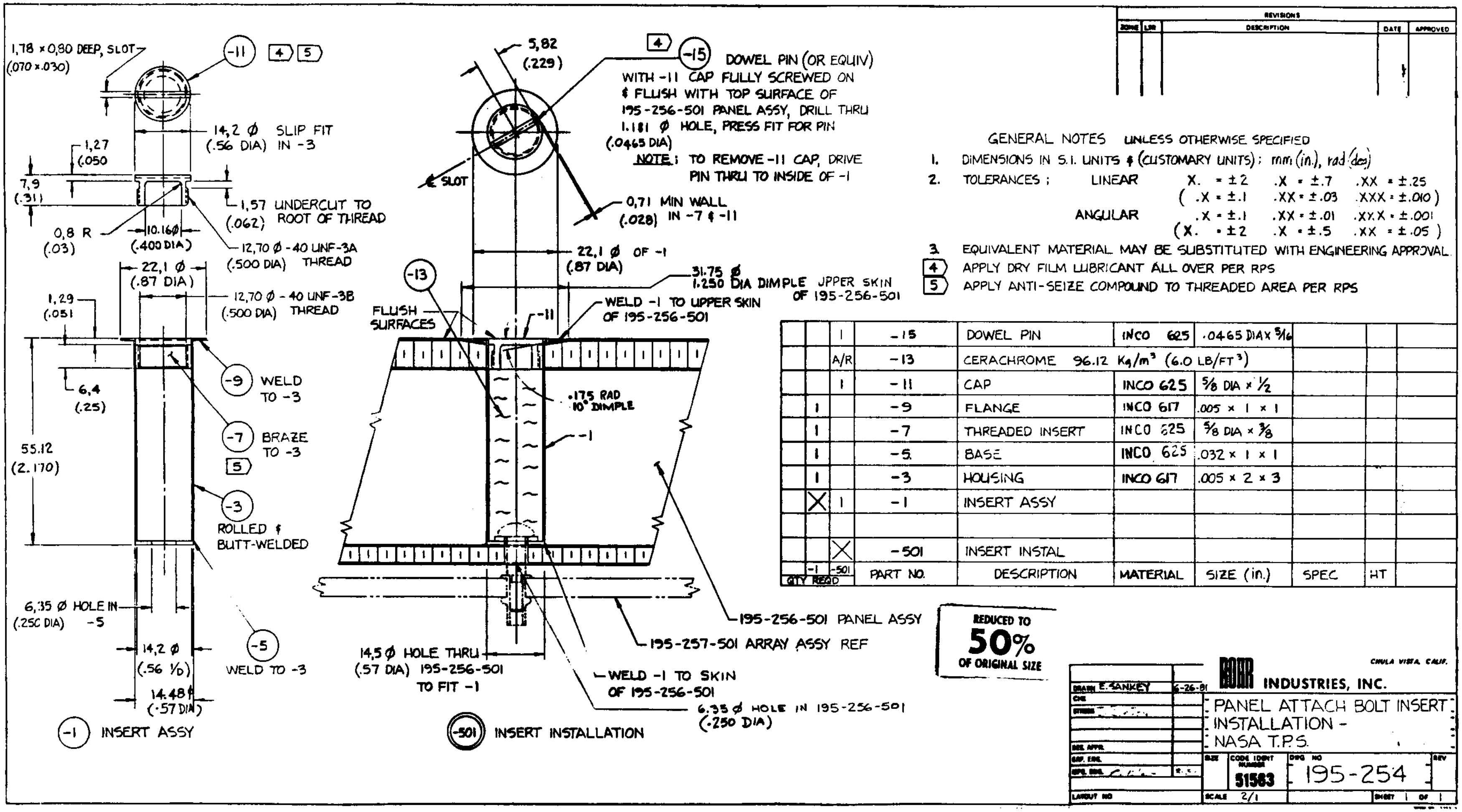


Figure 2. Bayonet Attachment Scheme



GENERAL NOTES UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS IN S.I. UNITS & (CUSTOMARY UNITS): mm (in.), rad (deg)
2. TOLERANCES ; LINEAR X. = ±2 .X = ±.7 .XX = ±.25
(.X = ±.1 .XX = ±.03 .XXX = ±.010)
ANGULAR .X = ±.1 .XX = ±.01 .XXX = ±.001
(X. = ±2 .X = ±.5 .XX = ±.05)
3. EQUIVALENT MATERIAL MAY BE SUBSTITUTED WITH ENGINEERING APPROVAL.
4 APPLY DRY FILM LUBRICANT ALL OVER PER RPS
5 APPLY ANTI-SEIZE COMPOUND TO THREADED AREA PER RPS

QTY REQD	-1	-501	PART NO.	DESCRIPTION	MATERIAL	SIZE (in.)	SPEC	HT	
		1	-15	DOWEL PIN	INCO 625	.0465 DIA × 5/16			
		A/R	-13	CERACHROME 96.12 Kg/m³ (6.0 LB/FT³)					
		1	-11	CAP	INCO 625	5/8 DIA × 1/2			
	1		-9	FLANGE	INCO 617	.005 × 1 × 1			
	1		-7	THREADED INSERT	INCO 625	5/8 DIA × 3/8			
	1		-5	BASE	INCO 625	.032 × 1 × 1			
	1		-3	HOUSING	INCO 617	.005 × 2 × 3			
	X	1	-1	INSERT ASSY					
		X	-501	INSERT INSTAL					

ROHR INDUSTRIES, INC.
CHULA VISTA, CALIF.
DRAWN E. SANKEY 6-26-81
CHK
STRESS
DES. APPR.
GRP. ENG.
PROJ. ENG.
PANEL ATTACH BOLT INSERT
INSTALLATION -
NASA T.P.S.
SIZE
CODE IDENT NUMBER 51563
DWG NO 195-254
REV
LAYOUT NO
SCALE 2/1
SHEET 1 OF 1

Figure 3. Panel Attach Bolt Insert Installation

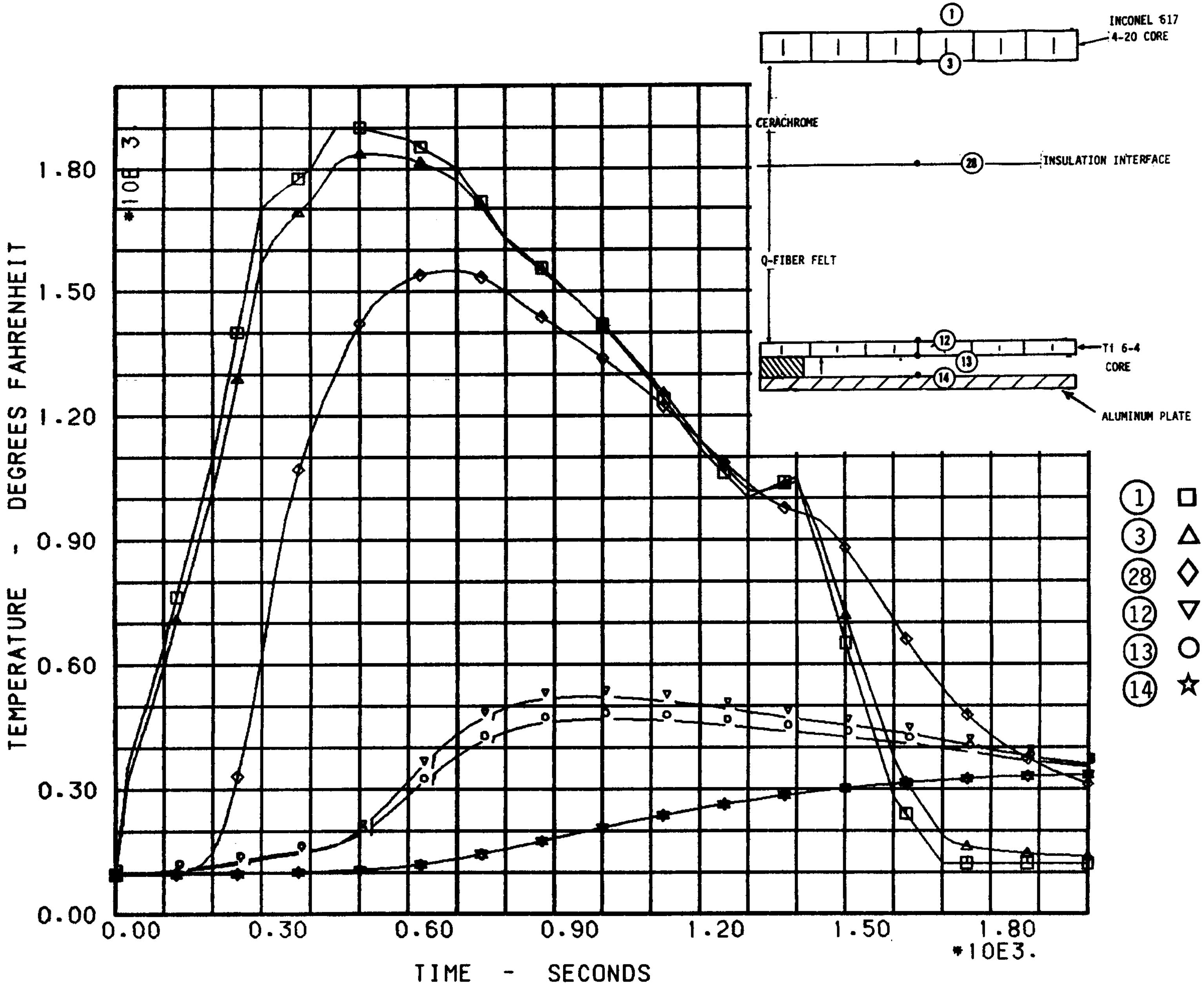


FIGURE 4 TYPICAL RESULTS FOR TRANSIENT ANALYSIS

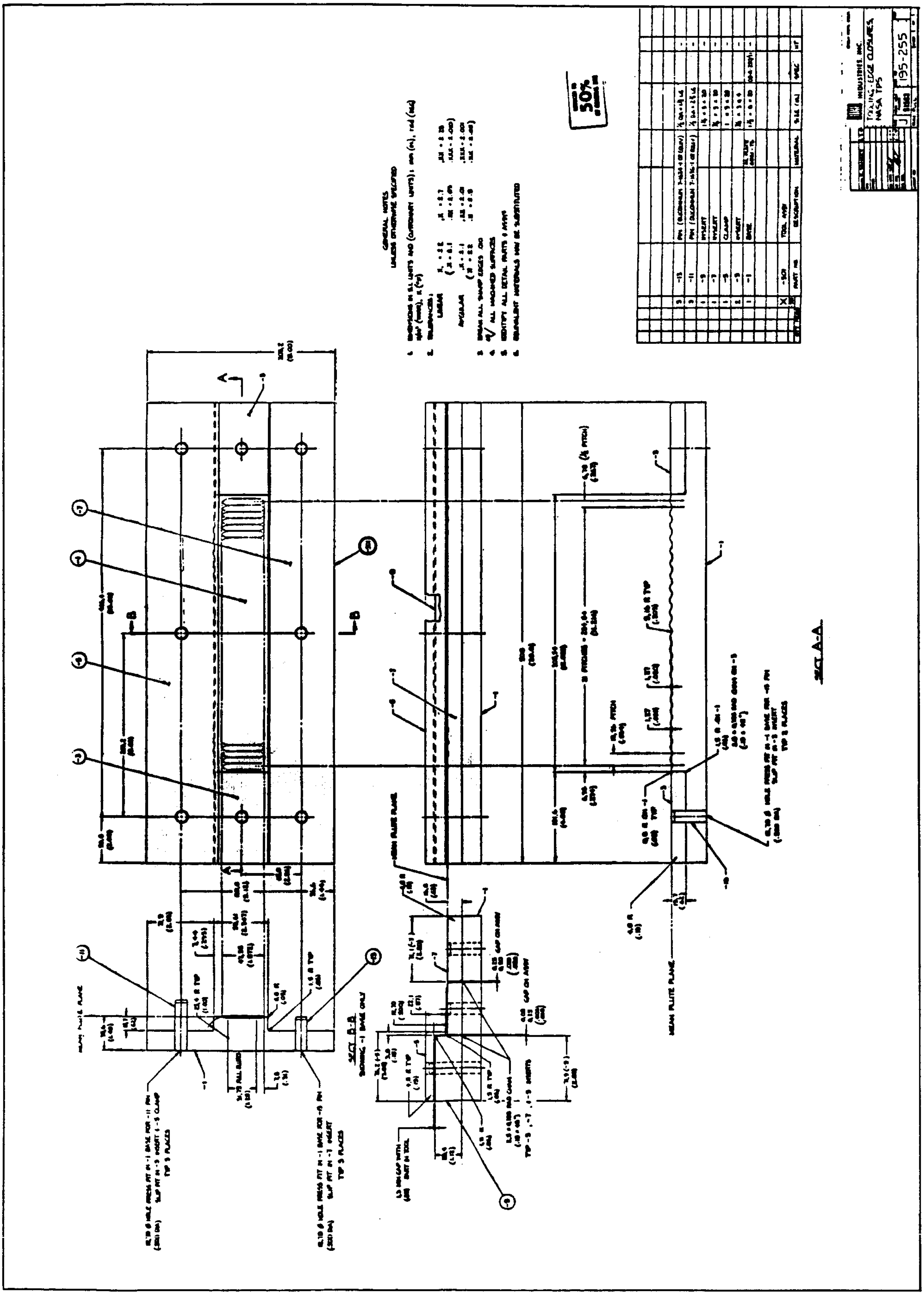


Figure 5. Edge Closure Tool

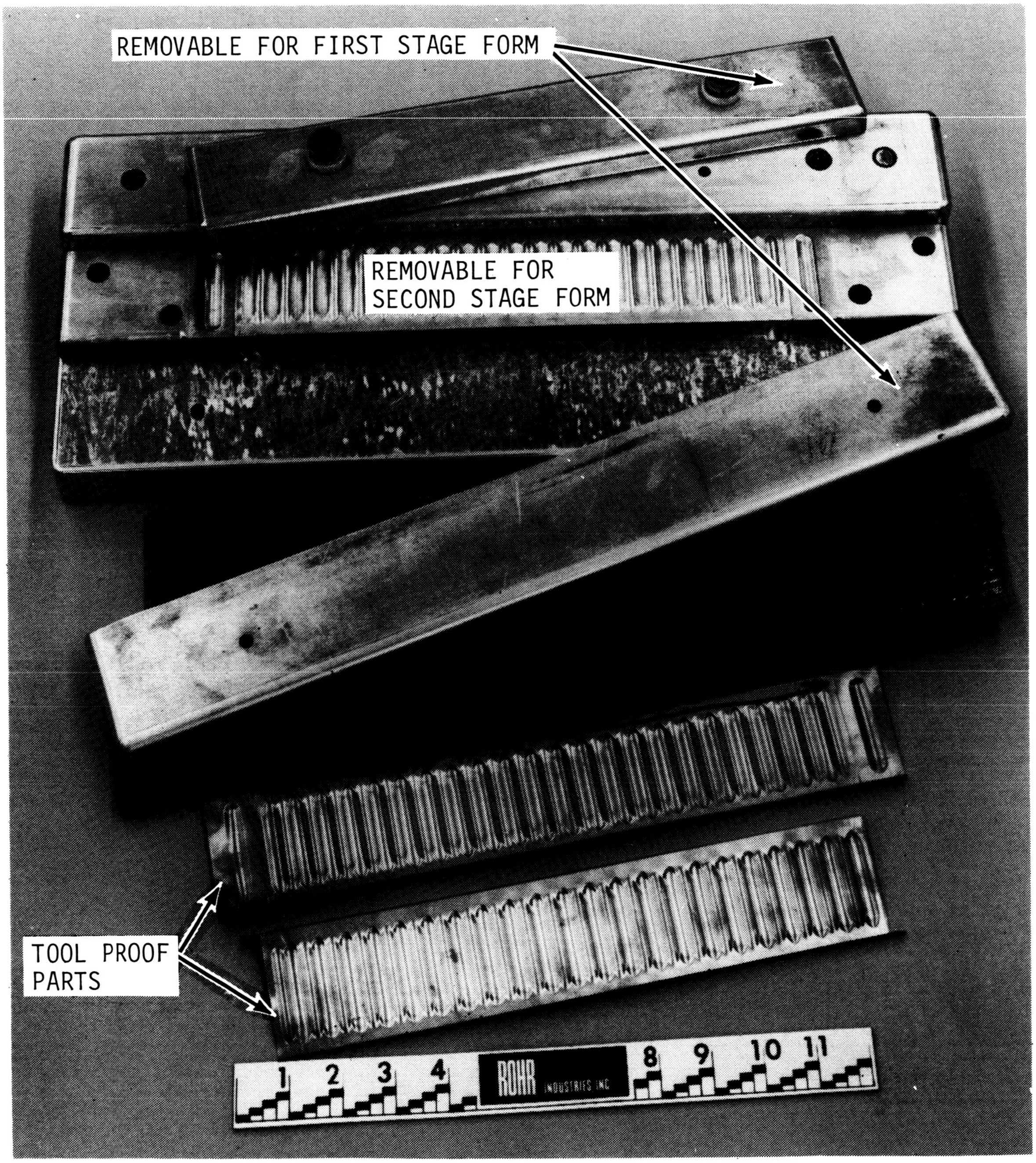


Figure 6. 6061 Aluminum Form Block With Removable Details and Tool Proof Parts

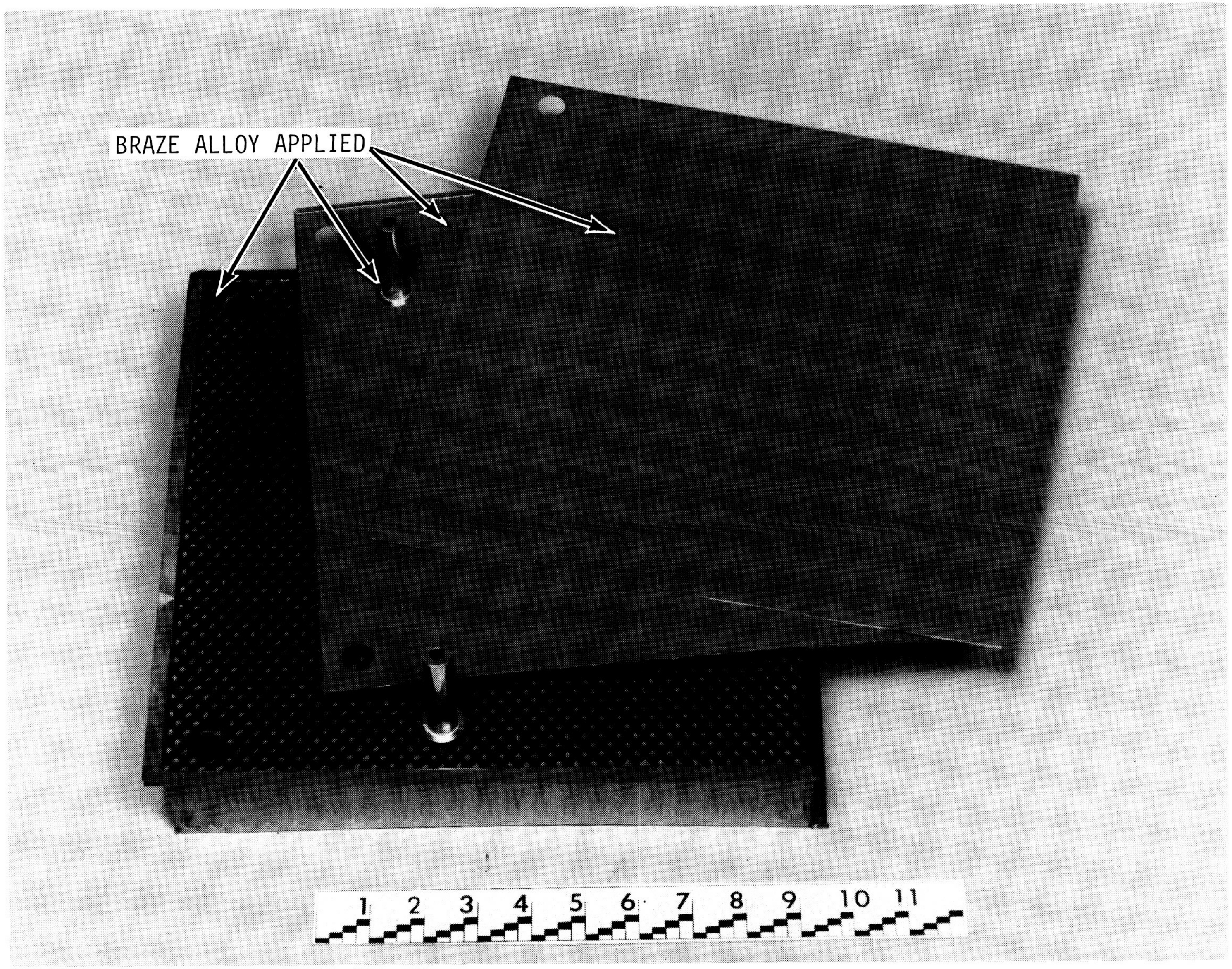


Figure 7. Braze Alloy Applied to all Interfaces

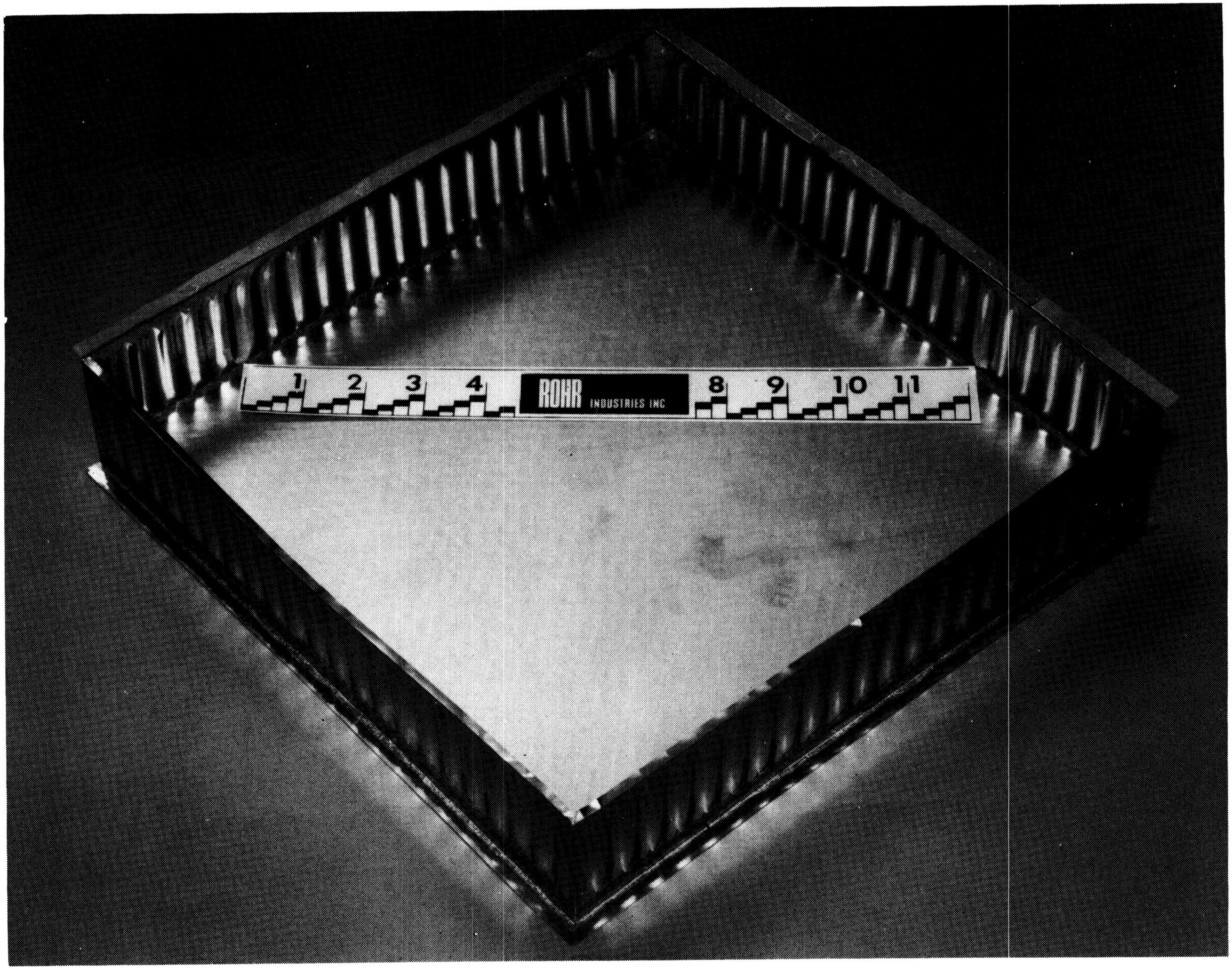


Figure 8. INCONEL 617 Subassembly after Brazing/Diffusion Bonding

Figure 9. Tool Proof Parts (Un-Trimmed Titanium Skins) Being Removed from SPF Tool

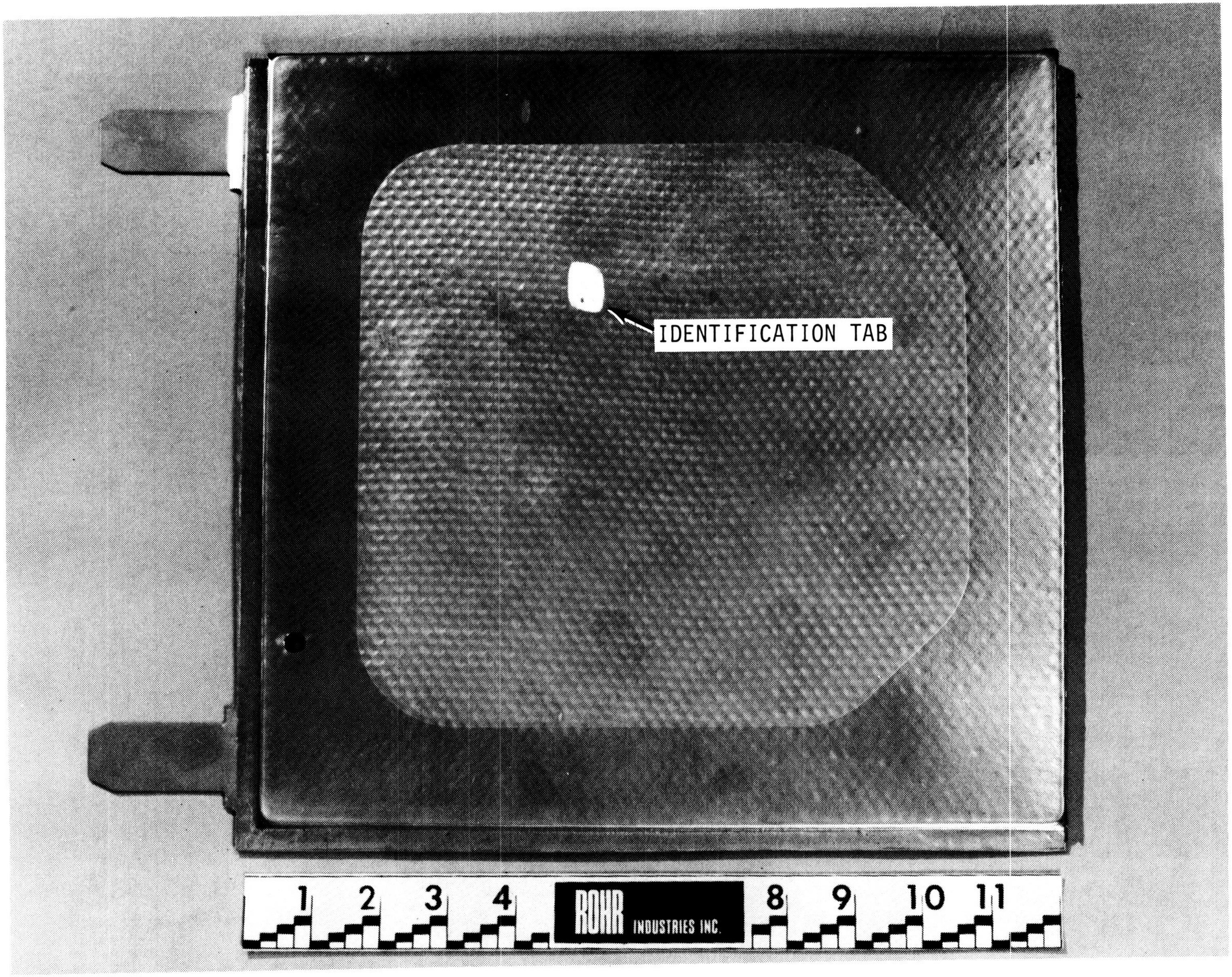
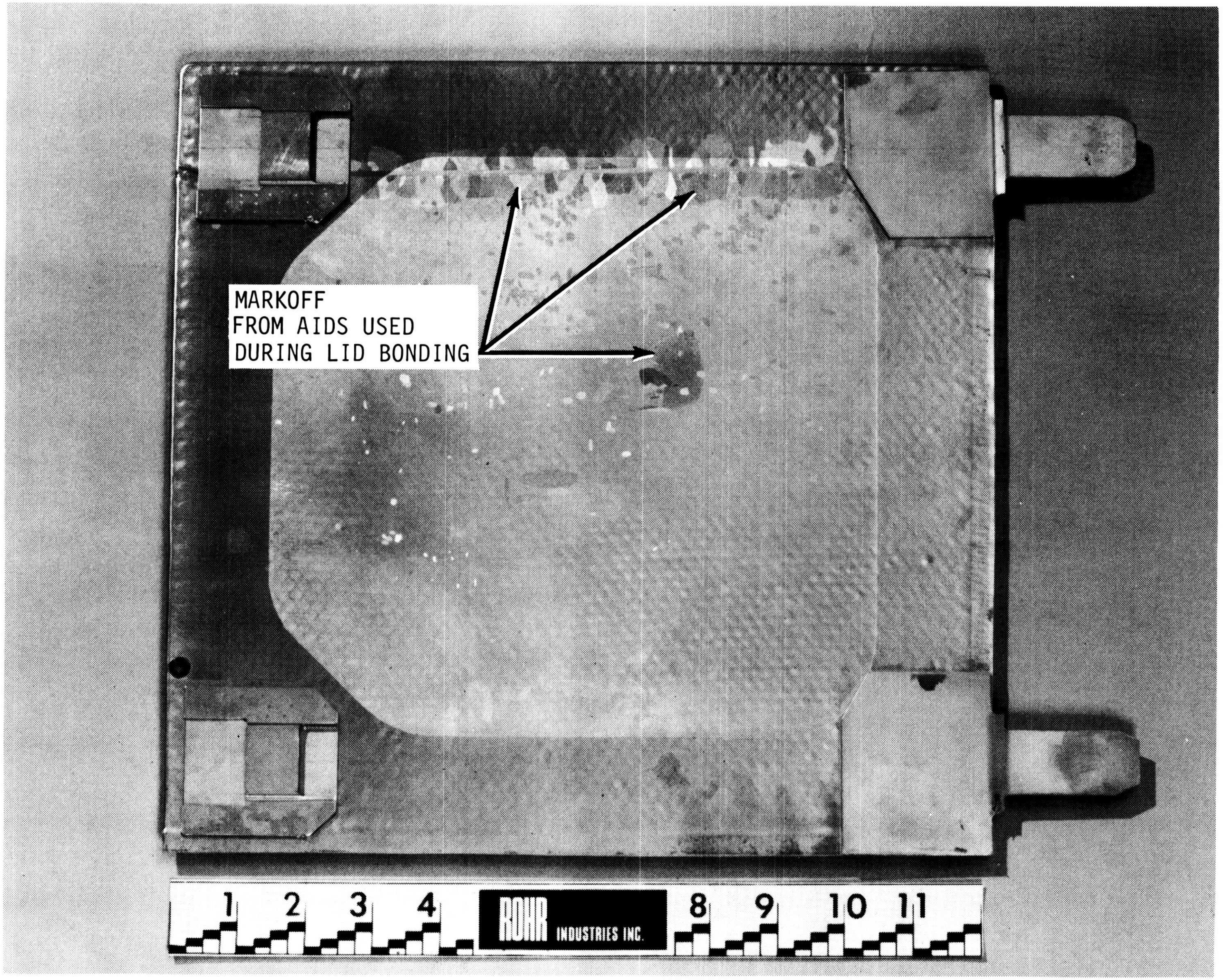


Figure 10. Top of Titanium Subassembly after LID Bonding



MARKOFF
FROM AIDS USED
DURING LID BONDING

Figure 11. Bottom of Titanium Subassembly after LID Bonding

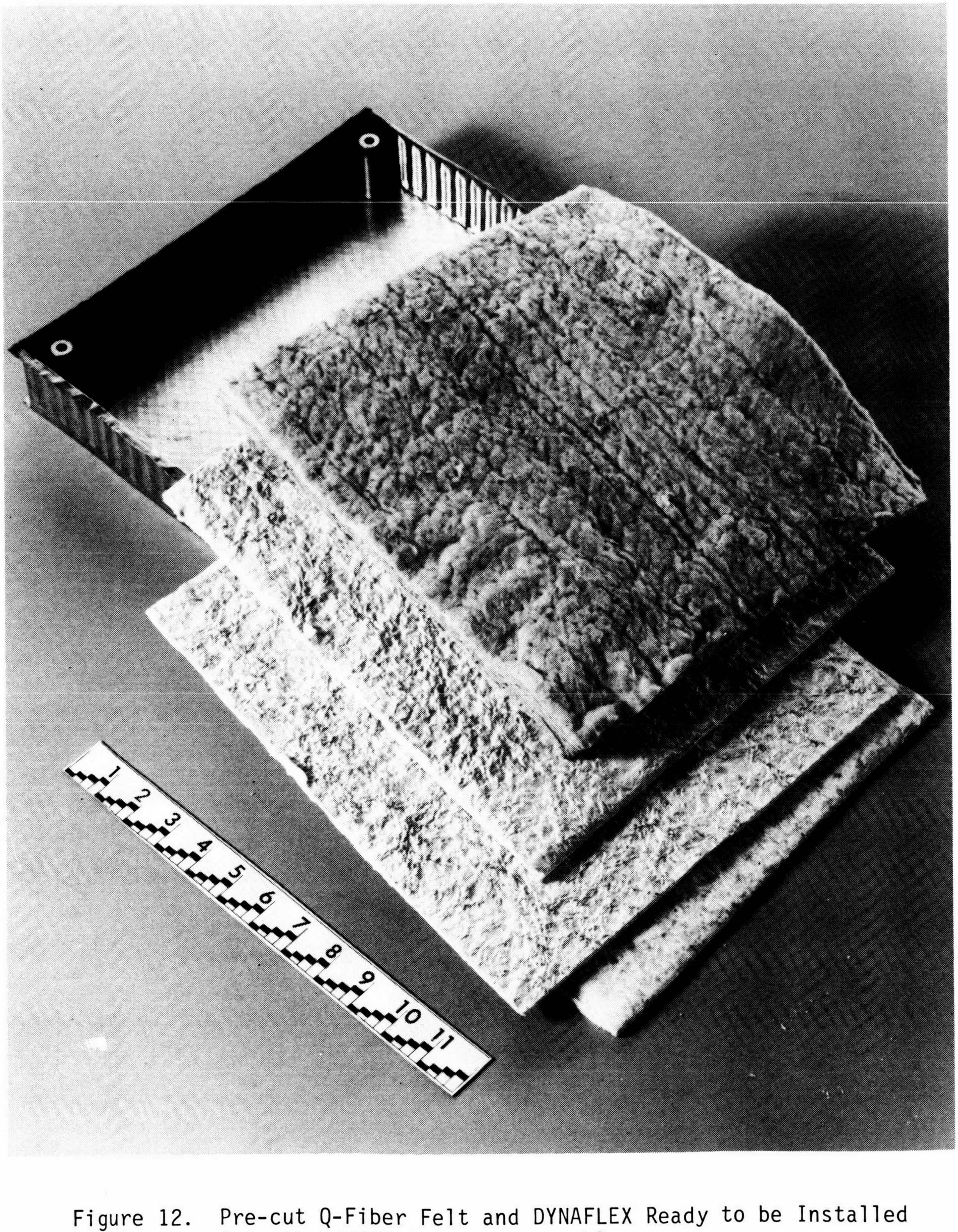


Figure 12. Pre-cut Q-Fiber Felt and DYNAFLEX Ready to be Installed into the INCONEL 617 Subassembly

Figure 13. INCONEL 617 Subassembly with DYNAFLEX and Q-FIBER FELT Installed

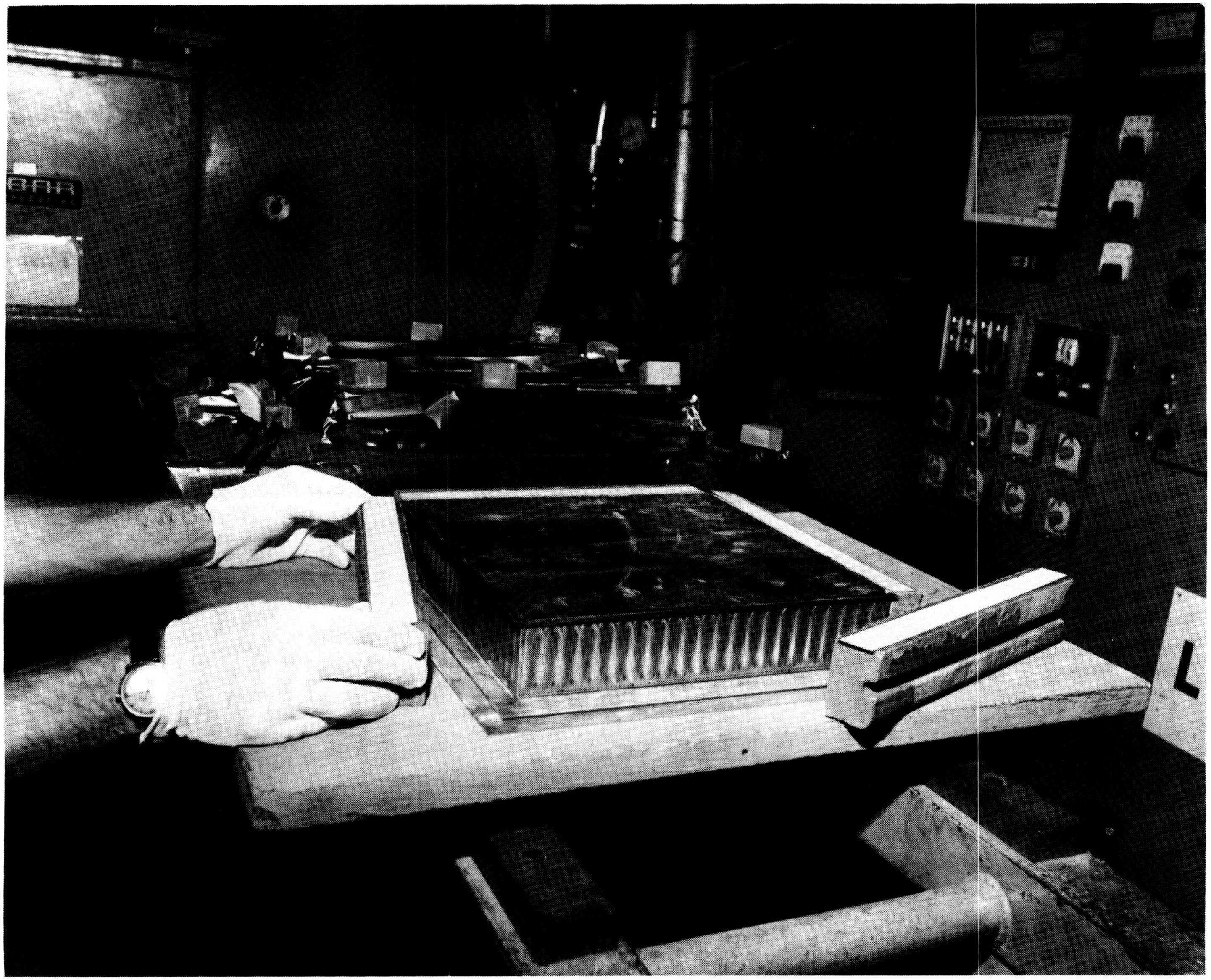


Figure 14. Bi-Metal Assembly Being Laid up for LID Bonding

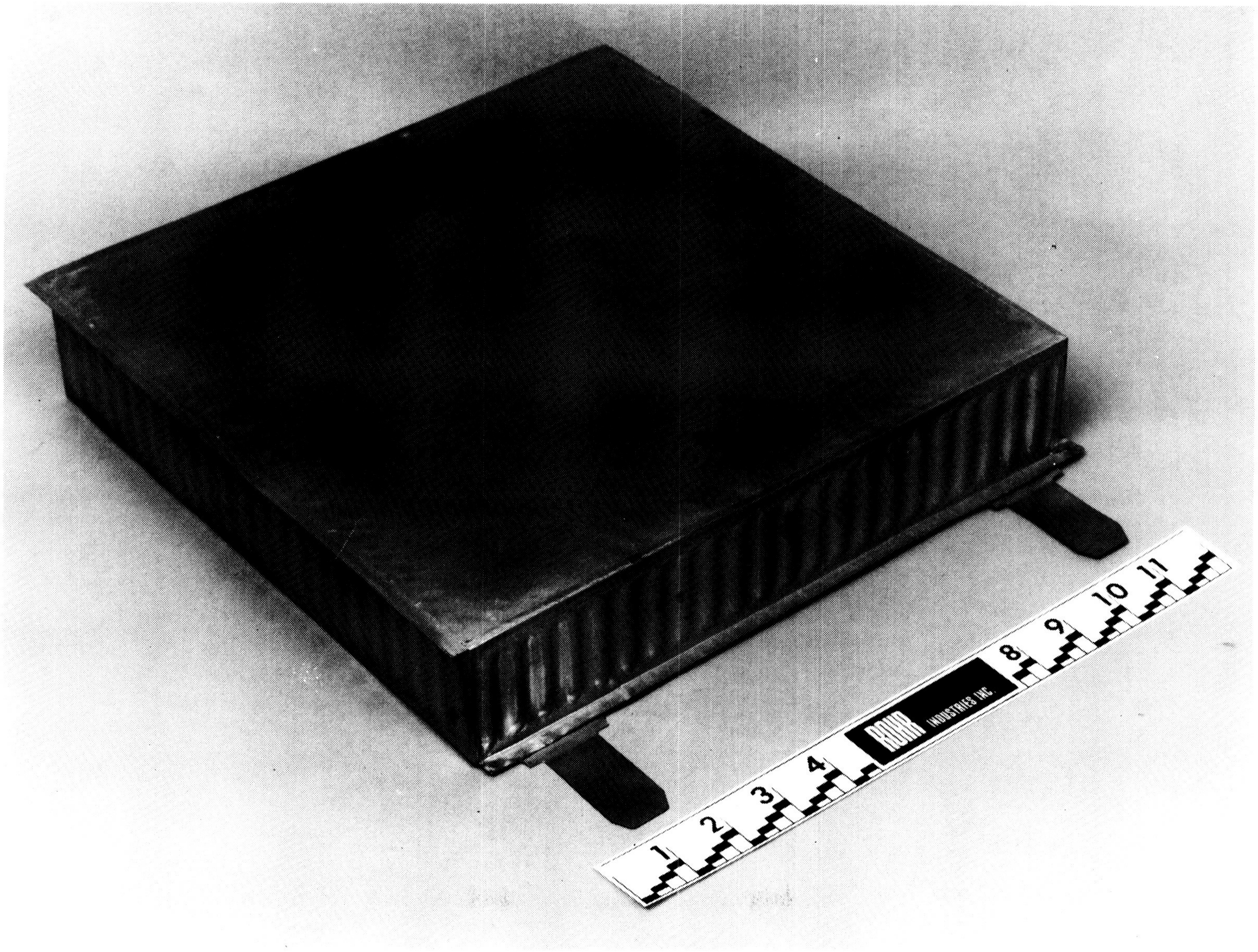


Figure 15. Top of Completed Bi-Metal Panel

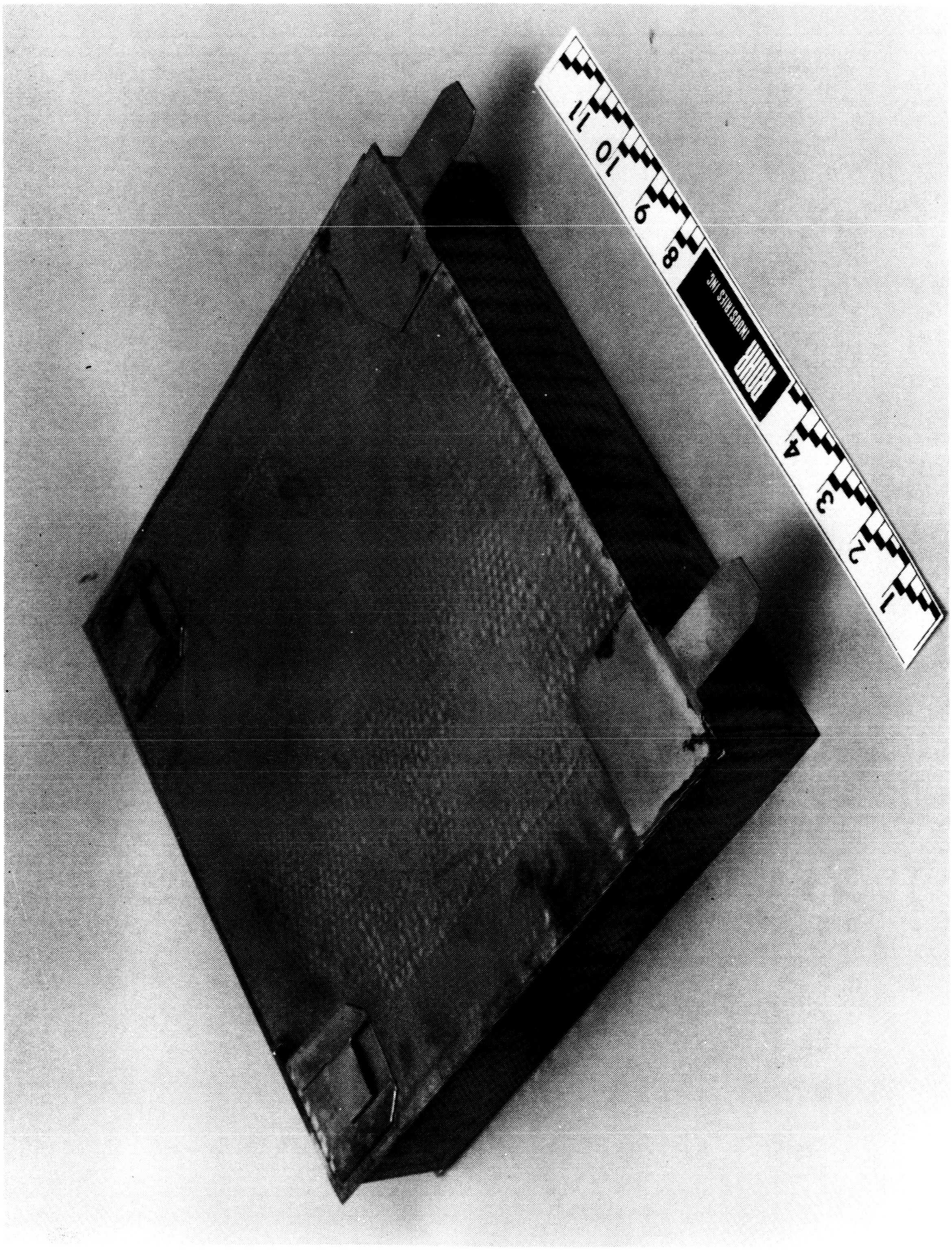
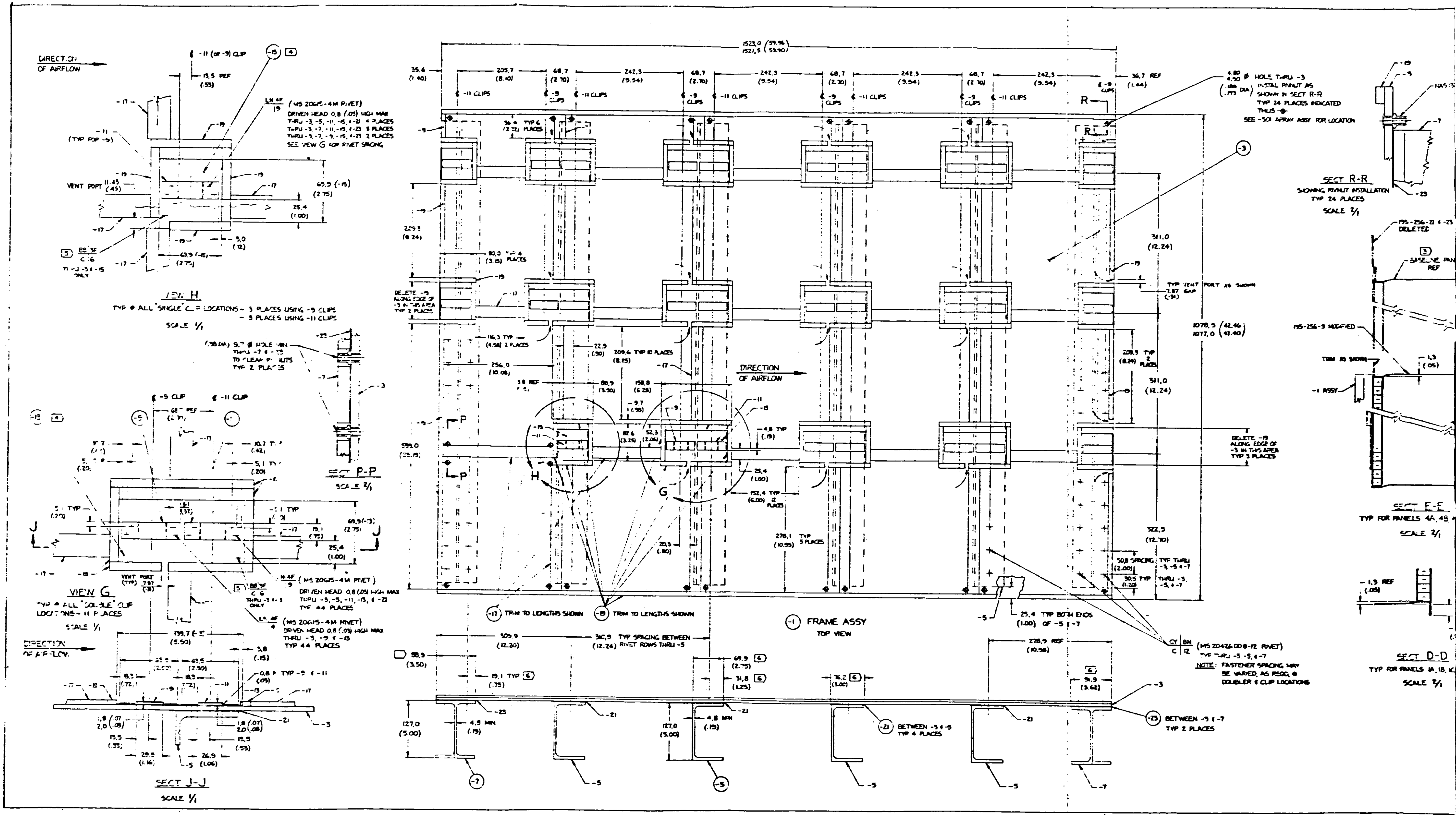
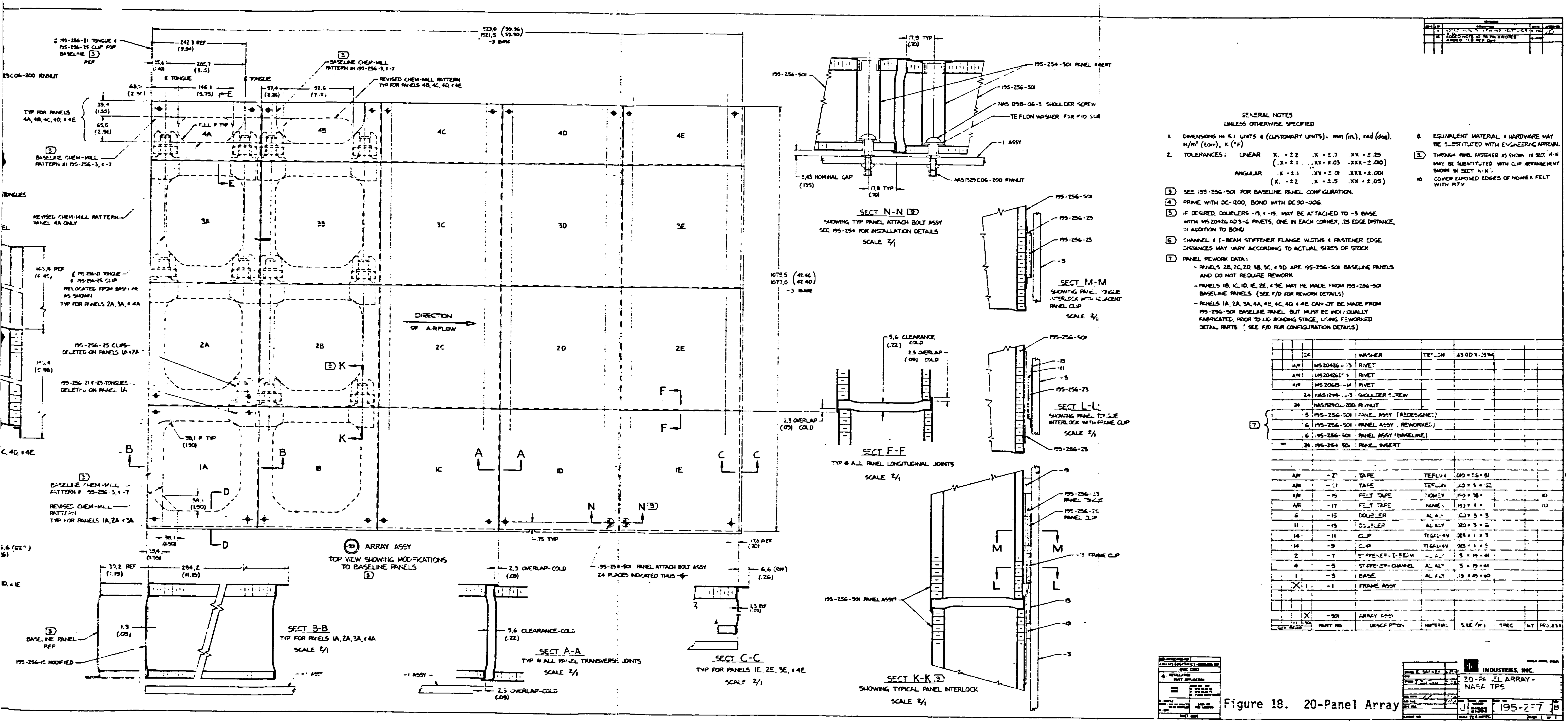


Figure 16. Bottom of Completed Bi-Metal Panel

Figure 17. Superalloy--Titanium--Silica Sandwich Panel--20-Panel Array


DIRECTION OF AIRFLOW
VIEW H
TYP @ ALL "SINGLE" CLIP LOCATIONS ~ 3 PLACES USING -9 CLIPS ~ 3 PLACES USING -11 CLIPS
SCALE 1/1
VENT PORT
(MS 20615-4M RIVET) DRIVEN HEAD 0,8 (.03) HIGH MAX
SEE VIEW G FOR RIVET SPACING
SECT P-P
SCALE 2/1
VIEW G
TYP @ ALL "DOUBLE" CLIP LOCATIONS ~ 11 PLACES
SCALE 1/1
SECT J-J
SCALE 1/1
1523,0 (59.96)
1521,5 (59.90)
-11 CLIPS
-9 CLIPS
DELETE -19 ALONG EDGE OF -3 IN THIS AREA TYP 2 PLACES
DELETE -19 ALONG EDGE OF -3 IN THIS AREA TYP 3 PLACES
TYP VENT PORT AS SHOWN 7.87 GAP (.31)
1078,5 (42.46)
1077,0 (42.40)
4.80 Ø HOLE THRU -3 INSTALL RIVNUT AS SHOWN IN SECT R-R TYP 24 PLACES INDICATED THUS
SEE -501 ARRAY ASSY FOR LOCATION
-17 TRIM TO LENGTHS SHOWN
-19 TRIM TO LENGTHS SHOWN
-1 FRAME ASSY
TOP VIEW
310,9 TYP SPACING BETWEEN RIVET ROWS THRU -5
25,4 TYP BOTH ENDS (1.00) OF -5 & -7
(MS 20426 D08-12 RIVET) TYP THRU -3, -5, & -7
NOTE: FASTENER SPACING MAY BE VARIED, AS REQ'D, @ DOUBLER & CLIP LOCATIONS
-21 BETWEEN -3 & -5 TYP 4 PLACES
-23 BETWEEN -5 & -7 TYP 2 PLACES
SECT R-R
SHOWING RIVNUT INSTALLATION TYP 24 PLACES
SCALE 2/1
195-256-21 & -23 DELETED
BASELINE PANEL REF
195-256-5 MODIFIED
TRIM AS SHOWN
-1 ASSY
SECT E-E
TYP FOR PANELS 4A, 4B
SCALE 2/1
SECT D-D
TYP FOR PANELS 1A, 1B
SCALE 2/1
-3
-5
-7
-9
-11
-13
-15
-17
-19
-21
-23



GENERAL NOTES
UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS IN S.I. UNITS & (CUSTOMARY UNITS): mm (in.), rad (deg), N/m² (torr), K (°F)
2. TOLERANCES: LINEAR X. = ±2 .X = ±.7 .XX = ±.25 (.X = ±.1 .XX = ±.03 .XXX = ±.010) ANGULAR .X = ±.1 .XX = ±.01 .XXX = ±.001 (X. = ±2 .X = ±.5 .XX = ±.05)
③ SEE 195-256-501 FOR BASELINE PANEL CONFIGURATION.
④ PRIME WITH DC-1200, BOND WITH DC 90-006.
⑤ IF DESIRED, DOUBLERS -13, & -15, MAY BE ATTACHED TO -3 BASE WITH MS 20426 AD 3-6 RIVETS, ONE IN EACH CORNER, .25 EDGE DISTANCE, IN ADDITION TO BOND
⑥ CHANNEL & I-BEAM STIFFENER FLANGE WIDTHS & FASTENER EDGE DISTANCES MAY VARY ACCORDING TO ACTUAL SIZES OF STOCK
⑦ PANEL REWORK DATA:
- PANELS 2B, 2C, 2D, 3B, 3C, & 3D ARE 195-256-501 BASELINE PANELS AND DO NOT REQUIRE REWORK.
- PANELS 1B, 1C, 1D, 1E, 2E, & 3E MAY BE MADE FROM 195-256-501 BASELINE PANELS (SEE F/D FOR REWORK DETAILS)
- PANELS 1A, 2A, 3A, 4A, 4B, 4C, 4D, & 4E CANNOT BE MADE FROM 195-256-501 BASELINE PANEL, BUT MUST BE INDIVIDUALLY FABRICATED, PRIOR TO LID BONDING STAGE, USING REWORKED DETAIL PARTS (SEE F/D FOR CONFIGURATION DETAILS)
8. EQUIVALENT MATERIAL & HARDWARE MAY BE SUBSTITUTED WITH ENGINEERING APPROVAL
⑨ THROUGH PANEL FASTENER AS SHOWN IN SECT N-N MAY BE SUBSTITUTED WITH CLIP ARRANGEMENT SHOWN IN SECT K-K.
10 COVER EXPOSED EDGES OF NOMEX FELT WITH RTV

QTY REQD -1	QTY REQD -501	PART NO.	DESCRIPTION	MATERIAL	SIZE (in)	SPEC	WT	PROCESS
	24		WASHER	TEFLON	.43 OD X .35			
A/R		MS 20426-3	RIVET					
A/R		MS 20426D3-4	RIVET					
A/R		MS 20615-M	RIVET					
	24	NAS 1298-06-3	SHOULDER SCREW					
	24	NAS 1329C06-200	RIVNUT					
	8	195-256-501	PANEL ASSY (REDESIGNED)					
	6	195-256-501	PANEL ASSY (REWORKED)					
	6	195-256-501	PANEL ASSY (BASELINE)					
	24	195-254-501	PANEL INSERT					
A/R		-23	TAPE	TEFLON	.010 × 3.6 × 51			
A/R		-21	TAPE	TEFLON	.010 × 3 × 62			
A/R		-19	FELT TAPE	NOMEX	.150 × .38 ×			10
A/R		-17	FELT TAPE	NOMEX	.150 × 1 ×			10
6		-15	DOUBLER	AL ALY	.020 × 3 × 3			
11		-13	DOUBLER	AL ALY	.020 × 3 × 6			
14		-11	CLIP	TI 6AL-4V	.025 × 1 × 3			
14		-9	CLIP	TI 6AL-4V	.025 × 1 × 3			
2		-7	STIFFENER-I-BEAM	AL ALY	.5 × .19 × 41			
4		-5	STIFFENER-CHANNEL	AL ALY	.5 × .19 × 41			
1		-3	BASE	AL ALY	.19 × 45 × 60			
X	1	-1	FRAME ASSY					
	X	-501	ARRAY ASSY					

Figure 18. 20-Panel Array

2

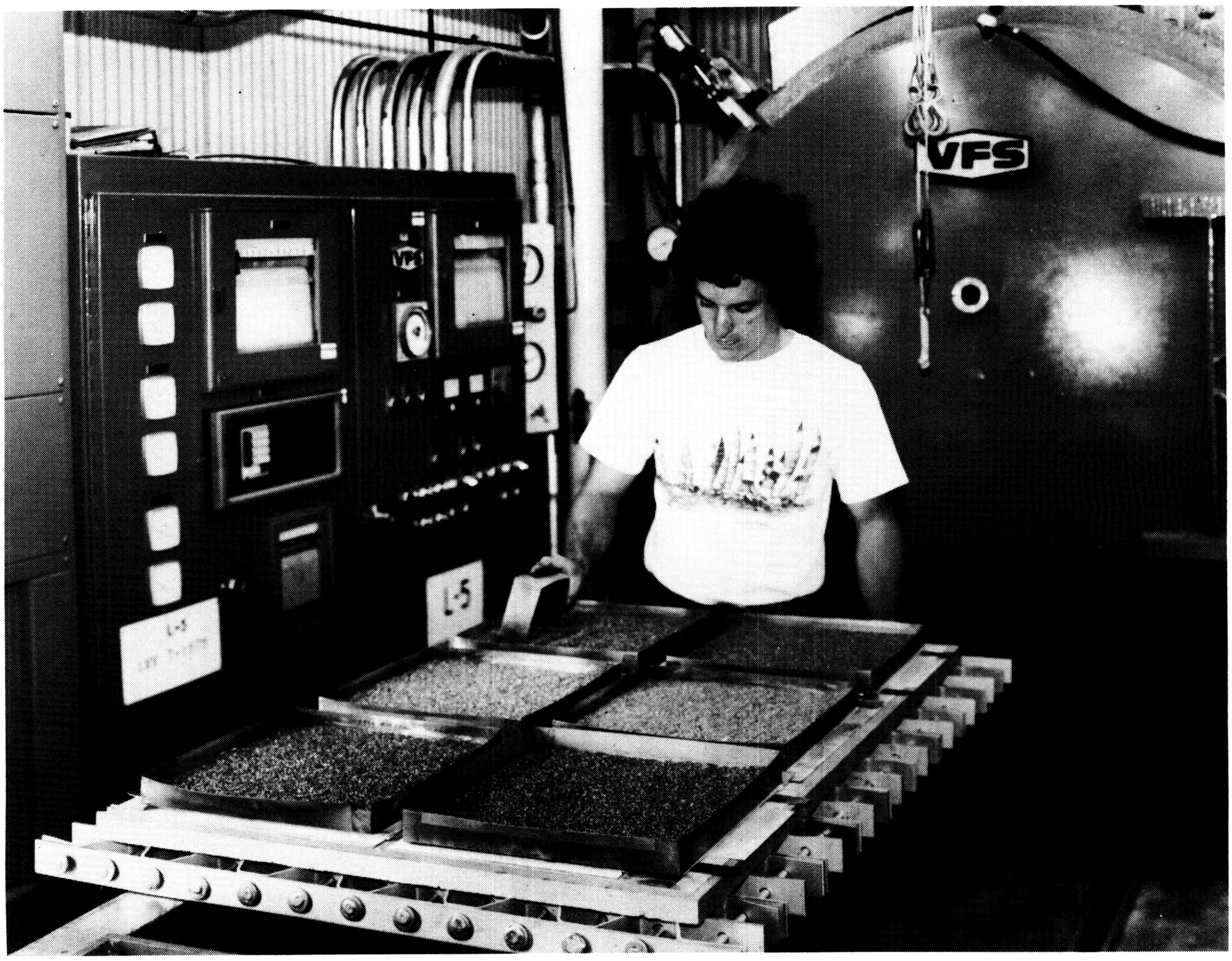


Figure 19. Six Titanium Subassemblies being Removed from Vacuum Furnace after LID Bonding

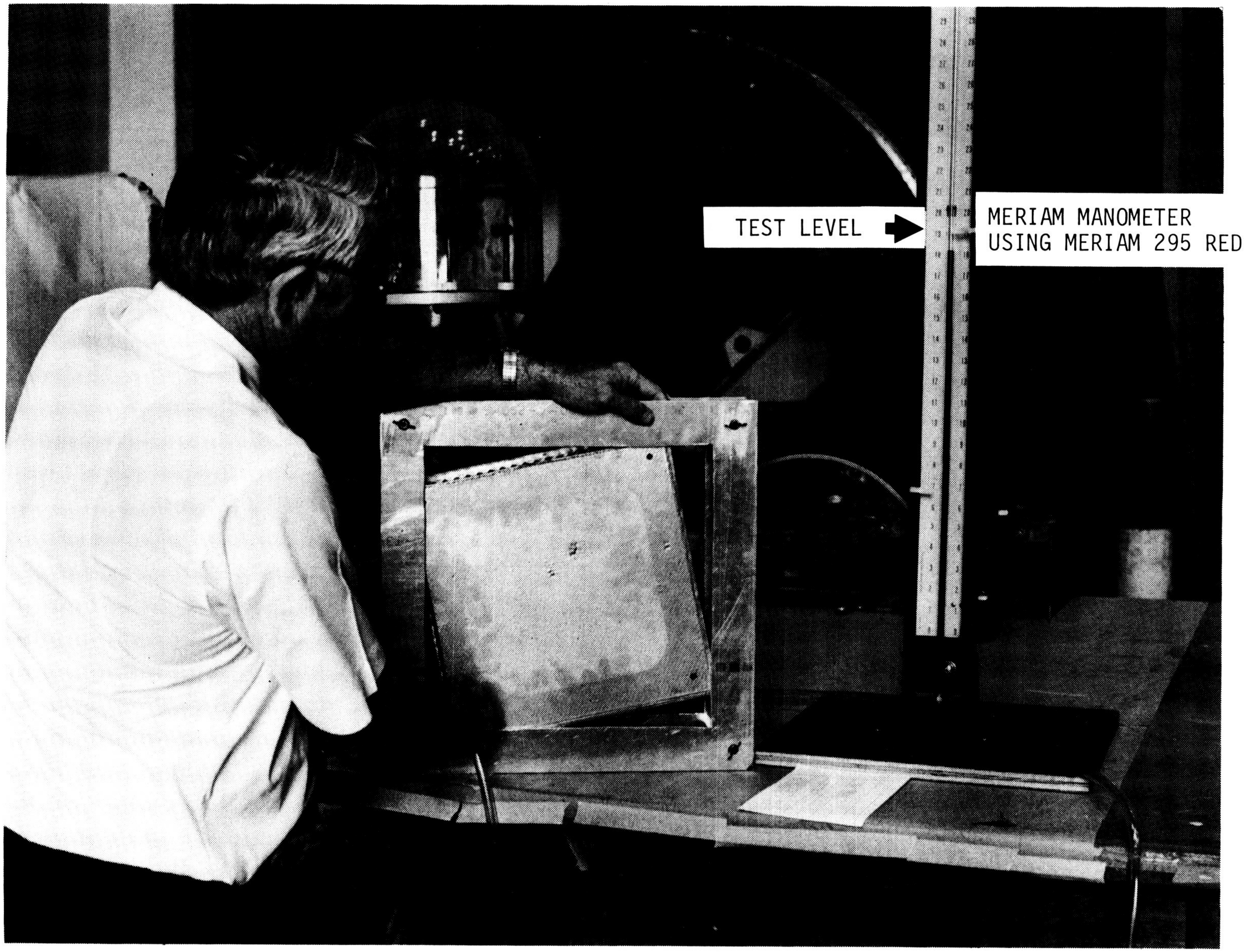


Figure 20. Pressure Testing Superalloy Sandwich Panel

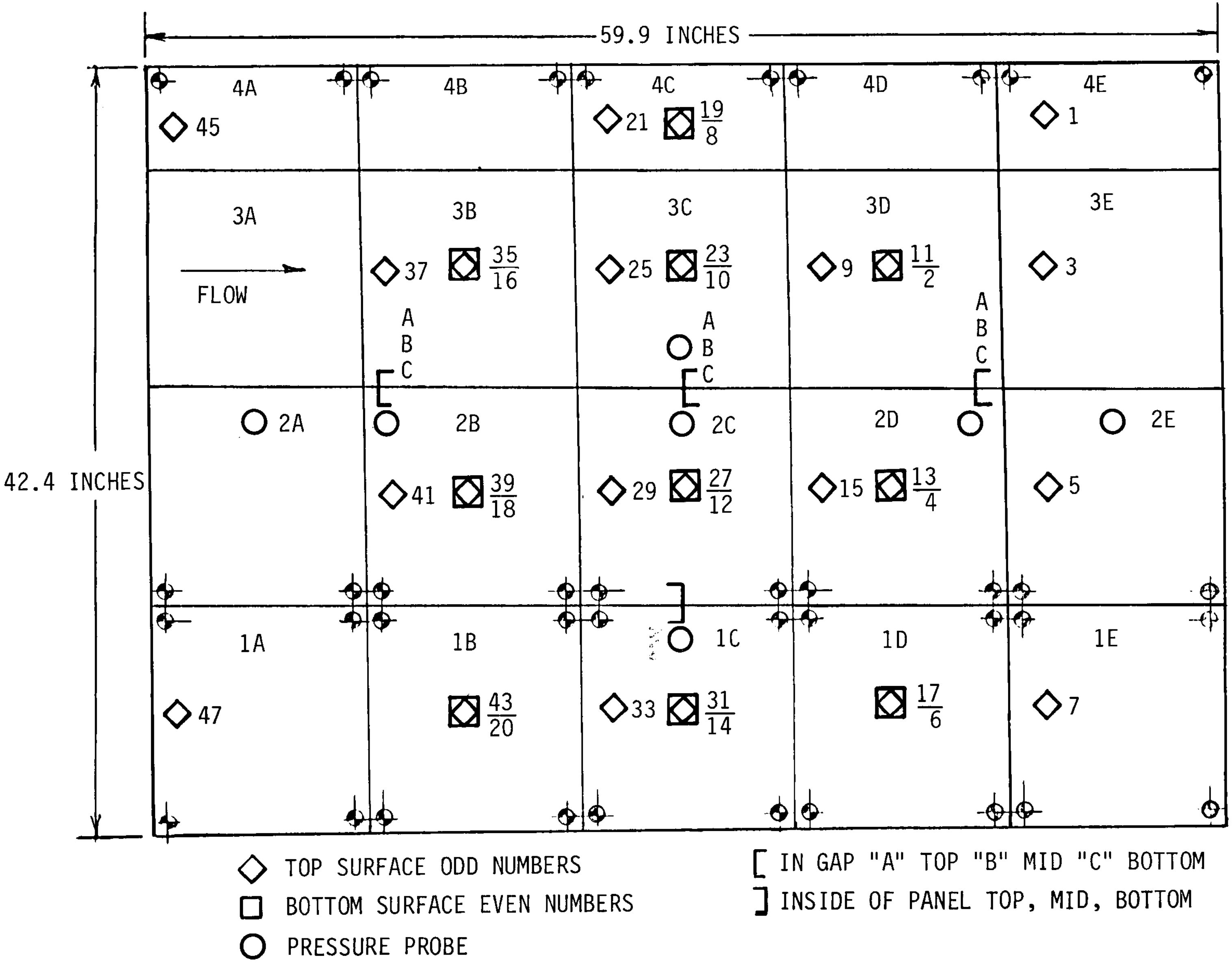


Figure 21. Thermocouple Layout by Panel Serial Number

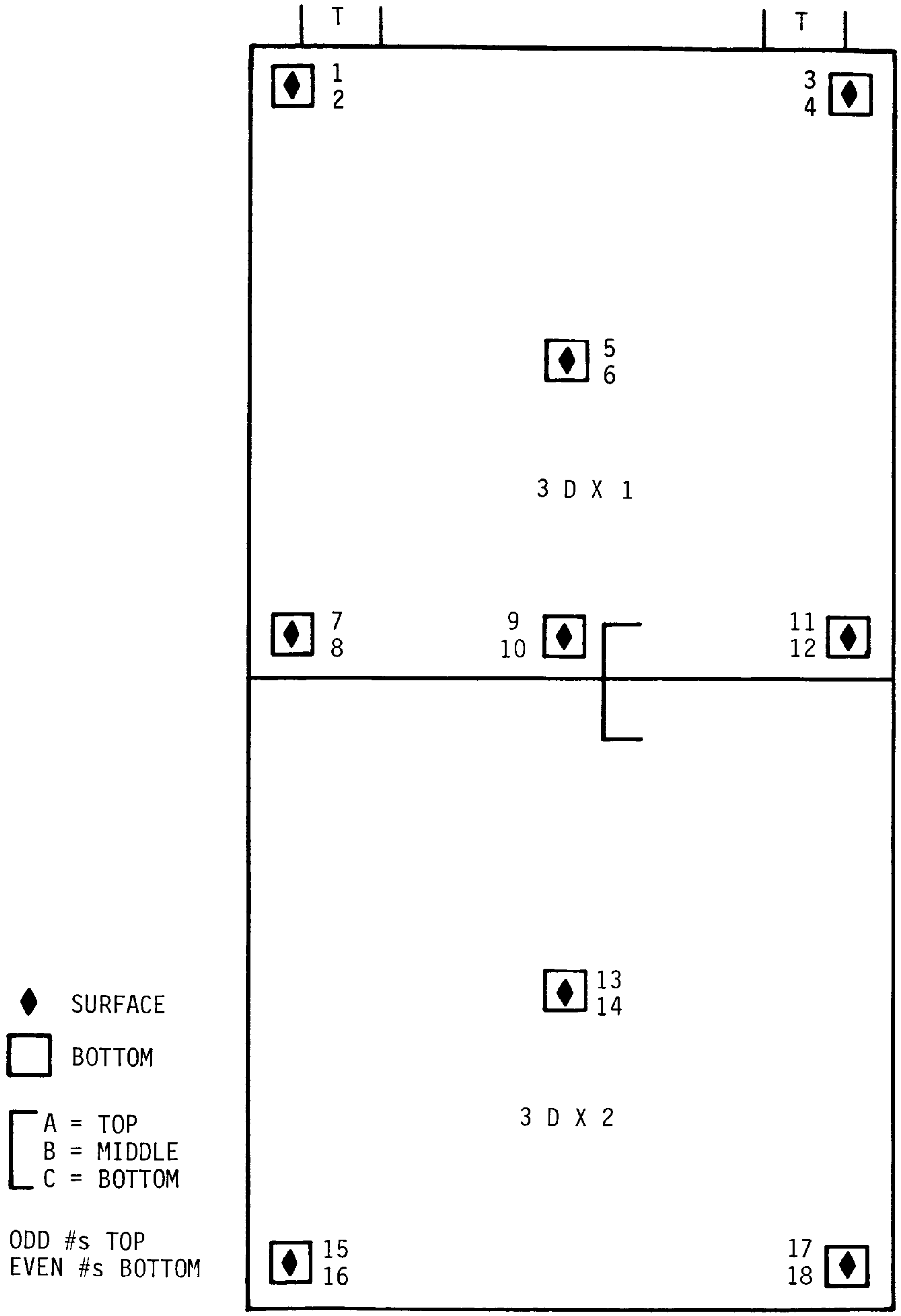


Figure 22. Thermocouple Layout for 2-Panel Array

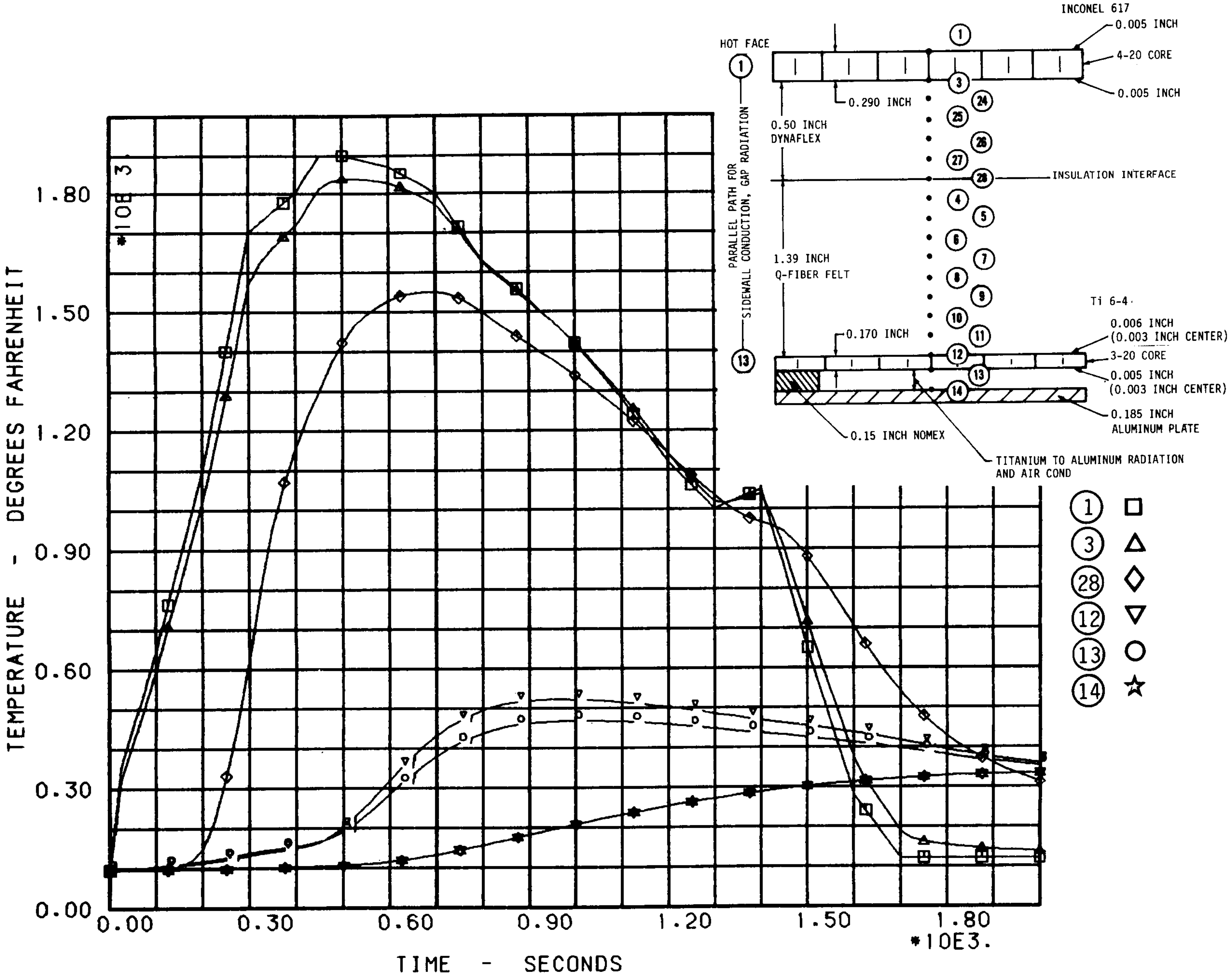


Figure 23. Thermal Math Model, Transient Analysis

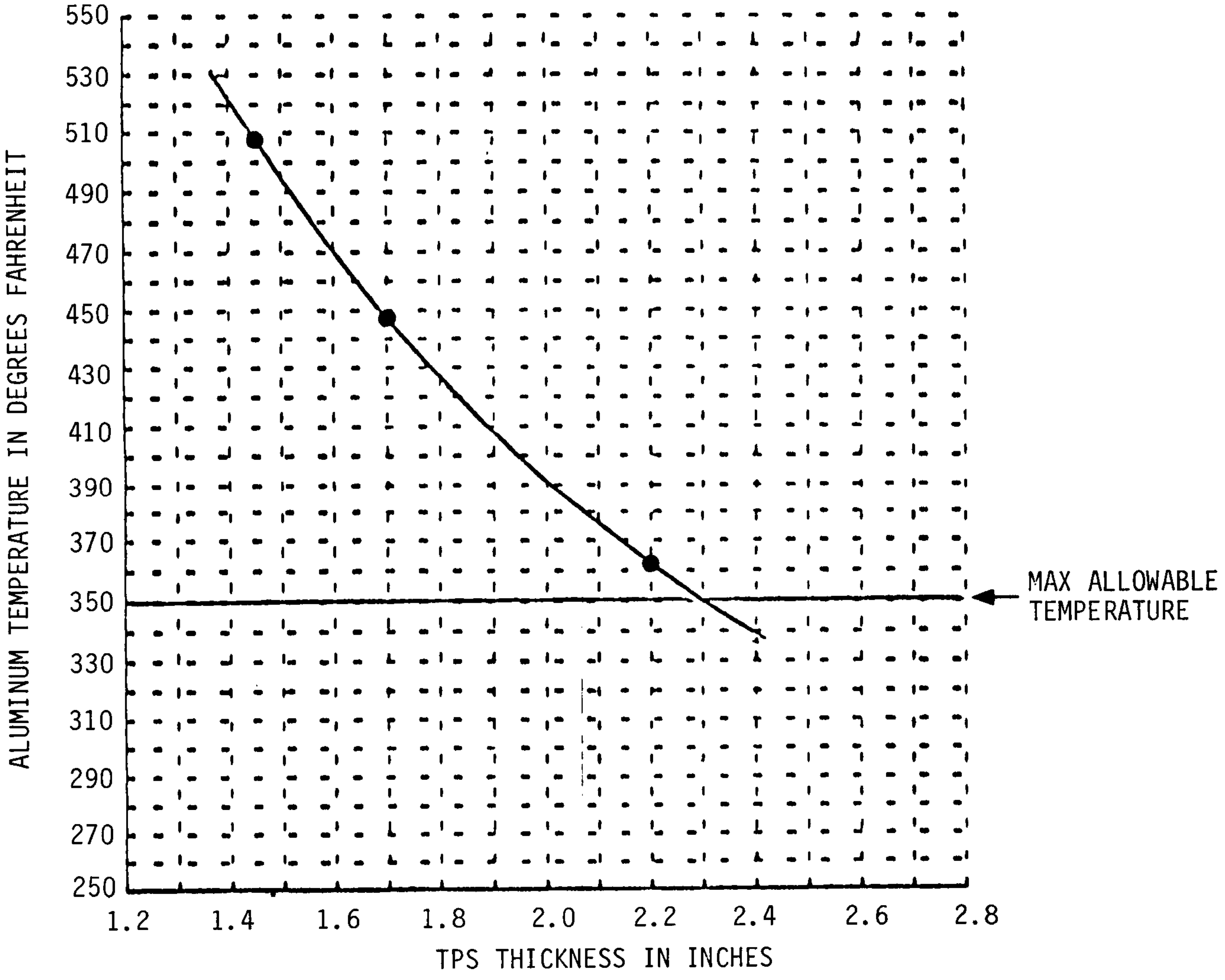


Figure 24. B.P. 1300 Aluminum Temperature Versus TPS Thickness NOMEX Thickness is Not Included

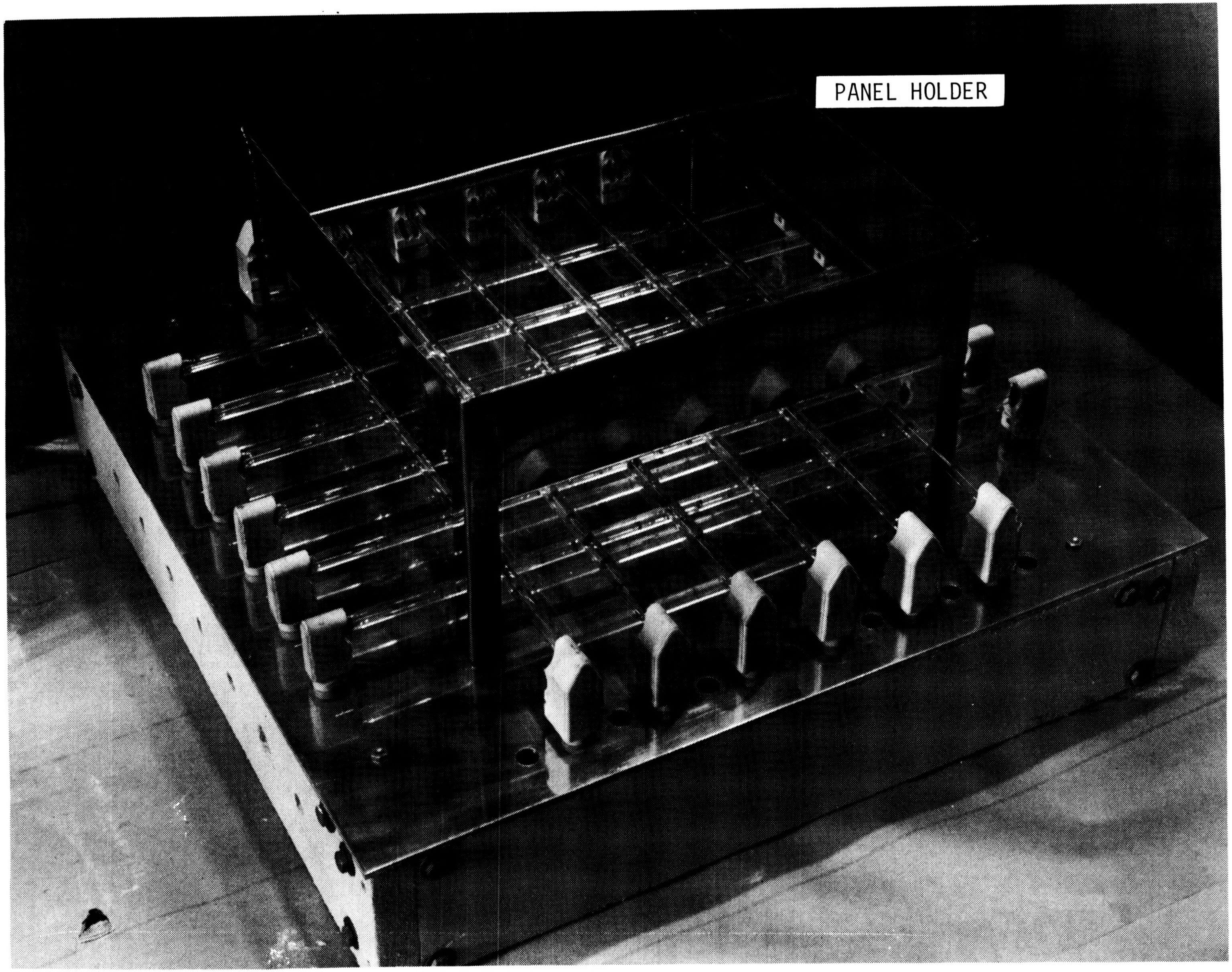


Figure 25. Guarded Hot Plate with Zoned Heating

Figure 26. Guarded Hot Plate with Thermac Controller

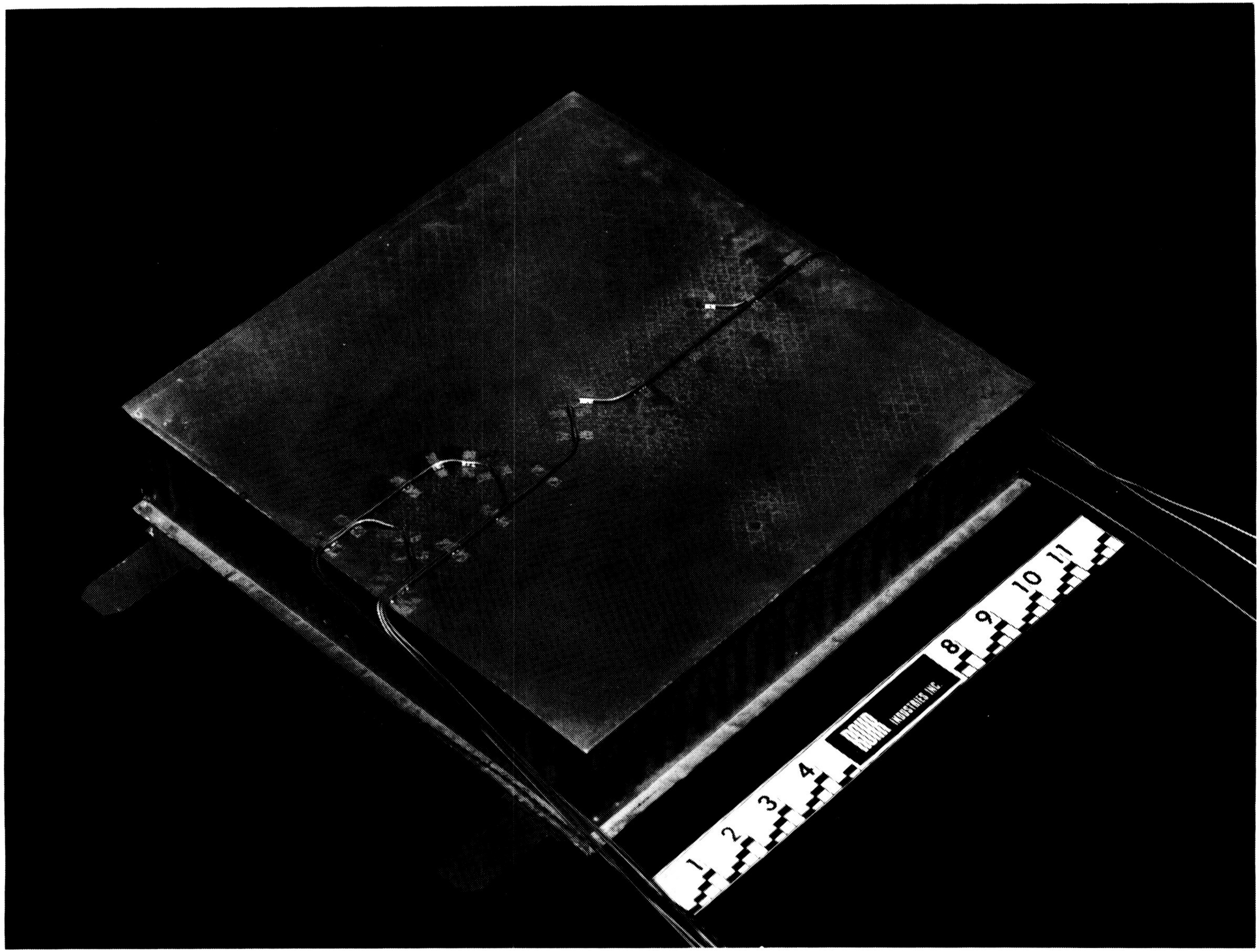


Figure 27. Superalloy Panel with Thermocouples Installed.

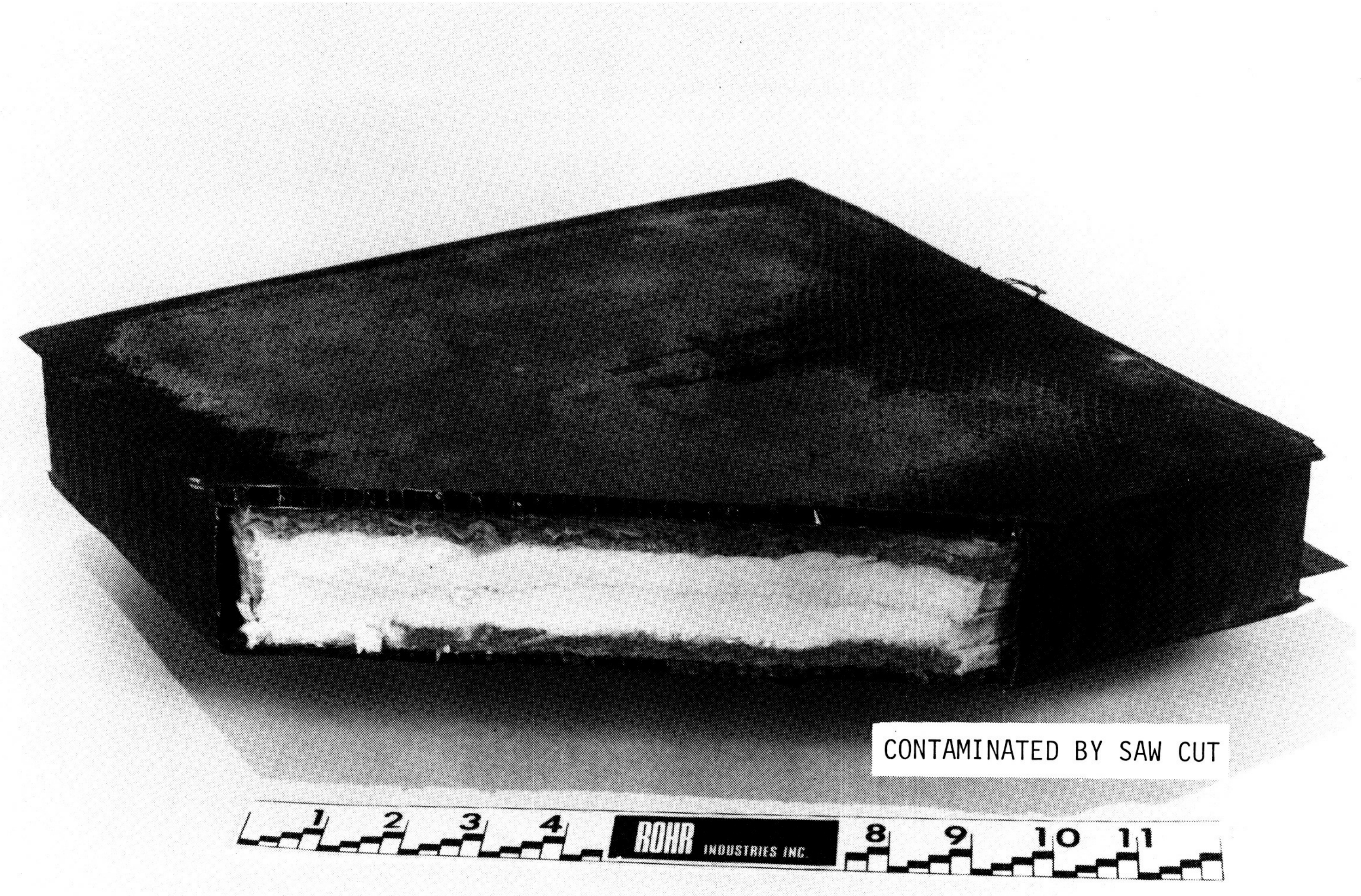


Figure 28. Superalloy Panel Section after Thermal Conductivity Tests

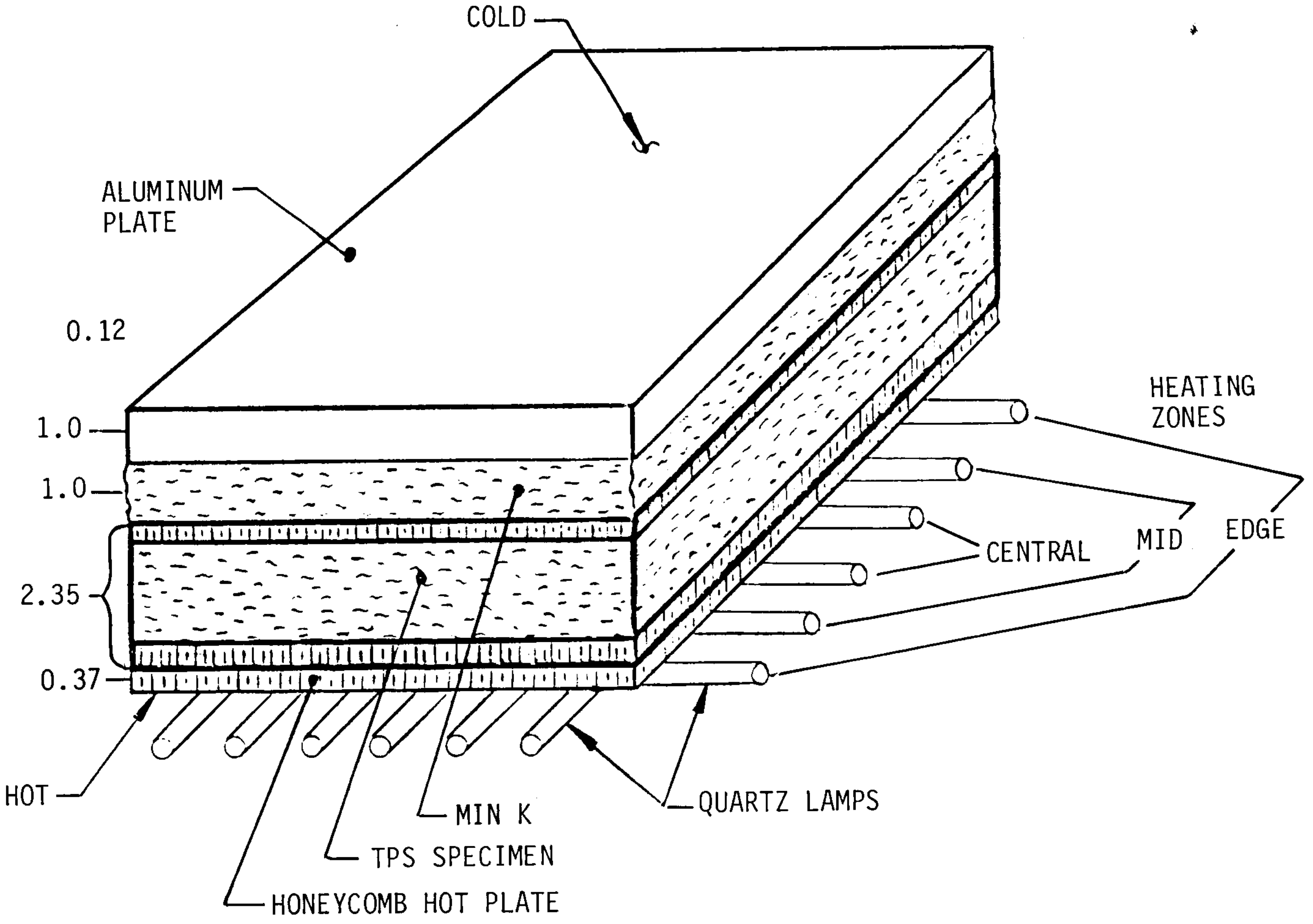


Figure 29. Thermal Conductivity Test Setup

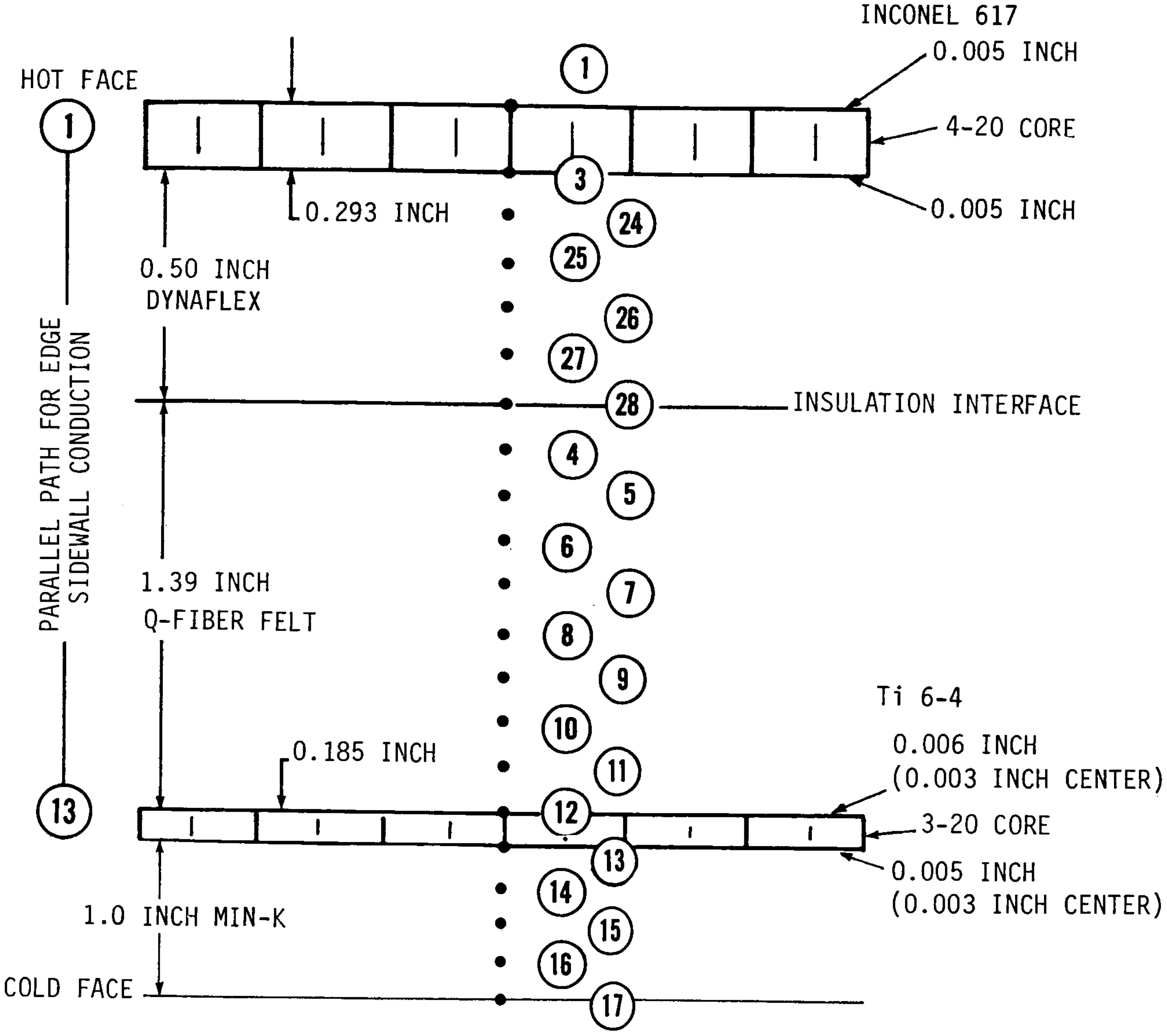


Figure 30. Thermal Math Model, Steady State Analysis

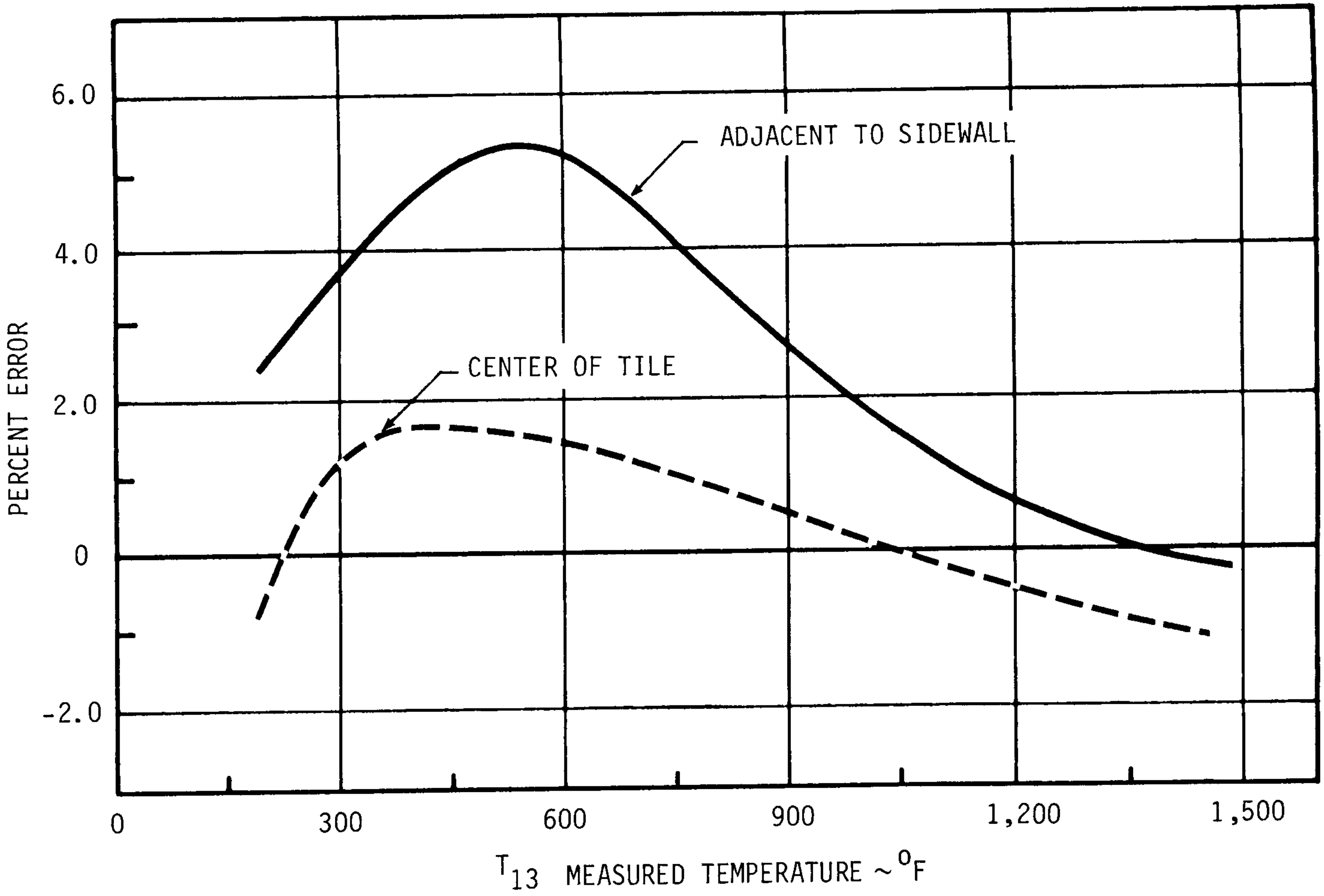


Figure 31. Percent Error Versus Measured Temperature

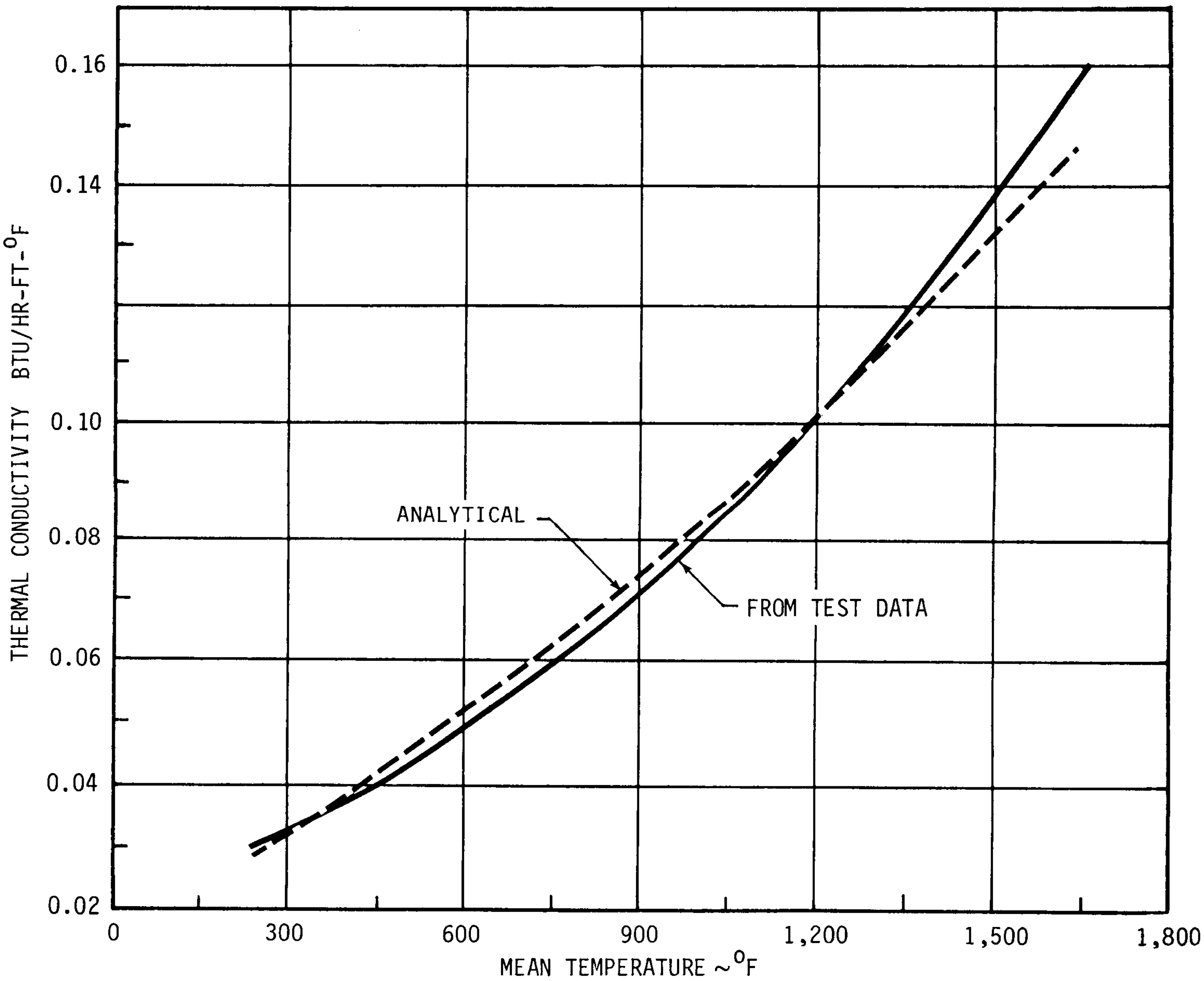
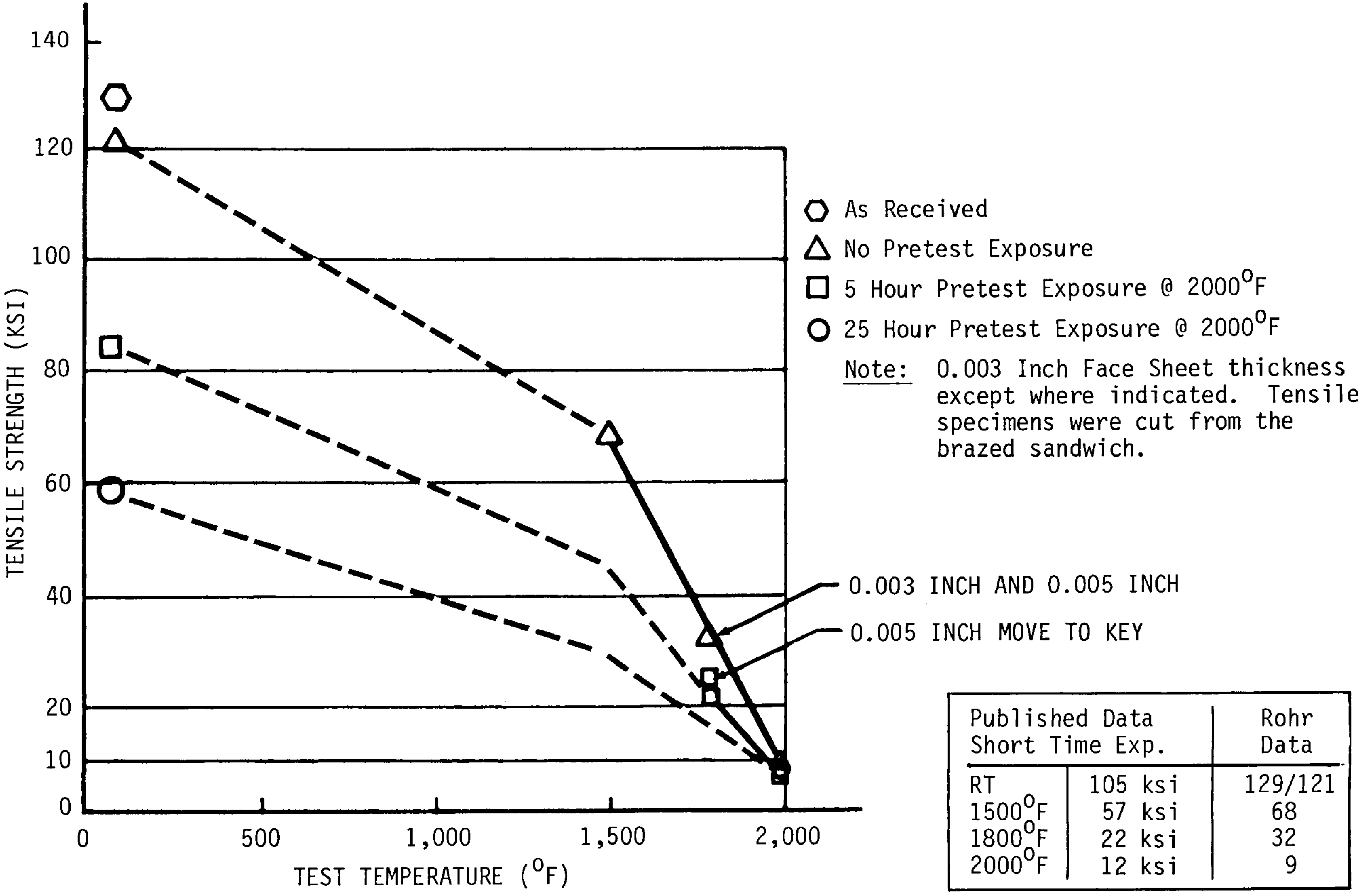


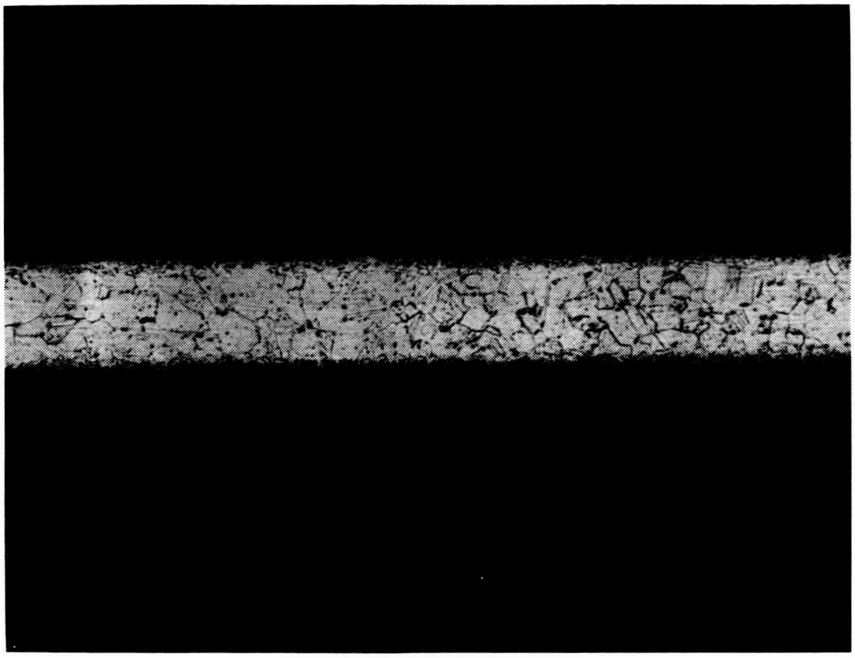
Figure 32. Effective Thermal Conductivity as a Function of Temperature



Note: 0.003 Inch Face Sheet thickness except where indicated. Tensile specimens were cut from the brazed sandwich.

Published Data Short Time Exp.		Rohr Data
RT	105 ksi	129/121
1500°F	57 ksi	68
1800°F	22 ksi	32
2000°F	12 ksi	9

Figure 33. Face Sheet Ultimate Tensile Strength Versus Test Temperature INCONEL 617

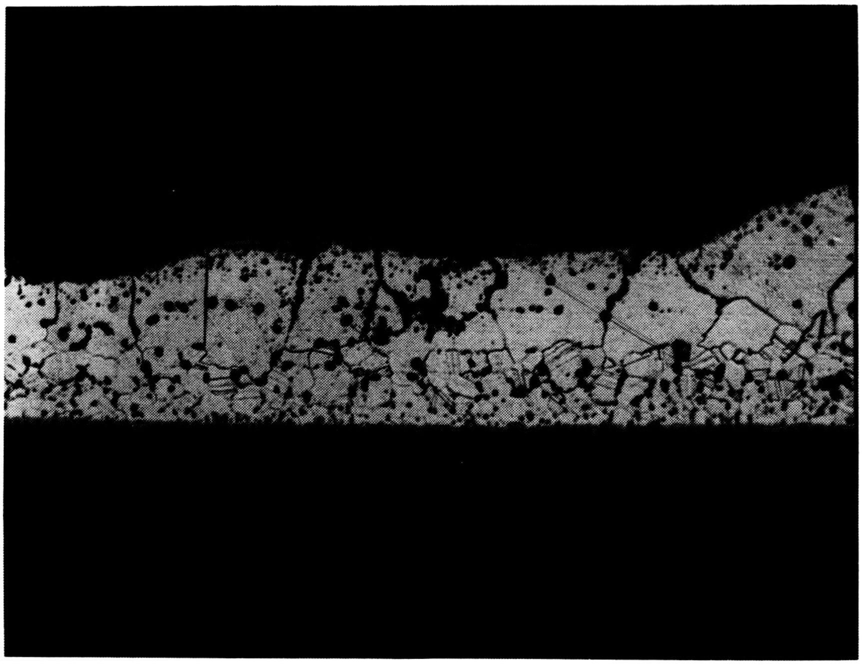


81-1036-5   200X   KALLINGS ETCH

Figure 34. Photomicrograph of As-Received Foil

81-1036-1 200X KALLINGS ETCH

Figure 35. Photomicrograph of Brazed Foil after 5 Hours of Exposure to 2000°F



81-1036-4 200X KALLINGS ETCH

Figure 36. Photomicrograph of Brazed Foil after 25 Hours of Exposure to 2000°F

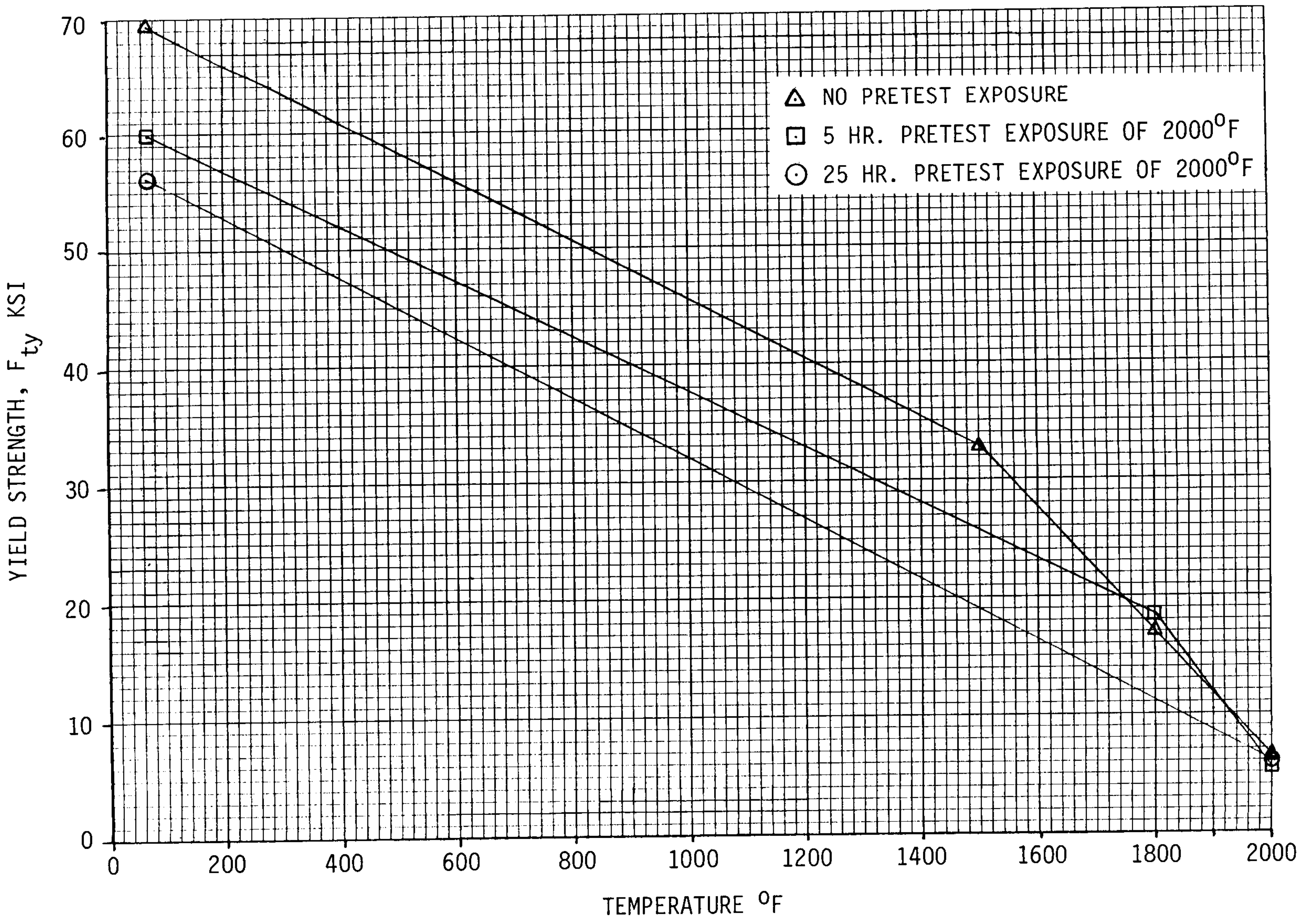


Figure 37. Tensile Yield Strength of Inco 617 Face Sheets - Brazed

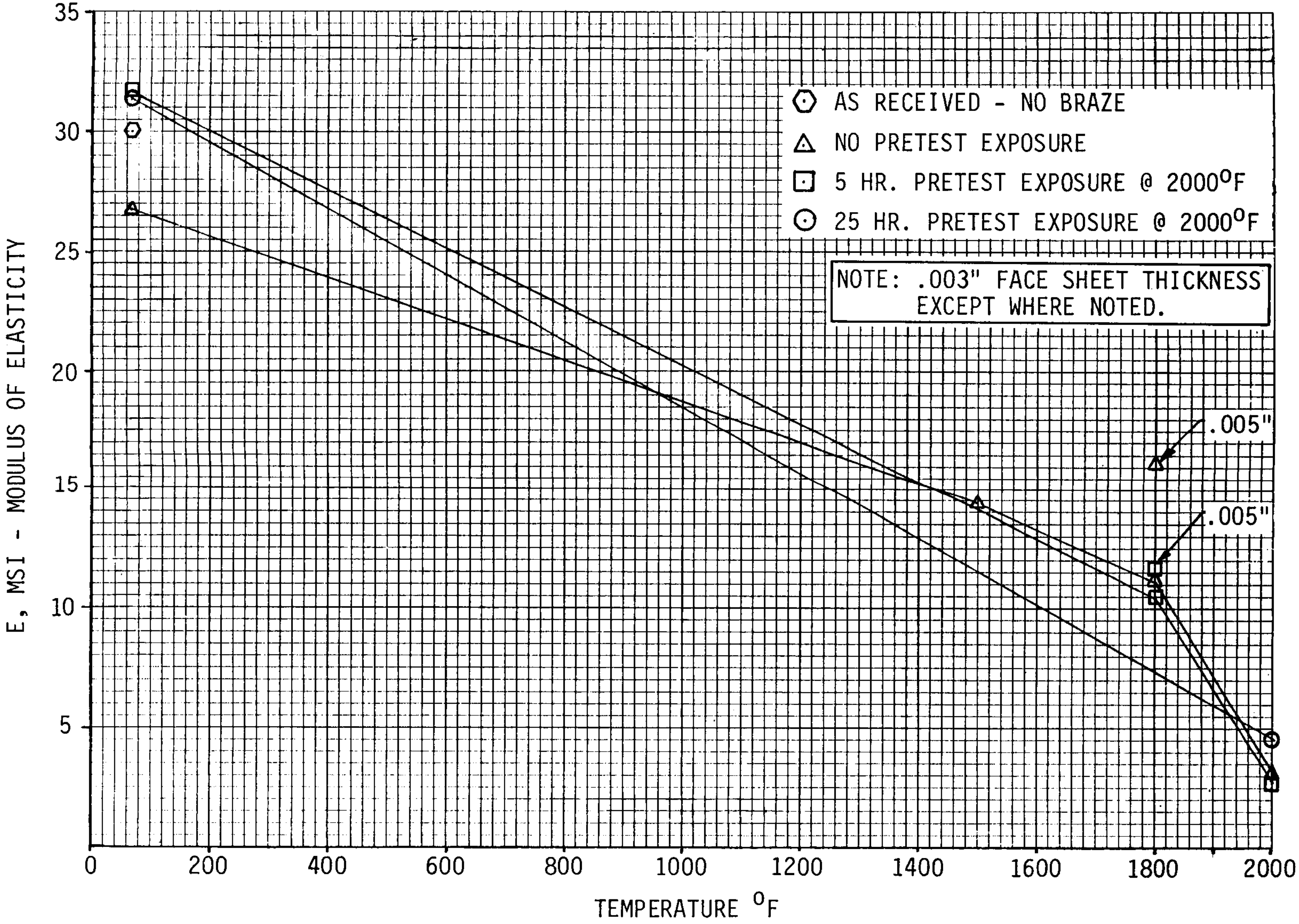


Figure 38. Modulus of Elasticity, E, of Inco 617 Face Sheets - Brazed

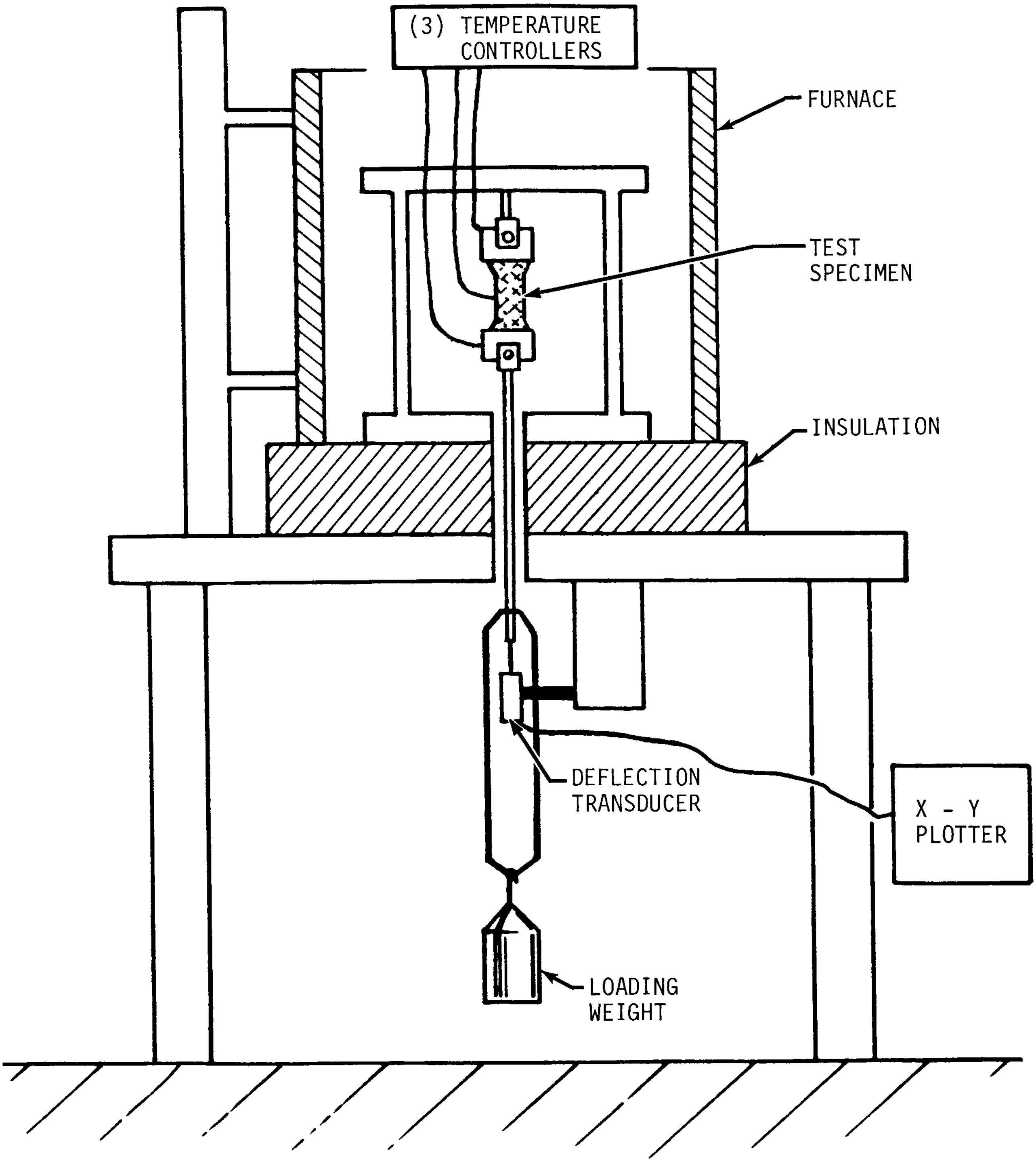


Figure 39. Schematic of Creep Test Setup

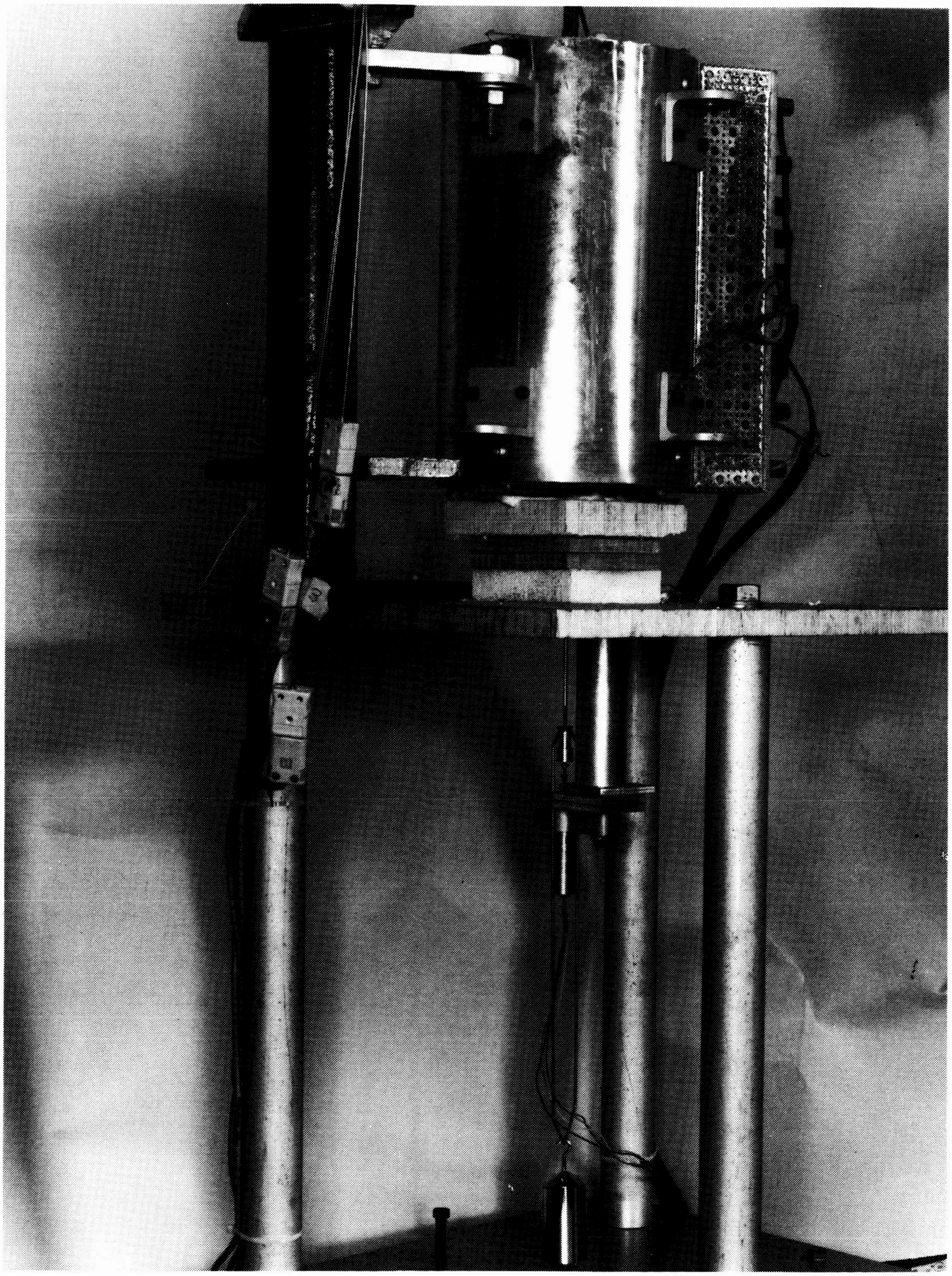


Figure 40. Overall View of Creep Test Setup

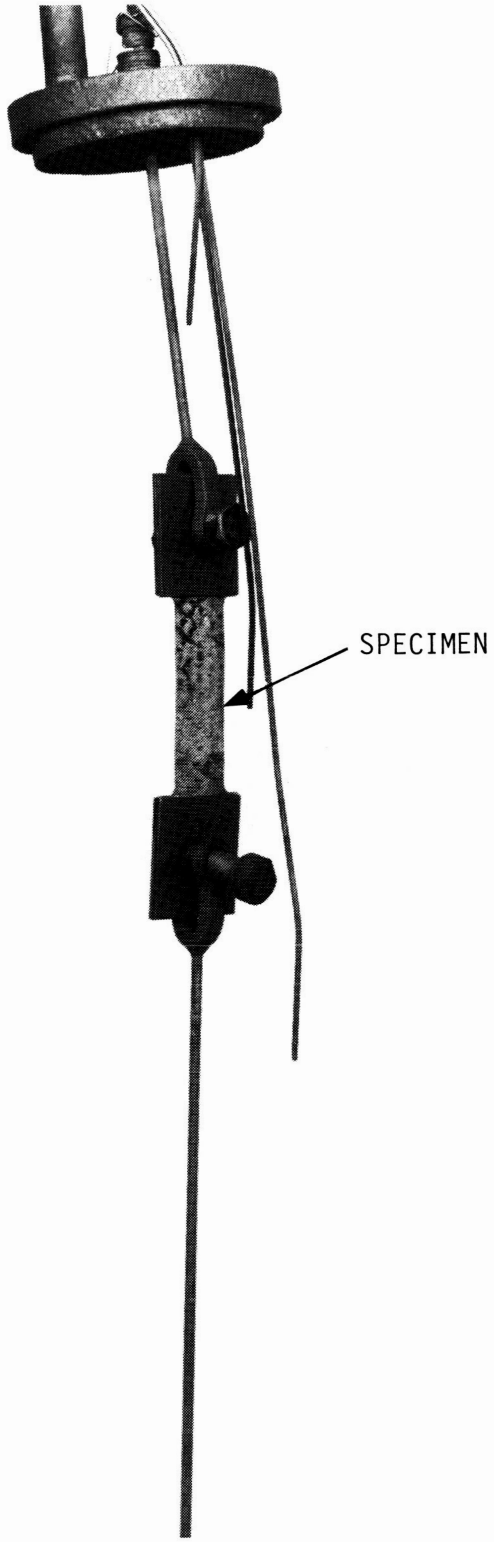


Figure 41. Large Creep Test Specimen

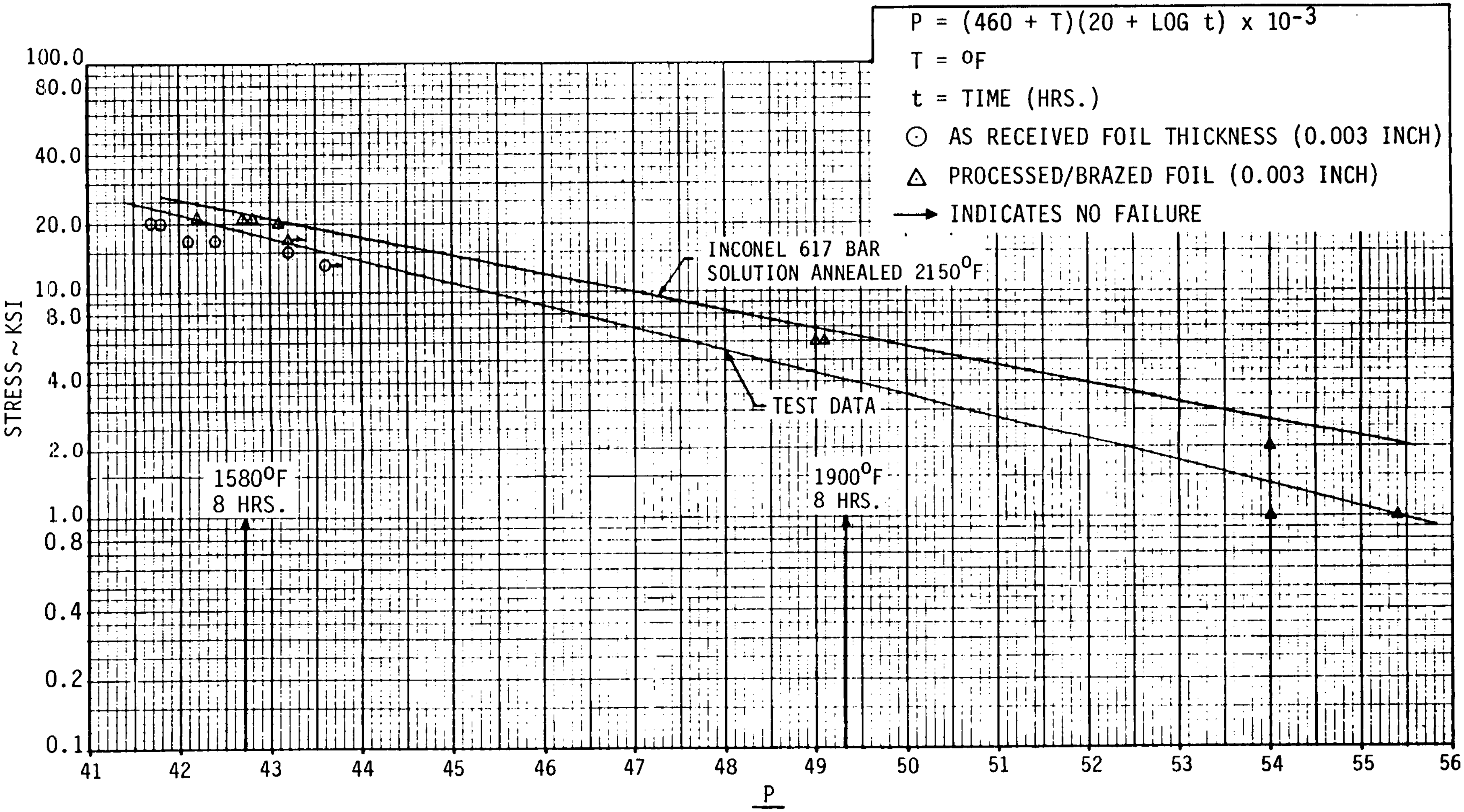


Figure 42. INCONEL 617 Creep Rupture Larson--Miller Plot

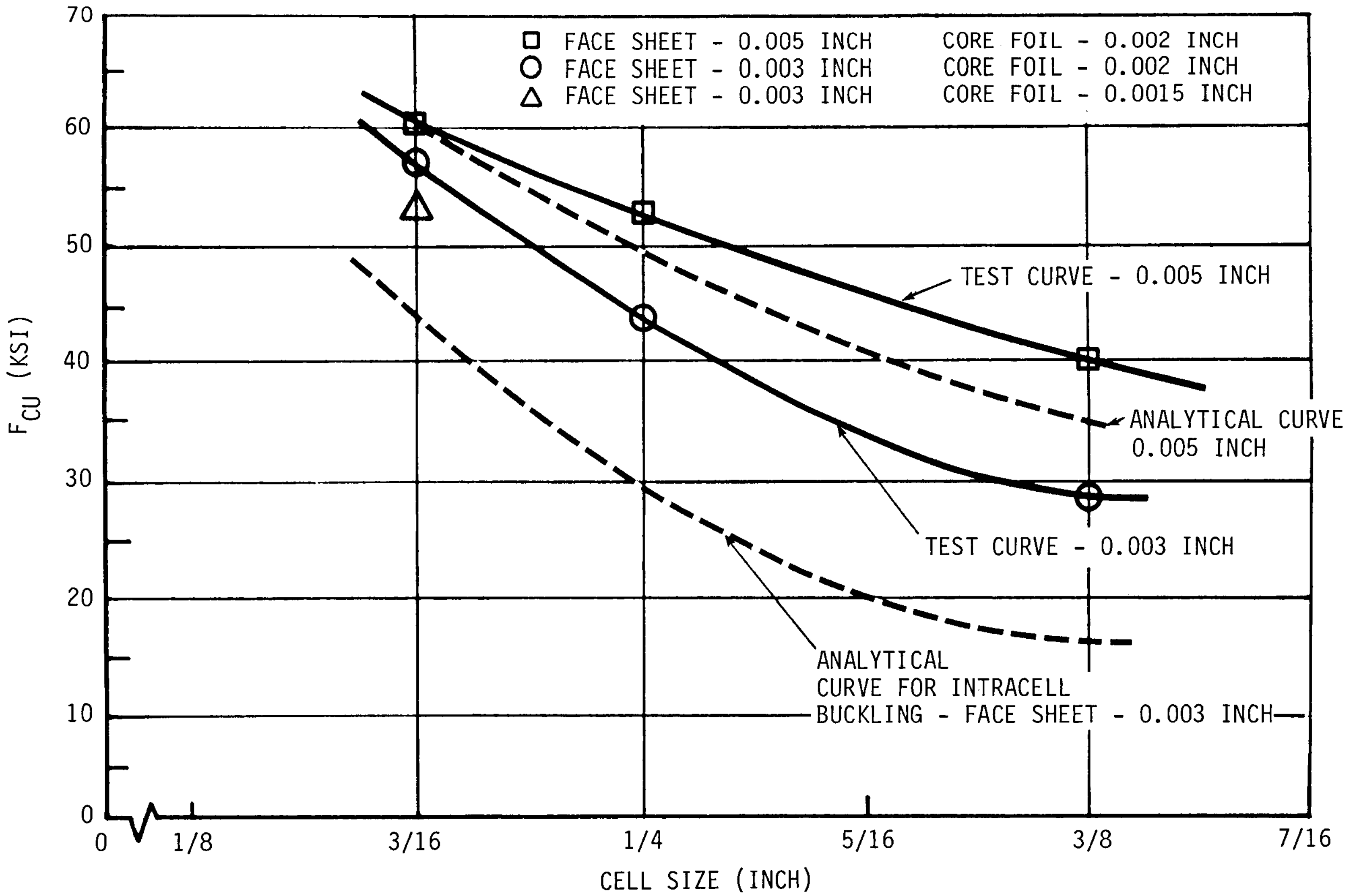


Figure 43. Edgewise Compression Strength Versus Cell Size INCONEL 617 (Room-Temp)
7.4.1 (see table 17)

Figure 44. Room Temperature Flatwise Tension Test Setup

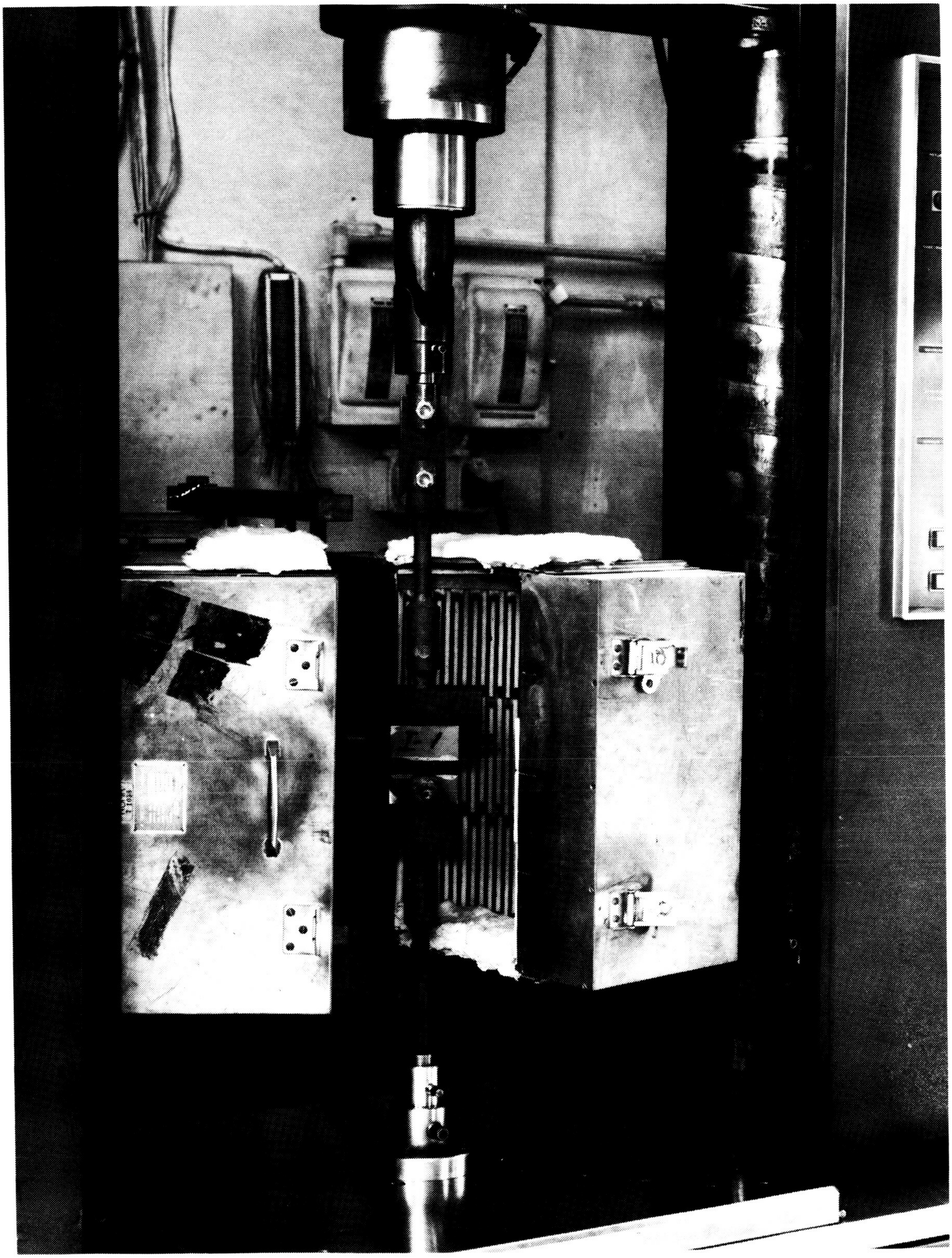
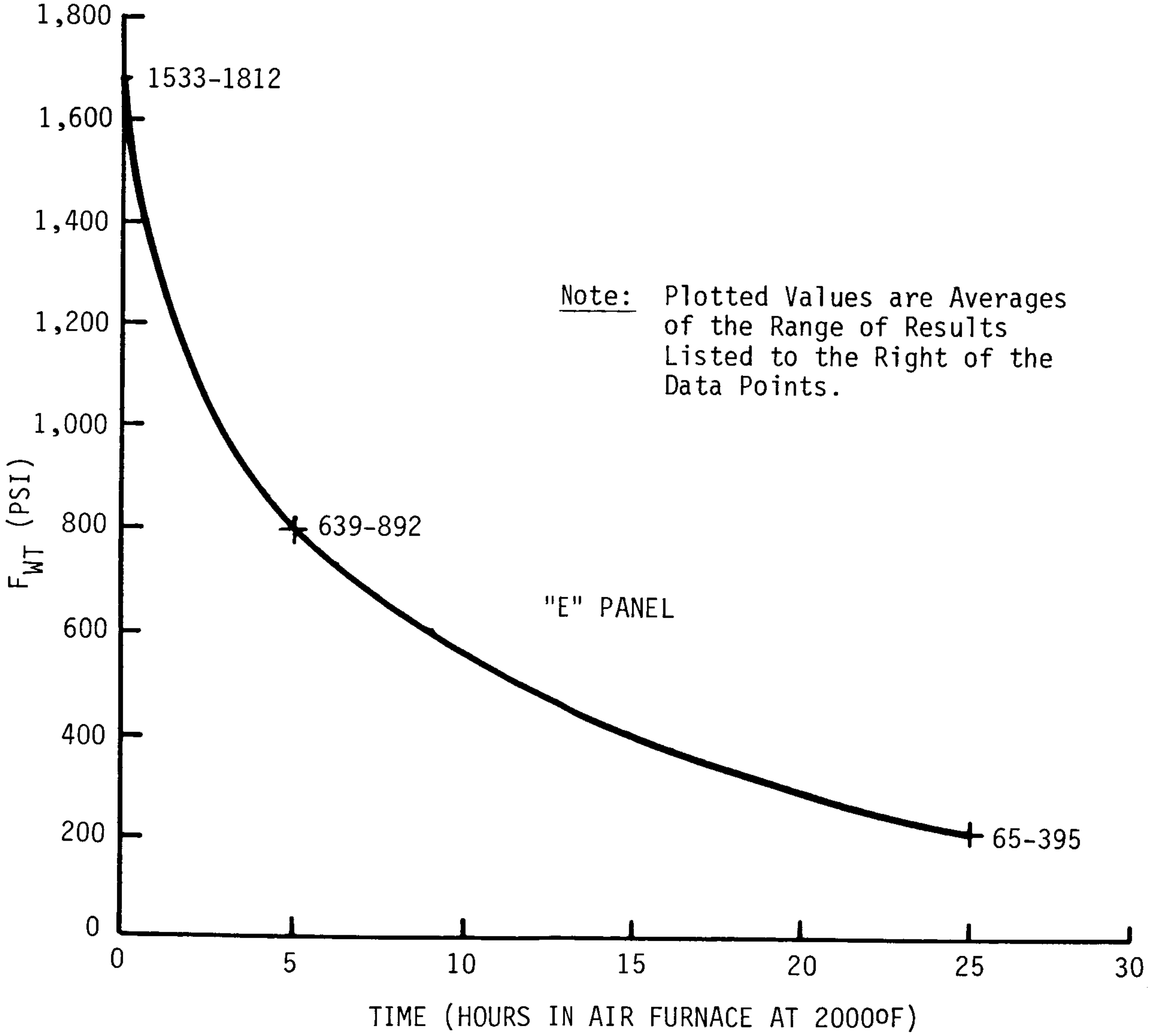
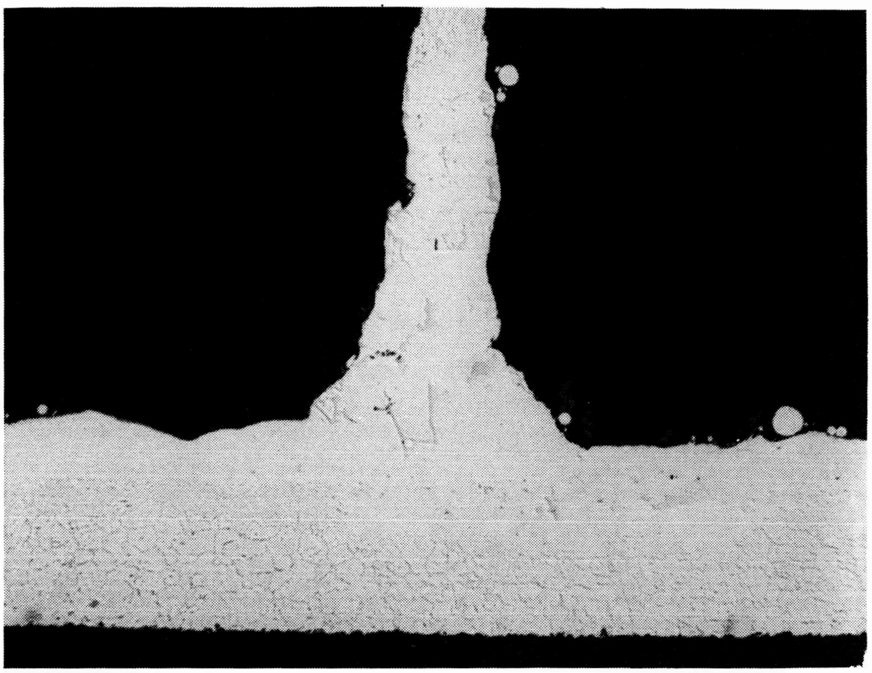


Figure 45. Elevated Temperature Flatwise Tension Test Setup



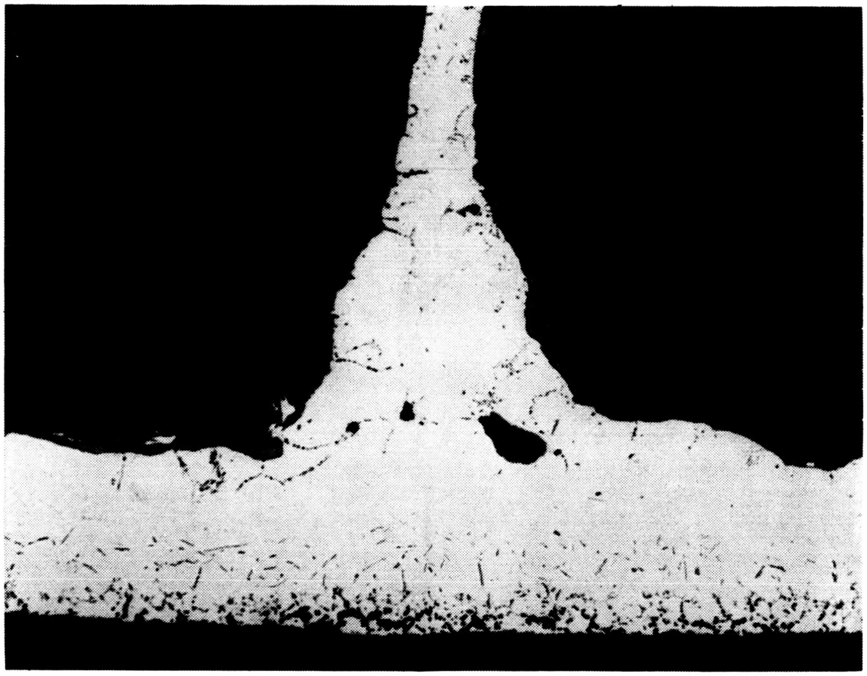
Note: Plotted Values are Averages of the Range of Results Listed to the Right of the Data Points.

Figure 46. Flatwise Tension Strength Versus Exposure Time INCONEL 617 (Room Temperature Test)



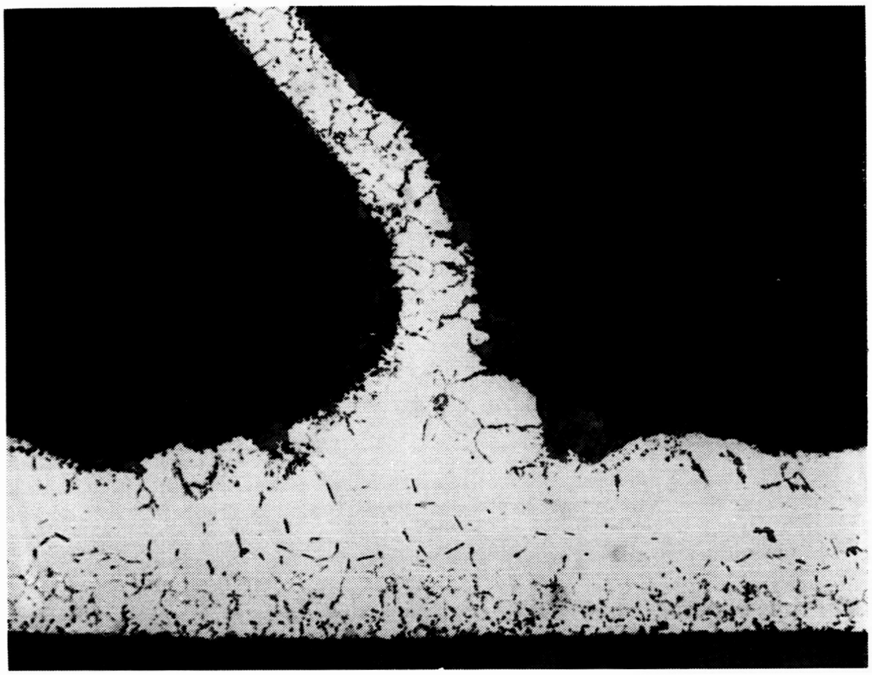
150X SCALE

Figure 47. Photomicrograph of Brazed Sandwich Joint--No Thermal Exposure



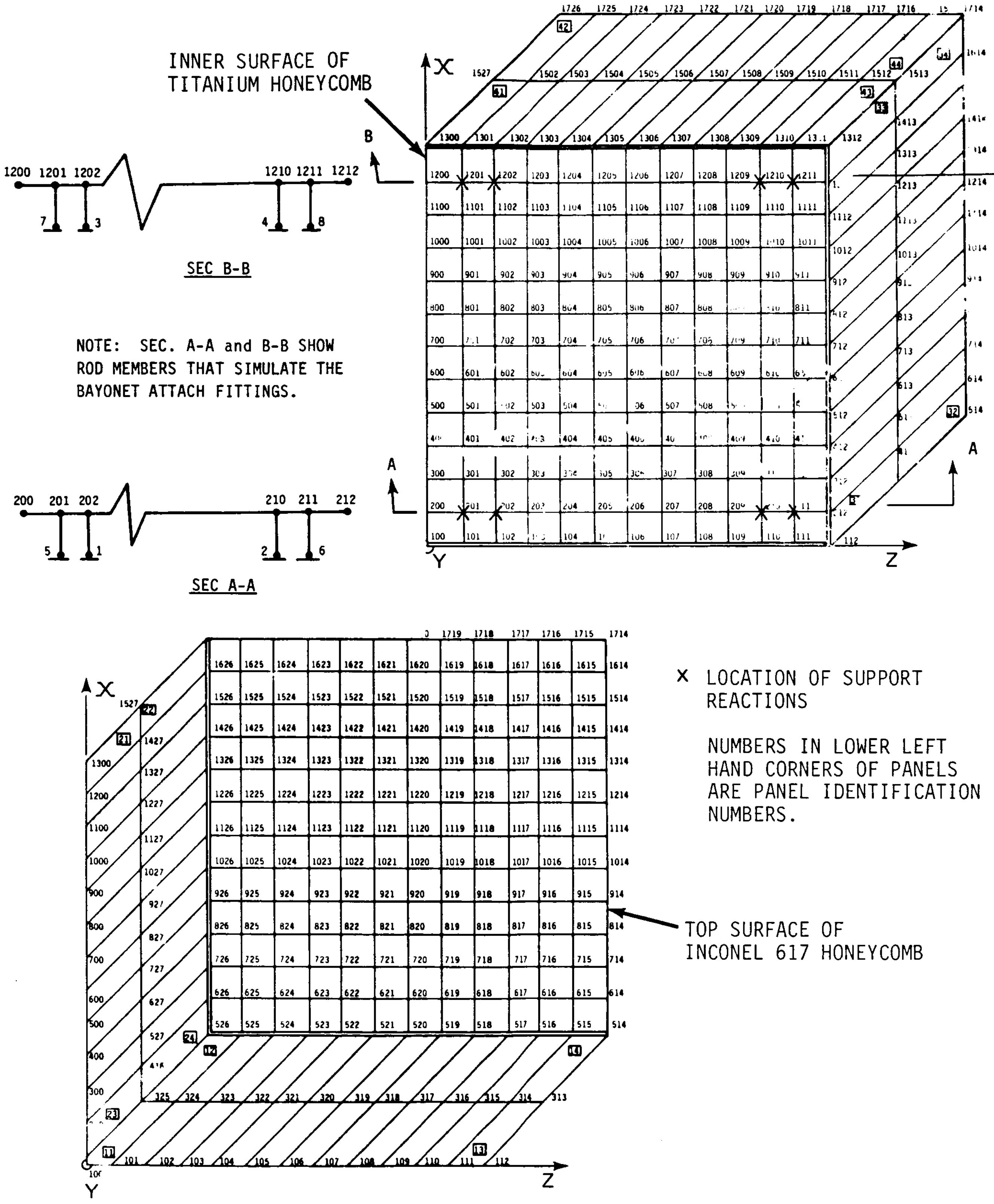
150X SCALE

Figure 48. Photomicrograph of Brazed Sandwich Joint--5 Hours of $2000^{\circ}F$ Exposure



150X SCALE

Figure 49. Photomicrograph of Brazed Sandwich Joint--25 Hours of 2000°F Exposure



INNER SURFACE OF TITANIUM HONEYCOMB

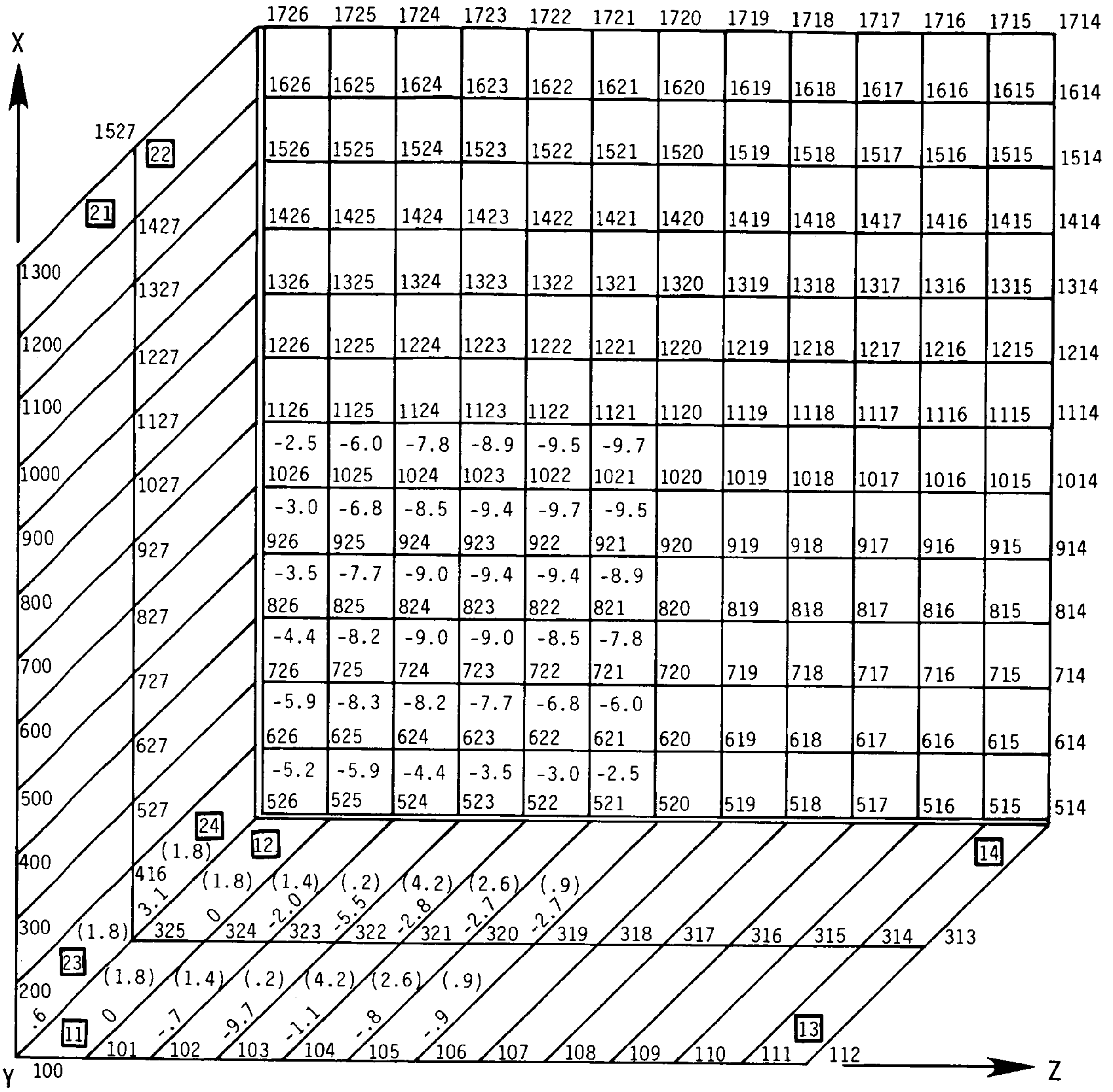
NOTE: SEC. A-A and B-B SHOW ROD MEMBERS THAT SIMULATE THE BAYONET ATTACH FITTINGS.

X LOCATION OF SUPPORT REACTIONS

NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.

TOP SURFACE OF INCONEL 617 HONEYCOMB

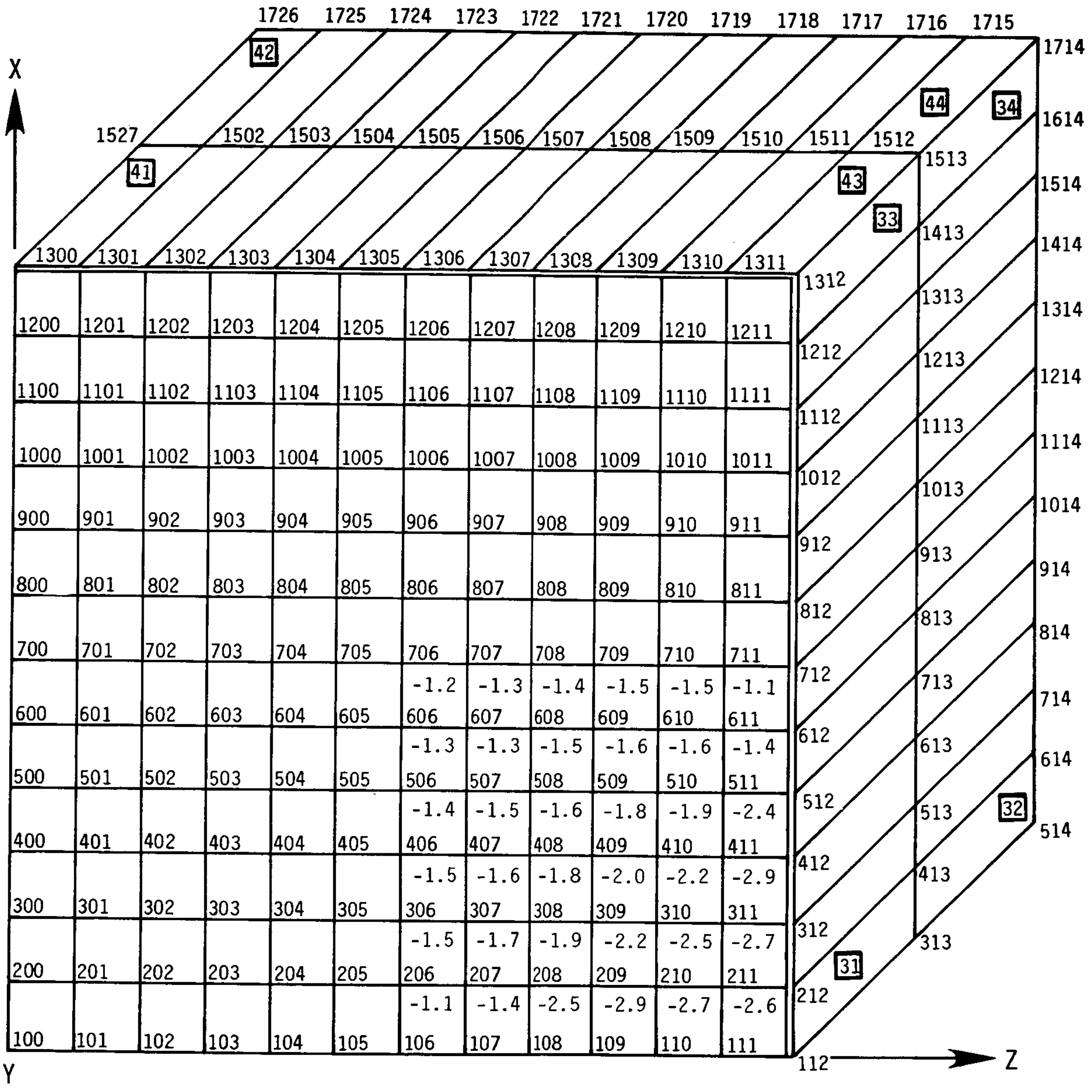
Figure 50. Finite Element Model



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

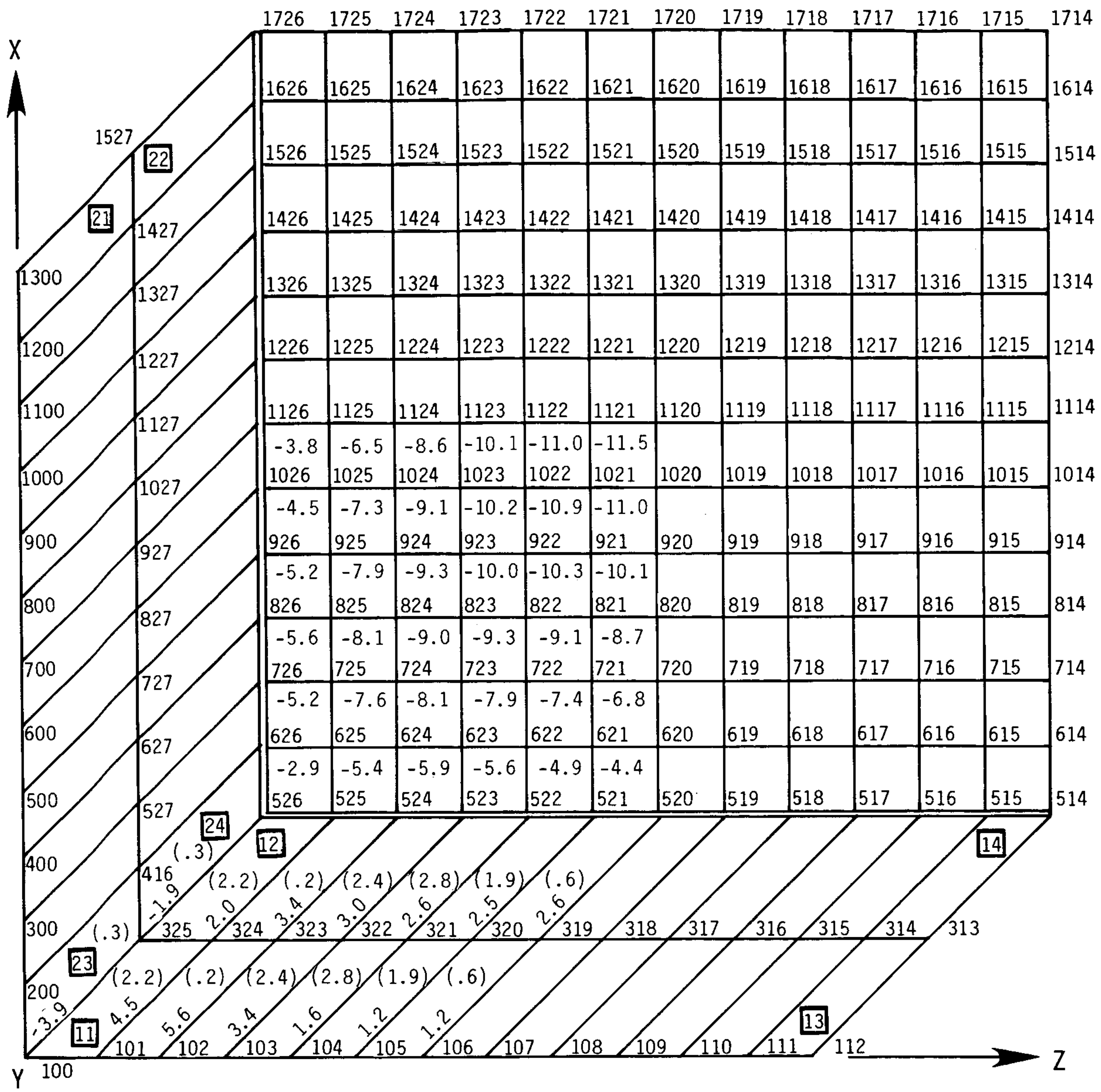
Figure 51-A. Ascent Crush Pressure Condition Top Surface of Panel ~ Inconel Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

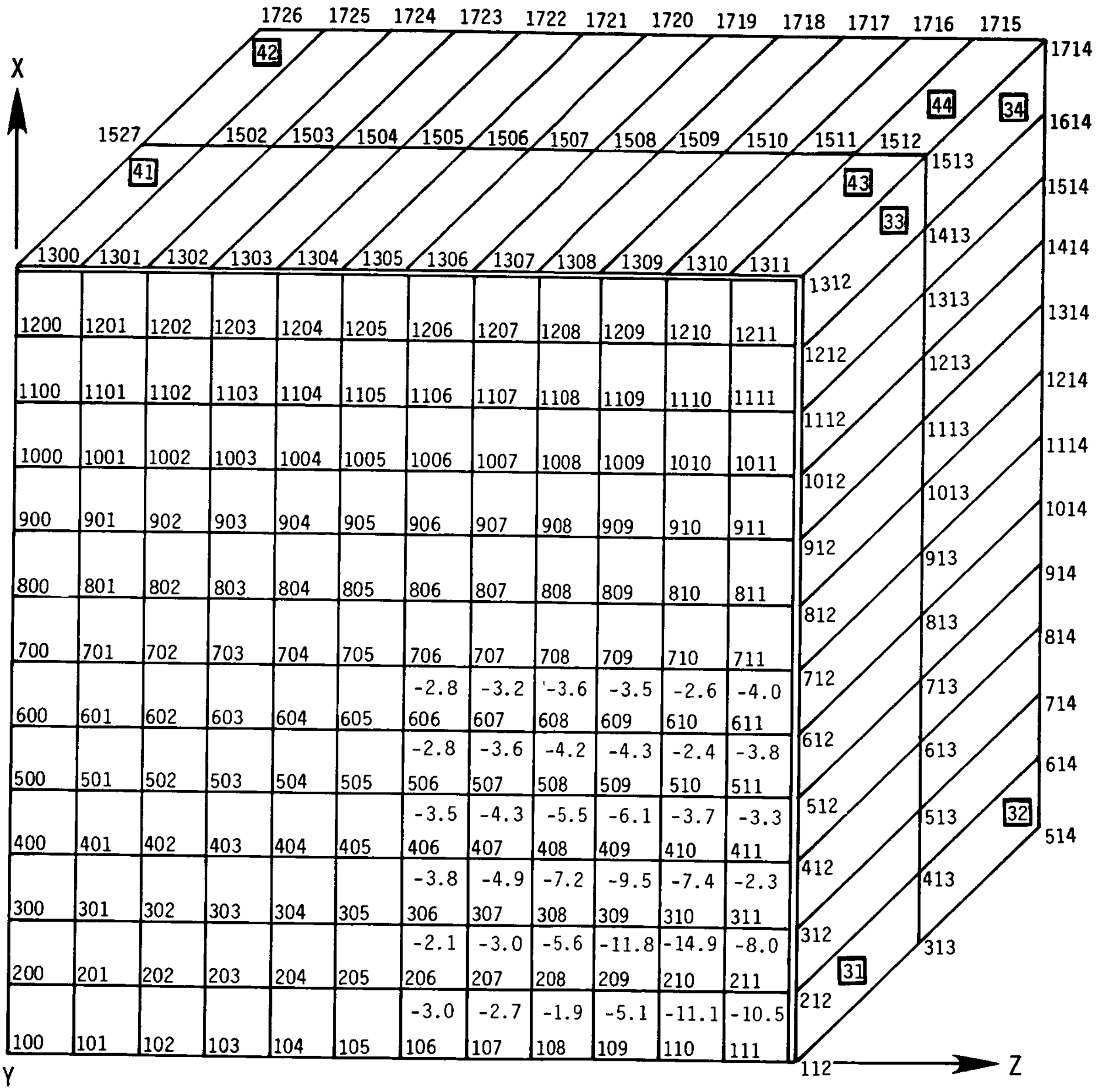
Figure 51-B. Ascent Crush Pressure Condition Bottom Surface of Panel ~ Titanium Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

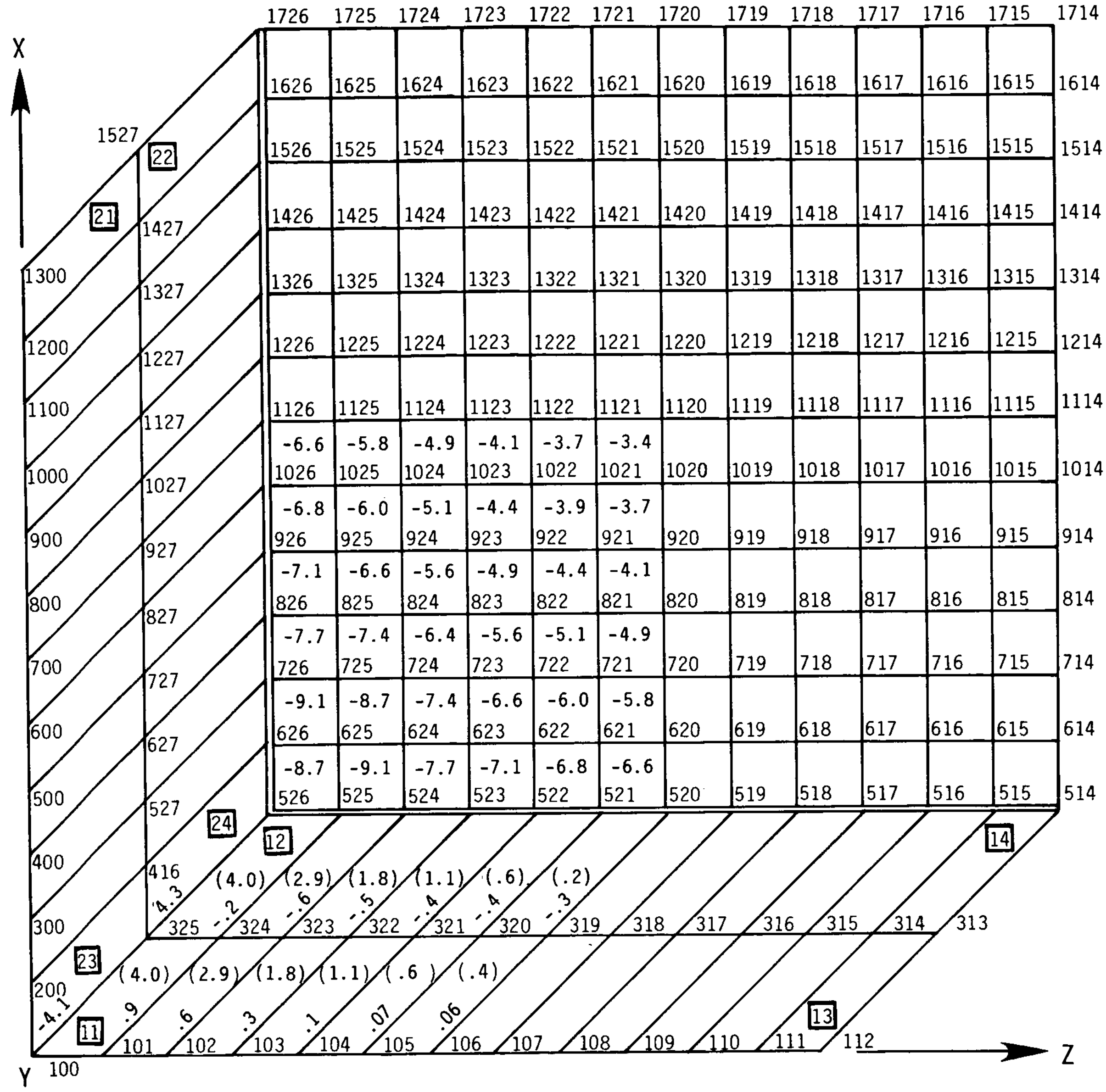
Figure 51-C. Ascent Blowoff Pressure Condition Top Surface of Panel ~ Inconel Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

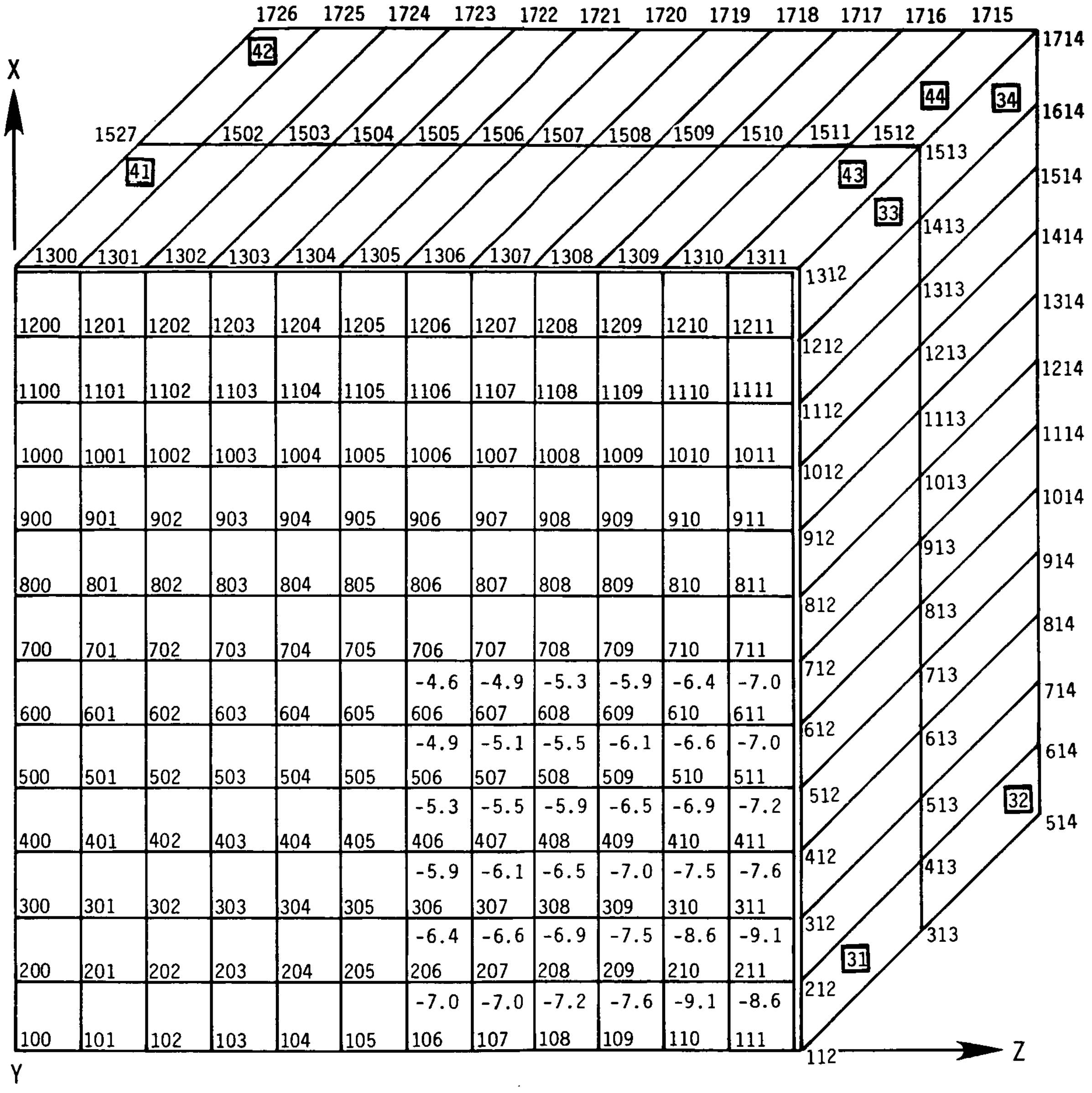
Figure 51-D. Ascent Blowoff Pressure Condition Bottom Surface of Panel ~ Titanium Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

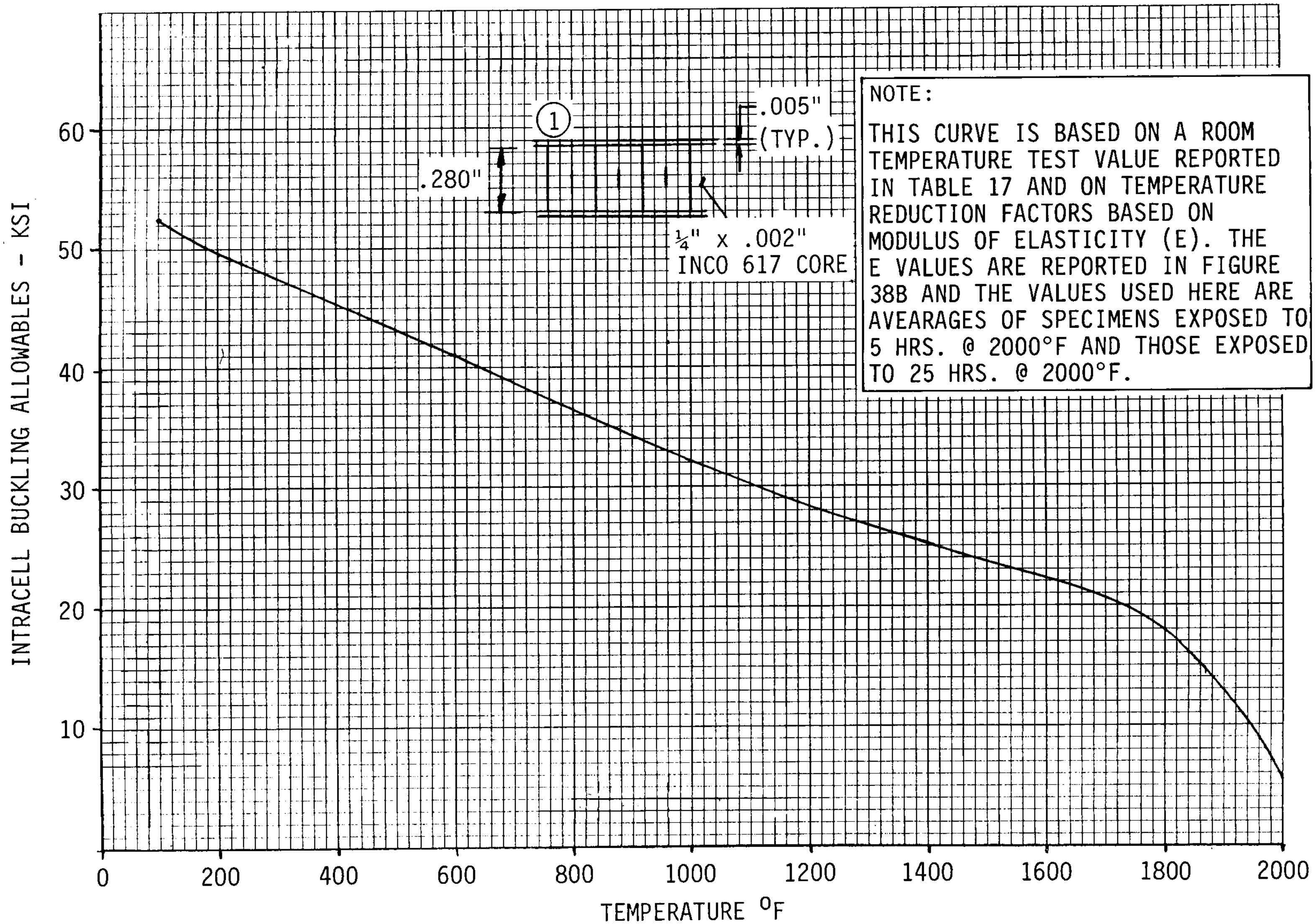
Figure 51-E. Descent Condition Top Surface of Panel ~ Inconel Honeycomb - Stress Output



NOTES:

1. NUMBERS IN LOWER LEFT HAND CORNERS OF PANELS ARE PANEL IDENTIFICATION NUMBERS.
2. NUMBERS IN MIDDLE OF PANELS ARE PRINCIPAL STRESS VALUES IN UNITS OF KSI.
3. (+) ARE TENSION.
   (-) ARE COMPRESSION.
4. NUMBERS IN ( ) ARE SHEAR STRESSES.

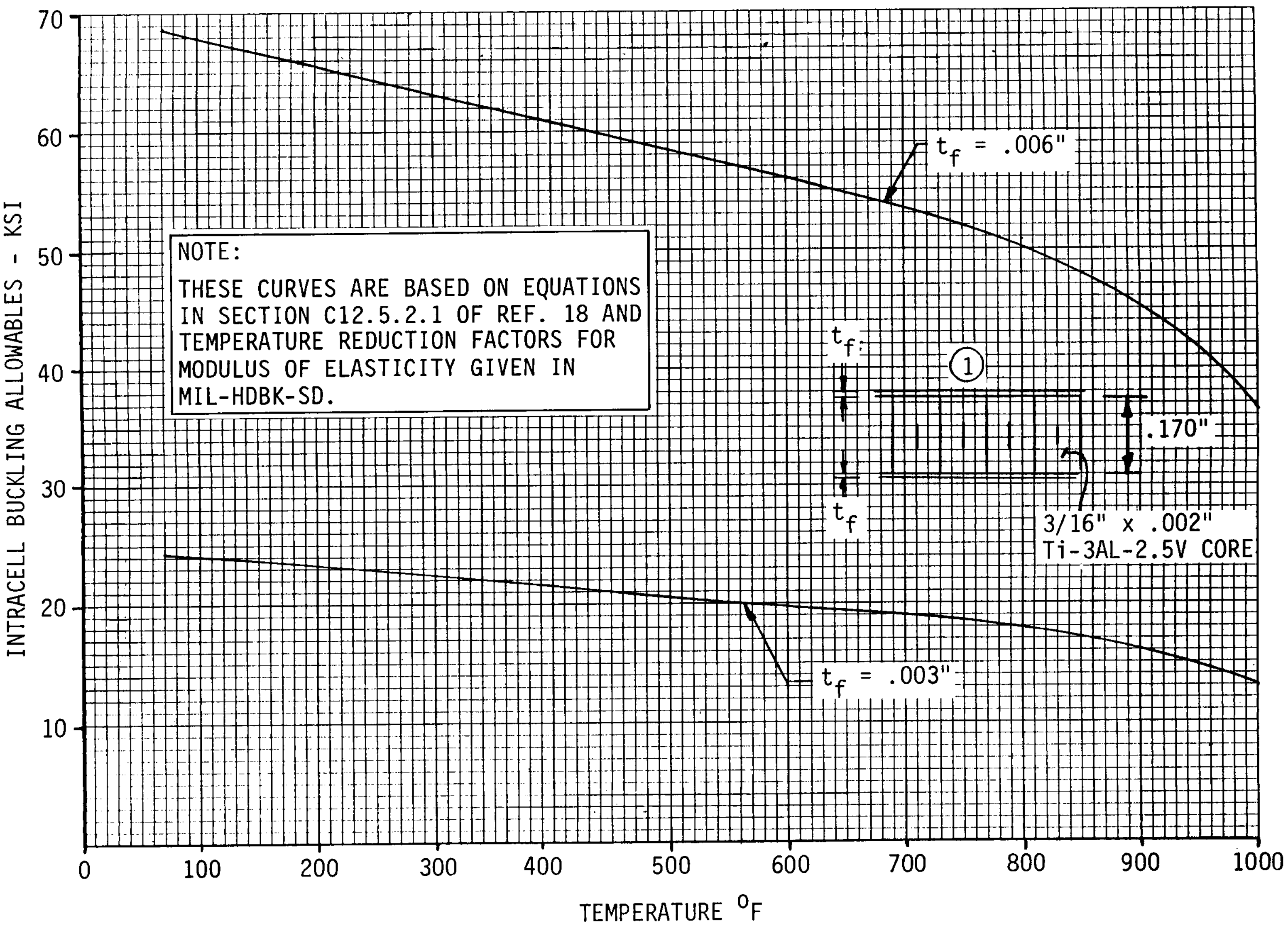
Figure 51-F. Descent Condition Bottom Surface of Panel ~ Titanium Honeycomb - Stress Output



NOTE:

THIS CURVE IS BASED ON A ROOM TEMPERATURE TEST VALUE REPORTED IN TABLE 17 AND ON TEMPERATURE REDUCTION FACTORS BASED ON MODULUS OF ELASTICITY (E). THE E VALUES ARE REPORTED IN FIGURE 38B AND THE VALUES USED HERE ARE AVEARAGES OF SPECIMENS EXPOSED TO 5 HRS. @ 2000°F AND THOSE EXPOSED TO 25 HRS. @ 2000°F.

Figure 52. Inconel Honeycomb Compression Allowables



NOTE:

THESE CURVES ARE BASED ON EQUATIONS IN SECTION C12.5.2.1 OF REF. 18 AND TEMPERATURE REDUCTION FACTORS FOR MODULUS OF ELASTICITY GIVEN IN MIL-HDBK-SD.

Figure 53. Titanium Honeycomb Compression Allowables

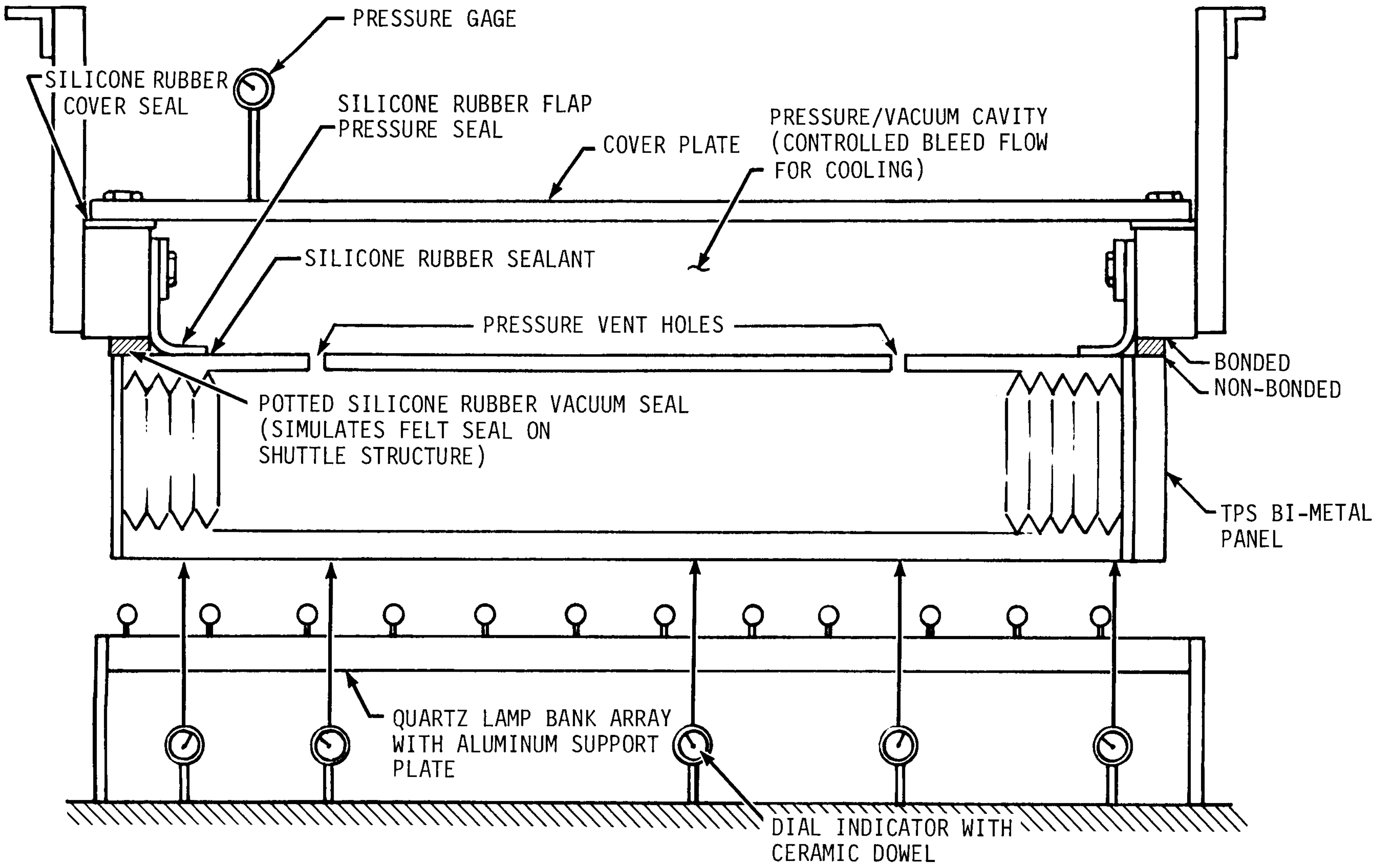


Figure 54. Schematic of Text Fixture for Thermal/Pressure Gradient Tests

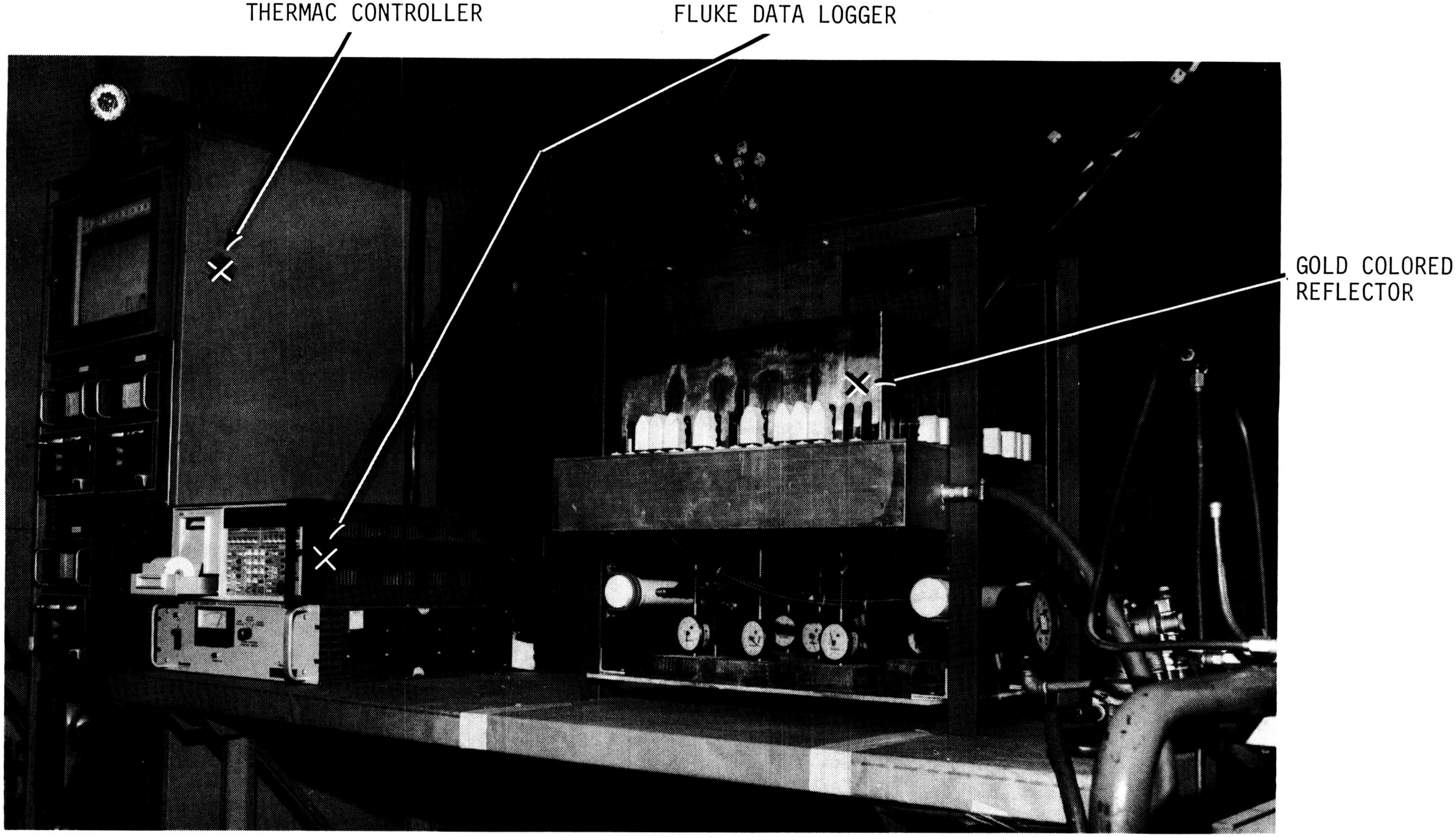


Figure 55. Test Apparatus for Pressure Testing with Thermal Gradient

Figure 56. Quartz Lamp Bank Array

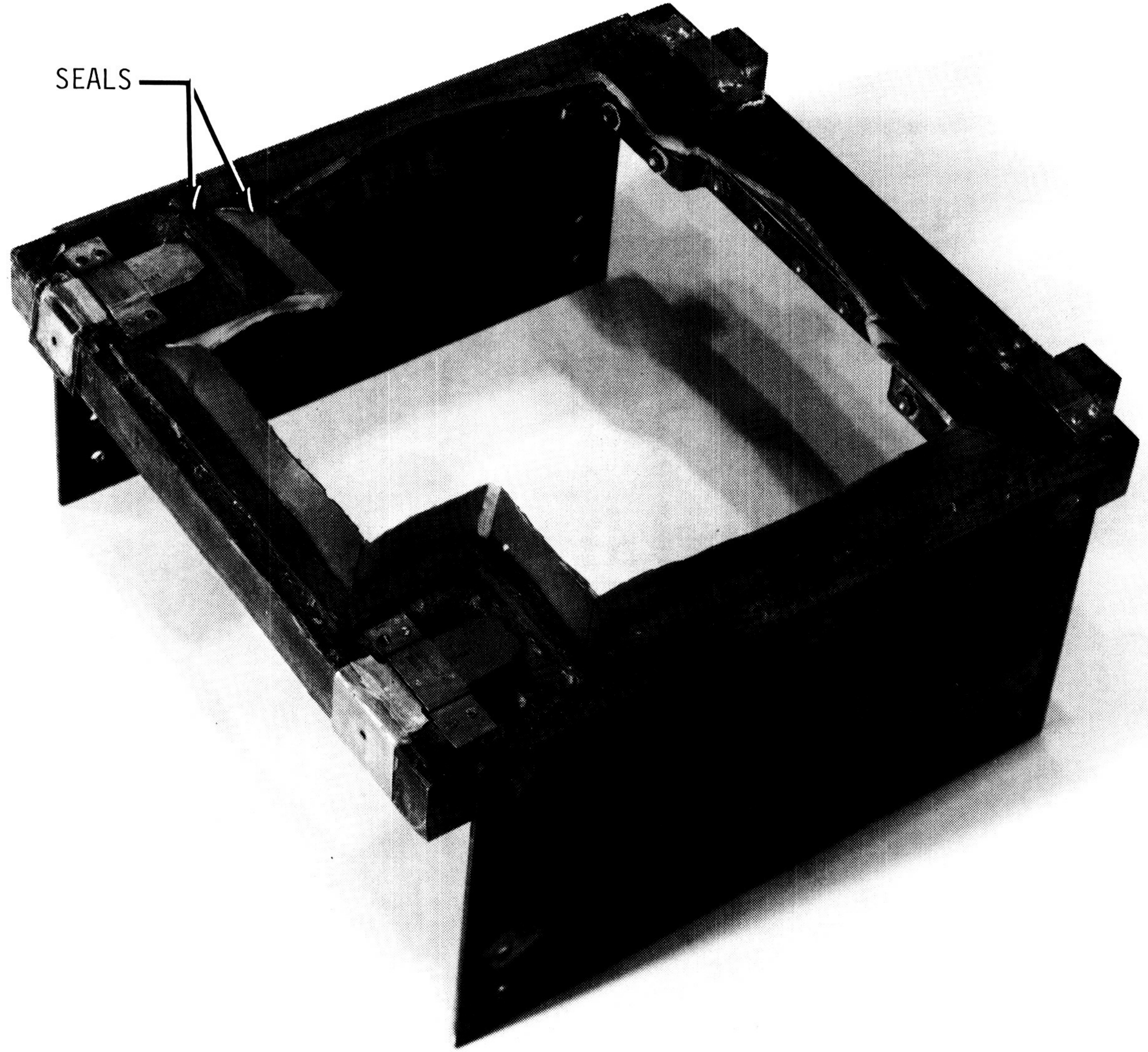


Figure 57. Test Chamber in Inverted Position

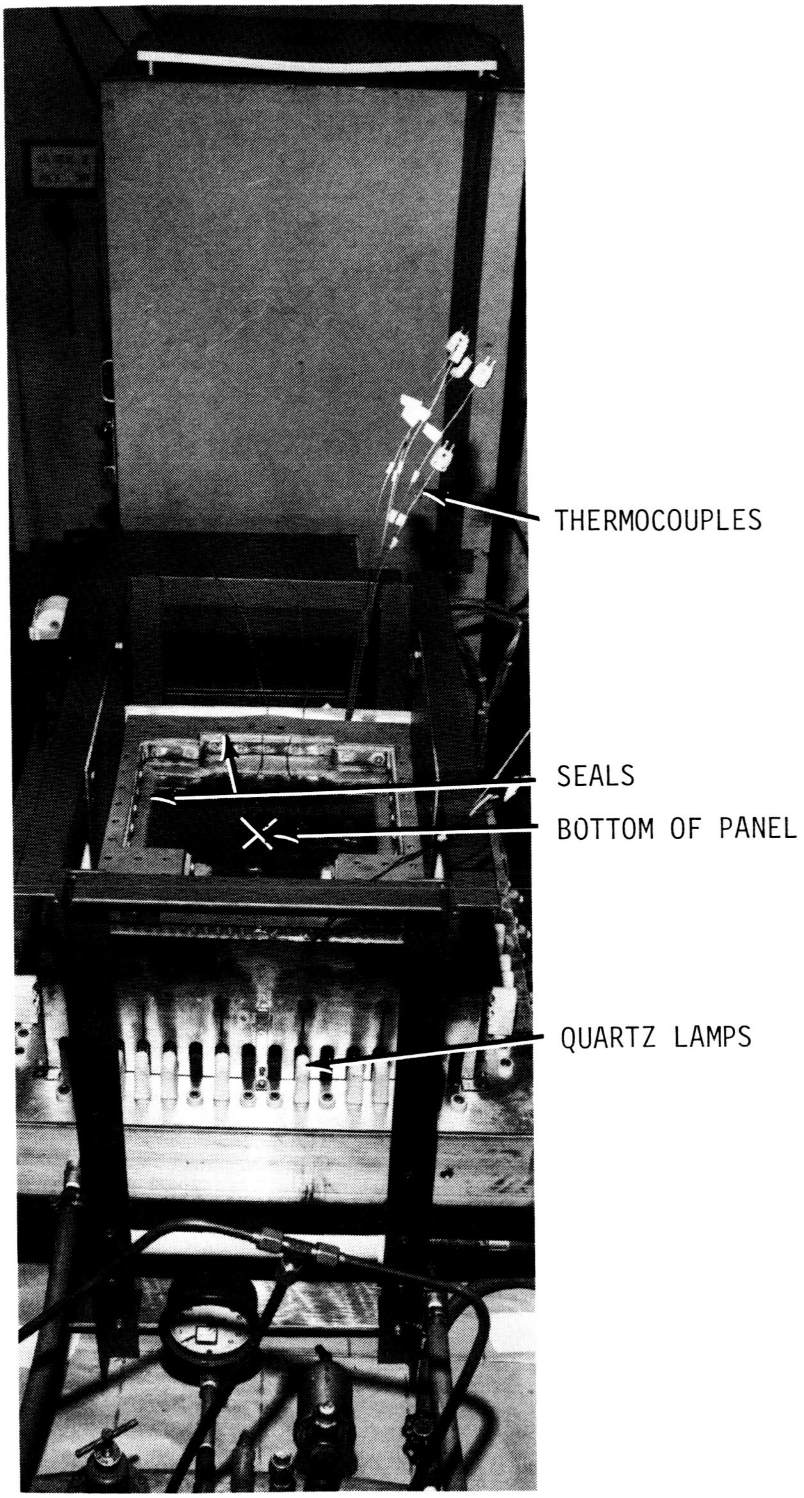


Figure 58. Pressure Test Apparatus

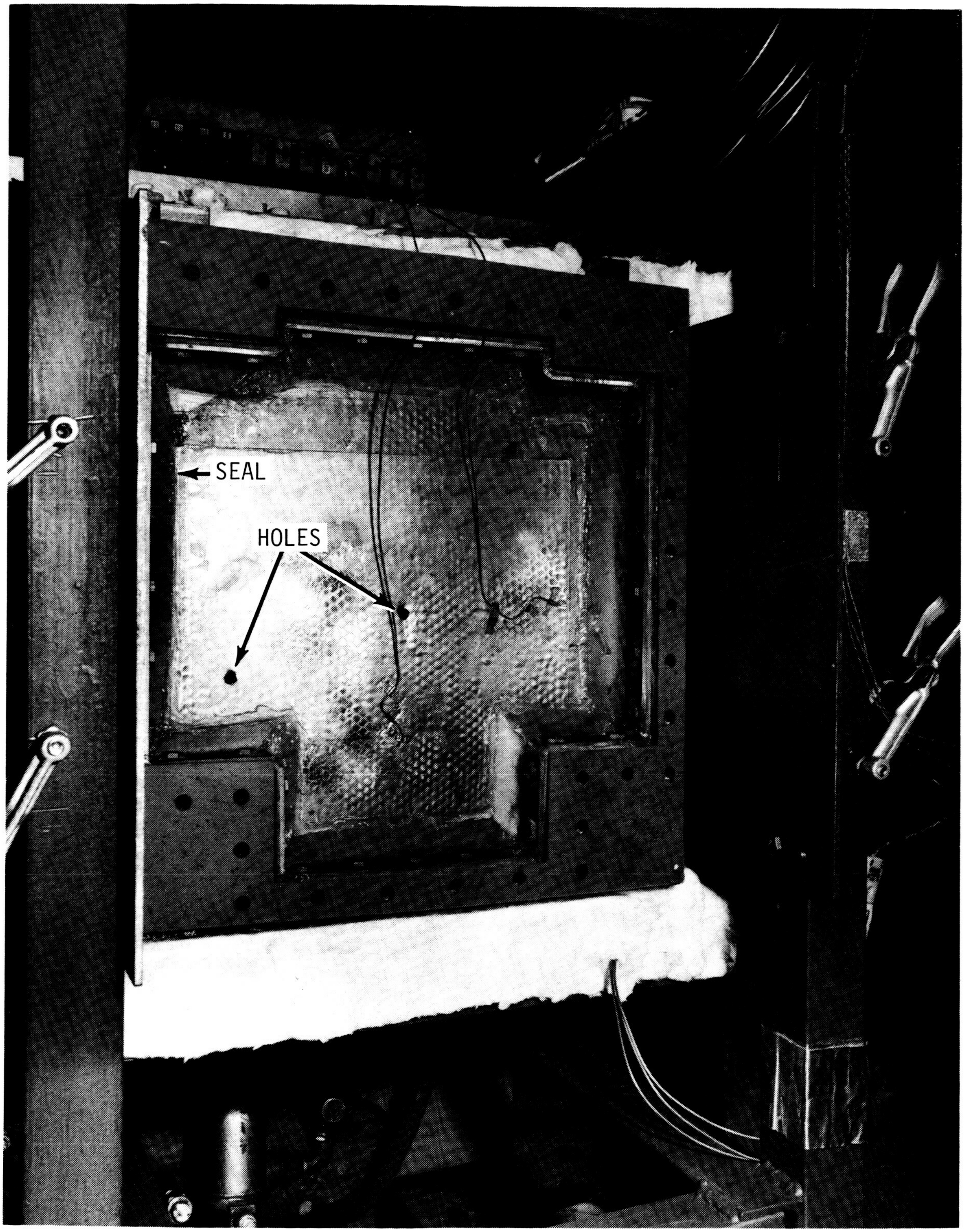


Figure 59. Bottom of Panel with Seals in Place for Testing

Figure 60. Panel Failed at 3.6 psi in the INCONEL 617 Material at the Bi-Metallic Joints During the Second Test, View 1

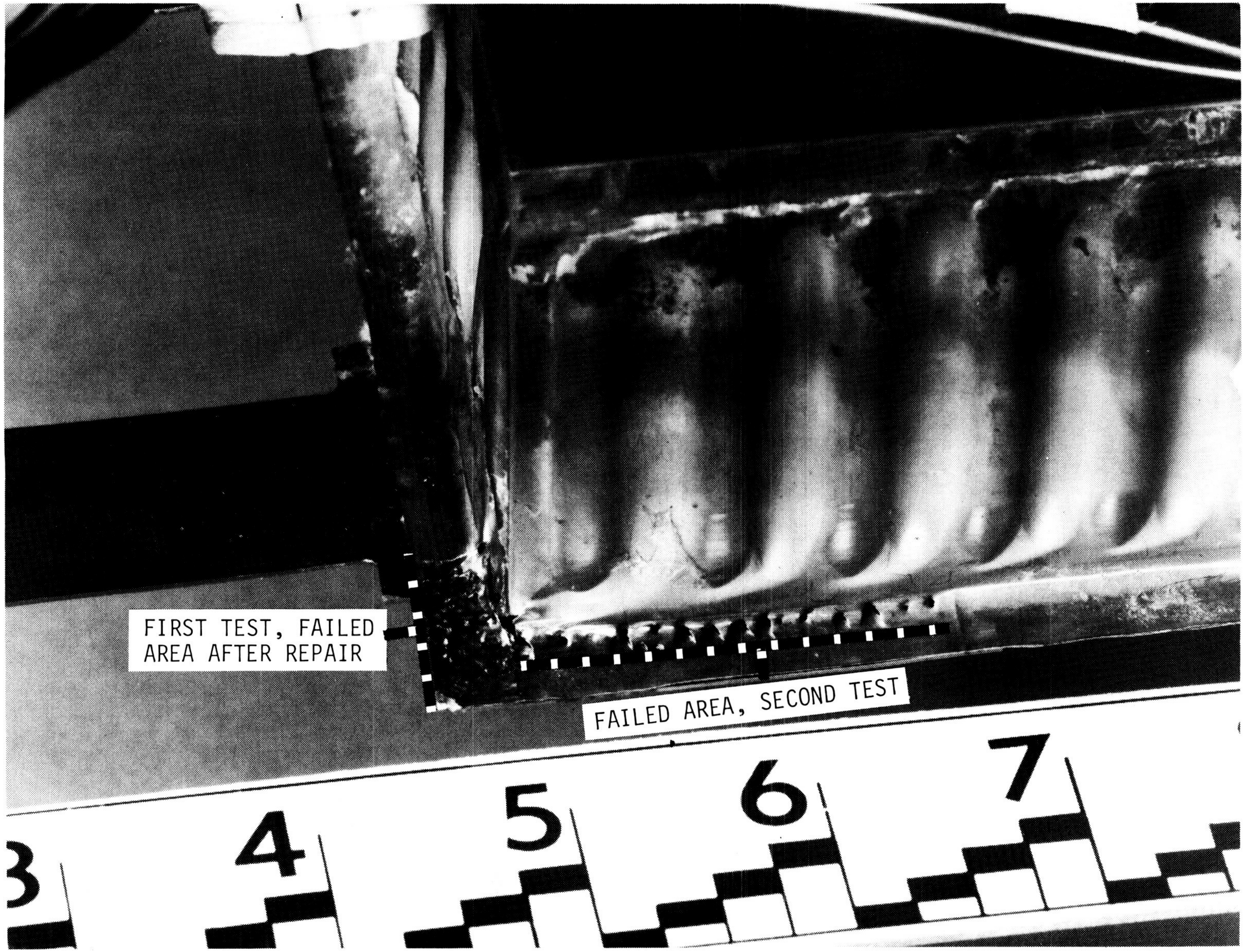


Figure 61. Panel Failed at 3.6 psi in the INCONEL 617 Material at the Bi-Metallic Joint During the Second Test, View 2

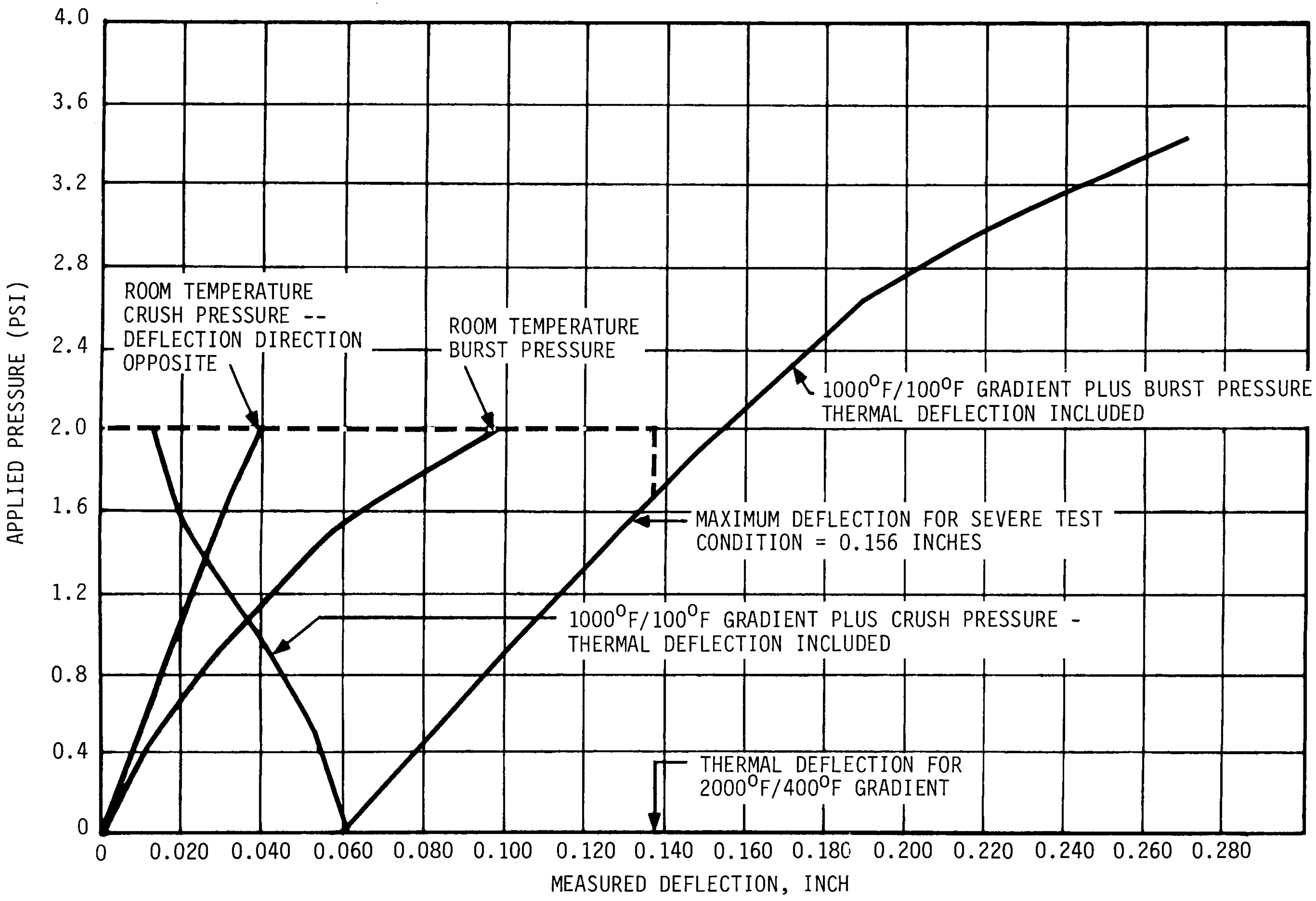
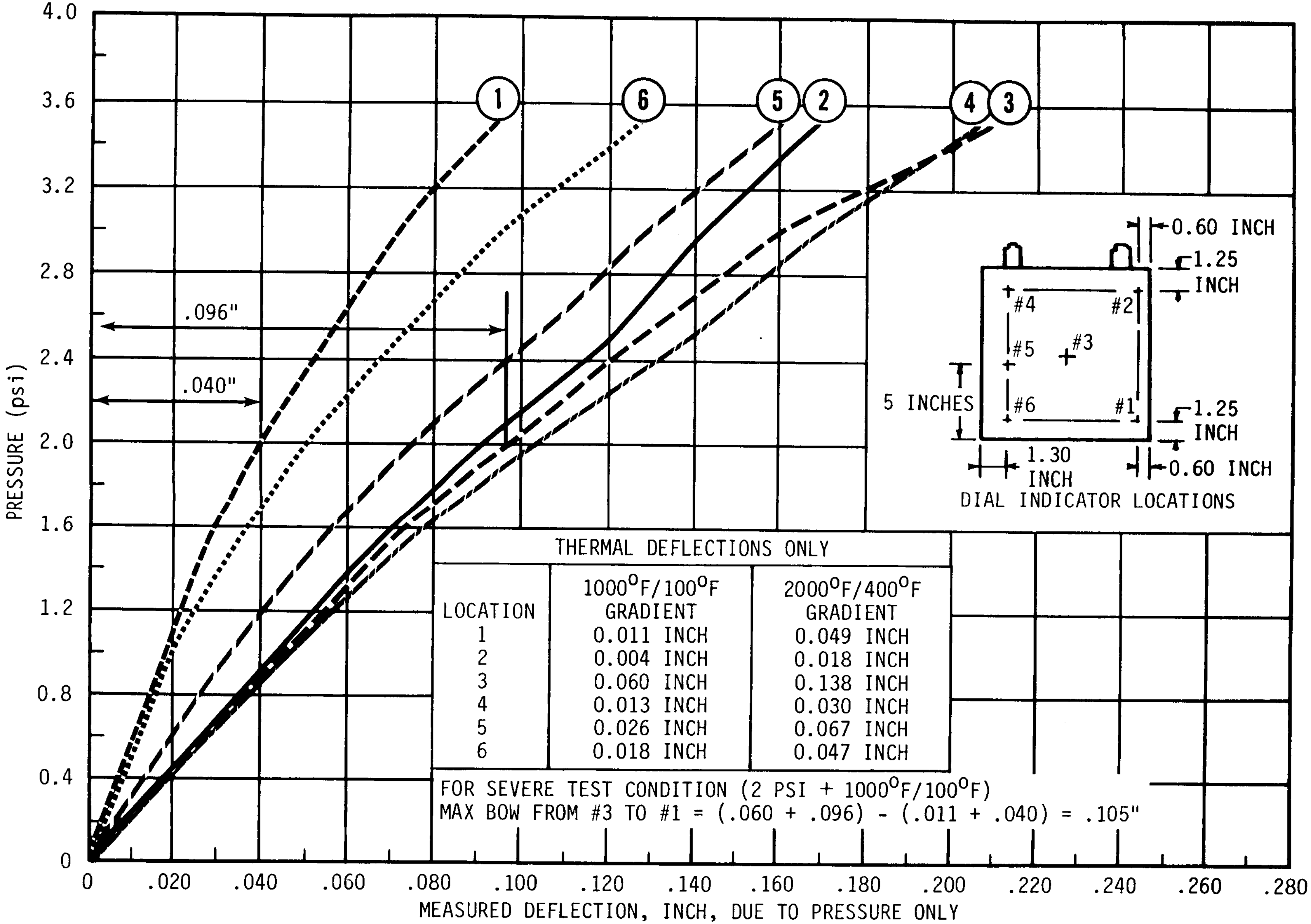


Figure 62. INCONEL 617, Ti-6-4, Silica Fiber Sandwich Panel Applied Pressure (psi) Versus Center Panel Deflections (inch) for Various Loading Conditions



THERMAL DEFLECTIONS ONLY

LOCATION	1000°F/100°F GRADIENT	2000°F/400°F GRADIENT
1	0.011 INCH	0.049 INCH
2	0.004 INCH	0.018 INCH
3	0.060 INCH	0.138 INCH
4	0.013 INCH	0.030 INCH
5	0.026 INCH	0.067 INCH
6	0.018 INCH	0.047 INCH

FOR SEVERE TEST CONDITION (2 PSI + 1000°F/100°F)
MAX BOW FROM #3 TO #1 = (.060 + .096) - (.011 + .040) = .105"

Figure 63. INCONEL Bi-Metal Panel Deflections

APPENDIX

TPS THREE DIMENSIONAL "NASTRAN" FINITE ELEMENT MODEL

THE FOLLOWING PAGES CONTAIN CODED SAMPLE OF TPS PANEL FOR THREE DIMENSIONAL "NASTRAN" FINITE ELEMENT ANALYSIS. SAMPLE INPUT REPRESENTS BOTH PRESSURE AND THERMAL STATIC ANALYSIS.

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* *                                 * *
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* *                                 * *
* *      M S C / N A S T R A N      * *
* *                                 * *
* *         VERSION - 63            * *
* *                                 * *
* *        JUL 20, 1983             * *
* *                                 * *
* *       DIGITAL EQUIPMENT         * *
* *                                 * *
* *        MODEL VAX 11/750         * *
* *                                 * *
* *                                 * *
* *                                 * *
* *             ROHR                * *
* * * * * * * * * * * * * * * * * * * *
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    N A S T R A N    E X E C U T I V E    C O N T R O L    D E C K    E C H O


ID A, PANEL
TIME 60
APP DISPLACEMENT
SOL 24
READ 9
$ BEGINNING OF RF ALTER 24$74
$ GENERATE SEQGP BULK DATA CARDS FOR EFFICIENCY IN SYMMETRIC DECOMP.
$ THE FOLLOWING ARE USER INPUT PARAMETERS
$ VALUE                    OPTION
$ SEQOUT--OUTPUT OPTIONS FOR SEQGP CARDS
$    0   DEFAULT-NO PRINTED OR PUNCH OUTPUT
$    1   PRINT TABLE OF INTERNAL/EXTERNAL SEQUENCE IN INTERNAL ORDER
$    2   TRANSMIT THE SEQGP CARDS TO THE SYSTEM PUNCH FILE
$    3   PRINT TABLE AND PUNCH SEQGP CARDS
$ NEWSEQ--OPTIONS FOR SEQUENCING LOGIC
$   -1   DO NOT RESEQUENCE
$    1   USE ACTIVE COLUMN SEQUENCING OPTION
$    2   USE BAND SEQUENCING OPTION
$    3   DEFAULT-RUN BOTH ACTIVE COLUMN AND BAND SEQUENCING--SAVE THE SEQU       ENCE
$           WITH THE LOWEST TIME ESTIMATE FOR DECOMPOSITION
$ SUPER--OPTIONS FOR TYPES OF SEQUENCING
$    0   DEFAULT-USE PASSIVE COLUMN SEQUENCING OPTION
$   -1   USE SUPERELEMENT SEQUENCING OPTION
$ FACTOR--USED FOR THE GENERATION OF THE INTERNAL SEQUENCE NUMBER
$    SEQID = FACTOR * SEID + SEQ NUMBER
$        DEFAULT = 10000
$ MPCX--OPTION FOR MPC PROCESSING
$   -1   DO NOT PROCESS MPC BULK DATA CARDS OR RIGID ELEMENTS
$    0   DEFAULT-PROCESS RIGID ELEMENTS ONLY
$    N   POSITIVE INTEGER IS THE NUMBER OF THE MPC SET TO PROCESS
$           ALONG WITH ANY RIGID ELEMENTS PRESENT
$ START--STARTING POINT OPTIONS
$    0   DEFAULT-PROGRAM SELECTS STARTING POINT
$    N   INTEGER IS NUMBER OF POINTS TO BE USED TO START SEQUENCING
ALTER 8
COND    NOSEQP,NEWSEQ $
SEQP   GEOM1,GEOM2,GEOM4,/GEOM1Q,MATPARM/C,Y,SEQOUT=0/V,Y,NEWSEQ=+3//
           C,Y,SUPER= 0/C,Y,FACTOR=10000/C,Y,MPCX=0/C,Y,START=0 $
EQUIV      GEOM1Q,GEOM1/ALWAYS $
LABEL   NOSEQP
$ END OF RF ALTER 24$74
CEND
```

```
                        C A S E   C O N T R O L   D E C K   E C H O
 CARD
 COUNT
   1      TITLE = TPS PANEL
   2      OUTPUT
   3      TEMP(MATERIAL)=2
   4      SPCFORCE=ALL
   5      $
   6      $
   7      $
   8      SUBCASE 1
   9      LABEL= TEMP. LOAD ONLY 1900 F/ 203 F
  10      TEMP(LOAD)=2
  11      $
  12      DISPLACEMENT=ALL
  13      ELSTRESS=ALL
  14      ELFORCE=ALL
  15      BEGIN BULK
              INPUT BULK DATA CARD COUNT =     1290
```

```
                                 S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
   1-        BAROR           2                               0.      0.      10.     1
   2-        CBAR    101     1       101     324                                     +B101
   3-        +B101   5
   4-        CBAR    102     1       102     323                                     +B102
   5-        +B102   5
   6-        CBAR    103     1       103     322                                     +B103
   7-        +B103   5
   8-        CBAR    104     1       104     321                                     +B104
   9-        +B104   5
  10-        CBAR    105     1       105     320                                     +B105
  11-        +B105   5
  12-        CBAR    106     1       106     319                                     +B106
  13-        +B106   5
  14-        CBAR    107     1       107     318                                     +B107
  15-        +B107   5
  16-        CBAR    108     1       108     317                                     +B108
  17-        +B108   5
  18-        CBAR    109     1       109     316                                     +B109
  19-        +B109   5
  20-        CBAR    110     1       110     315                                     +B110
  21-        +B110   5
  22-        CBAR    111     1       111     314                                     +B111
  23-        +B111   5
  24-        CBAR    200             200     416                                     +B200
  25-        +B200   6
  26-        CBAR    212             212     413                                     +B212
  27-        +B212   6
  28-        CBAR    300             300     527                                     +B300
  29-        +B300   6
  30-        CBAR    312             312     513                                     +B312
  31-        +B312   6
  32-        CBAR    314     1       314     515                                     +B314
  33-        +B314           5
  34-        CBAR    315     1       315     516                                     +B315
  35-        +B315           5
  36-        CBAR    316     1       316     517                                     +B316
  37-        +B316           5
  38-        CBAR    317     1       317     518                                     +B317
  39-        +B317           5
  40-        CBAR    318     1       318     519                                     +B318
  41-        +B318           5
  42-        CBAR    319     1       319     520                                     +B319
  43-        +B319           5
  44-        CBAR    320     1       320     521                                     +B320
  45-        +B320           5
  46-        CBAR    321     1       321     522                                     +B321
  47-        +B321           5
  48-        CBAR    322     1       322     523                                     +B322
  49-        +B322           5
  50-        CBAR    323     1       323     524                                     +B323
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                                         S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT       .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  51-        +B323           5
  52-        CBAR    324     1       324     525                                     +B324
  53-        +B324           5
  54-        CBAR    400             400     627                                     +B400
  55-        +B400   6
  56-        CBAR    412             412     613                                     +B412
  57-        +B412   6
  58-        CBAR    413             413     614                                     +B413
  59-        +B413           6
  60-        CBAR    416             416     626                                     +B416
  61-        +B416           6
  62-        CBAR    500             500     727                                     +B500
  63-        +B500   6
  64-        CBAR    512             512     713                                     +B512
  65-        +B512   6
  66-        CBAR    513             513     714                                     +B513
  67-        +B513           6
  68-        CBAR    527             527     726                                     +B527
  69-        +B527           6
  70-        CBAR    600             600     827                                     +B600
  71-        +B600   6
  72-        CBAR    612             612     813                                     +B612
  73-        +B612   6
  74-        CBAR    613             613     814                                     +B613
  75-        +B613           6
  76-        CBAR    627             627     826                                     +B627
  77-        +B627           6
  78-        CBAR    700             700     927                                     +B700
  79-        +B700   6
  80-        CBAR    712             712     913                                     +B712
  81-        +B712   6
  82-        CBAR    713             713     914                                     +B713
  83-        +B713           6
  84-        CBAR    727             727     926                                     +B727
  85-        +B727           6
  86-        CBAR    800             800     1027                                    +B800
  87-        +B800   6
  88-        CBAR    812             812     1013                                    +B812
  89-        +B812   6
  90-        CBAR    813             813     1014                                    +B813
  91-        +B813           6
  92-        CBAR    827             827     1026                                    +B827
  93-        +B827           6
  94-        CBAR    900             900     1127                                    +B900
  95-        +B900   6
  96-        CBAR    912             912     1113                                    +B912
  97-        +B912   6
  98-        CBAR    913             913     1114                                    +B913
  99-        +B913           6
 100-        CBAR    927             927     1126                                    +B927
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                                 S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
 101-        +B927           6
 102-        CBAR    1000            1000    1227                                    +B1000
 103-        +B1000  6
 104-        CBAR    1012            1012    1213                                    +B1012
 105-        +B1012  6
 106-        CBAR    1013            1013    1214                                    +B1013
 107-        +B1013          6
 108-        CBAR    1027            1027    1226                                    +B1027
 109-        +B1027          6
 110-        CBAR    1100            1100    1327                                    +B1100
 111-        +B1100  6
 112-        CBAR    1112            1112    1313                                    +B1112
 113-        +B1112  6
 114-        CBAR    1113            1113    1314                                    +B1113
 115-        +B1113          6
 116-        CBAR    1127            1127    1326                                    +B1127
 117-        +B1127          6
 118-        CBAR    1200            1200    1427                                    +B1200
 119-        +B1200  6
 120-        CBAR    1212            1212    1413                                    +B1212
 121-        +B1212  6
 122-        CBAR    1213            1213    1414                                    +B1213
 123-        +B1213          6
 124-        CBAR    1227            1227    1426                                    +B1227
 125-        +B1227          6
 126-        CBAR    1301    1       1301    1502                                    +B1301
 127-        +B1301  5
 128-        CBAR    1302    1       1302    1503                                    +B1302
 129-        +B1302  5
 130-        CBAR    1303    1       1303    1504                                    +B1303
 131-        +B1303  5
 132-        CBAR    1304    1       1304    1505                                    +B1304
 133-        +B1304  5
 134-        CBAR    1305    1       1305    1506                                    +B1305
 135-        +B1305  5
 136-        CBAR    1306    1       1306    1507                                    +B1306
 137-        +B1306  5
 138-        CBAR    1307    1       1307    1508                                    +B1307
 139-        +B1307  5
 140-        CBAR    1308    1       1308    1509                                    +B1308
 141-        +B1308  5
 142-        CBAR    1309    1       1309    1510                                    +B1309
 143-        +B1309  5
 144-        CBAR    1310    1       1310    1511                                    +B1310
 145-        +B1310  5
 146-        CBAR    1311    1       1311    1512                                    +B1311
 147-        +B1311  5
 148-        CBAR    1313            1313    1514                                    +B1313
 149-        +B1313          6
 150-        CBAR    1327            1327    1526                                    +B1327
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                                S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT       .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
151-        +B1327          6
152-        CBAR    1413            1413    1614                                    +B1413
153-        +B1413          6
154-        CBAR    1427            1427    1626                                    +B1427
155-        +B1427          6
156-        CBAR    1502    1       1502    1725                                    +B1502
157-        +B1502          5
158-        CBAR    1503    1       1503    1724                                    +B1503
159-        +B1503          5
160-        CBAR    1504    1       1504    1723                                    +B1504
161-        +B1504          5
162-        CBAR    1505    1       1505    1722                                    +B1505
163-        +B1505          5
164-        CBAR    1506    1       1506    1721                                    +B1506
165-        +B1506          5
166-        CBAR    1507    1       1507    1720                                    +B1507
167-        +B1507          5
168-        CBAR    1508    1       1508    1719                                    +B1508
169-        +B1508          5
170-        CBAR    1509    1       1509    1718                                    +B1509
171-        +B1509          5
172-        CBAR    1510    1       1510    1717                                    +B1510
173-        +B1510          5
174-        CBAR    1511    1       1511    1716                                    +B1511
175-        +B1511          5
176-        CBAR    1512    1       1512    1715                                    +B1512
177-        +B1512          5
178-        CORD2R  2               -2.     1.057   -2.     -2.     1.057   12.     +C02
179-        +C02    12.     1.057   -2.0
180-        CORD2R  4               -4.     2.114   -4.     -4.     2.114   12.     +C04
181-        +C04    12.     2.114   -4.0
182-        CQUAD4  100     60      100     101     201     200
183-        CQUAD4  101     60      101     102     202     201
184-        CQUAD4  102     60      102     103     203     202
185-        CQUAD4  103     60      103     104     204     203
186-        CQUAD4  104     60      104     105     205     204
187-        CQUAD4  105     60      105     106     206     205
188-        CQUAD4  106     60      106     107     207     206
189-        CQUAD4  107     60      107     108     208     207
190-        CQUAD4  108     60      108     109     209     208
191-        CQUAD4  109     60      109     110     210     209
192-        CQUAD4  110     60      110     111     211     210
193-        CQUAD4  111     60      111     112     212     211
194-        CQUAD4  200     60      200     201     301     300
195-        CQUAD4  201     600     201     202     302     301
196-        CQUAD4  202     600     202     203     303     302
197-        CQUAD4  203     600     203     204     304     303
198-        CQUAD4  204     600     204     205     305     304
199-        CQUAD4  205     600     205     206     306     305
200-        CQUAD4  206     600     206     207     307     306
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                                 S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  201-        CQUAD4  207     600     207     208     308     307
  202-        CQUAD4  208     600     208     209     309     308
  203-        CQUAD4  209     600     209     210     310     309
  204-        CQUAD4  210     600     210     211     311     310
  205-        CQUAD4  211     60      211     212     312     311
  206-        CQUAD4  300     60      300     301     401     400
  207-        CQUAD4  301     600     301     302     402     401
  208-        CQUAD4  302     6       302     303     403     402
  209-        CQUAD4  303     6       303     304     404     403
  210-        CQUAD4  304     6       304     305     405     404
  211-        CQUAD4  305     6       305     306     406     405
  212-        CQUAD4  306     6       306     307     407     406
  213-        CQUAD4  307     6       307     308     408     407
  214-        CQUAD4  308     6       308     309     409     408
  215-        CQUAD4  309     6       309     310     410     409
  216-        CQUAD4  310     600     310     311     411     410
  217-        CQUAD4  311     60      311     312     412     411
  218-        CQUAD4  400     60      400     401     501     500
  219-        CQUAD4  401     600     401     402     502     501
  220-        CQUAD4  402     6       402     403     503     502
  221-        CQUAD4  403     6       403     404     504     503
  222-        CQUAD4  404     6       404     405     505     504
  223-        CQUAD4  405     6       405     406     506     505
  224-        CQUAD4  406     6       406     407     507     506
  225-        CQUAD4  407     6       407     408     508     507
  226-        CQUAD4  408     6       408     409     509     508
  227-        CQUAD4  409     6       409     410     510     509
  228-        CQUAD4  410     600     410     411     511     510
  229-        CQUAD4  411     60      411     412     512     511
  230-        CQUAD4  500     60      500     501     601     600
  231-        CQUAD4  501     600     501     502     602     601
  232-        CQUAD4  502     6       502     503     603     602
  233-        CQUAD4  503     6       503     504     604     603
  234-        CQUAD4  504     6       504     505     605     604
  235-        CQUAD4  505     6       505     506     606     605
  236-        CQUAD4  506     6       506     507     607     606
  237-        CQUAD4  507     6       507     508     608     607
  238-        CQUAD4  508     6       508     509     609     608
  239-        CQUAD4  509     6       509     510     610     609
  240-        CQUAD4  510     600     510     511     611     610
  241-        CQUAD4  511     60      511     512     612     611
  242-        CQUAD4  515     5       515     514     614     615
  243-        CQUAD4  516     5       516     515     615     616
  244-        CQUAD4  517     5       517     516     616     617
  245-        CQUAD4  518     5       518     517     617     618
  246-        CQUAD4  519     5       519     518     618     619
  247-        CQUAD4  520     5       520     519     619     620
  248-        CQUAD4  521     5       521     520     620     621
  249-        CQUAD4  522     5       522     521     621     622
  250-        CQUAD4  523     5       523     522     622     623
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                                    S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  251-        CQUAD4  524     5       524     523     623     624
  252-        CQUAD4  525     5       525     524     624     625
  253-        CQUAD4  526     5       526     525     625     626
  254-        CQUAD4  600     60      600     601     701     700
  255-        CQUAD4  601     600     601     602     702     701
  256-        CQUAD4  602     6       602     603     703     702
  257-        CQUAD4  603     6       603     604     704     703
  258-        CQUAD4  604     6       604     605     705     704
  259-        CQUAD4  605     6       605     606     706     705
  260-        CQUAD4  606     6       606     607     707     706
  261-        CQUAD4  607     6       607     608     708     707
  262-        CQUAD4  608     6       608     609     709     708
  263-        CQUAD4  609     6       609     610     710     709
  264-        CQUAD4  610     600     610     611     711     710
  265-        CQUAD4  611     60      611     612     712     711
  266-        CQUAD4  615     5       615     614     714     715
  267-        CQUAD4  616     5       616     615     715     716
  268-        CQUAD4  617     5       617     616     716     717
  269-        CQUAD4  618     5       618     617     717     718
  270-        CQUAD4  619     5       619     618     718     719
  271-        CQUAD4  620     5       620     619     719     720
  272-        CQUAD4  621     5       621     620     720     721
  273-        CQUAD4  622     5       622     621     721     722
  274-        CQUAD4  623     5       623     622     722     723
  275-        CQUAD4  624     5       624     623     723     724
  276-        CQUAD4  625     5       625     624     724     725
  277-        CQUAD4  626     5       626     625     725     726
  278-        CQUAD4  700     60      700     701     801     800
  279-        CQUAD4  701     600     701     702     802     801
  280-        CQUAD4  702     6       702     703     803     802
  281-        CQUAD4  703     6       703     704     804     803
  282-        CQUAD4  704     6       704     705     805     804
  283-        CQUAD4  705     6       705     706     806     805
  284-        CQUAD4  706     6       706     707     807     806
  285-        CQUAD4  707     6       707     708     808     807
  286-        CQUAD4  708     6       708     709     809     808
  287-        CQUAD4  709     6       709     710     810     809
  288-        CQUAD4  710     600     710     711     811     810
  289-        CQUAD4  711     60      711     712     812     811
  290-        CQUAD4  715     5       715     714     814     815
  291-        CQUAD4  716     5       716     715     815     816
  292-        CQUAD4  717     5       717     716     816     817
  293-        CQUAD4  718     5       718     717     817     818
  294-        CQUAD4  719     5       719     718     818     819
  295-        CQUAD4  720     5       720     719     819     820
  296-        CQUAD4  721     5       721     720     820     821
  297-        CQUAD4  722     5       722     721     821     822
  298-        CQUAD4  723     5       723     722     822     823
  299-        CQUAD4  724     5       724     723     823     824
  300-        CQUAD4  725     5       725     724     824     825
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                                    S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT            .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
 301-            CQUAD4  726     5       726     725     825     826
 302-            CQUAD4  800     60      800     801     901     900
 303-            CQUAD4  801     600     801     802     902     901
 304-            CQUAD4  802     6       802     803     903     902
 305-            CQUAD4  803     6       803     804     904     903
 306-            CQUAD4  804     6       804     805     905     904
 307-            CQUAD4  805     6       805     806     906     905
 308-            CQUAD4  806     6       806     807     907     906
 309-            CQUAD4  807     6       807     808     908     907
 310-            CQUAD4  808     6       808     809     909     908
 311-            CQUAD4  809     6       809     810     910     909
 312-            CQUAD4  810     600     810     811     911     910
 313-            CQUAD4  811     60      811     812     912     911
 314-            CQUAD4  815     5       815     814     914     915
 315-            CQUAD4  816     5       816     815     915     916
 316-            CQUAD4  817     5       817     816     916     917
 317-            CQUAD4  818     5       818     817     917     918
 318-            CQUAD4  819     5       819     818     918     919
 319-            CQUAD4  820     5       820     819     919     920
 320-            CQUAD4  821     5       821     820     920     921
 321-            CQUAD4  822     5       822     821     921     922
 322-            CQUAD4  823     5       823     822     922     923
 323-            CQUAD4  824     5       824     823     923     924
 324-            CQUAD4  825     5       825     824     924     925
 325-            CQUAD4  826     5       826     825     925     926
 326-            CQUAD4  900     60      900     901     1001    1000
 327-            CQUAD4  901     600     901     902     1002    1001
 328-            CQUAD4  902     6       902     903     1003    1002
 329-            CQUAD4  903     6       903     904     1004    1003
 330-            CQUAD4  904     6       904     905     1005    1004
 331-            CQUAD4  905     6       905     906     1006    1005
 332-            CQUAD4  906     6       906     907     1007    1006
 333-            CQUAD4  907     6       907     908     1008    1007
 334-            CQUAD4  908     6       908     909     1009    1008
 335-            CQUAD4  909     6       909     910     1010    1009
 336-            CQUAD4  910     600     910     911     1011    1010
 337-            CQUAD4  911     60      911     912     1012    1011
 338-            CQUAD4  915     5       915     914     1014    1015
 339-            CQUAD4  916     5       916     915     1015    1016
 340-            CQUAD4  917     5       917     916     1016    1017
 341-            CQUAD4  918     5       918     917     1017    1018
 342-            CQUAD4  919     5       919     918     1018    1019
 343-            CQUAD4  920     5       920     919     1019    1020
 344-            CQUAD4  921     5       921     920     1020    1021
 345-            CQUAD4  922     5       922     921     1021    1022
 346-            CQUAD4  923     5       923     922     1022    1023
 347-            CQUAD4  924     5       924     923     1023    1024
 348-            CQUAD4  925     5       925     924     1024    1025
 349-            CQUAD4  926     5       926     925     1025    1026
 350-            CQUAD4  1000    60      1000    1001    1101    1100
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                                          S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  351-       CQUAD4  1001    600     1001    1002    1102    1101
  352-       CQUAD4  1002    6       1002    1003    1103    1102
  353-       CQUAD4  1003    6       1003    1004    1104    1103
  354-       CQUAD4  1004    6       1004    1005    1105    1104
  355-       CQUAD4  1005    6       1005    1006    1106    1105
  356-       CQUAD4  1006    6       1006    1007    1107    1106
  357-       CQUAD4  1007    6       1007    1008    1108    1107
  358-       CQUAD4  1008    6       1008    1009    1109    1108
  359-       CQUAD4  1009    6       1009    1010    1110    1109
  360-       CQUAD4  1010    600     1010    1011    1111    1110
  361-       CQUAD4  1011    60      1011    1012    1112    1111
  362-       CQUAD4  1015    5       1015    1014    1114    1115
  363-       CQUAD4  1016    5       1016    1015    1115    1116
  364-       CQUAD4  1017    5       1017    1016    1116    1117
  365-       CQUAD4  1018    5       1018    1017    1117    1118
  366-       CQUAD4  1019    5       1019    1018    1118    1119
  367-       CQUAD4  1020    5       1020    1019    1119    1120
  368-       CQUAD4  1021    5       1021    1020    1120    1121
  369-       CQUAD4  1022    5       1022    1021    1121    1122
  370-       CQUAD4  1023    5       1023    1022    1122    1123
  371-       CQUAD4  1024    5       1024    1023    1123    1124
  372-       CQUAD4  1025    5       1025    1024    1124    1125
  373-       CQUAD4  1026    5       1026    1025    1125    1126
  374-       CQUAD4  1100    60      1100    1101    1201    1200
  375-       CQUAD4  1101    600     1101    1102    1202    1201
  376-       CQUAD4  1102    600     1102    1103    1203    1202
  377-       CQUAD4  1103    600     1103    1104    1204    1203
  378-       CQUAD4  1104    600     1104    1105    1205    1204
  379-       CQUAD4  1105    600     1105    1106    1206    1205
  380-       CQUAD4  1106    600     1106    1107    1207    1206
  381-       CQUAD4  1107    600     1107    1108    1208    1207
  382-       CQUAD4  1108    600     1108    1109    1209    1208
  383-       CQUAD4  1109    600     1109    1110    1210    1209
  384-       CQUAD4  1110    600     1110    1111    1211    1210
  385-       CQUAD4  1111    60      1111    1112    1212    1211
  386-       CQUAD4  1115    5       1115    1114    1214    1215
  387-       CQUAD4  1116    5       1116    1115    1215    1216
  388-       CQUAD4  1117    5       1117    1116    1216    1217
  389-       CQUAD4  1118    5       1118    1117    1217    1218
  390-       CQUAD4  1119    5       1119    1118    1218    1219
  391-       CQUAD4  1120    5       1120    1119    1219    1220
  392-       CQUAD4  1121    5       1121    1120    1220    1221
  393-       CQUAD4  1122    5       1122    1121    1221    1222
  394-       CQUAD4  1123    5       1123    1122    1222    1223
  395-       CQUAD4  1124    5       1124    1123    1223    1224
  396-       CQUAD4  1125    5       1125    1124    1224    1225
  397-       CQUAD4  1126    5       1126    1125    1225    1226
  398-       CQUAD4  1200    60      1200    1201    1301    1300
  399-       CQUAD4  1201    60      1201    1202    1302    1301
  400-       CQUAD4  1202    60      1202    1203    1303    1302
```

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                                   S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  401-        CQUAD4  1203    60              1203    1204    1304    1303
  402-        CQUAD4  1204    60              1204    1205    1305    1304
  403-        CQUAD4  1205    60              1205    1206    1306    1305
  404-        CQUAD4  1206    60              1206    1207    1307    1306
  405-        CQUAD4  1207    60              1207    1208    1308    1307
  406-        CQUAD4  1208    60              1208    1209    1309    1308
  407-        CQUAD4  1209    60              1209    1210    1310    1309
  408-        CQUAD4  1210    60              1210    1211    1311    1310
  409-        CQUAD4  1211    60              1211    1212    1312    1311
  410-        CQUAD4  1215    5               1215    1214    1314    1315
  411-        CQUAD4  1216    5               1216    1215    1315    1316
  412-        CQUAD4  1217    5               1217    1216    1316    1317
  413-        CQUAD4  1218    5               1218    1217    1317    1318
  414-        CQUAD4  1219    5               1219    1218    1318    1319
  415-        CQUAD4  1220    5               1220    1219    1319    1320
  416-        CQUAD4  1221    5               1221    1220    1320    1321
  417-        CQUAD4  1222    5               1222    1221    1321    1322
  418-        CQUAD4  1223    5               1223    1222    1322    1323
  419-        CQUAD4  1224    5               1224    1223    1323    1324
  420-        CQUAD4  1225    5               1225    1224    1324    1325
  421-        CQUAD4  1226    5               1226    1225    1325    1326
  422-        CQUAD4  1315    5               1315    1314    1414    1415
  423-        CQUAD4  1316    5               1316    1315    1415    1416
  424-        CQUAD4  1317    5               1317    1316    1416    1417
  425-        CQUAD4  1318    5               1318    1317    1417    1418
  426-        CQUAD4  1319    5               1319    1318    1418    1419
  427-        CQUAD4  1320    5               1320    1319    1419    1420
  428-        CQUAD4  1321    5               1321    1320    1420    1421
  429-        CQUAD4  1322    5               1322    1321    1421    1422
  430-        CQUAD4  1323    5               1323    1322    1422    1423
  431-        CQUAD4  1324    5               1324    1323    1423    1424
  432-        CQUAD4  1325    5               1325    1324    1424    1425
  433-        CQUAD4  1326    5               1326    1325    1425    1426
  434-        CQUAD4  1415    5               1415    1414    1514    1515
  435-        CQUAD4  1416    5               1416    1415    1515    1516
  436-        CQUAD4  1417    5               1417    1416    1516    1517
  437-        CQUAD4  1418    5               1418    1417    1517    1518
  438-        CQUAD4  1419    5               1419    1418    1518    1519
  439-        CQUAD4  1420    5               1420    1419    1519    1520
  440-        CQUAD4  1421    5               1421    1420    1520    1521
  441-        CQUAD4  1422    5               1422    1421    1521    1522
  442-        CQUAD4  1423    5               1423    1422    1522    1523
  443-        CQUAD4  1424    5               1424    1423    1523    1524
  444-        CQUAD4  1425    5               1425    1424    1524    1525
  445-        CQUAD4  1426    5               1426    1425    1525    1526
  446-        CQUAD4  1515    5               1515    1514    1614    1615
  447-        CQUAD4  1516    5               1516    1515    1615    1616
  448-        CQUAD4  1517    5               1517    1516    1616    1617
  449-        CQUAD4  1518    5               1518    1517    1617    1618
  450-        CQUAD4  1519    5               1519    1518    1618    1619
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                                  S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  451-        CQUAD4  1520    5          1520    1519    1619    1620
  452-        CQUAD4  1521    5          1521    1520    1620    1621
  453-        CQUAD4  1522    5          1522    1521    1621    1622
  454-        CQUAD4  1523    5          1523    1522    1622    1623
  455-        CQUAD4  1524    5          1524    1523    1623    1624
  456-        CQUAD4  1525    5          1525    1524    1624    1625
  457-        CQUAD4  1526    5          1526    1525    1625    1626
  458-        CQUAD4  1615    5          1615    1614    1714    1715
  459-        CQUAD4  1616    5          1616    1615    1715    1716
  460-        CQUAD4  1617    5          1617    1616    1716    1717
  461-        CQUAD4  1618    5          1618    1617    1717    1718
  462-        CQUAD4  1619    5          1619    1618    1718    1719
  463-        CQUAD4  1620    5          1620    1619    1719    1720
  464-        CQUAD4  1621    5          1621    1620    1720    1721
  465-        CQUAD4  1622    5          1622    1621    1721    1722
  466-        CQUAD4  1623    5          1623    1622    1722    1723
  467-        CQUAD4  1624    5          1624    1623    1723    1724
  468-        CQUAD4  1625    5          1625    1624    1724    1725
  469-        CQUAD4  1626    5          1626    1625    1725    1726
  470-        CROD    1       1          1       202     2       1       2       210
  471-        CROD    3       1          3       1202    4       1       4       1210
  472-        CROD    100     3          100     325
  473-        CROD    112     3          112     313
  474-        CROD    313     3          313     514
  475-        CROD    325     3          325     526
  476-        CROD    1300    3          1300    1527
  477-        CROD    1312    3          1312    1513
  478-        CROD    1513    3          1513    1714
  479-        CROD    1527    3          1527    1726
  480-        CSHEAR  11      1          100     101     324     325
  481-        CSHEAR  12      1          325     324     525     526
  482-        CSHEAR  13      1          111     112     313     314
  483-        CSHEAR  14      1          314     313     514     515
  484-        CSHEAR  21      2          1300    1200    1427    1527
  485-        CSHEAR  22      2          1527    1427    1626    1726
  486-        CSHEAR  23      2          200     100     325     416
  487-        CSHEAR  24      2          416     325     526     626
  488-        CSHEAR  31      3          212     112     313     413
  489-        CSHEAR  32      3          413     313     514     614
  490-        CSHEAR  34      3          1312    1212    1413    1513
  491-        CSHEAR  35      3          1513    1413    1614    1714
  492-        CSHEAR  41      4          1300    1301    1502    1527
  493-        CSHEAR  42      4          1527    1502    1725    1726
  494-        CSHEAR  43      4          1311    1312    1513    1512
  495-        CSHEAR  44      4          1512    1513    1714    1715
  496-        CSHEAR  101     1          101     102     323     324
  497-        CSHEAR  102     1          102     103     322     323
  498-        CSHEAR  103     1          103     104     321     322
  499-        CSHEAR  104     1          104     105     320     321
  500-        CSHEAR  105     1          105     106     319     320
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                                   S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT       .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  501-       CSHEAR  106     1        106     107     318     319
  502-       CSHEAR  107     1        107     108     317     318
  503-       CSHEAR  108     1        108     109     316     317
  504-       CSHEAR  109     1        109     110     315     316
  505-       CSHEAR  110     1        110     111     314     315
  506-       CSHEAR  300     2        300     200     416     527
  507-       CSHEAR  312     3        312     212     413     513
  508-       CSHEAR  315     1        315     314     515     516
  509-       CSHEAR  316     1        316     315     516     517
  510-       CSHEAR  317     1        317     316     517     518
  511-       CSHEAR  318     1        318     317     518     519
  512-       CSHEAR  319     1        319     318     519     520
  513-       CSHEAR  320     1        320     319     520     521
  514-       CSHEAR  321     1        321     320     521     522
  515-       CSHEAR  322     1        322     321     522     523
  516-       CSHEAR  323     1        323     322     523     524
  517-       CSHEAR  324     1        324     323     524     525
  518-       CSHEAR  400     2        400     300     527     627
  519-       CSHEAR  412     3        412     312     513     613
  520-       CSHEAR  500     2        500     400     627     727
  521-       CSHEAR  512     3        512     412     613     713
  522-       CSHEAR  513     3        513     413     614     714
  523-       CSHEAR  527     2        527     416     626     726
  524-       CSHEAR  600     2        600     500     727     827
  525-       CSHEAR  612     3        612     512     713     813
  526-       CSHEAR  613     3        613     513     714     814
  527-       CSHEAR  627     2        627     527     726     826
  528-       CSHEAR  700     2        700     600     827     927
  529-       CSHEAR  712     3        712     612     813     913
  530-       CSHEAR  713     3        713     613     814     914
  531-       CSHEAR  727     2        727     627     826     926
  532-       CSHEAR  800     2        800     700     927     1027
  533-       CSHEAR  812     3        812     712     913     1013
  534-       CSHEAR  813     3        813     713     914     1014
  535-       CSHEAR  827     2        827     727     926     1026
  536-       CSHEAR  900     2        900     800     1027    1127
  537-       CSHEAR  912     3        912     812     1013    1113
  538-       CSHEAR  913     3        913     813     1014    1114
  539-       CSHEAR  927     2        927     827     1026    1126
  540-       CSHEAR  1000    2        1000    900     1127    1227
  541-       CSHEAR  1012    3        1012    912     1113    1213
  542-       CSHEAR  1013    3        1013    913     1114    1214
  543-       CSHEAR  1027    2        1027    927     1126    1226
  544-       CSHEAR  1100    2        1100    1000    1227    1327
  545-       CSHEAR  1112    3        1112    1012    1213    1313
  546-       CSHEAR  1113    3        1113    1013    1214    1314
  547-       CSHEAR  1127    2        1127    1027    1226    1326
  548-       CSHEAR  1200    2        1200    1100    1327    1427
  549-       CSHEAR  1212    3        1212    1112    1313    1413
  550-       CSHEAR  1213    3        1213    1113    1314    1414
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                                        S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  551-        CSHEAR  1227    2               1227    1127    1326    1426
  552-        CSHEAR  1301    4               1301    1302    1503    1502
  553-        CSHEAR  1302    4               1302    1303    1504    1503
  554-        CSHEAR  1303    4               1303    1304    1505    1504
  555-        CSHEAR  1304    4               1304    1305    1506    1505
  556-        CSHEAR  1305    4               1305    1306    1507    1506
  557-        CSHEAR  1306    4               1306    1307    1508    1507
  558-        CSHEAR  1307    4               1307    1308    1509    1508
  559-        CSHEAR  1308    4               1308    1309    1510    1509
  560-        CSHEAR  1309    4               1309    1310    1511    1510
  561-        CSHEAR  1310    4               1310    1311    1512    1511
  562-        CSHEAR  1313    3               1313    1213    1414    1514
  563-        CSHEAR  1327    2               1327    1227    1426    1526
  564-        CSHEAR  1413    3               1413    1313    1514    1614
  565-        CSHEAR  1427    2               1427    1327    1526    1626
  566-        CSHEAR  1502    4               1502    1503    1724    1725
  567-        CSHEAR  1503    4               1503    1504    1723    1724
  568-        CSHEAR  1504    4               1504    1505    1722    1723
  569-        CSHEAR  1505    4               1505    1506    1721    1722
  570-        CSHEAR  1506    4               1506    1507    1720    1721
  571-        CSHEAR  1507    4               1507    1508    1719    1720
  572-        CSHEAR  1508    4               1508    1509    1718    1719
  573-        CSHEAR  1509    4               1509    1510    1717    1718
  574-        CSHEAR  1510    4               1510    1511    1716    1717
  575-        CSHEAR  1511    4               1511    1512    1715    1716
  576-        GRDSET                                                          5
  577-        GRID    1               1.      -1.     2.              12346
  578-        GRID    2               1.      -1.     10.             12346
  579-        GRID    3               11.     -1.     2.              12346
  580-        GRID    4               11.     -1.     10.             12346
  581-        GRID    100                             0.
  582-        GRID    101                             1.              0
  583-        GRID    102                             2.              0
  584-        GRID    103                             3.              0
  585-        GRID    104                             4.              0
  586-        GRID    105                             5.              0
  587-        GRID    106                             6.              0
  588-        GRID    107                             7.              0
  589-        GRID    108                             8.              0
  590-        GRID    109                             9.              0
  591-        GRID    110                             10.             0
  592-        GRID    111                             11.             0
  593-        GRID    112                             12.
  594-        GRID    200             1.              0.
  595-        GRID    201             1.              1.              35
  596-        GRID    202             1.              2.              5
  597-        GRID    203             1.              3.
  598-        GRID    204             1.              4.
  599-        GRID    205             1.              5.
  600-        GRID    206             1.              6.
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                                   S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
   601-        GRID    207             1.              7.
   602-        GRID    208             1.              8.
   603-        GRID    209             1.              9.
   604-        GRID    210             1.              10.                     5
   605-        GRID    211             1.              11.                     5
   606-        GRID    212             1.              12.
   607-        GRID    300             2.      0       0.
   608-        GRID    301             2.              1.
   609-        GRID    302             2.              2.
   610-        GRID    303             2.              3.
   611-        GRID    304             2.              4.
   612-        GRID    305             2.              5.
   613-        GRID    306             2.              6.
   614-        GRID    307             2.              7.
   615-        GRID    308             2.              8.
   616-        GRID    309             2.              9.
   617-        GRID    310             2.              10.
   618-        GRID    311             2.              11.
   619-        GRID    312             2.      0       12.
   620-        GRID    313     2       2.              14.                     456
   621-        GRID    314     2       2.              13.                     0
   622-        GRID    315     2       2.              12.                     0
   623-        GRID    316     2       2.              11.                     0
   624-        GRID    317     2       2.              10.                     0
   625-        GRID    318     2       2.              9.                      0
   626-        GRID    319     2       2.              8.                      0
   627-        GRID    320     2       2.              7.                      0
   628-        GRID    321     2       2.              6.                      0
   629-        GRID    322     2       2.              5.                      0
   630-        GRID    323     2       2.              4.                      0
   631-        GRID    324     2       2.              3.                      0
   632-        GRID    325     2       2.              2.                      456
   633-        GRID    400             3.      0       0.
   634-        GRID    401             3.      0       1.
   635-        GRID    402             3.      0       2.
   636-        GRID    403             3.              3.
   637-        GRID    404             3.              4.
   638-        GRID    405             3.              5.
   639-        GRID    406             3.              6.
   640-        GRID    407             3.              7.
   641-        GRID    408             3.              8.
   642-        GRID    409             3.              9.
   643-        GRID    410             3.      0       10.
   644-        GRID    411             3.      0       11.
   645-        GRID    412             3.      0       12.
   646-        GRID    413     2       3.      0       14.
   647-        GRID    416     2       3.      0       2.
   648-        GRID    500             4.      0       0.
   649-        GRID    501             4.              1.
   650-        GRID    502             4.              2.
```

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CARD                             S O R T E D   B U L K   D A T A   E C H O
COUNT            1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
 651-        GRID    503             4.             3.
 652-        GRID    504             4.             4.
 653-        GRID    505             4.             5.
 654-        GRID    506             4.             6.
 655-        GRID    507             4.             7.
 656-        GRID    508             4.             8.
 657-        GRID    509             4.             9.
 658-        GRID    510             4.             10.
 659-        GRID    511             4.             11.
 660-        GRID    512             4.0            12.
 661-        GRID    513     2       4.0            14.
 662-        GRID    514     4       4.             16.
 663-        GRID    515     4       4.             15.             0
 664-        GRID    516     4       4.             14.             0
 665-        GRID    517     4       4.             13.             0
 666-        GRID    518     4       4.             12.             0
 667-        GRID    519     4       4.             11.             0
 668-        GRID    520     4       4.             10.             0
 669-        GRID    521     4       4.             9.              0
 670-        GRID    522     4       4.             8.              0
 671-        GRID    523     4       4.             7.              0
 672-        GRID    524     4       4.             6.              0
 673-        GRID    525     4       4.             5.              0
 674-        GRID    526     4       4.             4.
 675-        GRID    527     2       4.0            2.
 676-        GRID    600             5.0            0.
 677-        GRID    601             5.0            1.
 678-        GRID    602             5.0            2.
 679-        GRID    603             5.             3.
 680-        GRID    604             5.             4.
 681-        GRID    605             5.             5.
 682-        GRID    606             5.             6.
 683-        GRID    607             5.             7.
 684-        GRID    608             5.             8.
 685-        GRID    609             5.             9.
 686-        GRID    610             5.0            10.
 687-        GRID    611             5.0            11.
 688-        GRID    612             5.0            12.
 689-        GRID    613     2       5.0            14.
 690-        GRID    614     4       5.0            16.
 691-        GRID    615     4       5.             15.
 692-        GRID    616     4       5.             14.
 693-        GRID    617     4       5.             13.
 694-        GRID    618     4       5.             12.
 695-        GRID    619     4       5.             11.
 696-        GRID    620     4       5.             10.
 697-        GRID    621     4       5.             9.
 698-        GRID    622     4       5.             8.
 699-        GRID    623     4       5.             7.
 700-        GRID    624     4       5.             6.
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                                   S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT          1    ..   2    ..   3    ..   4    ..   5    ..   6    ..   7    ..   8    ..   9    ..   10   .
 701-        GRID    625     4        5.            5.
 702-        GRID    626     4        5.0           4.
 703-        GRID    627     2        5.            2.
 704-        GRID    700              6.0           0.
 705-        GRID    701              6.            1.
 706-        GRID    702              6.            2.
 707-        GRID    703              6.            3.
 708-        GRID    704              6.            4.
 709-        GRID    705              6.            5.
 710-        GRID    706              6.            6.
 711-        GRID    707              6.            7.
 712-        GRID    708              6.            8.
 713-        GRID    709              6.            9.
 714-        GRID    710              6.            10.
 715-        GRID    711              6.            11.
 716-        GRID    712              6.0           12.
 717-        GRID    713     2        6.0           14.
 718-        GRID    714     4        6.0           16.
 719-        GRID    715     4        6.            15.
 720-        GRID    716     4        6.            14.
 721-        GRID    717     4        6.            13.
 722-        GRID    718     4        6.            12.
 723-        GRID    719     4        6.            11.
 724-        GRID    720     4        6.            10.
 725-        GRID    721     4        6.            9.
 726-        GRID    722     4        6.            8.
 727-        GRID    723     4        6.            7.
 728-        GRID    724     4        6.            6.
 729-        GRID    725     4        6.            5.
 730-        GRID    726     4        6.0           4.
 731-        GRID    727     2        6.0           2.
 732-        GRID    800              7.0           0.
 733-        GRID    801              7.0           1.
 734-        GRID    802              7.0           2.
 735-        GRID    803              7.            3.
 736-        GRID    804              7.            4.
 737-        GRID    805              7.            5.
 738-        GRID    806              7.            6.
 739-        GRID    807              7.            7.
 740-        GRID    808              7.            8.
 741-        GRID    809              7.            9.
 742-        GRID    810              7.0           10.
 743-        GRID    811              7.0           11.
 744-        GRID    812              7.0           12.
 745-        GRID    813     2        7.0           14.
 746-        GRID    814     4        7.0           16.
 747-        GRID    815     4        7.            15.
 748-        GRID    816     4        7.            14.
 749-        GRID    817     4        7.            13.
 750-        GRID    818     4        7.            12.
```

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                                    S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT               1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
 751-         GRID    819     4       7.              11.
 752-         GRID    820     4       7.              10.
 753-         GRID    821     4       7.              9.
 754-         GRID    822     4       7.              8.
 755-         GRID    823     4       7.              7.
 756-         GRID    824     4       7.              6.
 757-         GRID    825     4       7.              5.
 758-         GRID    826     4       7.0             4.
 759-         GRID    827     2       7.0             2.
 760-         GRID    900             8.0             0.
 761-         GRID    901             8.              1.
 762-         GRID    902             8.              2.
 763-         GRID    903             8.              3.
 764-         GRID    904             8.              4.
 765-         GRID    905             8.              5.
 766-         GRID    906             8.              6.
 767-         GRID    907             8.              7.
 768-         GRID    908             8.              8.
 769-         GRID    909             8.              9.
 770-         GRID    910             8.              10.
 771-         GRID    911             8.              11.
 772-         GRID    912             8.0             12.
 773-         GRID    913     2       8.0             14.
 774-         GRID    914     4       8.0             16.
 775-         GRID    915     4       8.              15.
 776-         GRID    916     4       8.              14.
 777-         GRID    917     4       8.              13.
 778-         GRID    918     4       8.              12.
 779-         GRID    919     4       8.              11.
 780-         GRID    920     4       8.              10.
 781-         GRID    921     4       8.              9.
 782-         GRID    922     4       8.              8.
 783-         GRID    923     4       8.              7.
 784-         GRID    924     4       8.              6.
 785-         GRID    925     4       8.              5.
 786-         GRID    926     4       8.0             4.
 787-         GRID    927     2       8.0             2.
 788-         GRID    1000            9.0             0.
 789-         GRID    1001            9.              1.
 790-         GRID    1002            9.              2.
 791-         GRID    1003            9.              3.
 792-         GRID    1004            9.              4.
 793-         GRID    1005            9.              5.
 794-         GRID    1006            9.              6.
 795-         GRID    1007            9.              7.
 796-         GRID    1008            9.              8.
 797-         GRID    1009            9.              9.
 798-         GRID    1010            9.              10.
 799-         GRID    1011            9.              11.
 800-         GRID    1012            9.0             12.
```

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                                        S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT           .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
  801-          GRID    1013    2           9.0             14.
  802-          GRID    1014    4           9.0             16.
  803-          GRID    1015    4           9.              15.
  804-          GRID    1016    4           9.              14.
  805-          GRID    1017    4           9.              13.
  806-          GRID    1018    4           9.              12.
  807-          GRID    1019    4           9.              11.
  808-          GRID    1020    4           9.              10.
  809-          GRID    1021    4           9.              9.
  810-          GRID    1022    4           9.              8.
  811-          GRID    1023    4           9.              7.
  812-          GRID    1024    4           9.              6.
  813-          GRID    1025    4           9.              5.
  814-          GRID    1026    4           9.0             4.
  815-          GRID    1027    2           9.0             2.
  816-          GRID    1100                10.             0.
  817-          GRID    1101                10.             1.
  818-          GRID    1102                10.             2.
  819-          GRID    1103                10.             3.
  820-          GRID    1104                10.             4.
  821-          GRID    1105                10.             5.
  822-          GRID    1106                10.             6.
  823-          GRID    1107                10.             7.
  824-          GRID    1108                10.             8.
  825-          GRID    1109                10.             9.
  826-          GRID    1110                10.             10.
  827-          GRID    1111                10.             11.
  828-          GRID    1112                10.             12.
  829-          GRID    1113    2           10.0            14.
  830-          GRID    1114    4           10.             16.
  831-          GRID    1115    4           10.             15.
  832-          GRID    1116    4           10.             14.
  833-          GRID    1117    4           10.             13.
  834-          GRID    1118    4           10.             12.
  835-          GRID    1119    4           10.             11.
  836-          GRID    1120    4           10.             10.
  837-          GRID    1121    4           10.             9.
  838-          GRID    1122    4           10.             8.
  839-          GRID    1123    4           10.             7.
  840-          GRID    1124    4           10.             6.
  841-          GRID    1125    4           10.             5.
  842-          GRID    1126    4           10.             4.
  843-          GRID    1127    2           10.0            2.
  844-          GRID    1200                11.             0.
  845-          GRID    1201                11.             1.                      15
  846-          GRID    1202                11.             2.                      5
  847-          GRID    1203                11.             3.
  848-          GRID    1204                11.             4.
  849-          GRID    1205                11.             5.
  850-          GRID    1206                11.             6.
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                                 S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
 851-        GRID    1207            11.             7.
 852-        GRID    1208            11.             8.
 853-        GRID    1209            11.             9.
 854-        GRID    1210            11.             10.             5
 855-        GRID    1211            11.             11.             15
 856-        GRID    1212            11.             12.
 857-        GRID    1213    2       11. 0           14.
 858-        GRID    1214    4       11.             16.
 859-        GRID    1215    4       11.             15.
 860-        GRID    1216    4       11.             14.
 861-        GRID    1217    4       11.             13.
 862-        GRID    1218    4       11.             12.
 863-        GRID    1219    4       11.             11.
 864-        GRID    1220    4       11.             10.
 865-        GRID    1221    4       11.             9.
 866-        GRID    1222    4       11.             8.
 867-        GRID    1223    4       11.             7.
 868-        GRID    1224    4       11.             6.
 869-        GRID    1225    4       11.             5.
 870-        GRID    1226    4       11.             4.
 871-        GRID    1227    2       11. 0           2.
 872-        GRID    1300            12.             0.
 873-        GRID    1301            12.             1.              0
 874-        GRID    1302            12.             2.              0
 875-        GRID    1303            12.             3.              0
 876-        GRID    1304            12.             4.              0
 877-        GRID    1305            12.             5.              0
 878-        GRID    1306            12.             6.              0
 879-        GRID    1307            12.             7.              0
 880-        GRID    1308            12.             8.              0
 881-        GRID    1309            12.             9.              0
 882-        GRID    1310            12.             10.             0
 883-        GRID    1311            12.             11.             0
 884-        GRID    1312            12.             12.
 885-        GRID    1313    2       12. 0           14.
 886-        GRID    1314    4       12.             16.
 887-        GRID    1315    4       12.             15.
 888-        GRID    1316    4       12.             14.
 889-        GRID    1317    4       12.             13.
 890-        GRID    1318    4       12.             12.
 891-        GRID    1319    4       12.             11.
 892-        GRID    1320    4       12.             10.
 893-        GRID    1321    4       12.             9.
 894-        GRID    1322    4       12.             8.
 895-        GRID    1323    4       12.             7.
 896-        GRID    1324    4       12.             6.
 897-        GRID    1325    4       12.             5.
 898-        GRID    1326    4       12.             4.
 899-        GRID    1327    2       12. 0           2.
 900-        GRID    1413    2       13. 0           14.
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                                      S O R T E D   B U L K   D A T A   E C H O
     CARD
     COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
      901-        GRID    1414    4       13.             16.
      902-        GRID    1415    4       13.             15.
      903-        GRID    1416    4       13.             14.
      904-        GRID    1417    4       13.             13.
      905-        GRID    1418    4       13.             12.
      906-        GRID    1419    4       13.             11.
      907-        GRID    1420    4       13.             10.
      908-        GRID    1421    4       13.             9.
      909-        GRID    1422    4       13.             8.
      910-        GRID    1423    4       13.             7.
      911-        GRID    1424    4       13.             6.
      912-        GRID    1425    4       13.             5.
      913-        GRID    1426    4       13.             4.
      914-        GRID    1427    2       13. 0           2.
      915-        GRID    1502    2       14.             3.              0
      916-        GRID    1503    2       14.             4.              0
      917-        GRID    1504    2       14.             5.              0
      918-        GRID    1505    2       14.             6.              0
      919-        GRID    1506    2       14.             7.              0
      920-        GRID    1507    2       14.             8.              0
      921-        GRID    1508    2       14.             9.              0
      922-        GRID    1509    2       14.             10.             0
      923-        GRID    1510    2       14.             11.             0
      924-        GRID    1511    2       14.             12.             0
      925-        GRID    1512    2       14.             13.             0
      926-        GRID    1513    2       14.             14.             456
      927-        GRID    1514    4       14.             16.
      928-        GRID    1515    4       14.             15.
      929-        GRID    1516    4       14.             14.
      930-        GRID    1517    4       14.             13.
      931-        GRID    1518    4       14.             12.
      932-        GRID    1519    4       14.             11.
      933-        GRID    1520    4       14.             10.
      934-        GRID    1521    4       14.             9.
      935-        GRID    1522    4       14.             8.
      936-        GRID    1523    4       14.             7.
      937-        GRID    1524    4       14.             6.
      938-        GRID    1525    4       14.             5.
      939-        GRID    1526    4       14.             4.
      940-        GRID    1527    2       14.             2.              456
      941-        GRID    1614    4       15.             16.
      942-        GRID    1615    4       15.             15.
      943-        GRID    1616    4       15.             14.
      944-        GRID    1617    4       15.             13.
      945-        GRID    1618    4       15.             12.
      946-        GRID    1619    4       15.             11.
      947-        GRID    1620    4       15.             10.
      948-        GRID    1621    4       15.             9.
      949-        GRID    1622    4       15.             8.
      950-        GRID    1623    4       15.             7.
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                                    S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT         .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
   951-       GRID    1624    4       15.             6.
   952-       GRID    1625    4       15.             5.
   953-       GRID    1626    4       15.             4.
   954-       GRID    1714    4       16.             16.
   955-       GRID    1715    4       16.             15.             0
   956-       GRID    1716    4       16.             14.             0
   957-       GRID    1717    4       16.             13.             0
   958-       GRID    1718    4       16.             12.             0
   959-       GRID    1719    4       16.             11.             0
   960-       GRID    1720    4       16.             10.             0
   961-       GRID    1721    4       16.             9.              0
   962-       GRID    1722    4       16.             8.              0
   963-       GRID    1723    4       16.             7.              0
   964-       GRID    1724    4       16.             6.              0
   965-       GRID    1725    4       16.             5.              0
   966-       GRID    1726    4       16.             4.
   967-       MAT1    10      30.6+6          .3              6.30-6  78.
   968-       MAT1    11              50.0+3  .3                      78.
   969-       MAT1    100     16.0+6          .31             4.90-6  78.
   970-       MAT1    101             .7+5    .3                      78.
   971-       MAT1    111     1.4+4           .3
   972-       MATT1   10      1                               2
   973-       MATT1   11              3
   974-       MATT1   100     4                               5
   975-       MATT1   101             6
   976-       PBAR    1       10      .0028   1.00-9  3.75-6  1.00-9
   977-       PBAR    2       10      .0028   3.75-6  1.00-9  1.00-9
   978-       PLOAD2  10      2.      615     THRU    626
   979-       PLOAD2  10      2.      715     THRU    726
   980-       PLOAD2  10      2.      815     THRU    826
   981-       PLOAD2  10      2.      915     THRU    926
   982-       PLOAD2  10      2.      1015    THRU    1026
   983-       PLOAD2  10      2.      1115    THRU    1126
   984-       PLOAD2  10      2.      1215    THRU    1226
   985-       PLOAD2  10      2.      1315    THRU    1326
   986-       PLOAD2  10      2.      1415    THRU    1426
   987-       PLOAD2  10      2.      1515    THRU    1526
   988-       PLOAD2  10      2.      1615    THRU    1626
   989-       PLOAD2  10      2.      515     THRU    526
   990-       PROD    1       111     .050    .000398
   991-       PROD    3       10      .0028   3.75-6
   992-       PSHEAR  1       10      .0028
   993-       PSHEAR  2       10      .0028
   994-       PSHEAR  3       10      .0028
   995-       PSHEAR  4       10      .0028
   996-       PSHELL  5       10      .0100   10      2437.2  11      28.             +P5
   997-       +P5     -.145   .145
   998-       PSHELL  6       100     .006    100     2494.4  101     28.33           +P6
   999-       +P6     -.0880  .0880
  1000-       PSHELL  60      100     .012    100     645.56  101     14.17           +P60
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                                    S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT         .   1  ..   2   ..   3   ..   4   ..   5   ..   6   ..   7   ..   8   ..   9   ..  10  .
1001-         +P60     -.0910  .0910
1002-         PSHELL   600     100     .009    100     1127.6  101     18.89           +P600
1003-         +P600    -.0895  .0895
1004-         TABLEM1  1                                                               +L1
1005-         +L1      78.0    31.6+6  200.    30.+6   400.    27.5+6  600.    25.0+6  +L2
1006-         +L2      800.    22.7+6  1000.   20.3+6  1200.   17.7+6  1400.   15.3+6  +L3
1007-         +L3      1600.   12.9+6  1800.   10.5+6  2000.   2.8+6   ENDT
1008-         TABLEM1  2                                                               +L10
1009-         +L10     78.0    6.3-6   200.    6.4-6   400.    7.0-6   600.    7.4-6   +L11
1010-         +L11     800.0   7.6-6   1000.   7.7-6   1200.   8.0-6   1400.   8.4-6   +L12
1011-         +L12     1600.   8.7-6   1800.   9.0-6   2000.   9.2-6   ENDT
1012-         TABLEM1  3                                                               +LAB110
1013-         +LAB110  78.0    50.0+3  200.    49.2+3  400.    47.5+3  600.    45.8+3  +LAB111
1014-         +LAB111  800.    44.1+3  1000.   41.9+3  1200.   40.3+3  1400.   38.1+3  +LAB112
1015-         +LAB112  1600.   35.6+3  1800.   33.1+3  2000.   30.1+3  ENDT
1016-         TABLEM1  4                                                               +LA1
1017-         +LA1     78.     16.+6   850.    11.8+6  1000.   8.+6    ENDT
1018-         TABLEM1  5                                                               +LAB50
1019-         +LAB50   78.     4.9-6   500.    5.3-6   1000.   5.6-6   ENDT
1020-         TABLEM1  6                                                               +LABL1
1021-         +LABL1   78.     .7+5    200.    5.88+4  400.    4.9+4   1000.   3.15+4  +LABL2
1022-         +LABL2   ENDT
1023-         TEMP     1       313     375.    1513    375.
1024-         TEMP     1       314     375.    416     375.
1025-         TEMP     1       315     375.    527     375.
1026-         TEMP     1       316     375.    627     375.
1027-         TEMP     1       317     375.    727     375.
1028-         TEMP     1       318     375.    827     375.
1029-         TEMP     1       319     375.    927     375.
1030-         TEMP     1       320     375.    1027    375.
1031-         TEMP     1       321     375.    1127    375.
1032-         TEMP     1       322     375.    1227    375.
1033-         TEMP     1       323     375.    1327    375.
1034-         TEMP     1       324     375.    1427    375.
1035-         TEMP     1       325     375.    1527    375.
1036-         TEMP     1       413     375.    1512    375.
1037-         TEMP     1       513     375.    1511    375.
1038-         TEMP     1       515     650.    1715    650.
1039-         TEMP     1       516     650.    1716    650.
1040-         TEMP     1       517     650.    1717    650.
1041-         TEMP     1       518     650.    1718    650.
1042-         TEMP     1       519     650.    1719    650.
1043-         TEMP     1       520     650.    1720    650.
1044-         TEMP     1       521     650.    1721    650.
1045-         TEMP     1       522     650.    1722    650.
1046-         TEMP     1       523     650.    1723    650.
1047-         TEMP     1       524     650.    1724    650.
1048-         TEMP     1       525     650.    1725    650.
1049-         TEMP     1       526     650.    514     650.
1050-         TEMP     1       613     375.    1510    375.
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                                        S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT                .  1  ..  2  ..  3  ..  4  ..  5  ..  6  ..  7  ..  8  ..  9  ..  10  .
1051-        TEMP    1       626     650.    614     650.
1052-        TEMP    1       713     375.    1509    375.
1053-        TEMP    1       726     650.    714     650.
1054-        TEMP    1       813     375.    1508    375.
1055-        TEMP    1       826     650.    814     650.
1056-        TEMP    1       913     375.    1507    375.
1057-        TEMP    1       926     650.    914     650.
1058-        TEMP    1       1013    375.    1506    375.
1059-        TEMP    1       1026    650.    1014    650.
1060-        TEMP    1       1113    375.    1505    375.
1061-        TEMP    1       1126    650.    1114    650.
1062-        TEMP    1       1213    375.    1504    375.
1063-        TEMP    1       1226    650.    1214    650.
1064-        TEMP    1       1313    375.    1503    375.
1065-        TEMP    1       1326    650.    1314    650.
1066-        TEMP    1       1413    375.    1502    375.
1067-        TEMP    1       1426    650.    1414    650.
1068-        TEMP    1       1526    650.    1514    650.
1069-        TEMP    1       1626    650.    1614    650.
1070-        TEMP    1       1726    650.    1714    650.
1071-        TEMP    2       313     1066.   1513    1066.
1072-        TEMP    2       314     1066.   416     1066.
1073-        TEMP    2       315     1066.   527     1066.
1074-        TEMP    2       316     1066.   627     1066.
1075-        TEMP    2       317     1066.   727     1066.
1076-        TEMP    2       318     1066.   827     1066.
1077-        TEMP    2       319     1066.   927     1066.
1078-        TEMP    2       320     1066.   1027    1066.
1079-        TEMP    2       321     1066.   1127    1066.
1080-        TEMP    2       322     1066.   1227    1066.
1081-        TEMP    2       323     1066.   1327    1066.
1082-        TEMP    2       324     1066.   1427    1066.
1083-        TEMP    2       325     1066.   1527    1066.
1084-        TEMP    2       413     1066.   1512    1066.
1085-        TEMP    2       513     1066.   1511    1066.
1086-        TEMP    2       515     1900.   1715    1900.
1087-        TEMP    2       516     1900.   1716    1900.
1088-        TEMP    2       517     1900.   1717    1900.
1089-        TEMP    2       518     1900.   1718    1900.
1090-        TEMP    2       519     1900.   1719    1900.
1091-        TEMP    2       520     1900.   1720    1900.
1092-        TEMP    2       521     1900.   1721    1900.
1093-        TEMP    2       522     1900.   1722    1900.
1094-        TEMP    2       523     1900.   1723    1900.
1095-        TEMP    2       524     1900.   1724    1900.
1096-        TEMP    2       525     1900.   1725    1900.
1097-        TEMP    2       526     1900.   514     1900.
1098-        TEMP    2       613     1066.   1510    1066.
1099-        TEMP    2       626     1900.   614     1900.
1100-        TEMP    2       713     1066.   1509    1066.
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                                          S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT          .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
1101-          TEMP    2       726     1900.   714     1900.
1102-          TEMP    2       813     1066.   1508    1066.
1103-          TEMP    2       826     1900.   814     1900.
1104-          TEMP    2       913     1066.   1507    1066.
1105-          TEMP    2       926     1900.   914     1900.
1106-          TEMP    2       1013    1066.   1506    1066.
1107-          TEMP    2       1026    1900.   1014    1900.
1108-          TEMP    2       1113    1066.   1505    1066.
1109-          TEMP    2       1126    1900.   1114    1900.
1110-          TEMP    2       1213    1066.   1504    1066.
1111-          TEMP    2       1226    1900.   1214    1900.
1112-          TEMP    2       1313    1066.   1503    1066.
1113-          TEMP    2       1326    1900.   1314    1900.
1114-          TEMP    2       1413    1066.   1502    1066.
1115-          TEMP    2       1426    1900.   1414    1900.
1116-          TEMP    2       1526    1900.   1514    1900.
1117-          TEMP    2       1626    1900.   1614    1900.
1118-          TEMP    2       1726    1900.   1714    1900.
1119-          TEMPD   1       100.
1120-          TEMPD   2       208.
1121-          TEMPP1  1       100     100.    0.      100.    100.                            +TT1
1122-          +TT1    101     THRU    111     1200    THRU    1211                            +TT2
1123-          +TT2    200     300     400     500     600     700                             +TT3
1124-          +TT3    800     900     1000    1100    211     311                             +TT4
1125-          +TT4    411     511     611     711     811     911                             +TT5
1126-          +TT5    1011    1111
1127-          TEMPP1  1       201     100.    0.      100.    100.                            +TT10
1128-          +TT10   202     THRU    210     1101    THRU    1110                            +TT20
1129-          +TT20   301     401     501     601     701     801                             +TT30
1130-          +TT30   901     1001    310     410     510     610                             +TT40
1131-          +TT40   710     810     910     1010
1132-          TEMPP1  1       302     100.    0.      100.    100.                            +TT100
1133-          +TT100  303     THRU    309     702     THRU    709                             +TT200
1134-          +TT200  402     THRU    409     802     THRU    809                             +TT300
1135-          +TT300  502     THRU    509     902     THRU    909                             +TT400
1136-          +TT400  602     THRU    609     1002    THRU    1009
1137-          TEMPP1  1       515     625.    175.4   600.    650.                            +T1
1138-          +T1     516     THRU    526     615     THRU    626                             +T2
1139-          +T2     715     THRU    726     815     THRU    826                             +T3
1140-          +T3     1015    THRU    1026    1115    THRU    1126                            +T4
1141-          +T4     1215    THRU    1226    1315    THRU    1326                            +T5
1142-          +T5     1415    THRU    1426    1515    THRU    1526                            +T6
1143-          +T6     1615    THRU    1626    915     THRU    926
1144-          TEMPP1  2       100     220.    136.4   208.    232.                            +WT1
1145-          +WT1    101     THRU    111     1200    THRU    1211                            +WT2
1146-          +WT2    200     300     400     500     600     700                             +WT3
1147-          +WT3    800     900     1000    1100    211     311                             +WT4
1148-          +WT4    411     511     611     711     811     911                             +WT5
1149-          +WT5    1011    1111
1150-          TEMPP1  2       201     220.    137.5   203.    232.                            +WT10
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                                             S O R T E D   B U L K   D A T A   E C H O
CARD
COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10
1151-        +WT10   202     THRU    210     1101    THRU    1110                    +WT20
1152-        +WT20   301     401     501     601     701     801                     +WT30
1153-        +WT30   901     1001    310     410     510     610                     +WT40
1154-        +WT40   710     810     910     1010
1155-        TEMPP1  2       302     220.    138.7   208.    232.                    +WT100
1156-        +WT100  303     THRU    309     702     THRU    709                     +WT200
1157-        +WT200  402     THRU    409     802     THRU    809                     +WT300
1158-        +WT300  502     THRU    509     902     THRU    909                     +WT400
1159-        +WT400  602     THRU    609     1002    THRU    1009
1160-        TEMPP1  2       515     1884.5  108.8   1869.   1900.                   +W1
1161-        +W1     516     THRU    526     615     THRU    626                     +W2
1162-        +W2     715     THRU    726     815     THRU    826                     +W3
1163-        +W3     1015    THRU    1026    1115    THRU    1126                    +W4
1164-        +W4     1215    THRU    1226    1315    THRU    1326                    +W5
1165-        +W5     1415    THRU    1426    1515    THRU    1526                    +W6
1166-        +W6     1615    THRU    1626    915     THRU    926
             ENDDATA

       TOTAL COUNT=  1167
```

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W. Blair, J. E. Meaney, and H. A. Rosenthal

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Langley Technical Monitor: John Shideler
Interim Report

16. Abstract

High temperature materials were surveyed, and Inconel 617 and titanium were selected for application to a honeycomb TPS configuration designed to withstand 2000° F. The configuration was analyzed both thermally and structurally. Component and full sized panels were fabricated and tested to obtain data for comparison with analysis. Results verified the panel design. Twenty five panels were delivered to NASA Langley Research Center for additional evaluation.

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