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# RESEARCH AND DEVELOPMENT FOR FABRICATING A SIMULATED TITANIUM ALLOY BASE GORE SEGMENT, LOWER BULKHEAD, FOR THE S-1C FUEL TANK (Final Report, Vol. I)

Prepared under Contract No. NAS 8-20534 by
THE BOEING COMPANY

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

April 1968

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THE BOEING COMPANY
Seattle, Washington

For

Manufacturing Engineering Laboratory

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NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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# 1.0 INTRODUCTION

The objective of this work was to establish design requirements and processes for fabricating an S-IC fuel tank base gore from 8Al-1Mo-1V titanium, thereby establishing the capability for fabricating large titanium aerospace components having reduced weight and increased reliability. In the accomplishment of the work, state-of-the-art advancements were made in producing large titanium plates; titanium-to-titanium diffusion bonding and in the development of a low cost, high temperature ceramic die for titanium forming. Technique improvements were also made in titanium hot flattening, and ultrasonic inspection of diffusion bonded structure.

Highlights of the basic feasibility work accomplished during the conduct of this program are:

1) Processing methods were developed for producing the largest 8Al-1Mo-1V titanium plates made to date (8 feet by 13 feet by 0.50 inch).

2) The titanium base gore design, sized to have an equivalent load carrying ability to the present 2219-T87 aluminum alloy gore, has a calculated weight of 211 pounds. This is a weight reduction of 65 pounds or 23.6 percent. Material costs, assuming a straight-line cost per pound, were kept at one-half the cost of a plate thick enough to provide reinforcement around the fuel line hole by diffusion bonding an 0.50 titanium ring to an 0.50 titanium plate.

3) Time, temperature, and pressure cycles were developed for diffusion bonding titanium to titanium in air, eliminating the need for protective atmospheres. A semi-portable, highly versatile tooling concept was also devised.

4) Hot flattening and stress relief cycles were developed to alleviate stresses and distortion caused by localized heating during diffusion bonding. Correlation of ultrasonic tests with metallographic examination of diffusion bonds provides a basis for development of a reliable production proof-test.

5) A full size, high temperature ceramic die was designed and fabricated and was cycled to 1450°F eight times for a total operating time of 60 hours with no malfunction or indication of degradation.

6) The design, tooling, and fabrication methods were demonstrated by diffusion bonding a ring doubler to a full size 8Al-1Mo-1V titanium plate, then sculpturing this assembly in the flat and "hot" vacuum forming it to contour, all according to a preplanned fabrication sequence.

## 2.0 GORE DESIGN

The contract specified that the contractor establish the design requirements for a titanium (8Al-1Mo-1V) base gore with flared or bolted openings made integrally with the gore. It was further required that the design meet all the requirements for the 2219-T87 aluminum alloy gore segment shown in the S-IC Drawing 60B25206-1 (gore, base, lower head, fuel tank). This particular tank head element has a 6.00-inch diameter port hole with a 0.86-inch thick flange. The structural requirement for the gore was such that 1/2-inch thick material was satisfactory for fabricating the entire gore except in the local area of the port flange.

The configuration of the titanium base gore segments fabricated for this program is defined in Figure 1. The general size and shape configuration is identical with the S-IC base gore part number 60B25206-1. The primary difference is the material change from 2219-T87 Aluminum to 8Al-1Mo-1V Mill Annealed Plate. Minor differences are the finished membrane shell thickness, the rib dimensions, and the number of hoop ribs which was increased from four to six.

The basic plate thickness is 0.500 inch to which a 0.500-inch thick doubler ring is diffusion bonded to provide the required thickness at the 6.00-inch port opening.

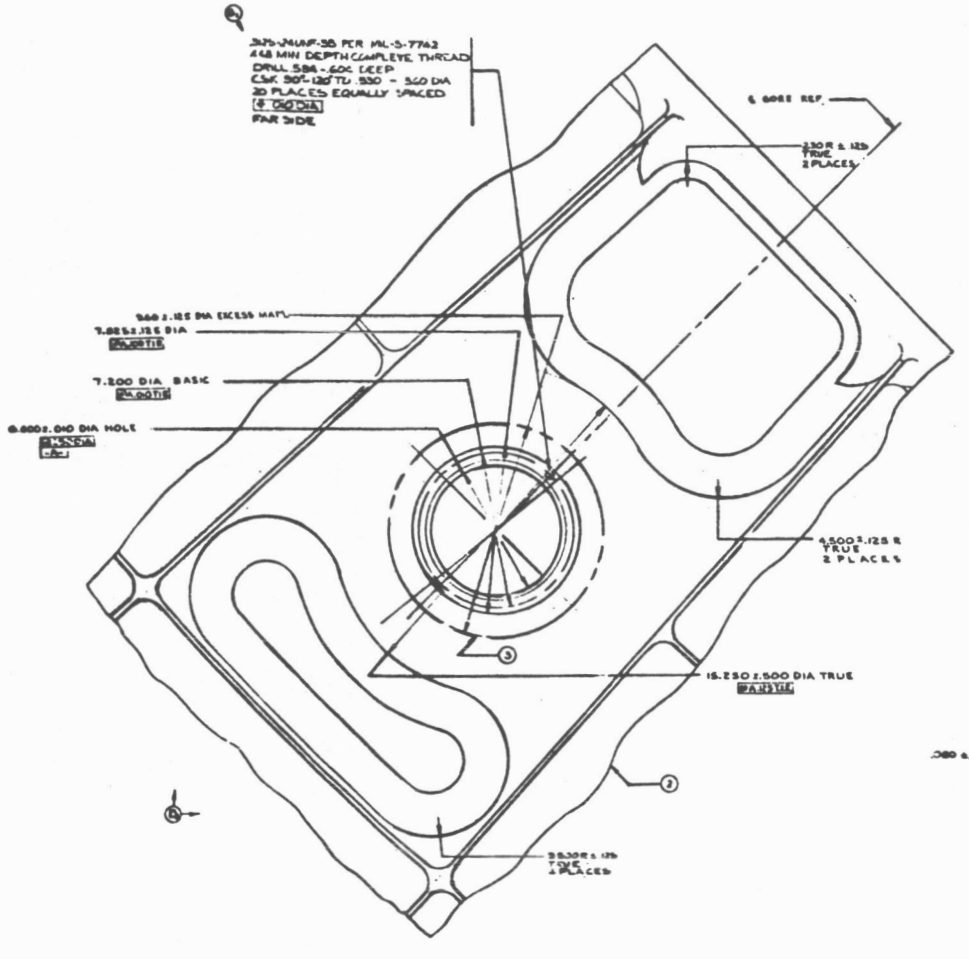
The titanium base gore was sized to have an equivalent load carrying ability to the S-IC base gore.

Four methods were considered for obtaining the thickness required at the port. These were:

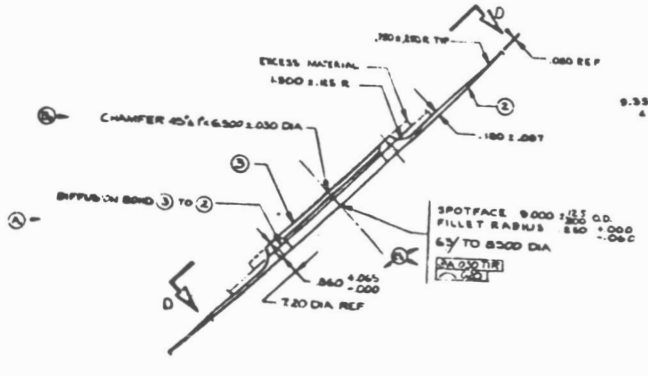
1) Fusion welding
2) Draw and upset
3) Machine from thick plate
4) Diffusion bonding

Fusion welding presented several restraint problems, required extensive weld setting development and was not considered entirely responsive to the request for an integral design with the primary effort directed at producing gores of single unit construction. The attachment of stiffeners by bonding, spot welding, etc., was to be considered only if significant cost or processing advantages could be demonstrated without a decrease in reliability. In addition, obtaining the required thickness locally by fusion welding in a 1-inch thick plate did not appear to have a satisfactory probability of meeting the cost and reliability requirements and was therefore not selected.

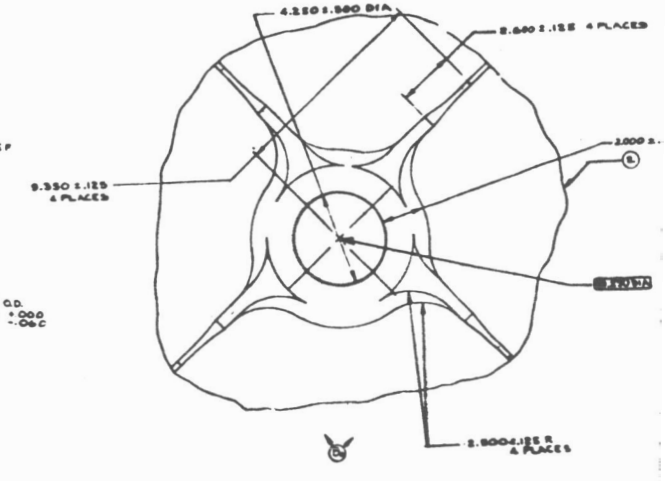
Drawing and upsetting could have been used to obtain the thickened section required as the port opening from a basic sheet of 0.5-inch thickness. Flanges are easily formed at elevated temperatures by drawing. A flange height of 0.2 times the hole diameter, with a 15 percent thinning at the lip edge and a nominal bend radius of 2 times the material thickness can be achieved. Flange thickening can then be obtained by expanding roller operations or draw-reform stages. It was estimated that these latter operations would require too costly a development program to be cost effective.




VIEW D-D
SCALE 1/2

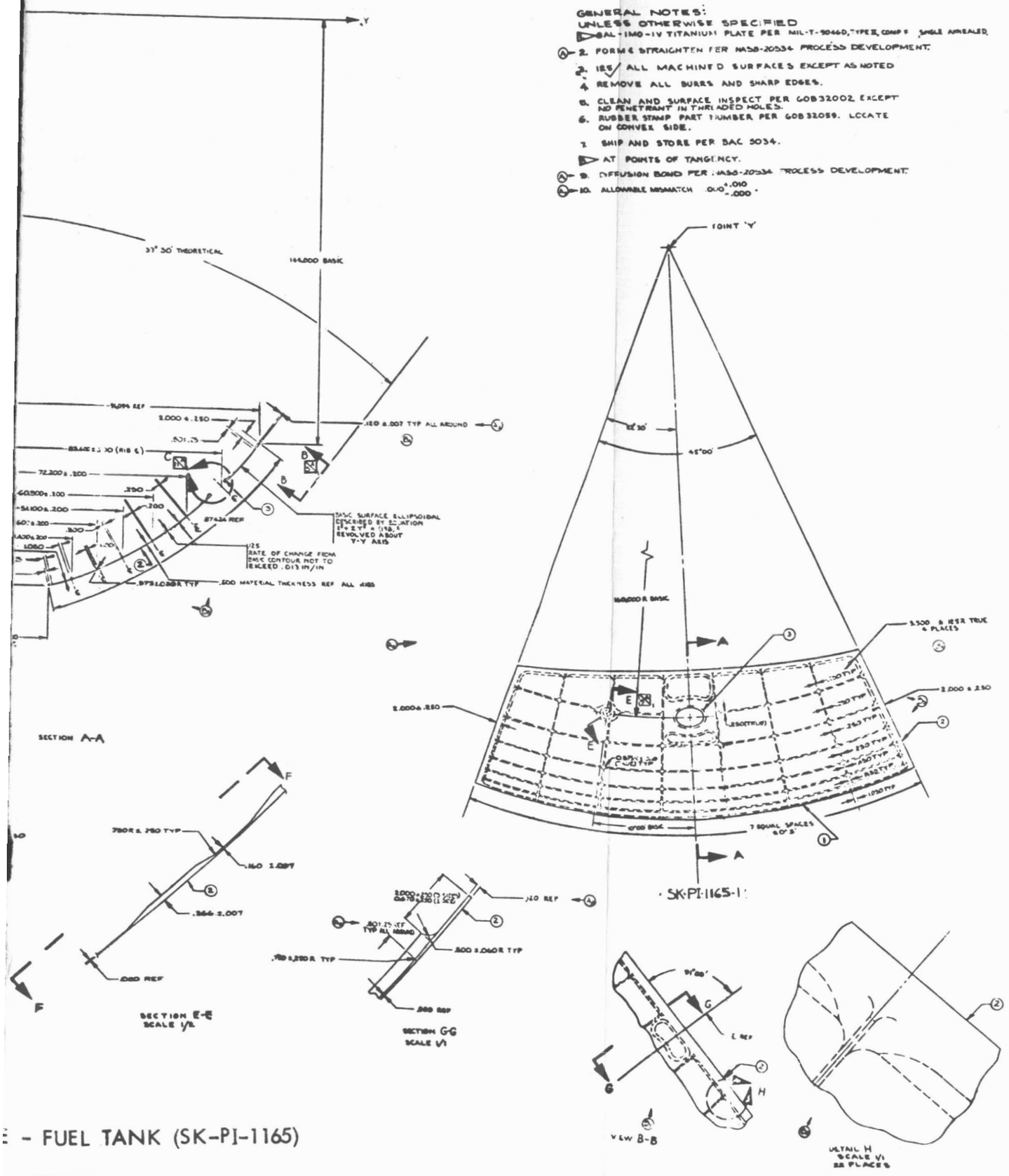



DETAIL C
SCALE 1/2




SECTION F-F
SCALE 1/2

GORE BASE




E - FUEL TANK (SK-PI-1165)

FIGURE 1

Machining the gore from a sufficiently thick plate (approximately 1 inch) would double the material costs. Since titanium is relatively expensive and this approach would also entail additional machining and handling expense it was decided that while the reliability would be excellent the cost would not be competitive with a design which provided the flange thickness required by diffusion bonding on a local doubler.

Since solid state diffusion bonds of high quality had been obtained with titanium alloys and a relatively simple tooling and processing concept had been developed for bonding the ring doubler around an opening of the part, this method was selected for its significant cost effectiveness advantage.

The weight of the titanium gore elements configurated in Figure 1 is 211 pounds. The weight of the existing S-IC aluminum gore element is 276 pounds. The titanium gore weight is 65 pounds less than the aluminum gore. This represents a 23.6 percent weight reduction.

## 3.0 TITANIUM MATERIAL

Purchase of 0.500 inch, 8Al-1Mo-1V alloy titanium in the mill annealed condition, with the following material properties, was planned:

| | |
|---|---|
| Ultimate tensile stress | 145 ksi |
| Yield stress in tension | 135 ksi |
| Compressive stress | 145 ksi |
| Modulus of elasticity | 17 by $10^6$ psi |
| Ultimate shearing stress | 87 ksi |
| Ultimate bearing stress | 223 ksi |
| Elongation | 10% |

Procurement experience with titanium plate indicated that obtaining the material to the thickness tolerance, surface finish and physical properties commonly specified should be no problem. We had on hand samples of this material which were being used in the supersonic development program which satisfied those requirements. Also, two suppliers provided quotations to provide the material to our D6-6051-1 Material Purchase Specifications*. However, rolling large titanium plate in the 8- by 13-foot size represented a significant advancement of the state of the art and the difficulties encountered caused a program schedule delay.

---

* The essential items of this specification are as follows:

Tolerances for Type C material in thickness, length, width, and straightness shall conform to the AMS 2242 standard as given for corrosion resistant steel plate.

Plate 0.500-inch thick must meet Class A material acceptance under ultrasonic inspection as defined in BAC 5439, Section 9.

Minimum tensile properties of mill anneal shall be 145 ksi ultimate, 135 ksi yield, and 10 percent elongation.

Uniform quality is required in terms of clean, sound material free from "oil cans" or ripples of depth in excess of the 4 percent flatness tolerance, foreign material, internal and external imperfections deleterious to fabrication and/or performance.

Surface imperfections such as folds, laminations, "orange peel" pits, cracks, blisters, etc., shall be cause for rejection. The Type C plate requires a surface finish equivalent to a No. 1 finish for commercial corrosion resistant steel sheet.

Chemical composition - in weight percentage: Al 7.35 - 8.35, Mo 0.75 - 1.25, V 0.75 - 1.25, Fe 0.25 max., C 0.08 max., N 0.03 max., H 0.0125 max., O 0.125 max. Other impurities 0.40 max., Ti balance.

Following negotiations with two vendors for the purchase of the three titanium plates, a vendor was selected and approval was received from MSFC. The order was placed with delivery scheduled in January 1966.

The week before the material was to arrive the vendor informed us of a problem in rolling the material at the mill. In satisfying the purchase specification of not allowing the material to be heated above the Beta transus temperature of 1900°F, the material had been rolled at too low a temperature and surface cracks had appeared on the plates when they were still 2-1/2 inches thick. They gave us a choice of either accepting the present material or waiting 3 months for a new run of material. We elected to wait 3 months (with the concurrence of MSFC) since the plates with the cracks would not clean up to the 8- by 13-foot dimension after the cracks were ground out and rolling was continued to the 0.500-inch dimension. The vendor also requested and received approval to roll subsequent material at a higher temperature (1950°F) to preclude cracking.

The three 8-1-1 titanium plates were received at Boeing on May 16, 1966. Prior to shipment the vendor notified us that the material failed to satisfy surface finish, thickness, and properties requirements. To reject this material would mean another three or four months delay in the program, and with this material the major objectives of the program could be met. On this basis permission was requested from MSFC to accept the below specification material. Permission was granted.

The material was tested for properties by the vendor before it was shipped; it received a thorough receiving inspection at Boeing before it was processed in the factory; and Part No. 002 was further tested for mechanical properties after forming.

The properties of the three plates of material, as tested by the vendor, are as follows:

| | Yield Strength | Tensile Strength | % Elongation |
|---|---|---|---|
| Typical | 130,000 | 142,200 | 15.0 |
| Low | 123,100 | 131,500 | 13.5 |
| High | 137,400 | 154,400 | 12.5 |

The properties of the material, as tested by Boeing receiving inspection, are as follows:

| | Yield Strength | Tensile Strength | % Elongation |
|---|---|---|---|
| Typical | 134,000 | 144,400 | 16 |
| Low | 130,000 | 140,000 | 8 |
| High | 142,100 | 155,200 | 13 |

The properties of Part No. 002 after forming are as follows:

| | Yield Strength | Ultimate Strength | % Elongation |
|---|---|---|---|
| Typical | 134,000 | 143,000 | 16 |
| Low | 133,700 | 140,600 | 15 |
| High | 134,900 | 145,600 | 11 |

The Boeing specified properties (D6-6051-1) were 135,000 psi yield strength, 145,000 psi ultimate strength, and 10 percent elongation. The above data would indicate that the 8-1-1 titanium plate received was from 10- to 20-percent low on strength properties and the elongation was satisfactory. It also shows that elevated temperature forming had no discernible effect on the properties of the material.

Visual, dimensional, chemical, metallurgical and ultrasonic inspection of the as-received plate was also performed. This inspection revealed many surface finish, surface waviness, thickness, and other discrepancies in the material.

Excerpts from the Receiving and Inspection Report follows:

a. "6 of 8 specimens examined have multiple pits and gouges on the exterior surfaces of the material. This condition is unacceptable per D6-6051-1 paragraph 5.4.

   NOTE: No evidence of oxygen contamination, overheating, segregation or other harmful conditions were found.

b. "Sheet No. 001 had 3 areas exceeding the multiple indication criteria of BAC 5439, Class A (ultrasonic inspection). Area "A" contained 3 indications within a circle of 1-inch diameter, these indications were all at a depth of approximately 1/4-inch, all three were approximately equal in size to a 3/65-inch FBH at 1/4-inch in the standard. Area "B" contained 1 indication at approximately 5/16-inch depth exceeding the 3/64-inch FBH response and 5 separate indications slightly less than 3/64-inch FBH response at approximately 1/8-inch depth with a 5-inch diameter circle.

c. "Sheet No. 003 contained 5 areas with flaws exceeding the specified level. Area "A" contained 4 flaws approximately equal to 3/64-inch FBH response at 1/4-inch depth within a circle 5-inch in diameter. Area "B" contained 3 indications exceeding 3/64-inch FBH response at 1/4-inch depth within a 1-1/2-inch diameter circle.

d. "Sheet No. 003. Flatness requirement exceeded. Strut had 0.25-inch deep crease in the material across the 8-foot width, approximately 2.5-feet from end.

e. "Material thickness varies from 0.500 to 0.700.

f. "One sheet 3 inches undersize. Material is 0.50 by 96 by 153 inches. Should be 0.50 by 96 by 156 inches."

The original plan was to purchase 0.500-inch thick material to a tolerance of 10 percent and machine only one side, thus saving the cost of extra thickness of titanium and the cost of machining the outside surface of the material. This plan was followed even though the material received was as much as 0.200-inch over thickness tolerance, out of flatness as much as 0.250-inch in a 1-1/2-foot span, and unsatisfactory in surface finish due to surface pits and gouges. These

discrepancies had no measurable effect on the success or failure of the program as an exercise in diffusion bonding and "Hot" vacuum forming process development; but they did have a significant effect on the cost of the program and the surface finish and thickness quality of the titanium gore delivered to MSFC.

## 3.1 CONCLUSIONS

The original intent of this program was to fabricate three gores; deliver two to MSFC; and, cut the third one up for material properties evaluation. Due to a program redirection, only one gore was completed and the one to be destructively tested was not completed. Therefore, the only material properties information available for evaluation is the data obtained from six specimens cut out of the part excess after forming. This data shows the material, after forming to have tensile strength, yield strength, and elongation no different than that of the as-received material.

When titanium is exposed to elevated temperature for a period of time in a hydrogen-oxygen atmosphere, degradation of properties has been reported. This phenomena should be studied relative to the "Hot" vacuum forming process; since a requirement for an inert gas atmosphere would make the process more complicated and most costly. Protective coating was used in this program to preclude degradation of properties.

The present limited data indicates suitable material properties but, before this material is production ready for this application, it is recommended that more data be obtained.

## 4.0 TOOLING

A number of tools had to be fabricated to manufacture a full size titanium gore: a diffusion bonding tool, to bond the ring to the plate material; a hot flattening tool, to remove plate distortion before machining; a vacuum chuck, to hold the plate in place for machining; a hot vacuum forming tool, for forming the part; and a trimming fixture, to hold the part for final trimming. This tooling was built as simple as possible to meet requirements. Only the diffusion bonding tool and the hot forming tool were complicated enough to require formal designs. The design drawings are appended to the report.

### 4.1 DIFFUSION BONDING TOOL

Design of the diffusion bonding tool was relatively simple and presented no problems or unusual techniques for fabrication. The basic component of the tool was the 85,000-pound capacity hydraulic cylinder which was modified only by extending the piston rod 20 inches with a 2-1/2-inch diameter A-7 steel extension. The cylinder was mounted vertically on a triangular steel base plate, with the piston rod extending upward. Three screw jacks were attached to the base plate at its apexes for leveling and vertical adjustment. Figure 2 is a schematic of the diffusion bonding tool.

Hollow cylindrical anvil blocks and the pressure cap were rough bored and turned from 10-inch diameter ASTM A-7 steel bar stock. The pressure susceptor ring was machined from "Inconel X750" nickel-chromium plate, one-inch thick. After machining, the ring was heat treated to achieve maximum creep strength at elevated temperature.

Insulator rings of "Molten Metal Maranite," a dense asbestos-mineral fiber composite, were band-sawed from one-inch thick sheet.

Construction of the induction heating coil followed standard techniques. Copper tubing, 3/8-inch diameter, was insulated with glass fiber sleeving, then wound around a 10-inch diameter mandrel to form a helical coil.

Additional turns were added in a flat spiral, in the plane of the last turn of the helix, to a diameter of approximately 11 inches. The coil was subsequently attached to a form machined from Maranite to stabilize it and maintain its configuration.

The tool functioned as anticipated throughout the entire program, with only minor difficulties occurring during final stages of its use. On bonding the first full size gore segment, threads on the shaft extension seized and galled severely during disassembly of the tool after bonding. Attempts to repair were unsatisfactory and a new rod extension was fabricated. During application of pressure for bonding the final gore segment, O-ring seals in the hydraulic cylinder failed, necessitating disassembly and overhaul of the cylinder.

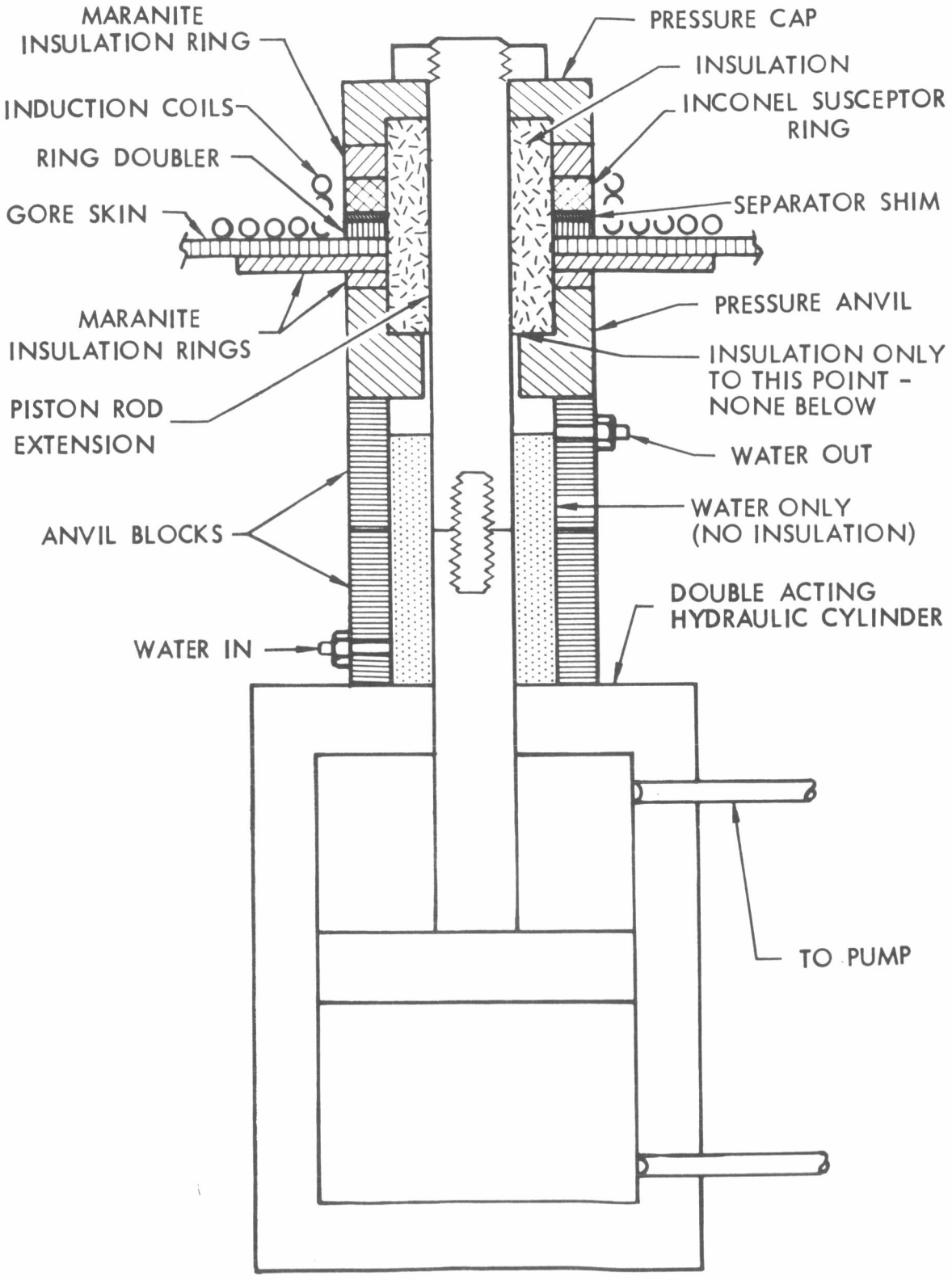



FIGURE 2

DIFFUSION BONDING - SCHEMATIC TOOLING DIAGRAM

## 4.2 HOT FLATTENING TOOL

Tools are required to hold the titanium plates for distortion removal during the hot flattening cycle (1200°F for 2 hours). These are 3-inch thick mild steel plates which support the part for the heat cycle and support extra weight which is placed on top of the tool to force the part into a flat plane.

Subsequent to the diffusion bonding operations, hot flattening is required to make the titanium assemblies flat enough to machine on a vacuum chuck.

To obtain the mild steel plates large enough to sandwich the titanium plate, it was necessary to weld two plates together to make one flattening plate. The final size of the two flattening plates is 3 by 108 by 200 inches. The weight of each is approximately 15,000 pounds. One side of each plate was machined to a tolerance of ±0.020-inch with a 125 RMS finish. Additional weight of 20,000 pounds or more is usually placed on top of the sandwich before the hot flattening operation. This additional weight provides greater flattening capability. One mild steel plate had a hole cut in it to accommodate the ring which was diffusion bonded to one side of the titanium plate. See Figure 3 for illustration of lower flattening plate located on car of furnace.

## 4.3 VACUUM CHUCK

An aluminum vacuum chuck is required to hold the titanium plate on the machine during the machining operation. A vacuum chuck approximately 4 by 7 feet was available, and another chuck of the same size was fabricated to give a total vacuum chuck size capacity of 4 by 14 feet. The machining operation was accomplished in two steps, the lower half of the part was machined first and then the plate was repositioned for machining the upper half.

## 4.4 HOT VACUUM FORMING TOOL

The titanium material must be heated to elevated temperature where it exhibits low yield strength and then forced to conform to the die contour without wrinkles or tears being generated in the material. The basic criteria for the tool was: uniform heating to 1450°F +75/-25; 90-minute heat up; vacuum tight die cavity; compatibility with the pressure diaphragm; satisfactory die life; contour tolerance to gore specifications. Subsequent to a design study, it was decided that a heated ceramic vacuum tool would satisfy this criteria.

### 4.4.1 Design - Hot Forming Tool

During the tool design study several factors were investigated before the design was finalized. These included: ceramic face material; ceramic insulation; pressure vessel design; diaphragm material; heating system; and fabrication concept. Each of these is briefly discussed below.

#### 4.4.1.1 Ceramic Face Material

A Glasrock castable face was chosen for this tool because of the comparative ease with which the elliptical contour could be swept in without any requirement for machining. It is an electrical insulator which allows the heating elements to be imbedded close to the working face, and is porous so a vacuum can be pulled

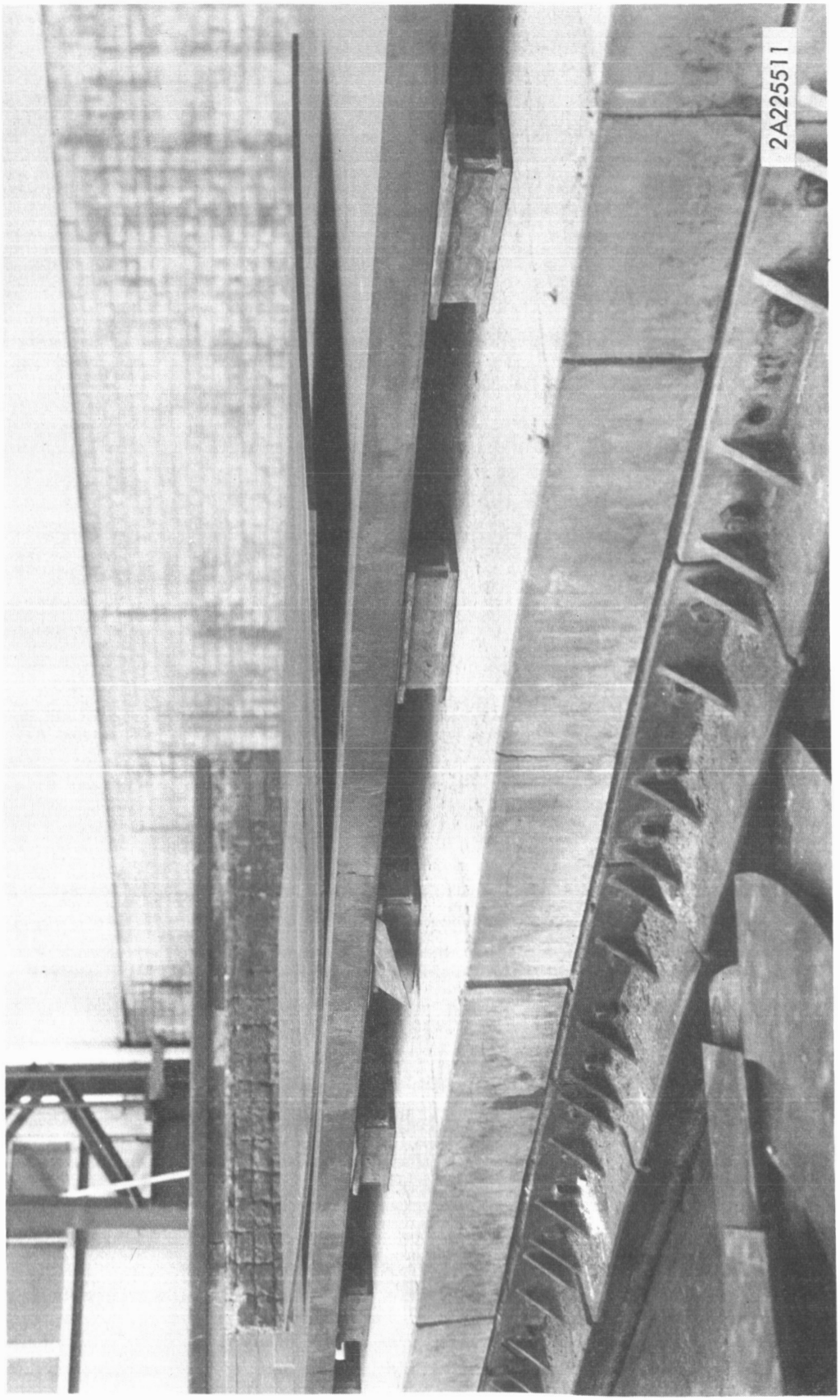



FIGURE 3

4 FT. BY 10 FT. DIFFUSION BONDED TITANIUM PANEL ON FLATTENING PLATE, BEFORE HOT FLATTENING

over the entire surface. It is immune to thermal shock; is chemically resistant and is dimensionally stable through the required range of temperatures.

4.4.1.2 Ceramic Insulation

Pre-cast Glasrock foam block (50 lb. per sq. ft.) was used for insulation directly under the Glasrock face because of its compatibility with the facing material and its insulating qualities. An underlayment of 4-1/2-inch thick block was used to ensure temperature uniformity across the face of the die. Low-cost commercial firebrick (S-20) was used to fill the balance of the die cavity.

4.4.1.3 Pressure Vessel

The steel container for the die is a pressure vessel which must withstand a force on the bottom of over 165 tons since it is 11 feet by 15 feet in the working area with a nominal vacuum of 26 inches of mercury. The size of the vessel was determined by the part blank size of 8 feet by 13 feet plus 6 inches of heated area outside the part, plus a minimum of 9 inches of insulation between the heated area and the steel structure on all sides and the bottom. To reduce flowtime and costs, a reinforced concrete base with a steel face was used with 1-inch gusseted side walls making up the rest of the vessel. This construction allowed an ample safety factor and eliminated any deflections which would damage the ceramic or heating facilities within the die. A 1-inch thick by 10-inch wide steel flange was welded completely around the top of the vessel for structural strength and to allow an area for clamping the vacuum diaphragm.

4.4.1.4 Diaphragm

A 0.020-inch thick stainless steel diaphragm proved satisfactory for tool tryout and qualification. See Figure 4. However, there were some problems with it. A single diaphragm is welded in 6 places to cover the die, this means weld reliability will effect diaphragm performance. Also, to keep from tearing the diaphragm during forming it had to be "gathered" into the die area before being sealed. To "gather" the material three men must walk on the diaphragm to force it into the die prior to clamping and sealing it around the edges of the die for application of vacuum. Because of these problems, an effort was made to find a substitute material for stainless steel in this application. Nylon was found to be more economical and easier to use.

The nylon diaphragm was excellent as a pressure application material. See Figure 5 for example of usage. This is a single sheet of 0.005-inch thick nylon which will withstand 400°F. It performed very well when used above 1/2-inch of Kaowool and 5 to 6 inches of Vermiculite insulation, over a 1450°F titanium part. Also, it was easily sealed around the edge of the die with tape; and hot spots in the diaphragm which resulted in holes were readily repaired with tape. Nylon is now the vacuum diaphragm material prescribed for hot vacuum forming.

4.4.1.5 Heating System

Inconel 600 tubing was chosen for the heating elements because of the excellent performance which they displayed in previous ceramic die applications. Power requirements were calculated, then tube length and spacing was determined. Due to the poor conductivity of the ceramic castable die face, the tubes were placed very near the surface (1/2-inch below).

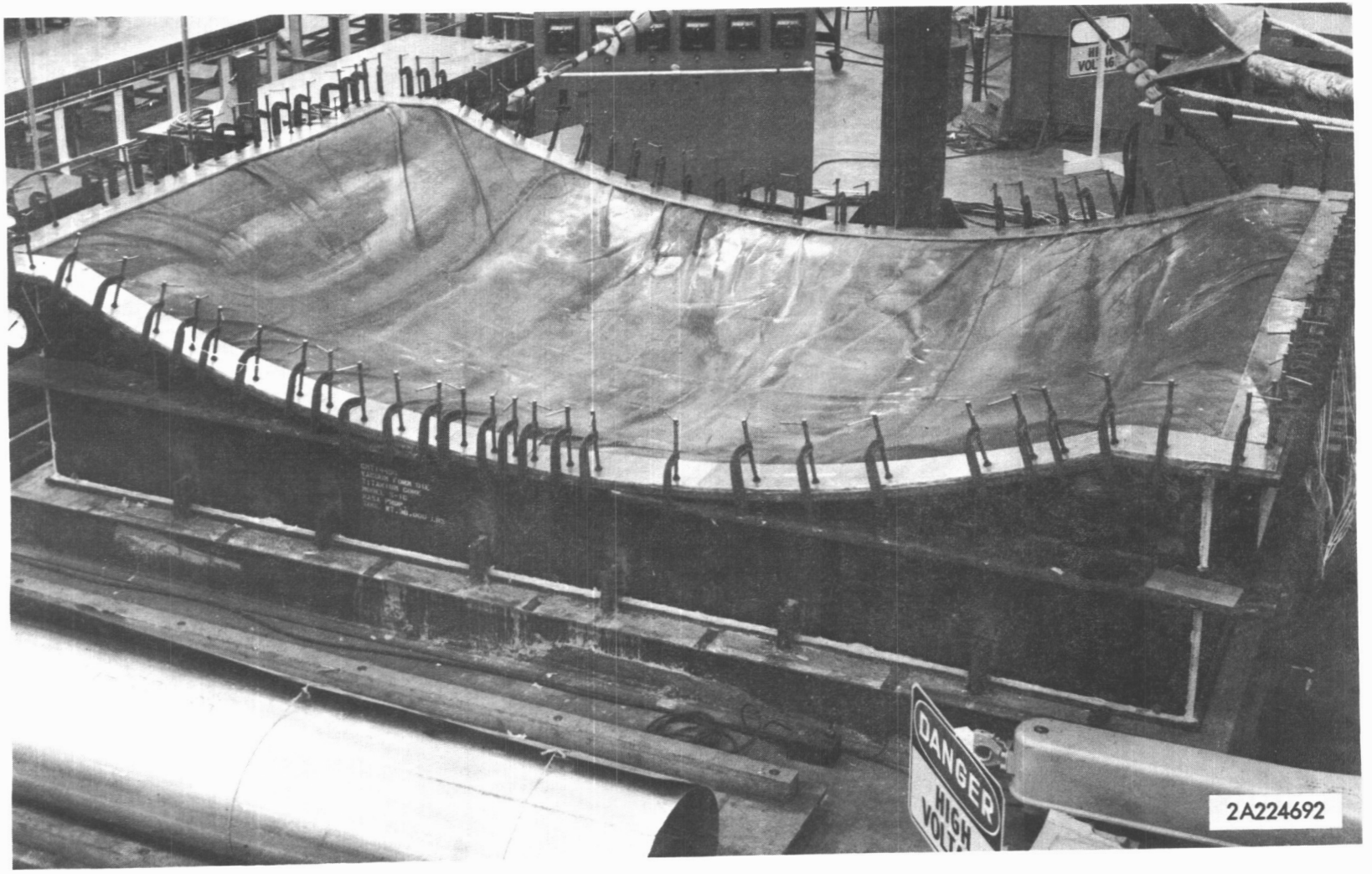



FIGURE 4

HOT VACUUM FORMING DIE - TOOL TRYOUT
(STAINLESS STEEL DIAPHRAGM)

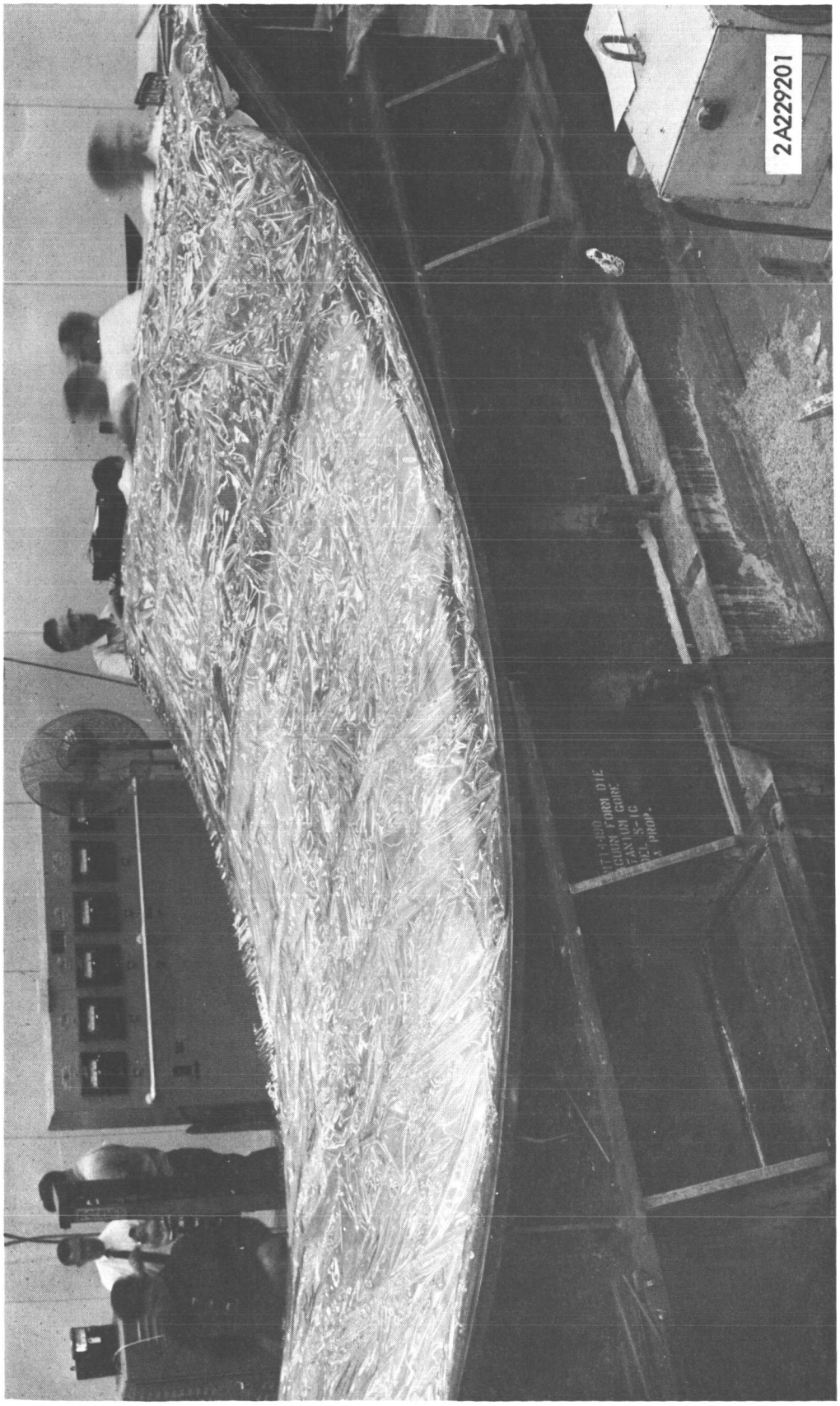



FIGURE 5
HOT VACUUM FORMING DIE
(5 MIL NYLON DIAPHRAGM)

The heating elements were arranged to enable operators to separately control the heat release in 16 separate zones. Three 75-KW power control packages were used to supply the 180 KW needed for 90 minute heat up.

Each control zone contained three thermocouples, one for control and two for recording purposes. Proportional band temperature controllers were used to gain continuous, reliable heating control.

4.4.1.6 Building Concept

The normal fabrication sequence for a ceramic die would be to cast the die face to a master model, install the heating elements, insulation, and back up structure, then turn the whole die over into its normal position. Due to the weight (approximately 30 tons) and the size (11- by 15-feet) the practicability of fabricating this die in the normal manner was not feasible so a different method was used. Tests had been completed using a screed or wiping tool to generate the finished die surface which were successful, so the decision was made to use this method and make the die in its normal position.

The tool was made by filling the vacuum chamber with firebrick, laying up the Glasrock blocks and heating elements, and then establishing the die surface by wiping it in with a cross section template rotated on the loci of the ellipse.

The hot vacuum forming tool was designed to the above criteria and a schematic is shown in Figure 6. The design of the tool is included in the Appendix as Drawing No. GMT 14490.

4.4.2 Fabrication - Hot Forming Tool

Fabrication of the vacuum forming tool is detailed below. The screed tool (EMIT 12R17260), used to facilitate fabrication of the form tool, is shown in Figure 7 and the design is included in the Appendix. (See Figure 8 for a graphic illustration of the fabrication steps required to build the form tool).

4.4.2.1 The concrete base was cast on the factory floor. It contained sufficient steel for reinforcement and for attachment to the steel box.

4.4.2.2 The steel box was welded together and was attached to the cement base by welding.

4.4.2.3 In adding the internal structure to the steel box, the screed tool was very helpful in maintaining control of the contour and buildup of each layer of material. The screed tool could be swung to any location for checking. The fabrication sequence of the internal structure of the steel box was as follows:

1) Conventional firebrick was cemented in place to within 6 inches of the final contour. The last layer of brick was band sawed when required to obtain the general gore configuration. Figure 9 shows laying of the firebrick and use of the screed tool for checking brick placement.

2) The firebrick surface was covered with a castable cement and screeded to contour with the screed tool. Figure 10 shows the screed tool being used to check the contour of the first Glasrock blocks placed on the castable cement which was screeded to contour by the screed tool.

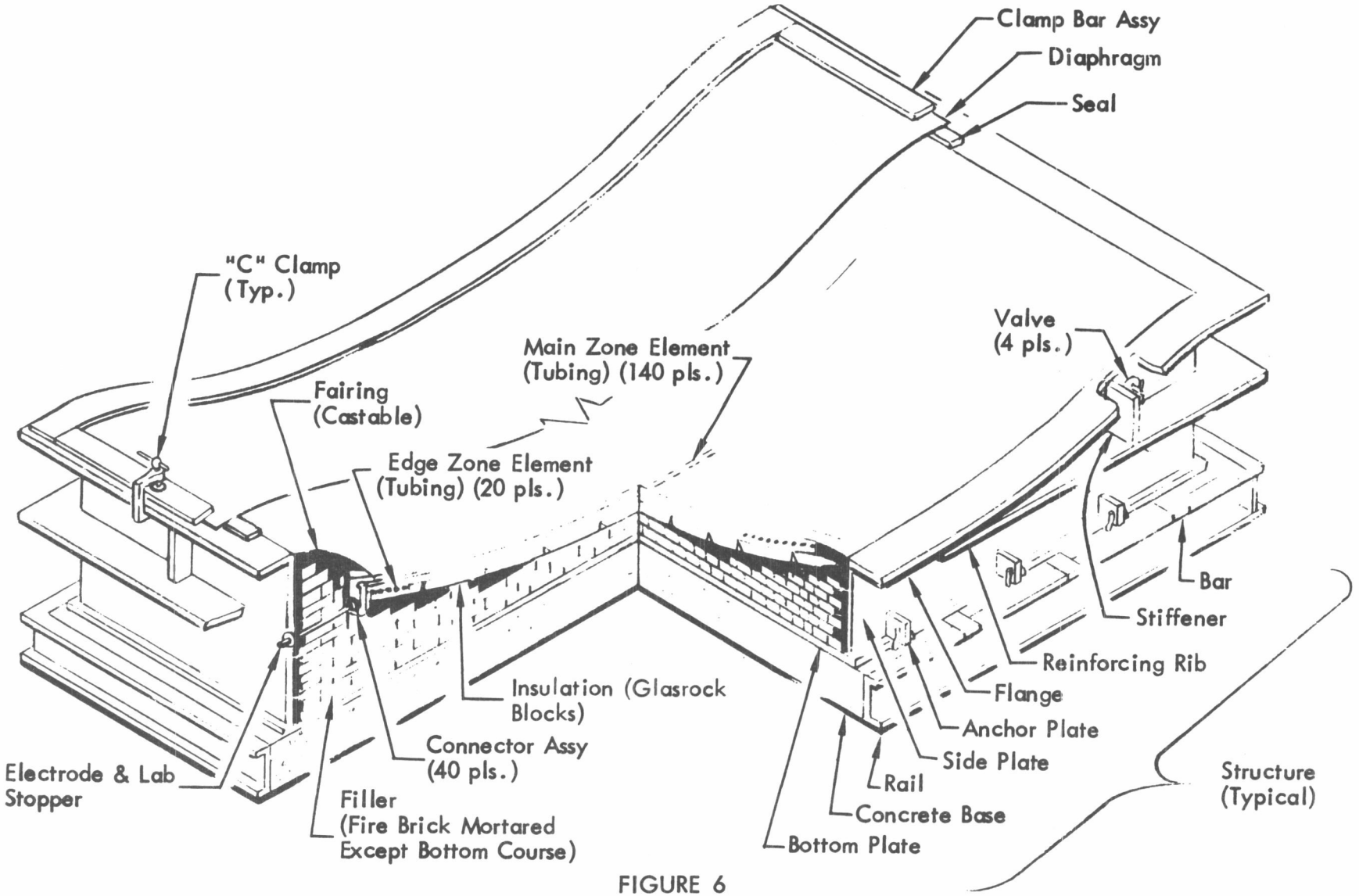



FIGURE 6

VACUUM FORM DIE FOR TITANIUM GORE

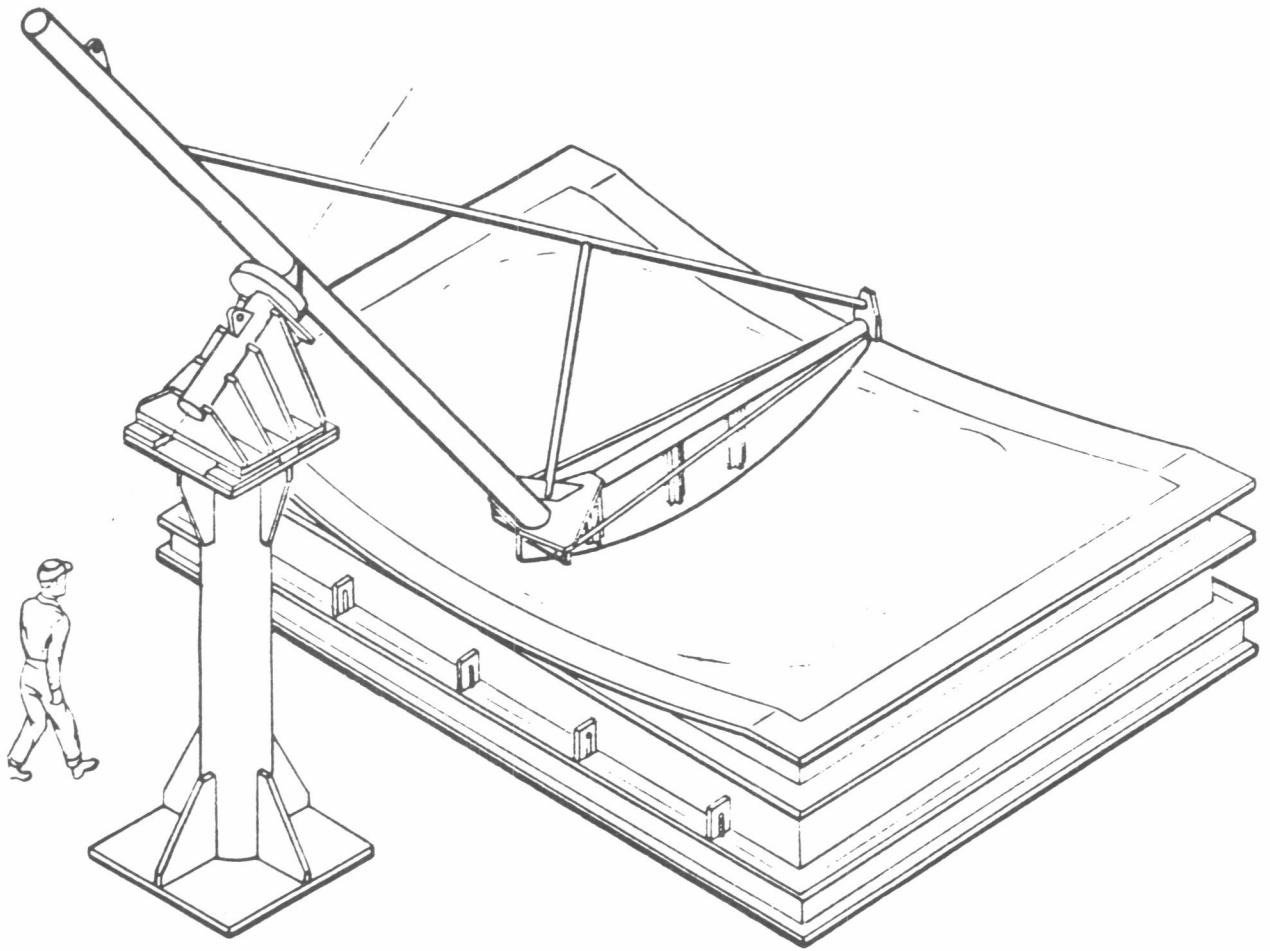
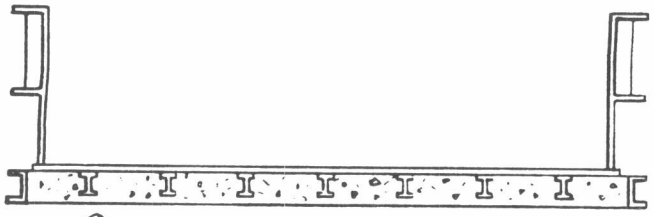
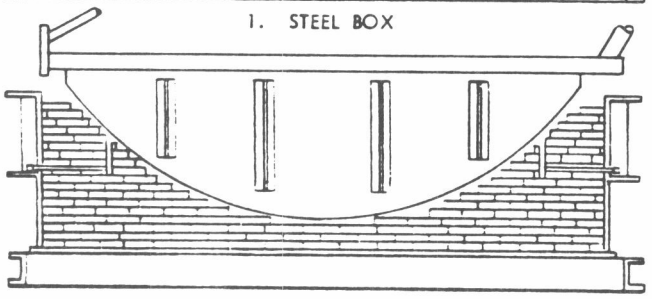


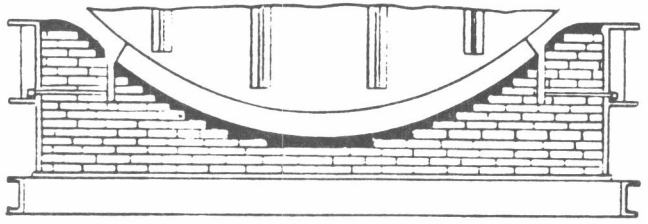
FIGURE 7
SCREED TOOL AND ITS RELATIONSHIP TO VACU-FORM TOOL



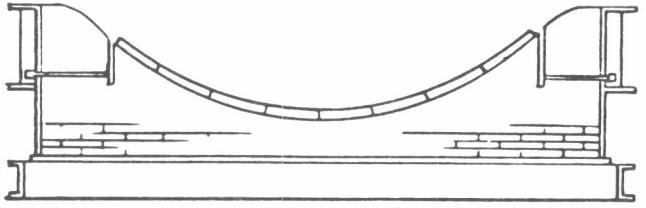
1. STEEL BOX



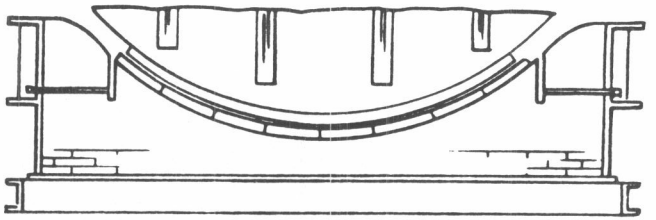
2. ROUGH BLOCK BACK-UP



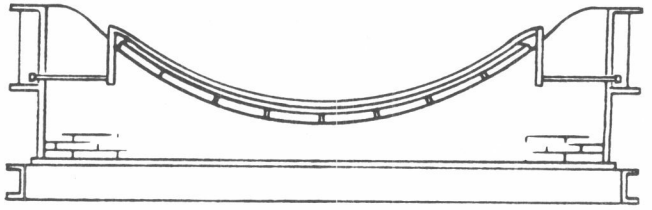
3. ROUGH SWEEP CERAMIC SUB-SURFACE



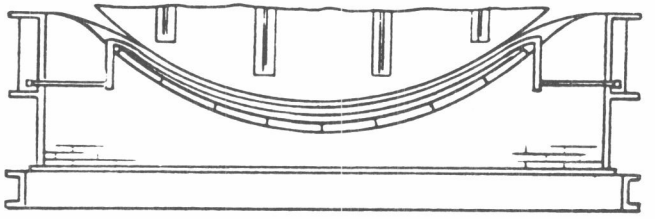
4. INSULATION (GLASS BLOCKS)



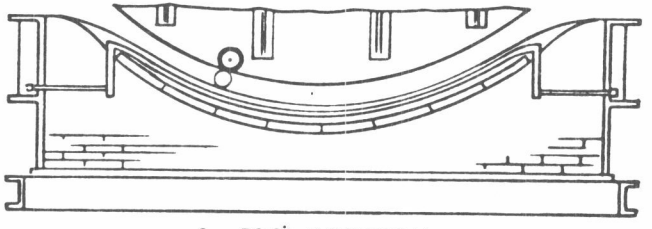
5. ROUGH CERAMIC COAT



6. TUBE INSTALLATION



7. FINAL CERAMIC COAT



8. TOOL INSPECTION

**FIGURE 8**
**FABRICATION SEQUENCE**

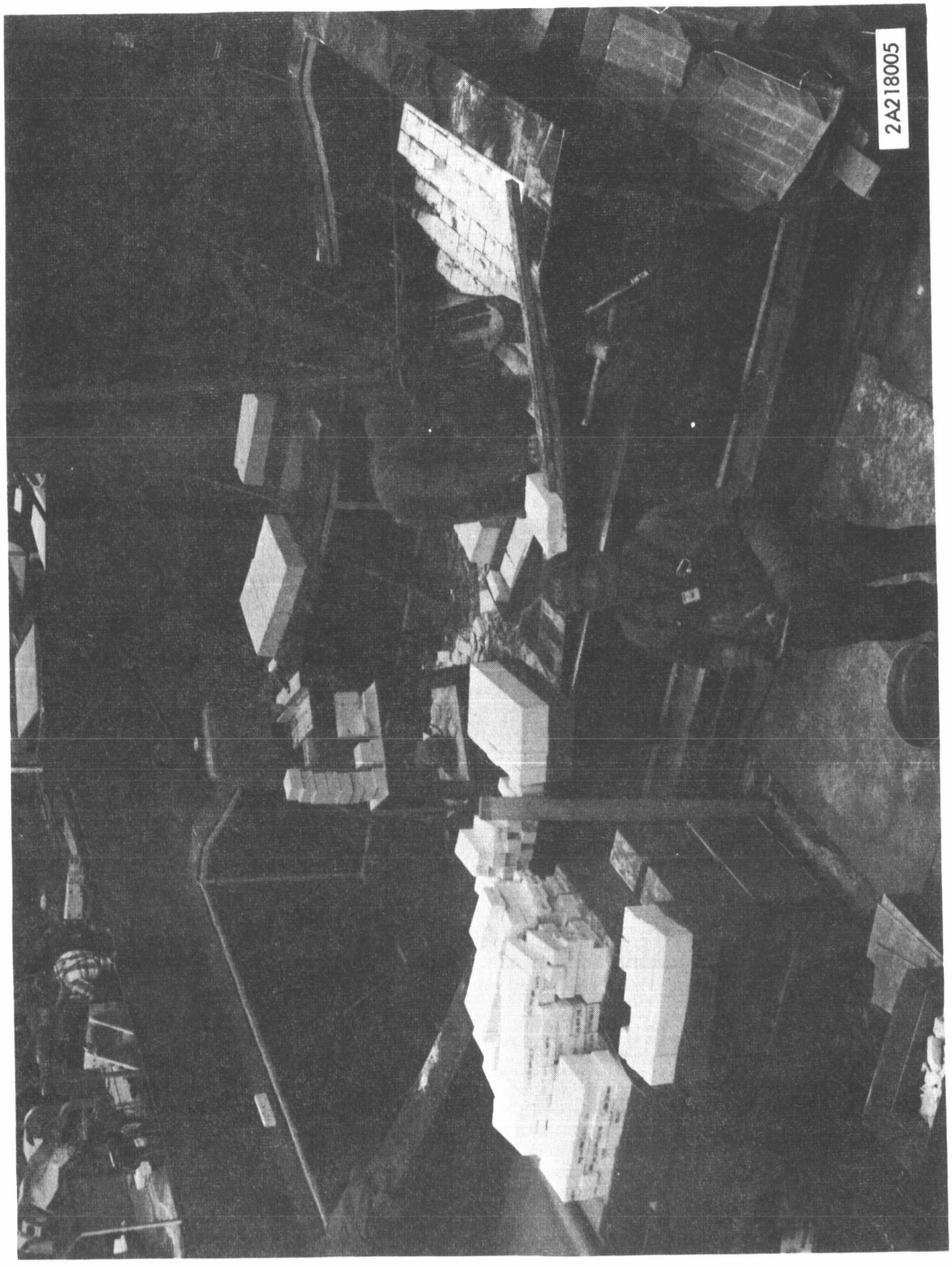



FIGURE 9
VACU-FORM TOOL - FIRE BRICK INSTALLATION

3) The Glasrock blocks (50-pound density, 4-1/2 by 18 by 18 inches) were cemented to the castable cement surfaces. See Figure 10.

4) Then wax* covered end edge heater tubes were cemented in place at either end of the tool. Figure 11 shows one end of the die, and the location of the 10 edge heater tubes. Both ends are the same and the end heaters are below the main heaters.

5) A 1/2-inch layer of Glasrock cement was screeded over the Glasrock blocks with the use of the screed tool.

6) Wax* covered tubes (140) were located in the die at a spacing of 0.75 inch, centerline measurement. Figure 12 shows the main heater tubes tacked in place by cement.

7) The finished surface was made by screeding a 3/8-inch coating of Glasrock cement over the top of the tubular heating elements. Figure 13 shows the heated area of the die with the finished surface. Both ends and sides are still open.

The final surface before heatup was inspected by Quality Control and waviness was found to vary less than 0.010 inch in any 6-inch area. The contour of the die was within ±0.50 inch of nominal and the radius of the die was within ±0.080 inch of nominal.

4.4.2.4 The electrical hookup of the die included the following items:

1) Steel braid, with provisions at each end for welding, was used to connect the tubular heating elements to each other in groups of ten to a zone. Figure 14 shows heating element connections at one end of the die. In turn each zone of 10 heating elements was connected to a bus bar which ran through a hole in the steel box. The bus bar was protected by a rubber insulator where it ran through the steel box.

2) The bus bars were bolted to wire leads on the outside of the tool. These wire leads in turn were connected to the three 75 KVA power carts. Figure 15 shows the terminal box in the foreground for connection of the power from the power carts to the die. The small diameter white wire is the thermocouple wire being connected from the power carts to the die. Figure 16 shows the three 75 KVA power carts in the background. The men in the photo are closing in one end of the die with firebrick and covering with Glasrock cement.

3) In construction of the Vacu-form tool, provisions were made for the use of 34 thermocouples for controlling die temperatures. The 34 thermocouples were installed, calibrated, and connected to the power carts. A controlling recording thermocouple was in each of the 16 zones, plus 14 recording only thermocouples in all zones except the two end zones. Four additional recording only thermocouples were located in the area of part corner location. See Figure 17 for thermocouple locations.

4) After all electrical connections were completed, an electrical check was made which showed there was good continuity.

5) The power was turned on, and the tool was heated to 200°F for eight hours. During this period, the wax on the heated elements melted and created

*Sheet wax (0.020-inch thick) is layed up on the tubes before the tubes are placed in the tool. This wax burns out when the tool is "fired" leaving space for tube expansion.

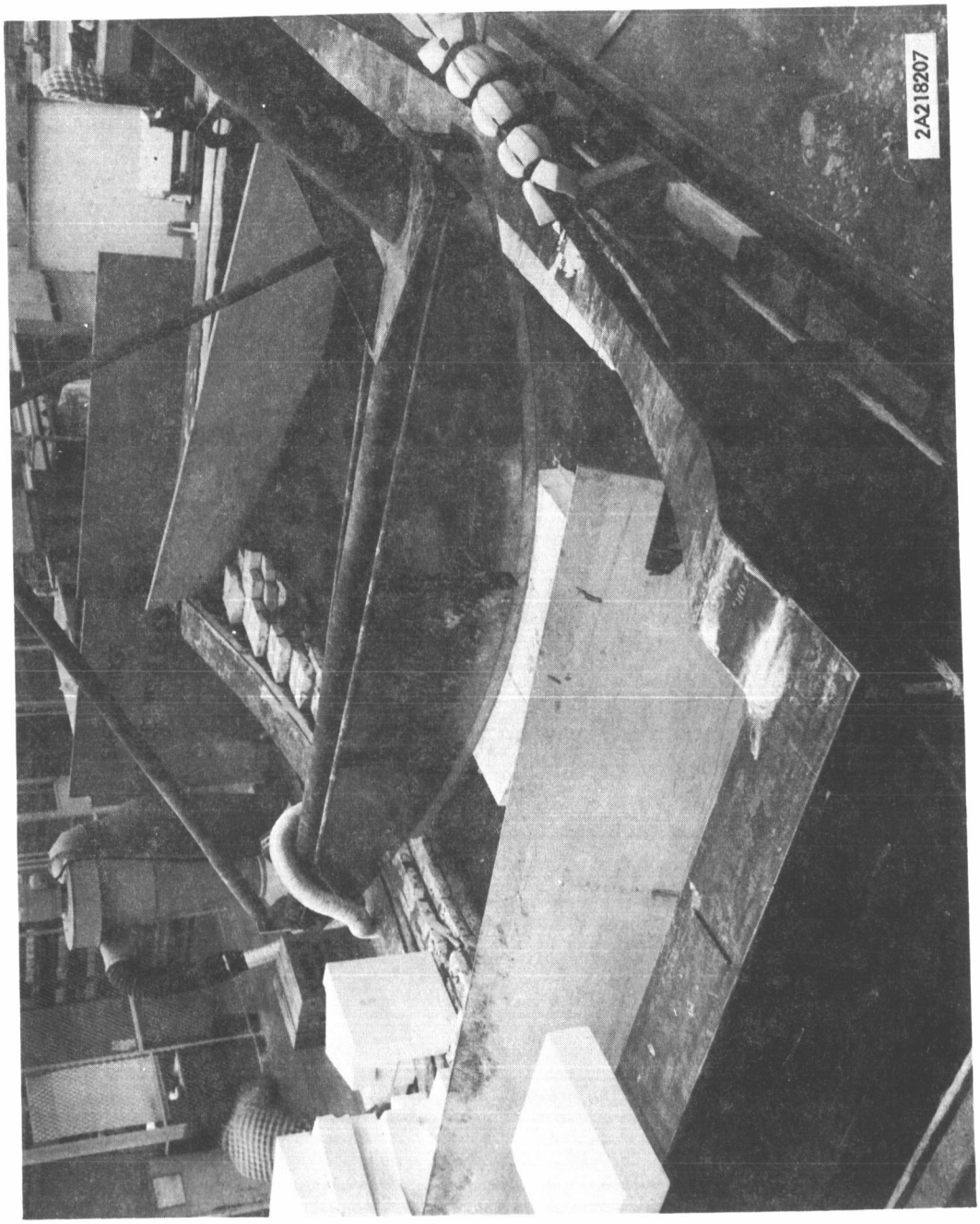



FIGURE 10
VACU-FORM TOOL GLASROCK FOAM BLOCK INSTALLATION

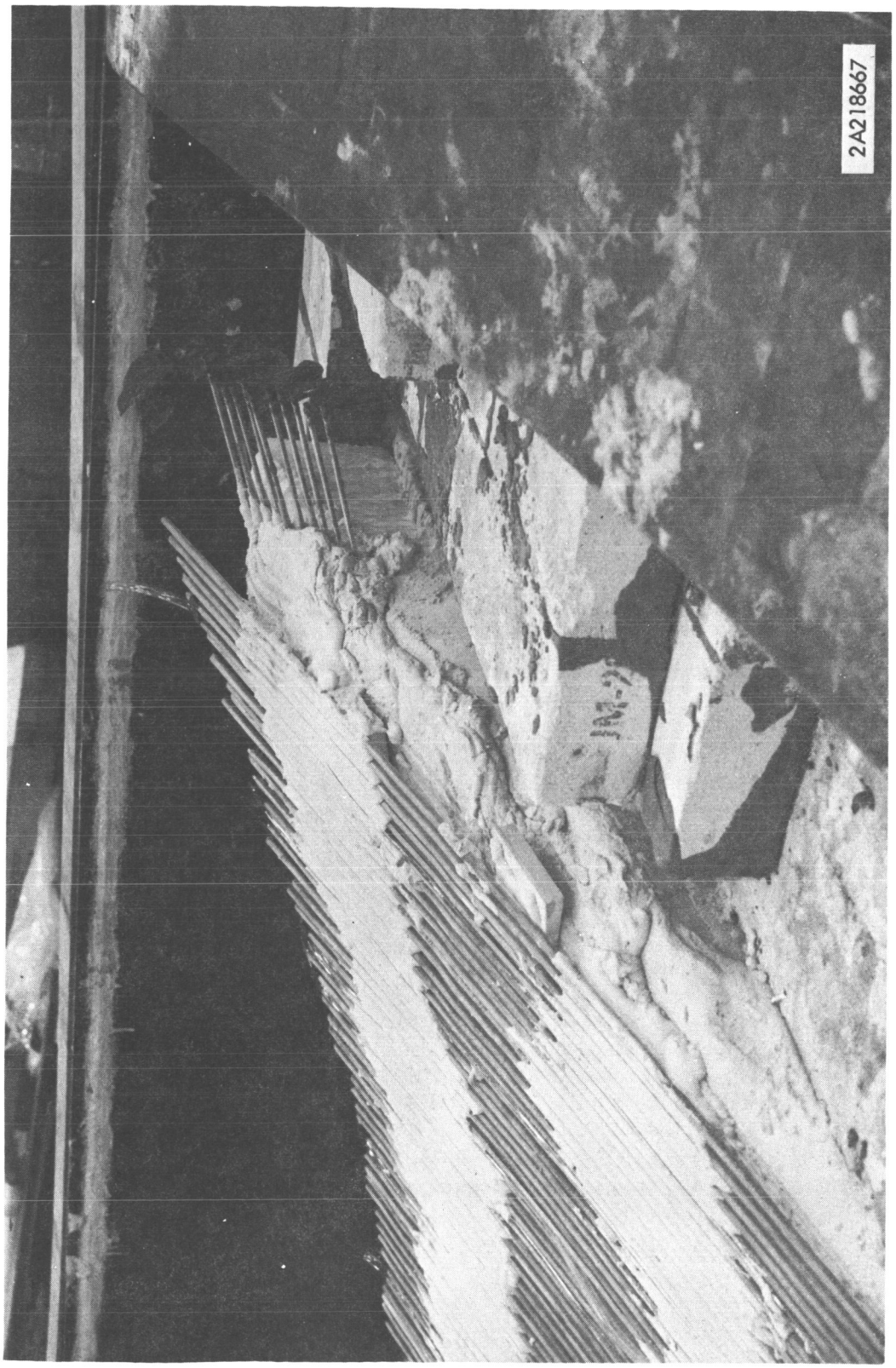



FIGURE 11
VACU-FORM TOOL - EDGE HEATER INSTALLATION

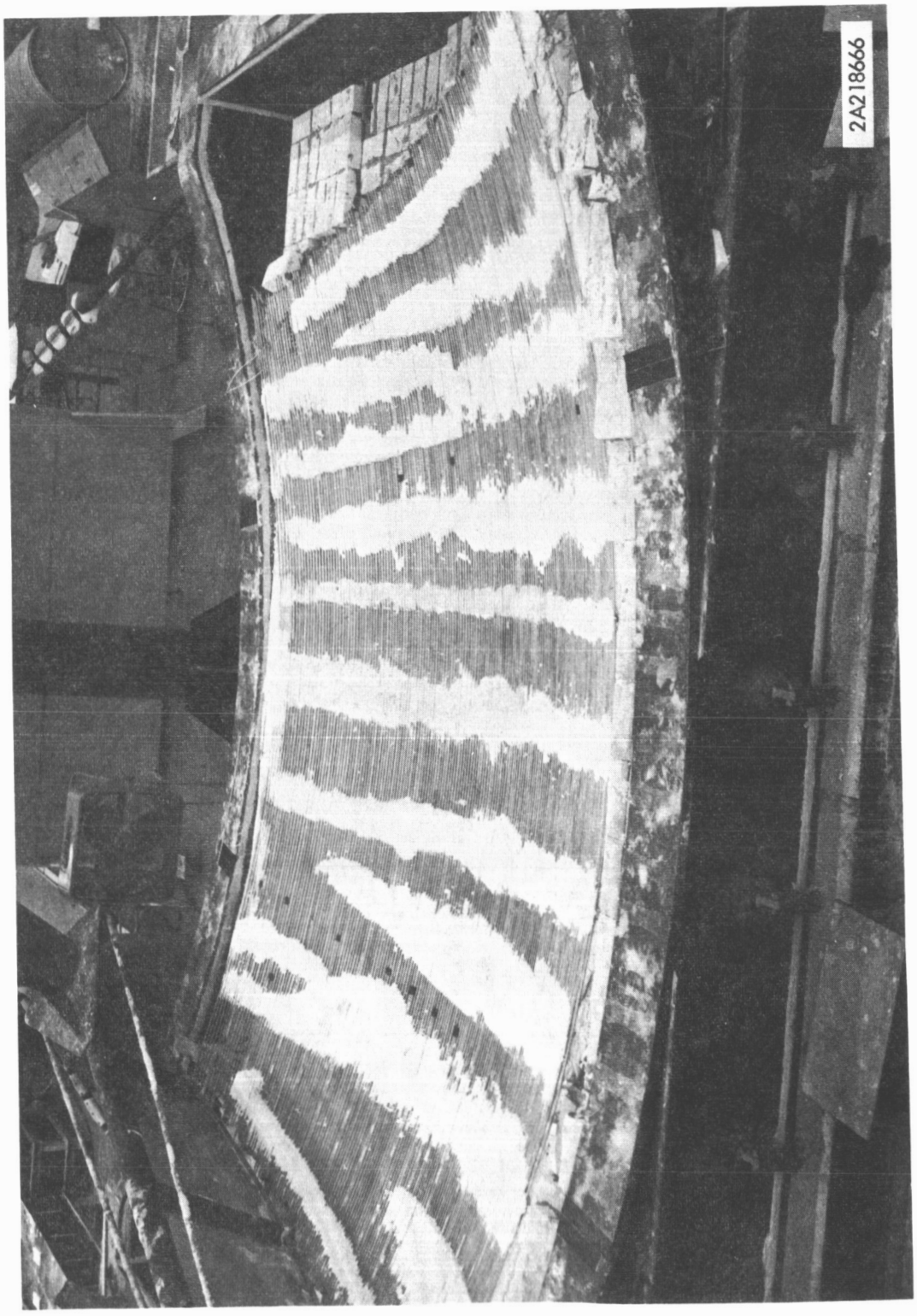



FIGURE 12
VACU-FORM TOOL - HEATER INSTALLATION

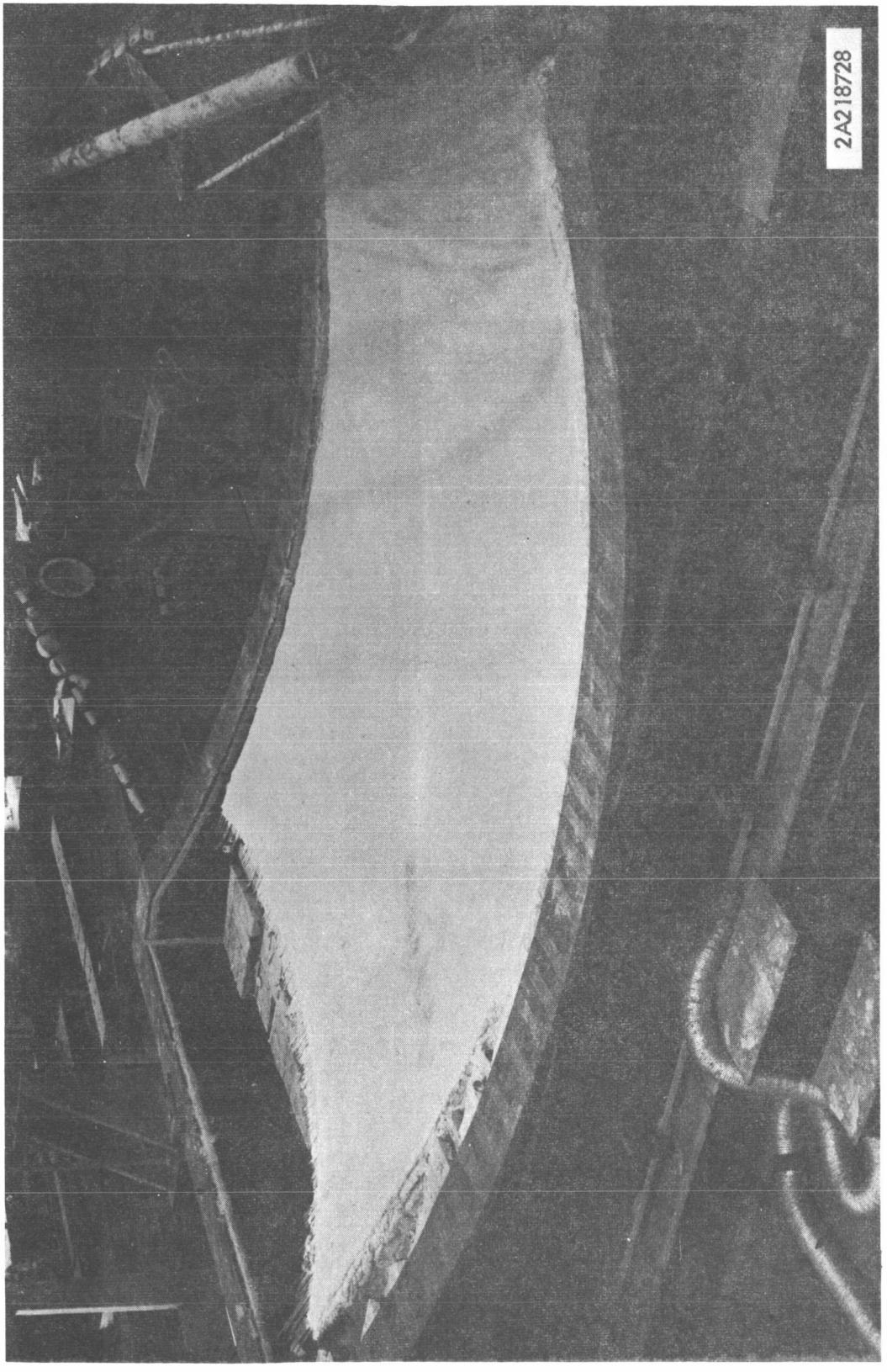



FIGURE 13
VACU-FORM TOOL - FINISH DIE SURFACE




FIGURE 14
VACU-FORM TOOL - HEATER CONNECTIONS

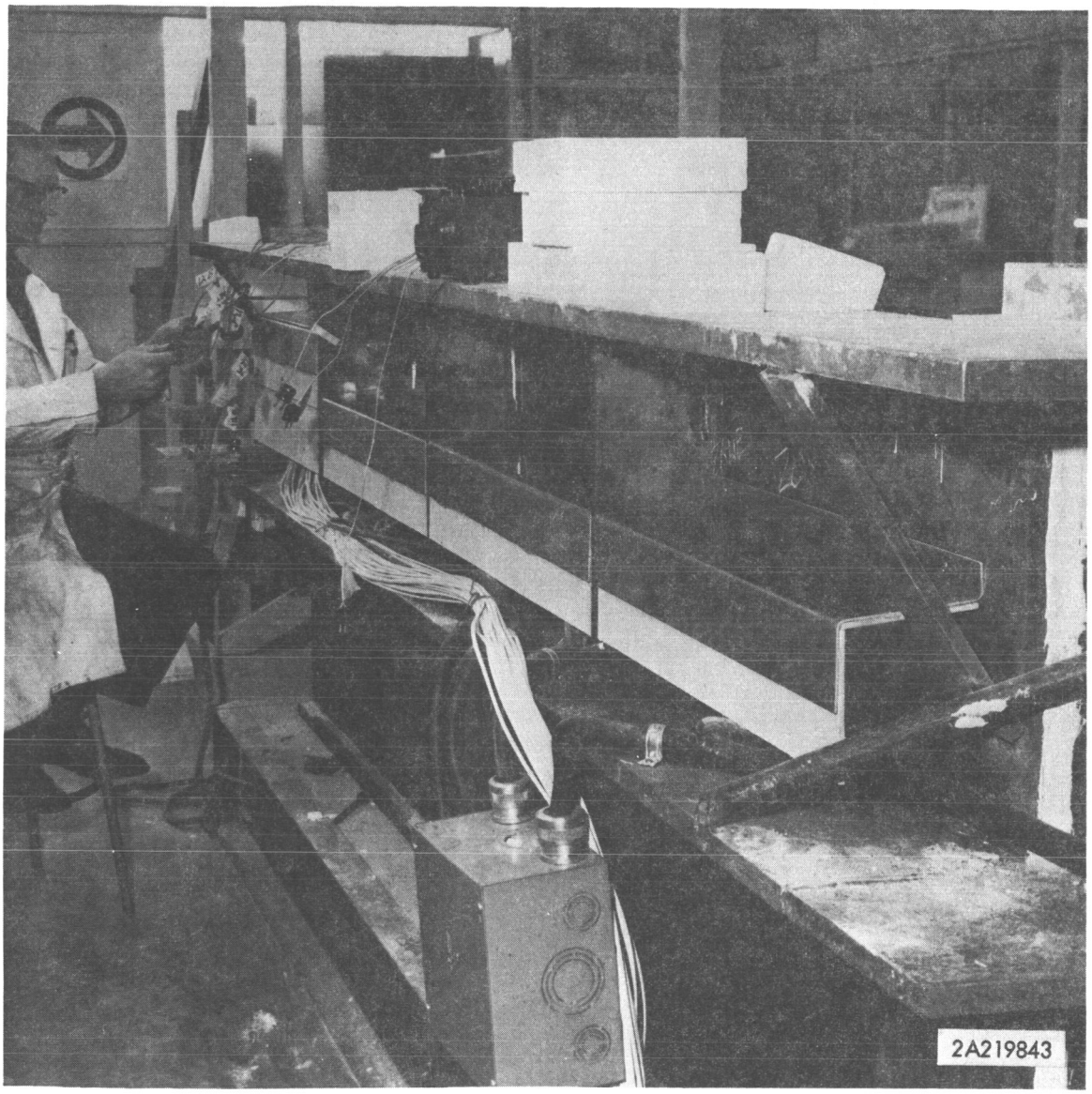



FIGURE 15
VACU-FORM TOOL - THERMOCOUPLE CONNECTIONS

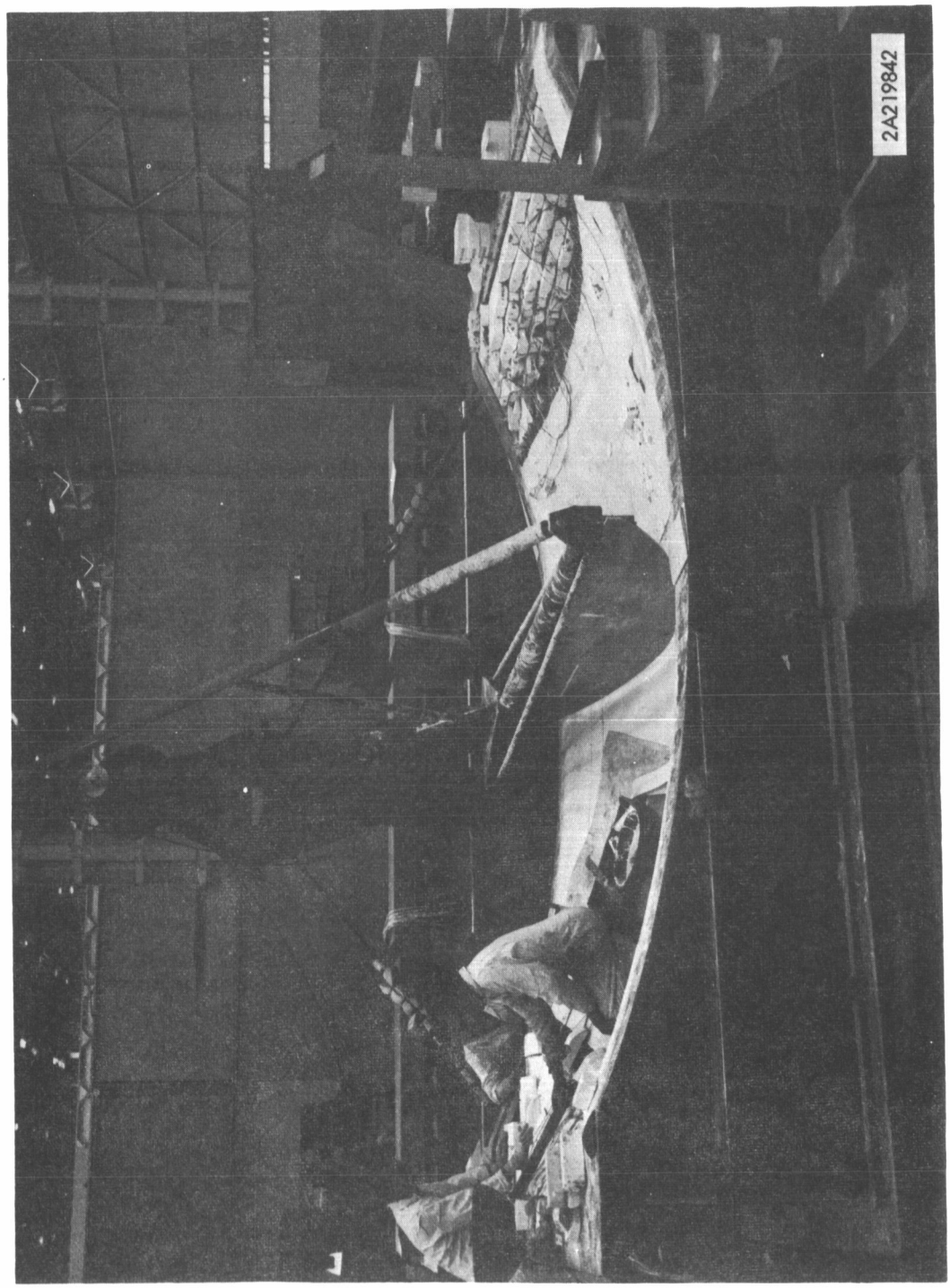
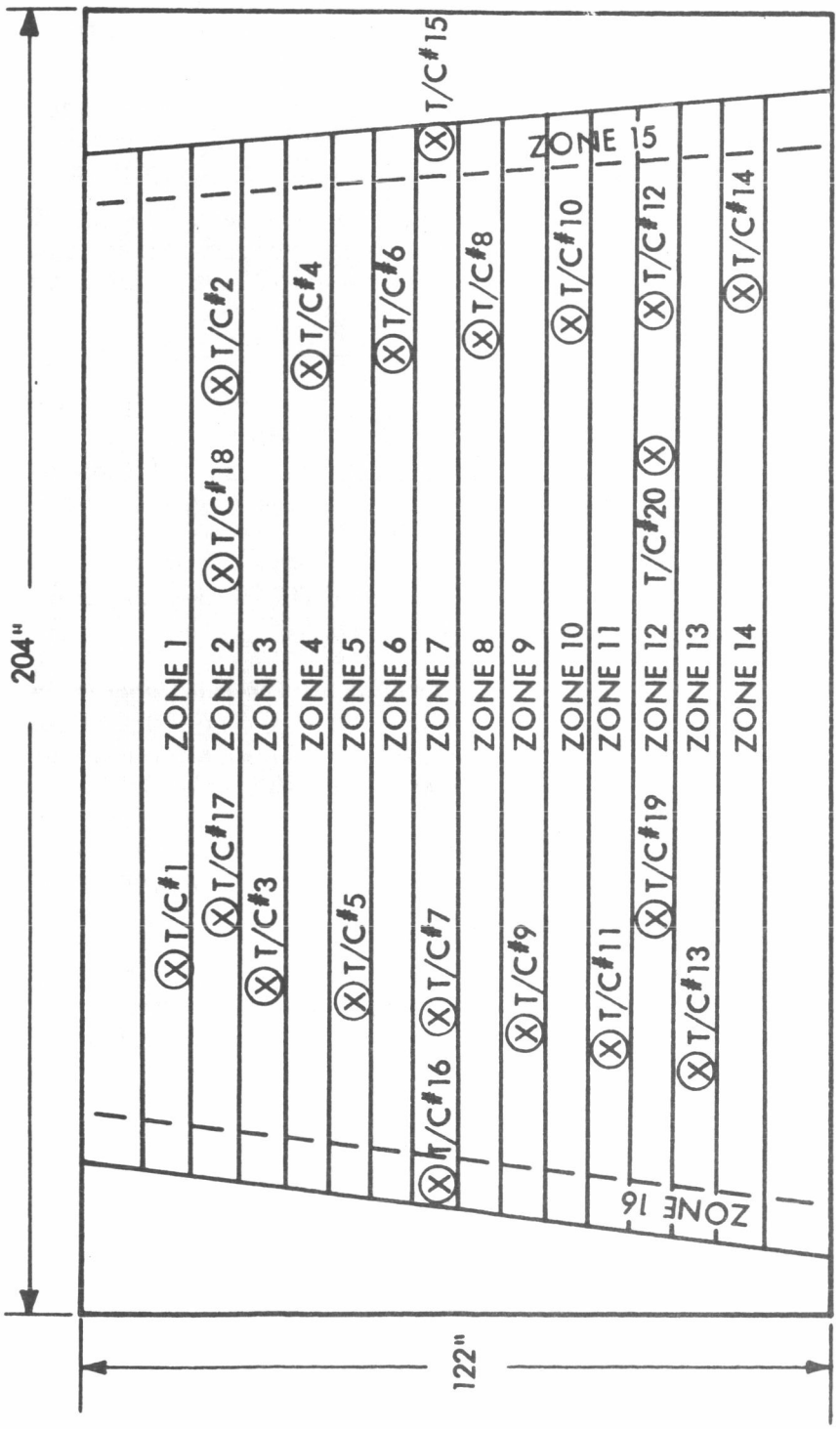



FIGURE 16
VACU-FORM TOOL - END CLOSE-OUT




NOTE: All Thermocouples are Recording and Control Except #17, #18, #19, and #20, These Record Only.

FIGURE 17
FORM DIE — THERMOCOUPLE LOCATIONS

a lot of smoke. Also, there were numerous small jets of flame emitting from the ends of the tubular heating elements. Although the smoke and flames were spectacular, they caused no damage. The heating of the die also forced out a considerable amount of moisture.

6) After 8 hours of heating at 200°F, the die was allowed to heat up to 1000°F to further bake out the die. The die was allowed to cool to room temperature, and it was noted that surface cracking was insignificant.

7) Because the heating elements are of different length, the power carts had to be adjusted to increase the voltage in the longer heating elements. The voltage ranged from 200 for the short tubes to 300 for the longest tubes.

8) After the voltages had been regulated, the tool was heated to 1200°F. All 16 zones were set at 1200°F, and this temperature was reached in 50 minutes. The die was covered with one thickness of asbestos cloth to retain the heat.

4.4.3 Proof Testing of Vacuum-Form Tool

The preliminary testing accomplished above assured us that the tool would meet the design requirements of heating a part to 1450°F in 1-1/2 hours. Therefore, we proceeded to close in the electrical hookup at either end of the die with firebrick and cement. The vacuum pump was connected and preparations were made for a complete test minus the actual part.

Proof testing was accomplished by two individual tests, a diaphragm test and a heat cycle test.

The diaphragm test was originally intended to satisfy the total requirements but the first stainless steel diaphragm split so the test was discontinued before the tool could be completely cycled. A second attempt was made to use the stainless steel diaphragm to hold the vacuum, this was successful as shown in Figure 18, but it required "gathering" technique to move excess material into the die cavity before vacuum was applied. This test proved 26 inches of mercury could be maintained by the tool and the pump selected for the job, however, another test was run to heat cycle the die.

The complete heat cycle test of the tool is shown in Figure 19. A layer of microquartz blanket insulation was placed over the complete die. The time was noted and the power was started. A continuous recording was made during the complete cycle. The temperature of the die reached 1450°F in 1-1/2 hours. The die was allowed to soak at this temperature 1/2 hour. After the soak period, the die was cooled to 900°F at a rate of a maximum of 100°F/hour. The insulation was left in place during the cool down. Every hour the power cart controls were set 100°F lower, except the last hour where the reduction was 50°F to 900°F. During each hour, the power would automatically come back on if the rate exceeded 100°F, which was the case during the whole cool down cycle. Even though we did not have a part in the die, and we did not use a diaphragm in this test, it is our opinion that outside cooling will not be necessary during a part forming run. See Figure 20 for the heatup and cool down cycle of the die.

4.4.4 Inspection of the Form Tool

Detailed inspection procedure for checking the screed tool and subsequently the vacuum forming tool are shown in Figure 21 and described below.

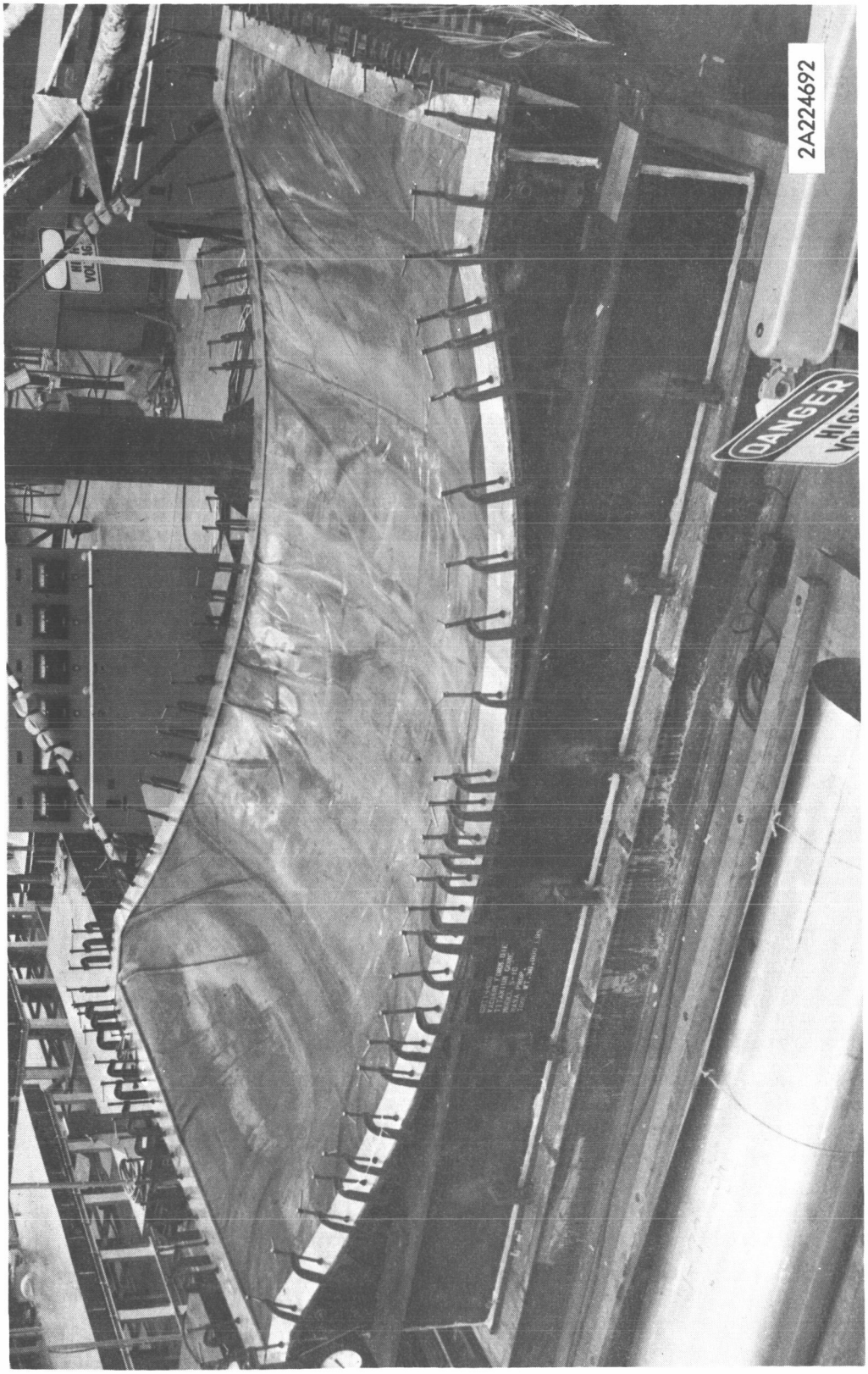



FIGURE 18
HOT VACUUM FORMING DIE - TOOL TRYOUT
(STAINLESS STEEL DIAPHRAGM)

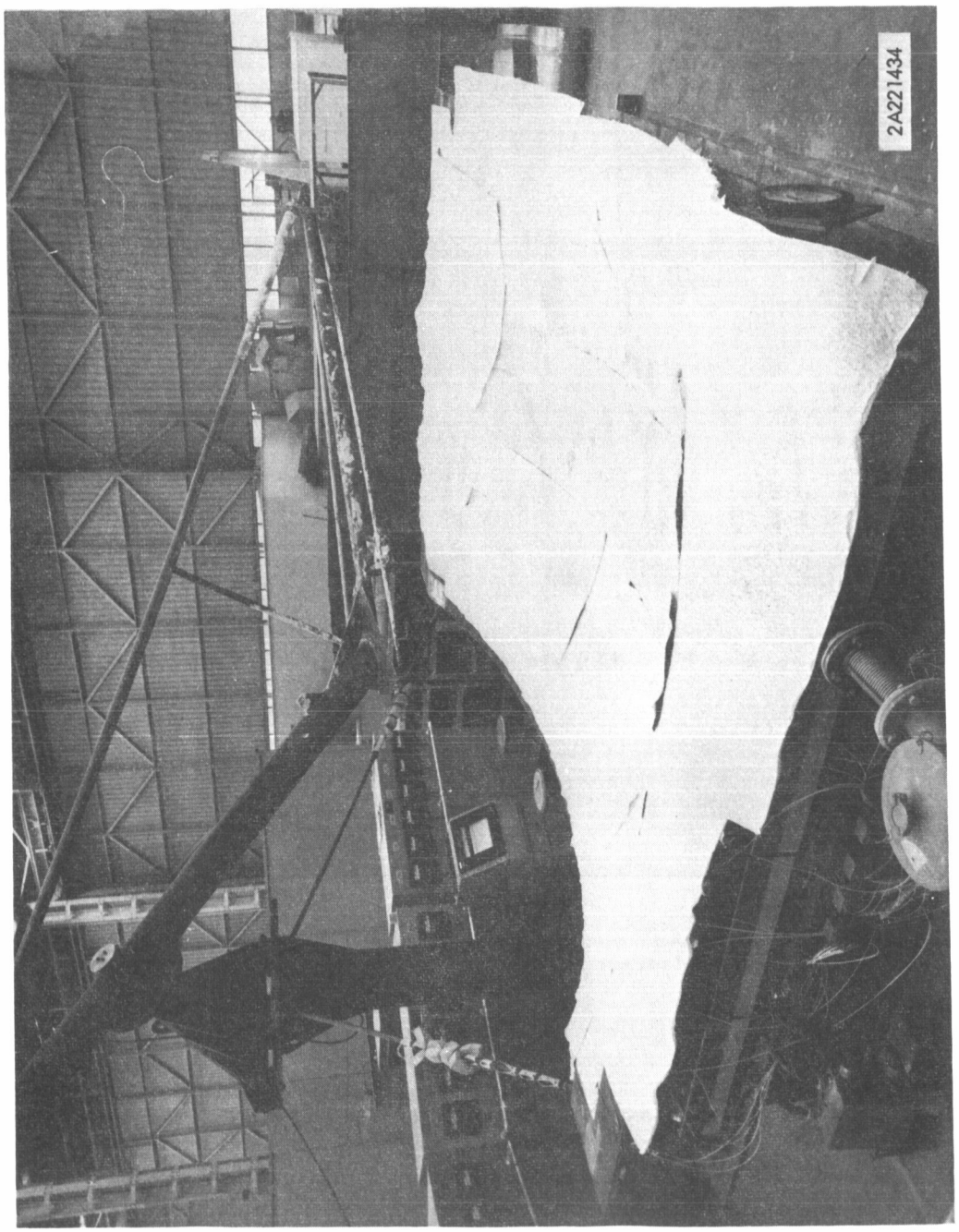



FIGURE 19
VACU-FORM TOOL - TOOL TRYOUT
(HEAT CYCLE)

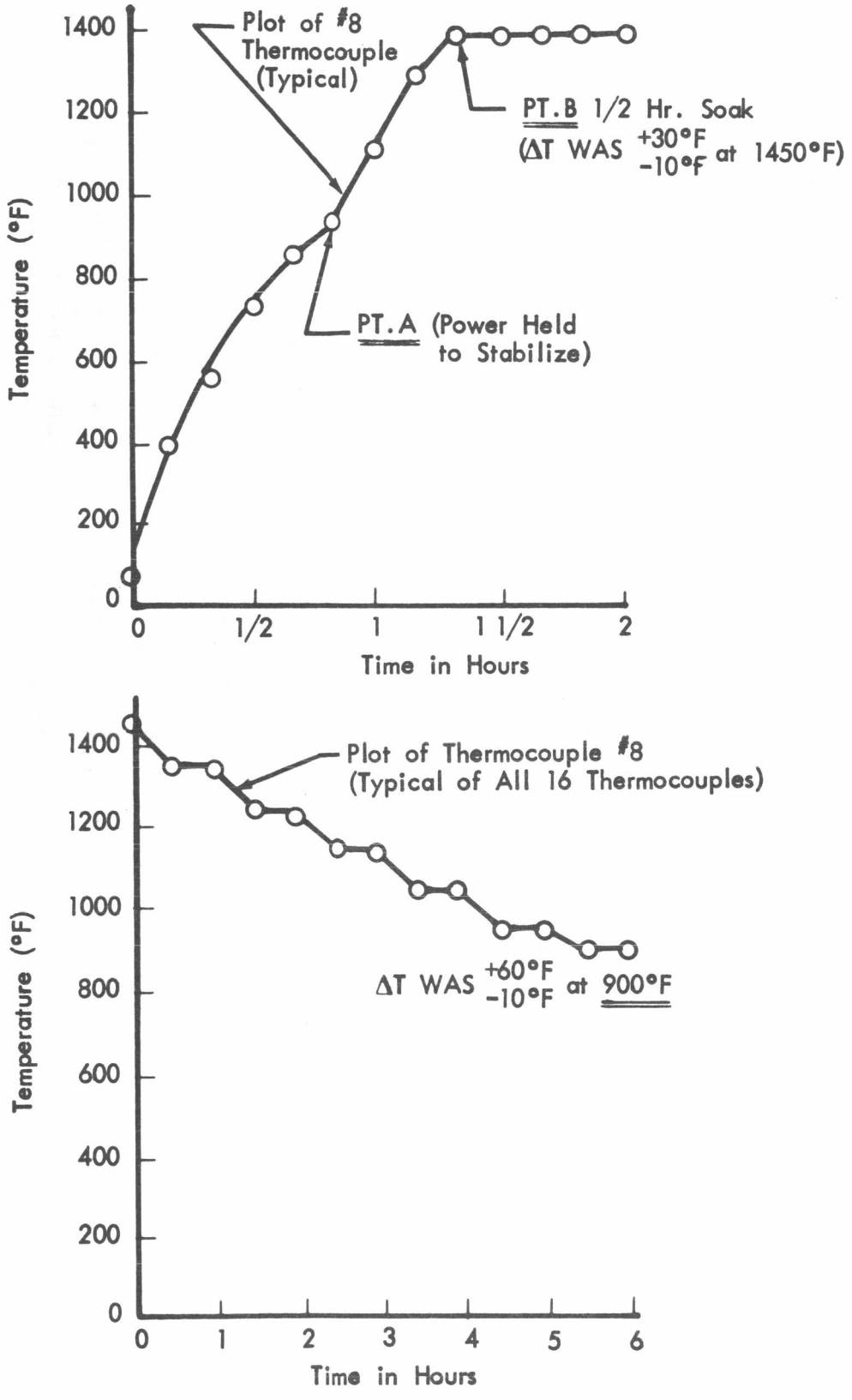



FIGURE 20
FORM DIE - HEAT CYCLE CHECKOUT

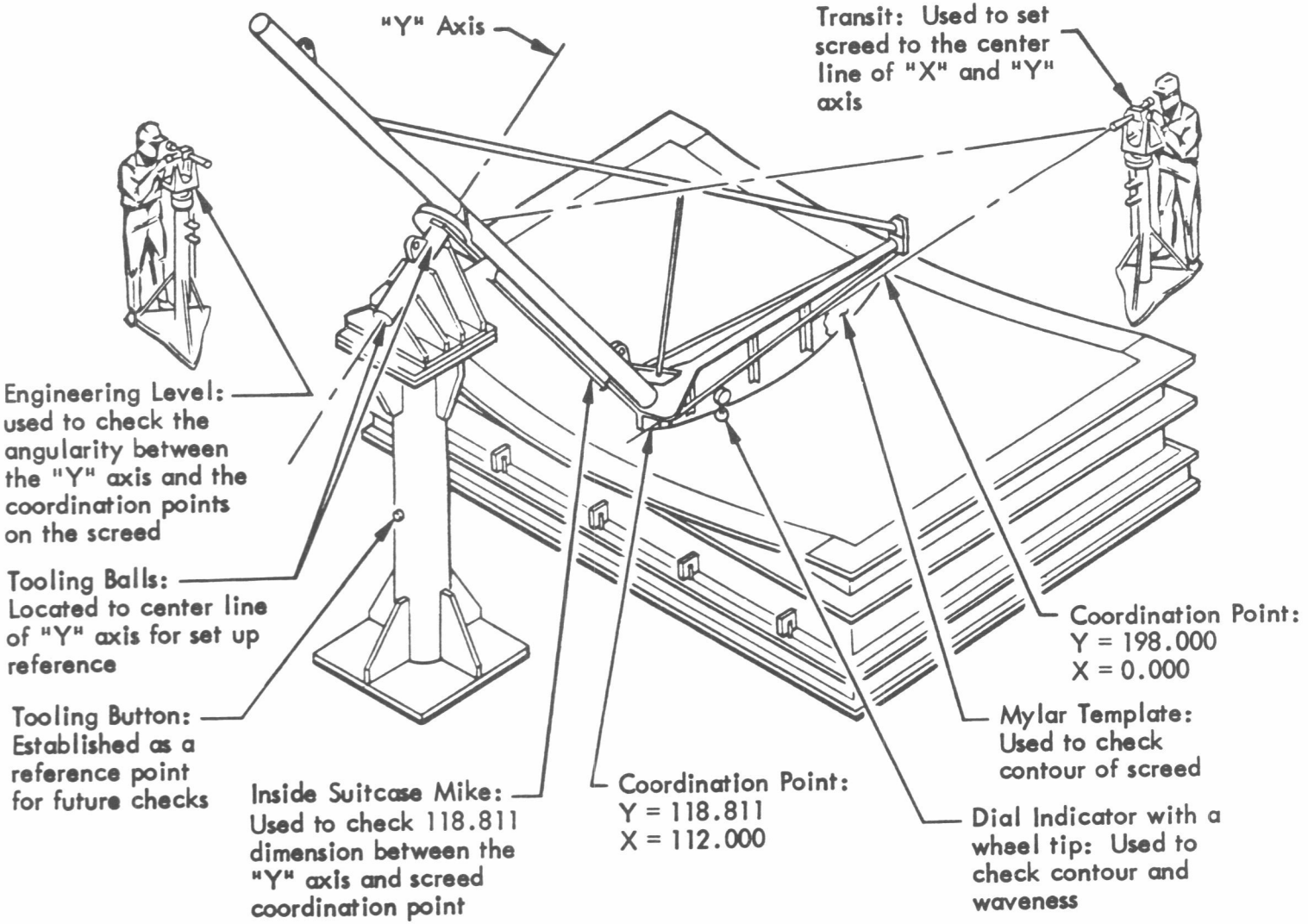



FIGURE 21

INSPECTION PROCEDURE FOR CHECKING SCREED AND VACU-FORM TOOLS

1) Set screed to the center line of "x" and "y" (center of rotation shaft) by means of a transit and two tooling balls on the shaft holder.

2) Determined the angle of the shaft from a horizontal plane using a level and two reference tooling balls.

3) Located a reference tooling button on the support post and noted distance from lower tooling ball.

4) Located mylar template (furnished by Q.C. Numerical Control) to the screed. This is accomplished by "miking" with inside micrometer from the shaft to the coordination point (118.811) marked on the mylar.

5) Checked the horizontal height of the marked coordination point on each end of the mylar with a level.

6) Checked contour of the screed to the mylar.

7) Checked contour of the die to the screed and mylar; removed screed and mylar.

8) Attached a dial indicator to the sweep and moved sweep to E.O.P. and checked contour variations. Set indicator to a minimum of five different places.

9) The inspection established that the screed is located properly to the point of rotation, contour of screed is correct, and the contour of the Vacu-form die matches the screed.

4.4.4.1 The results of the Vacu-form tool are as follows:

1) Waviness of the die does not vary more than 0.010 inch in any 6-inch area.

2) Contour of the die is within ±0.050 inch of nominal.

3) Radius of the die is within ±0.080 inch of nominal.

Having been functionally checked and inspected the hot vacuum forming tool was qualified to make full size test parts.

## 4.5 TRIM FIXTURE

A trim fixture of egg-crate design was fabricated from plywood. The fixture has the function of holding the formed gore segment during the trim operation. The original plan was to use a skate attachment for the final trim of the part. However, a quicker and more economical method involving friction sawing with a skill saw was used. The sawing operation was followed by belt sanding to finish the edge. The fixture and the sawing operation are shown in Figure 22. This fixture was also used as the base for the shipping container. A top was built for the fixture and the part was shipped to MSFC in this position.

## 4.6 TOOL FABRICATION COSTS AND SCHEDULES

Important results from this program are the tooling cost and schedules. These can be used as a guide for estimating similar tools in any future production program. Care must be exercised in applying these hours and costs to other situations since the figures presented are actual hours and material dollars for that particular time, with specific skills and facilities available at that time only. A listing of Tool Fabrication Costs and Schedules follows.

## TOOL FABRICATION COSTS AND SCHEDULES

| | | Costs | | |
|---|---|---|---|---|
| | | Manhour | Materials | Schedule |
| 1. | Diffusion Bonding Tool | 60 | $ 991 | 7-20-65 to 8-2-65 |
| 2. | Flattening Tool | 251 | 2,850 | 12-1-65 to 1-10-66 |
| 3. | Vacuum Chuck | 85 | 1,050 | 12-6-65 to 12-14-65 |
| 4. | N/C Part Programming | 120 | 0 | 12-14-65 to 1-10-66 |
| 5. | Screed Tool | 401 | 972 | 10-27-65 to 11-12-65 |
| 6. | Forming Tool | | 12,755* | |
| | Steel Box | 427 | | 10-25-65 to 11-12-65 |
| | Fire Brick (Instl.) | 100 | | 11-10-65 to 11-13-65 |
| | Filler Block (Instl.) | 118 | | 11-13-65 to 11-18-65 |
| | Cast. Sur. for Tubes | 106 | | 11-18-65 to 11-20-65 |
| | Bend and Locate Tubes | 221 | | 11-6-65 to 11-24-65 |
| | Screed Final Surface | 147 | | 11-24-65 to 11-30-65 |
| | Miscellaneous Die Finish Activity | 819 | | 11-12-65 to 1-7-66 |
| | Checkout | 26 | | 1-7-66 to 1-20-66 |
| | Total | 2,881 | $18,618 | All Complete by 1-20-66 |

*It is significant to note that the major cost items here were: Inconel Tubing ($1990); Glasrock Block ($4000); and Glasrock Cement ($2450).

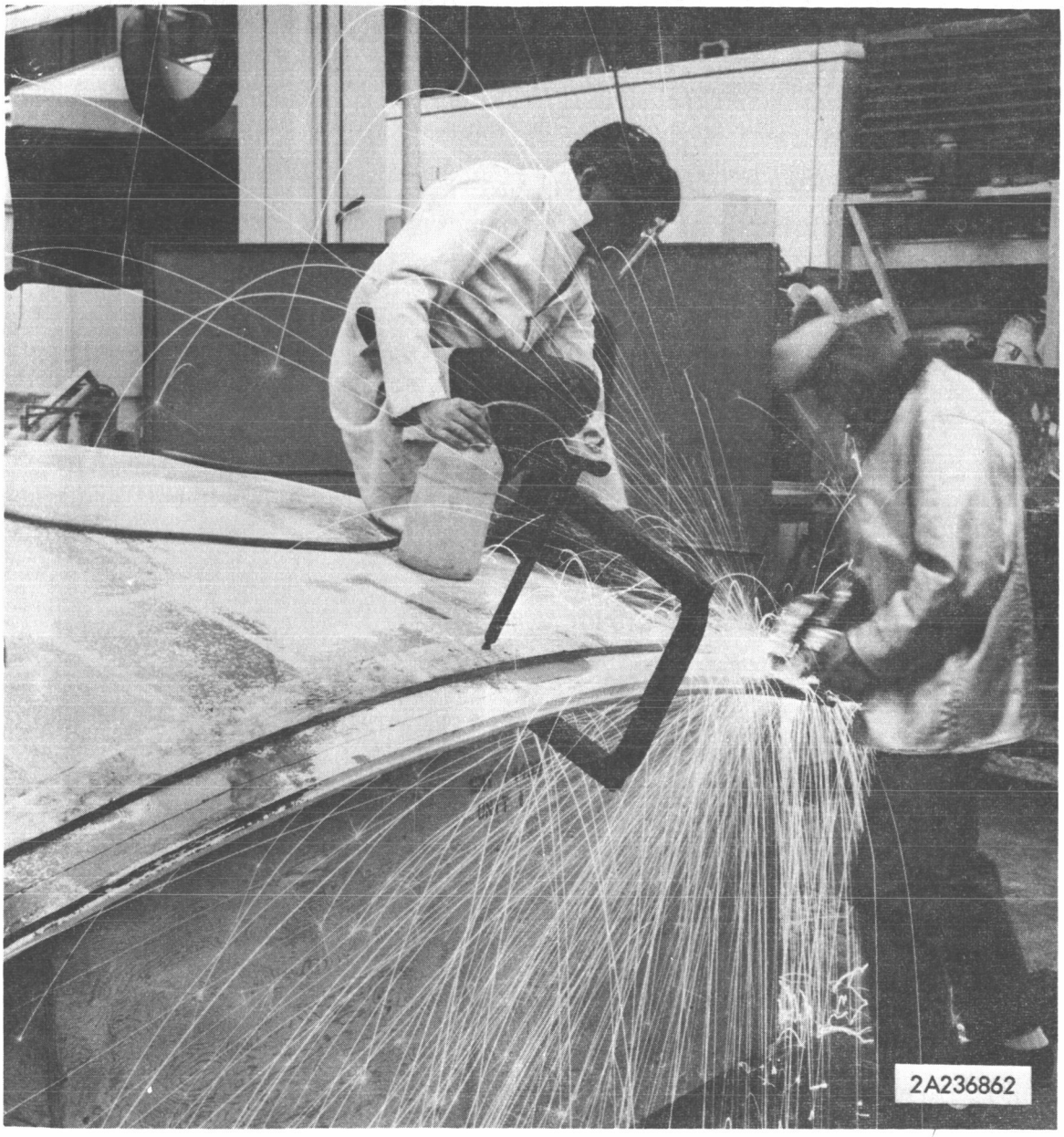



FIGURE 22

TRIMMING TITANIUM GORE USING SKIL SAW
WITH ABRASIVE DISK

## 5.0 MANUFACTURING PROCESSING

The basic process for fabricating the full size titanium gore was determined before subscale testing was started and it remained essentially unchanged throughout the entire program. Figure 23 illustrates the fabrication sequence. The basic process is as follows:

1) Obtain raw material (1/2 by 96 by 156 inches);
2) Machine fitting hole in plate;
3) Machine "fitting" ring out of excess material from corner of plate;
4) Clean plate and ring with methyl ethyl ketone (MEK) prior to bonding;
5) Diffusion bond;
6) Clean bonded assembly and hot flattening tools, wipe with MEK and apply 3 coats of Formcoat (Everlube) T-50 protective coating to the part and tools before stress relieving and hot flattening;
7) "Hot" flatten;
8) Clean scale off the part by pickling in a nitric hydrofluoric bath and rinse before machining;
9) Profile mill pockets in plate;
10) Alkaline clean and rinse prior to forming;
11) "Hot" vacuum form to contour;
12) Pickle scale off and rinse;
13) Trim, bore, and spotface;
14) Alkaline clean and inspect.

The deviations in the processing that were made as a result of the subscale testing and the full size part experience were all concerned with details of bonding, stress relieving, flattening, profile milling, and forming. The evolution of these details is discussed in the process development section of the report, and the developed process specifications are summarized at the end of this section.

## 5.1 FABRICATION OF THE TITANIUM GORES

Part fabrication was initiated following the completion of the tools, the approval of the Manufacturing Plan by MSFC and the receival of material.

Several variations were made in the processing of these parts to correct situations which developed. The majority of these changes involved the incorporation of process improvement from one part to the next. Other changes were made as a result of machine work load problems. Numerical Control Profilers were reserved for machining these parts, but machining could not be completed on them because the titanium material was three months late arriving and the machines had to be given up to previously scheduled work. Also, several changes in processing were made to recover from situations created by accepting titanium material out of specification.

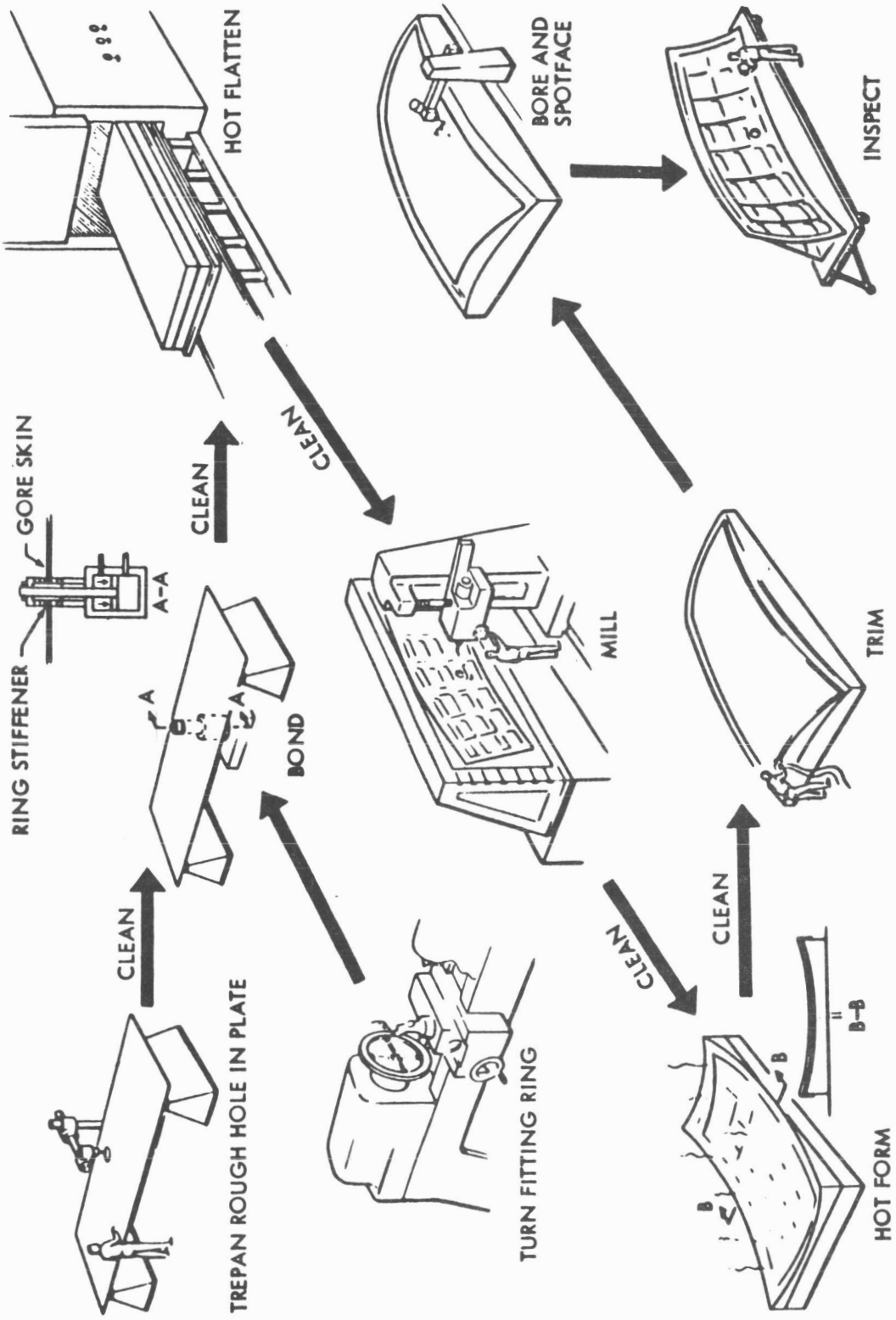



FIGURE 23
FABRICATION SEQUENCE CHART

The most significant changes in the forming process were the addition of a picture frame to the excess of the part to restrain it during forming. This 1/2-inch thick by 2-inch wide titanium frame was fusion welded to the flat gore before forming and trimmed off after forming. Another important change was the stretch out of the forming cycle to a creep forming situation; wherein forming was done in a slow 22-hour cycle rather than a previously used 12-hour cycle.

For diffusion bonding, the biggest change was the addition of more insulation to the gore surfaces, top and bottom, to provide better heat distribution during bonding to reduce residual stresses in the heat affected zone of the part.

The original plan was to fabricate three titanium gore parts; deliver two to MSFC and retain one for destructive testing. Due to contract redirection only one part was delivered and work on the other two was stopped at whatever stage in the fabrication the part was when the stop order was received. Part No. 002 was completely fabricated and delivered to MSFC according to the sequence described above. Part No. 001 was fabricated through the bonding, flattening, and machining stages; and Part No. 003 was completed only through the bonding stage.

Three plates of titanium material were received from the vendor and processed through Receiving Inspection. Each of the plates were inspected for visual and dimensional discrepancies, chemical properties, physical properties, metallurgical properties, and ultrasonic response according to Boeing Material Specification (D6-6051-1) for Condition 1, Type "C", 8-1-1 titanium plate material.

All three plates were rejected by Receiving Inspection. They were rejected for not meeting visual and dimensional requirements, physical properties limits, and ultrasonic limits. All three plates were released to production to be used "as is."

In reference to the above processing (Steps 1 through 14), each of the three parts (No. 001, No. 002, and No. 003) were fabricated through Step 8 of the processing. All the machining, cleaning, and diffusion bonding operations were identical, but there was considerable variation in the "Hot" flattening operation (Step 7). Part No. 002 was processed first and a crack developed after stress relief and pickling (see Process Development section for details) subsequent to bonding. Consequently, Parts No. 001 and No. 003 were processed differently. The pickling operation was moved to just before profile machining rather than just after bonding and the stress relieving operation was performed immediately after bonding (no delay). This corrected the situation because neither Part No. 001 nor No. 003 cracked.

Part No. 003 was completely unsatisfactory for machining after hot flattening. As was stated in Section 3.0 of this report, No. 003 contained 1/4-inch deep creases along one edge. These could not be removed by the first hot flattening cycle of 1200°F for two hours with a 10-ton load on the dies so a second hot flattening operation was performed. The creases in Part No. 003 could not be removed even when attempts shown in Figure 24 were made to force the part into a flat condition. The second hot flattening operation was at 1450°F for four hours with a 40-ton load on the dies and was unsuccessful. Further processing of Part No. 003 was discontinued because it was unsatisfactory for profile milling since neither vacuum hold down nor a combination of vacuum and clamping could force the material to the vacuum chuck for profile milling.

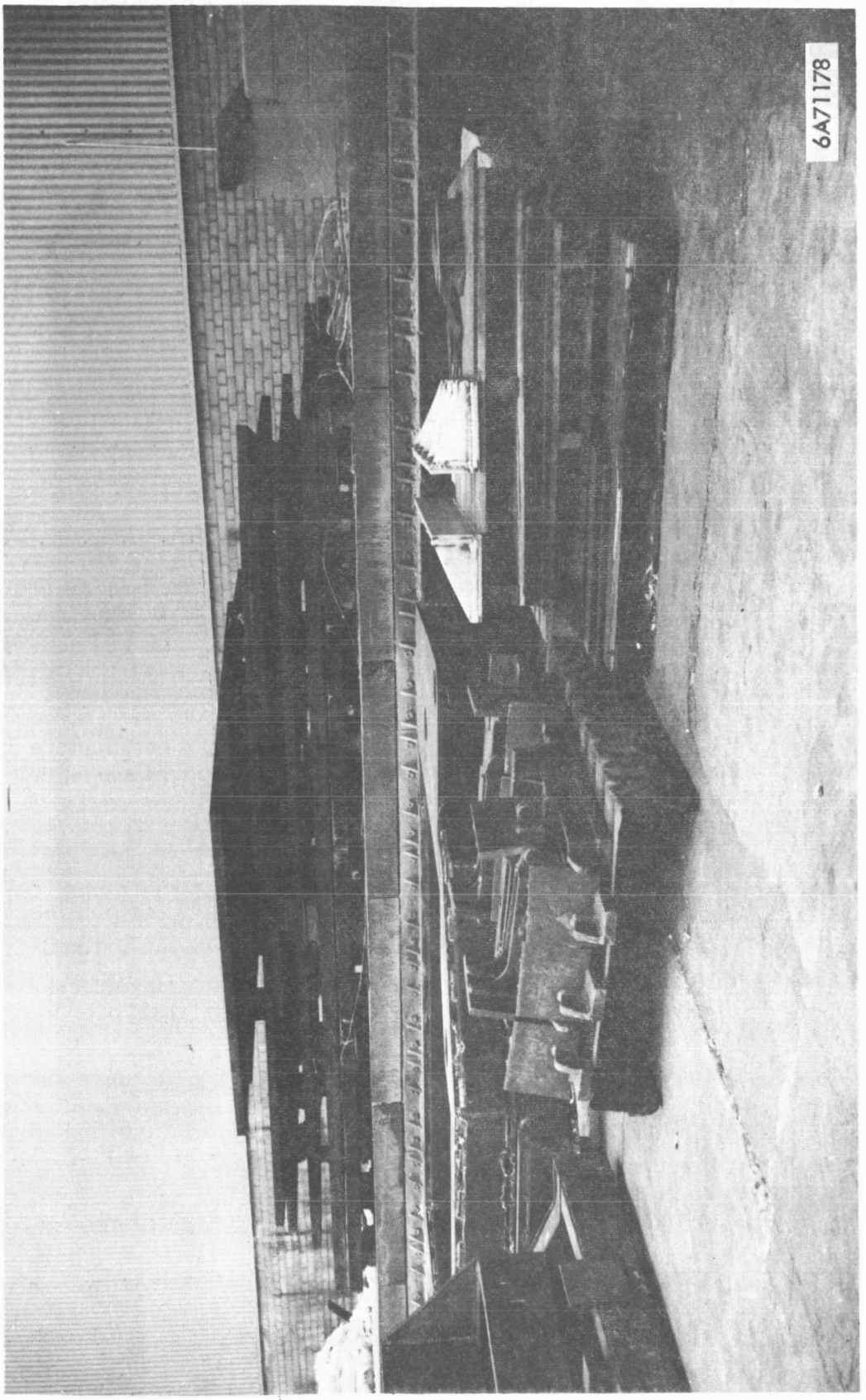



FIGURE 24
FORTY TON LOAD ON PART #003 FOR HOT FLATTENING

Both the remaining Parts No. 001 and No. 002 were processed through Step 10 of the processing. This included profile milling on both the numerical control machine and the tracer machine. Machining details are discussed in the Process Development, Section 6.0. After Step 10, processing of Part No. 001 was discontinued due to contract redirection. Part No. 002 was processed to completion.

There were a number of process variations associated with Part No. 002 because of conditions which developed.

Before being formed, the crack in the diffusion bonding area was repaired by fusion welding (see Process Development, Section 6.0) and a picture frame 1/2-inch thick and 2-inches wide was welded around the outside of the part to reinforce during forming. Also, the forming rate was slowed from 3-1/2 inches per hour to 1 inch per hour.

Since the forming of Part No. 002 was not entirely successful, a wrinkle removal operation was performed. Unanticipated thermal gradients in the part during this operation created new oil cans in the part rather than removing the original ones.

Steps 12, 13, and 14 were uneventful with Part No. 002 except during the handling of the part after forming, it was inadvertently lifted by a clamp on the lower edge and cracked. This crack was subsequently welded (see Section 6.0) but additional distortion of the part edge was caused by this weld repair. Following inspection Part No. 002 was delivered to MSFC.

## 5.2 PROCESS SPECIFICATIONS

The process detail specification critical to the production of a satisfactory part are summarized below. Special techniques required to support these specifications are found in the Process Development, Section 6.0 of this report.

- Step 5 - Diffusion bond at 1825°F ±25°F at 400 psi for one hour.
- Step 7 - "Hot" flatten by giving the part a stress relief at 1200°F for two hours immediately after bonding, and follow with hot flattening at 1200°F for two hours with a 10-ton load on the flattening dies.
- Step 9 - Profile mill according to good titanium machining practices. Plan to machine the chuck side of the material all over before attachment to the vacuum chuck.
- Step 11 - "Hot" vacuum form at 1450°F ±25°F for 14 to 20 hours using no more than 1/2-inch Hg to form the part. Use a nylon diaphragm to apply pressure.
- Step 13 - Use conventional machining practices, except for trimming, use a "Skill" saw rather than an end mill. Also, use a special fixture to transport the formed part from shop to prevent damage.

# 6.0 PROCESS DEVELOPMENT

For clarity, process development discussion is contained in this section, as a follow on to the detail manufacturing sequence contained in the foregoing section. The process development areas discussed include: diffusion bonding, machining, forming, ultrasonic inspection, and welding.

## 6.1 DIFFUSION BONDING PROCESS DEVELOPMENT

Results of previously conducted basic diffusion bonding parameter studies indicated a wide range of temperature, pressure, and time combinations would produce bonds in titanium with joint strengths in excess of 90 percent of base metal strength. Other programs confirmed that various assembly configurations could be successfully bonded utilizing different combinations of these variables most suitable to the specific configuration and tooling concept. For the purpose of bonding the reinforcing ring around the port hole in the base gore segment, a combination of high temperature, high pressure, and short time was selected. This selection was based upon simplicity of tooling and associated equipment, and process economy. In keeping with this basic philosophy of simplicity and economy, it was felt that the use of a shielding atmosphere of inert gas around the diffusion bond zone could be eliminated by achieving intimate contact of the parts, thereby excluding ambient atmosphere. This would be accomplished through application of high pressure until initial bonding provided a seal, at which time pressure would be reduced to avoid excessive thinning of the parts.

### 6.1.1 Diffusion Bonding Tool (Drawing No. GMT 14489)

The bonding tool was designed and fabricated for conduct of the subscale diffusion bonding process development.

The tool consists of a hydraulic cylinder mounted vertically on a pedestal with leveling jacks for vertical adjustment and alignment. Hollow cylindrical anvil blocks and a pressure cap were fabricated from A-7 steel, and an annular pressure distribution-susceptor ring was machined from Inconel X-750. Anvils, pressure ring, and cap were of such diameter to apply pressure only to the ring-plate bond area. Rings of "Molten-Metal-Maranite" heat resistant tooling material were fabricated to serve as thermal insulators between the heated ring and the pressure cap, and between the plate and the anvil blocks. Water cooling inside the hollow anvils was utilized to prevent overheating of the hydraulic cylinder. A schematic, Figure 2, shows the tooling and illustrates the relationship to the ring and plate assembly.

Heating the ring and plate to bonding temperature was accomplished by induction with a combination helical-pancake type coil. R.F. power at 4200 cycles per second was supplied by a 30 kilowatt motor-generator unit. The helical-pancake configuration of the induction coil was developed to heat the reinforcing and pressure-susceptor rings, as well as a zone of the plate approximately two-inches wide surrounding the ring.

6.1.2 Subsize Development Tests

To establish specific process parameters, and to prove the tooling concept for bonding the doubler ring to the gore segment skin, preliminary tests (summarized in Table I) were conducted with simulated gore assemblies. Three test assemblies consisted of full size 8-1-1 titanium doubler rings, 1/2-inch thick by 9.6 inches O.D. by 5.5 inches I.D., bonded to 1/2-inch thick 8-1-1 titanium plates 20 inches square with a 5.5-inch diameter hole through the center. A fourth test assembly consisted of a full size ring bonded to a 24- by 36-inch sculptured subscale simulated gore skin.

Initial tests were conducted to establish the induction coil design and to determine heating patterns. Simulated gore assemblies were assembled in the bonding tool and heating tests were conducted, varying generator output and time periods to establish a uniform heating cycle.

On establishing a suitable heating cycle, two 20- by 20-inch plate-ring assemblies and the 24- by 36-inch sculptured assembly were bonded. Figures 25 and 26 are photographs of one of the 20- by 20-inch plate-ring assemblies in the tool after bonding.

The annular doubler rings were machined to a surface finish of 32 RHR. After machining, the rings were chemically cleaned by pickling in a nitric-hydrofluoric bath. Subsequently, the bonding surface of each ring was hand abraded with 600 grit silicon carbide abrasive to polish the surface to a finish of approximately 20 RHR and then solvent cleaned. The plates were machine spotfaced around the port hole, to a diameter of approximately 10 inches and to a surface finish of approximately 63 RHR. The spotface surface was then hand abraded with 600 grit silicon carbide abrasive followed by manual cleaning with methyl ethyl ketone.

Bonding parameters for the two 20- by 20-inch plate-ring assemblies, Tests No. 1 and No. 2; and the 24- by 36-inch sculptured plate-ring assembly, Test No. 3, were as follows:

1) Faying surface pressure of 1500 psi was applied at room temperature and maintained during heatup to 1500°F. Time required to reach 1500°F varied from 10 to 15 minutes for these assemblies.

2) Upon reaching 1500°F, as indicated by the bond area thermocouples, pressure was reduced to 500 psi.

3) Pressure was further reduced to 200 psi after temperature of the bond area reached 1800°F, 20 minutes after heating was started.

4) Temperature of 1800°F and pressure of 200 psi was maintained for one hour, after which the assembly was allowed to cool to room temperature.

A plot of the temperatures and pressures versus time is shown in Figure 27.

The first 20- by 20-inch panel was sectioned for metallurgical examination. Bonding was complete except at inside and outside edges of the joint. Lack of bonding at ring edges due to atmospheric contamination had been anticipated, and did not extend into the joint beyond the excess provided to accommodate it. Excessive grain growth occurred as a result of exceeding temperature limitations.

TABLE I

| DIFFUSION BONDING TESTS | | | | | |
|---|---|---|---|---|---|
| Bonding Cycle | | | | | Comment |
| Test No. | Test Panel Size | Elapsed Cycle Time - Min | Temp. - °F | Press - PSI | |
| 1 | 20 x 20 | Start<br>10<br>15<br>75 | R.T.<br>1500<br>1800<br>1800 - 1850 | 1500<br>500<br>200<br>200 | Excessive grain growth - good bond |
| 2 | 20 x 20 | Start<br>10<br>15<br>75 | R.T.<br>1500<br>1800<br>1800 - 1850 | 1500<br>500<br>200<br>200 | Intentional contamination 1/3 bond area void |
| 3 | 24 x 36 | Start<br>10<br>15<br>75 | R.T.<br>1500<br>1800<br>1800 - 1850 | 1500<br>500<br>200<br>200 | Void - 1/2 x 2 |
| 4 | 20 x 20 | Start<br>10<br>15<br>75 | R.T.<br>1500<br>1800<br>1800 - 1850 | 2000<br>1000<br>400<br>400 | Excellent bond |
| 5 | 24 x 24 | Start<br>10<br>20<br>80 | R.T.<br>1500<br>1800<br>1800 - 1850 | 2000<br>1000<br>400<br>400 | Plate cracked at edge of ring - intermittent and edge voids |
| 6 | 24 x 24 | Start<br>10<br>20<br>80 | R.T.<br>1500<br>1800<br>1800 - 1850 | 2000<br>1000<br>400<br>400 | Plate cracked - intermittent voids |
| 7 | 24 x 24 | Start<br>14<br>24<br>84 | R.T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond |

TABLE I (Continued)

| DIFFUSION BONDING TESTS | | | | | |
|---|---|---|---|---|---|
| Bonding Cycle | | | | | Comment |
| Test No. | Test Panel Size | Elapsed Cycle Time - Min | Temp. - °F | Press - PSI | |
| 8 | 24 x 24 | Start<br>13<br>24<br>84 | R. T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond |
| 9 | 24 x 24 | Start<br>11<br>15<br>75 | R. T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond |
| 10 | 24 x 24 | Start<br>12<br>18<br>78 | R. T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond |
| 11 | 48 x 120 | Start<br>12<br>22<br>90 | R. T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond - plate cracked |
| 12 | 48 x 120 | Start<br>18<br>30<br>90 | R. T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond |

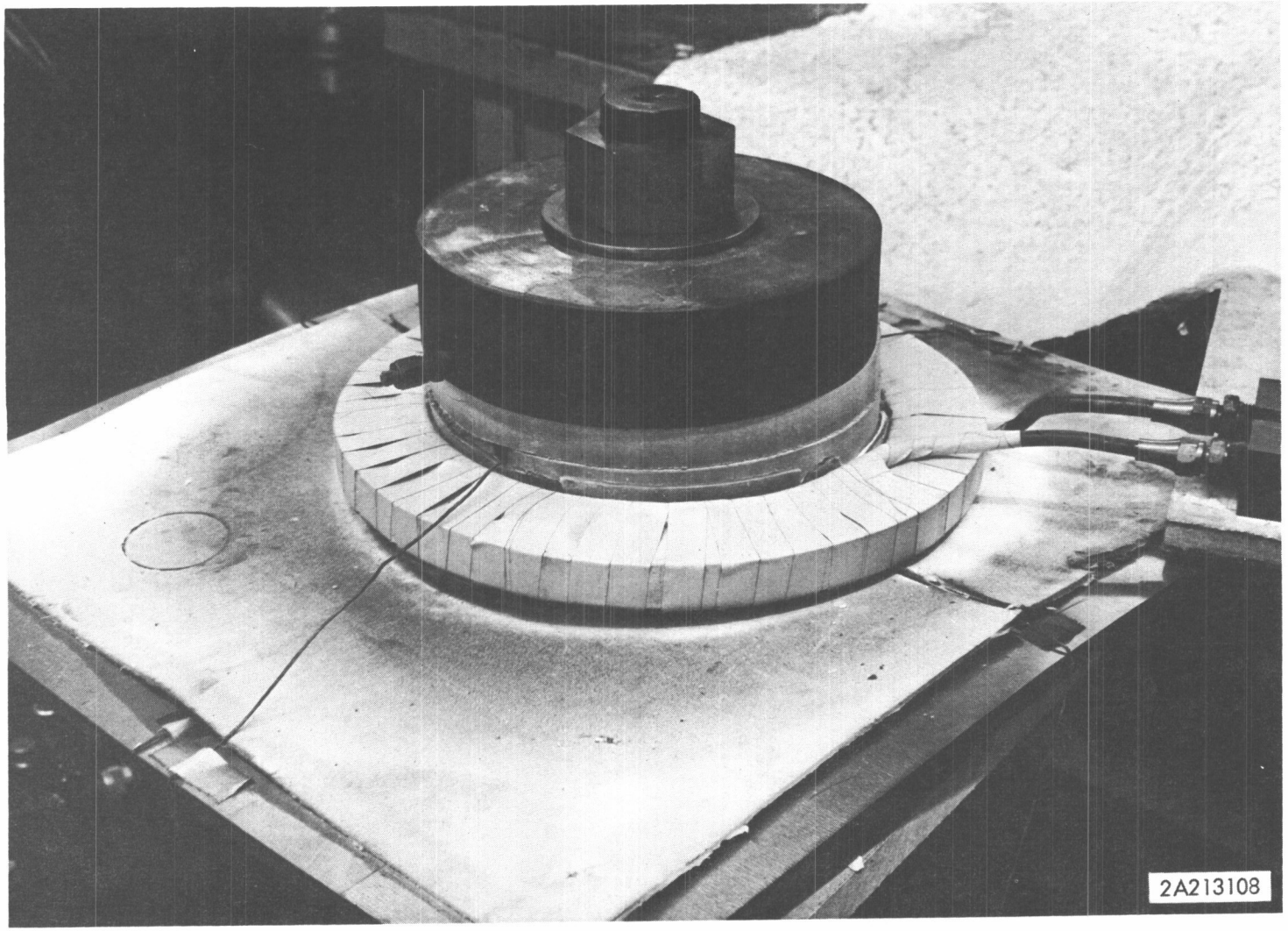



FIGURE 25
CLOSE-UP - DIFFUSION BONDING TOOL USED TO BOND TITANIUM RING TO TITANIUM PLATE

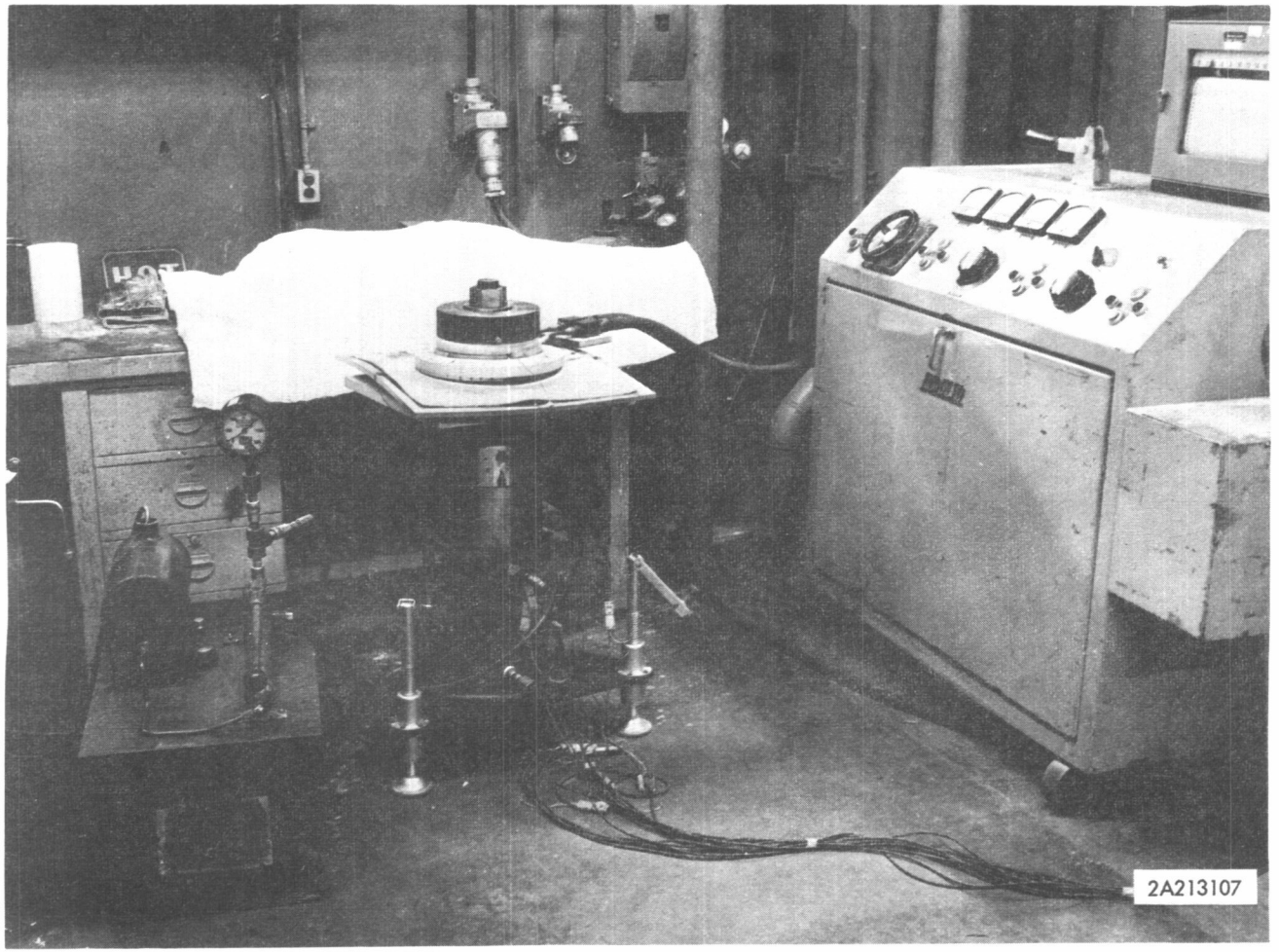



FIGURE 26

OVERALL VIEW OF THE DIFFUSION BONDING TOOL
BEING USED TO BOND A 1/2-INCH THICK TITANIUM RING DOUBLER
TO A 1/2-INCH THICK TITANIUM PLATE

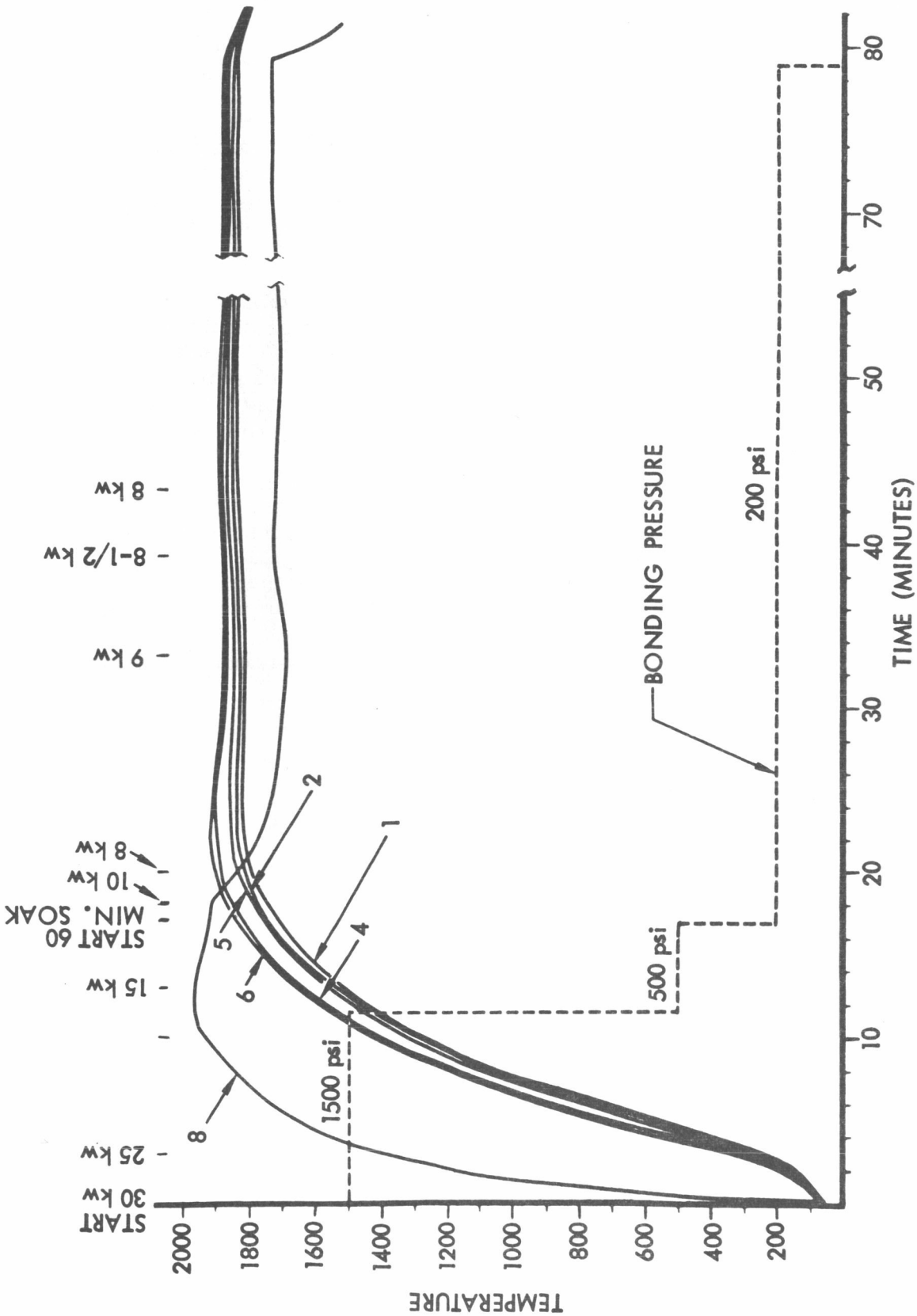



FIGURE 27
DIFFUSION BONDING CYCLE (No.'s 1, 2 & 3)

The second bonded panel, also 20 by 20 inches, had been intentionally contaminated in a specific pattern in an attempt to obtain a standard for ultrasonic inspection tests. After conducting the ultrasonic tests, the bonded assembly was sectioned and examined metallographically.

No correlation of ultrasonic and metallographic results could be established. Approximately one-third of the joint, in the area intentionally contaminated, failed to bond, while the remaining two-thirds of the joint area was well bonded. The contamination, applied in several spots of different sizes, apparently spread over the entire unbonded third of the joint rather than remaining in the localized spots to create voids of known size and shape.

Test Assembly No. 3 was the 24- by 36-inch sculptured panel. After the bonding cycle was completed, the ring and surrounding area was machined to final configuration and the panel was formed in the subscale die. Examination after forming revealed an unbonded area of the ring at the edge of the port hole, approximately 1/2-inch wide by 2-inches long. The separation of the ring from the plate resulting from this bond void is shown in the photograph (Figure 28).

As a result of the unacceptable bonding of the 24- by 36-inch sculptured panel, bonding procedures and results of the previous tests were reviewed to determine process and/or tooling revisions necessary to achieve consistently acceptable bonds. Increased pressure, to achieve improved interface contact and sealing, was established as the necessary correction. Subsequently, Test No. 4, 20-20-inch ring-plate assembly was bonded, using the following pressure-temperature schedule:

1) Apply 2000 psi pressure at room temperature and maintain during heatup to 1500°F.

2) At 1500°F, reduce pressure to 1000 psi, then further reduce pressure to 400 psi at 1800°F.

3) Maintain 400 psi throughout remainder of the bonding cycle at 1800 to 1850°F. See Figure 29 for Time-Temperature-Pressure Curve.

### 6.1.3 Subsize Process Verification Tests

To demonstrate repeatability of results achieved with the revised process, six additional 24- by 24-inch ring-plate assemblies were bonded. Surface preparation and assembly procedures were unchanged from those previously used.

The bonding cycle for 24- by 24-inch assembly, Test No. 5, had been completed and the assembly was cooling when a severe crack in the plate occurred at the edge of the ring. The crack extended around the outer edge of the ring through approximately 60 degrees of arc, then away from the ring toward opposite edges of the plate. The crack was completely through the plate and extended roughly parallel to the plate rolling direction to within one inch of opposite edges (Figure 30). Sections taken from the bond area showed failure to bond at the inside edge of the ring extended approximately 0.10-inch beyond the excess provided. Intermittent small voids were also evident across the full width of the bond.

Test No. 6, 24- by 24-inch ring-plate assembly was prepared and bonded using the same procedure. This plate also cracked at some time during cool down

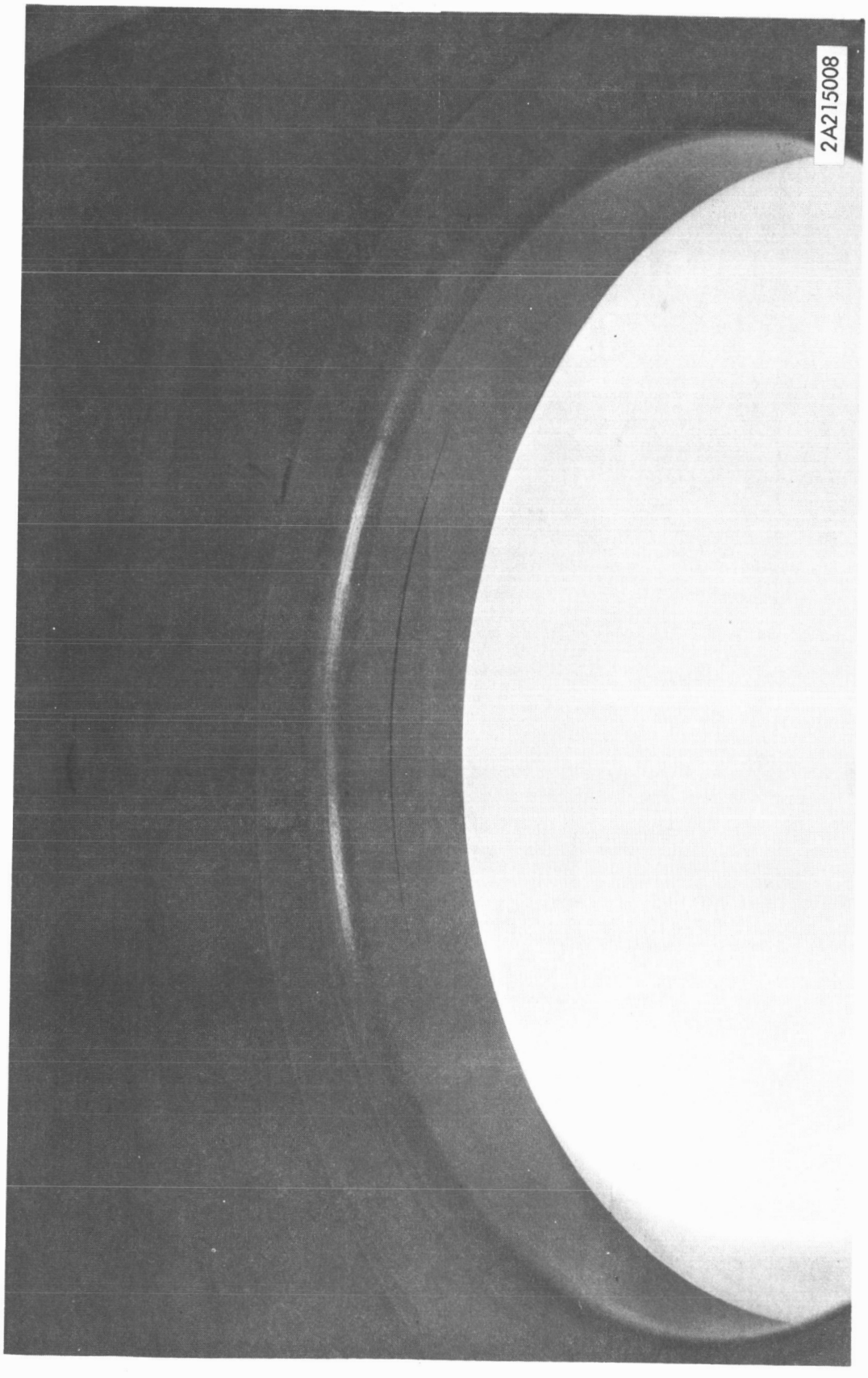



FIGURE 28

SEPARATION OF DIFFUSION BONDED (TI) RING FROM (TI) PLATE- AFTER FORMING

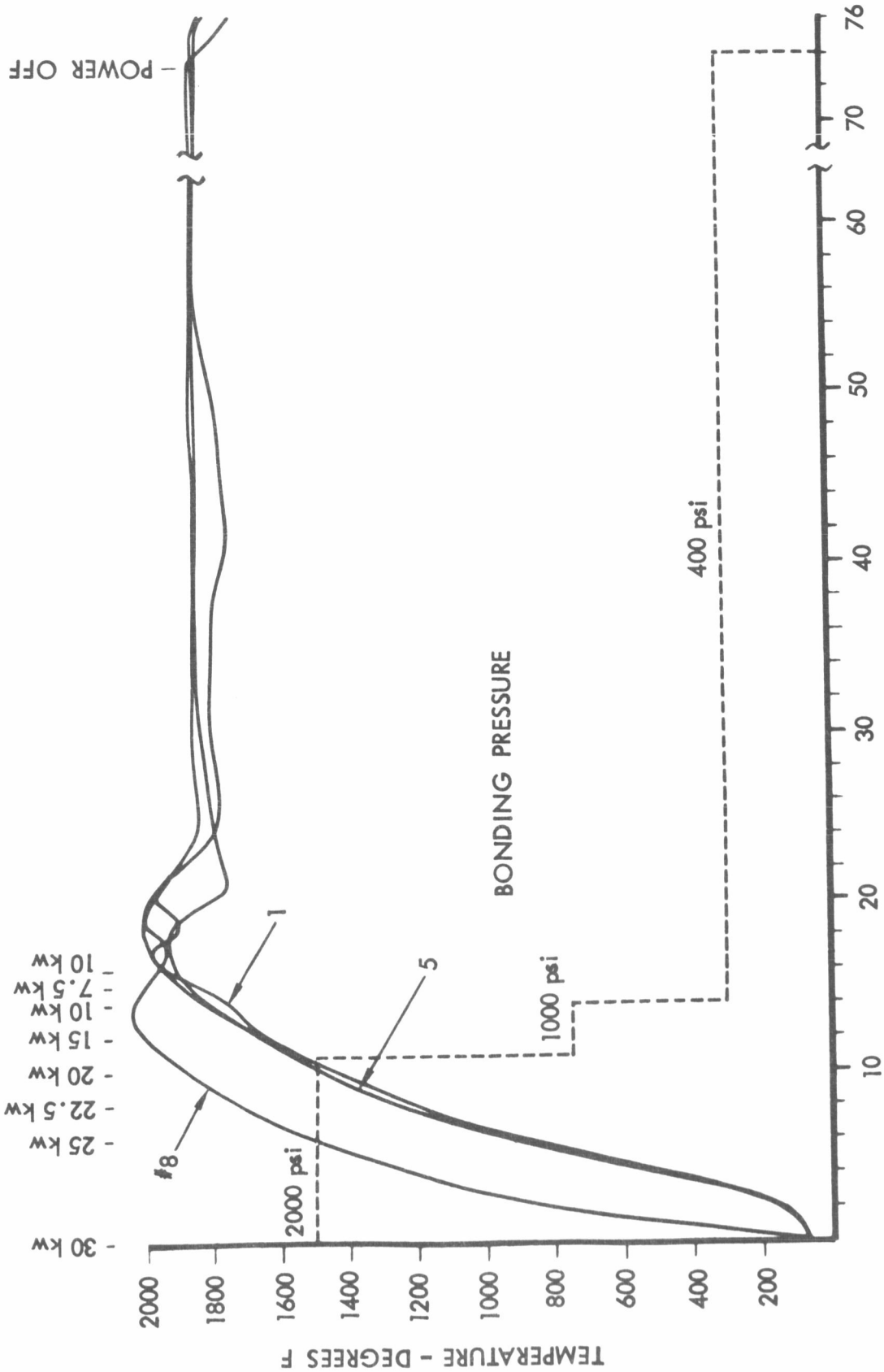



FIGURE 29

DIFFUSION BONDING CYCLE (4, 5 & 6)

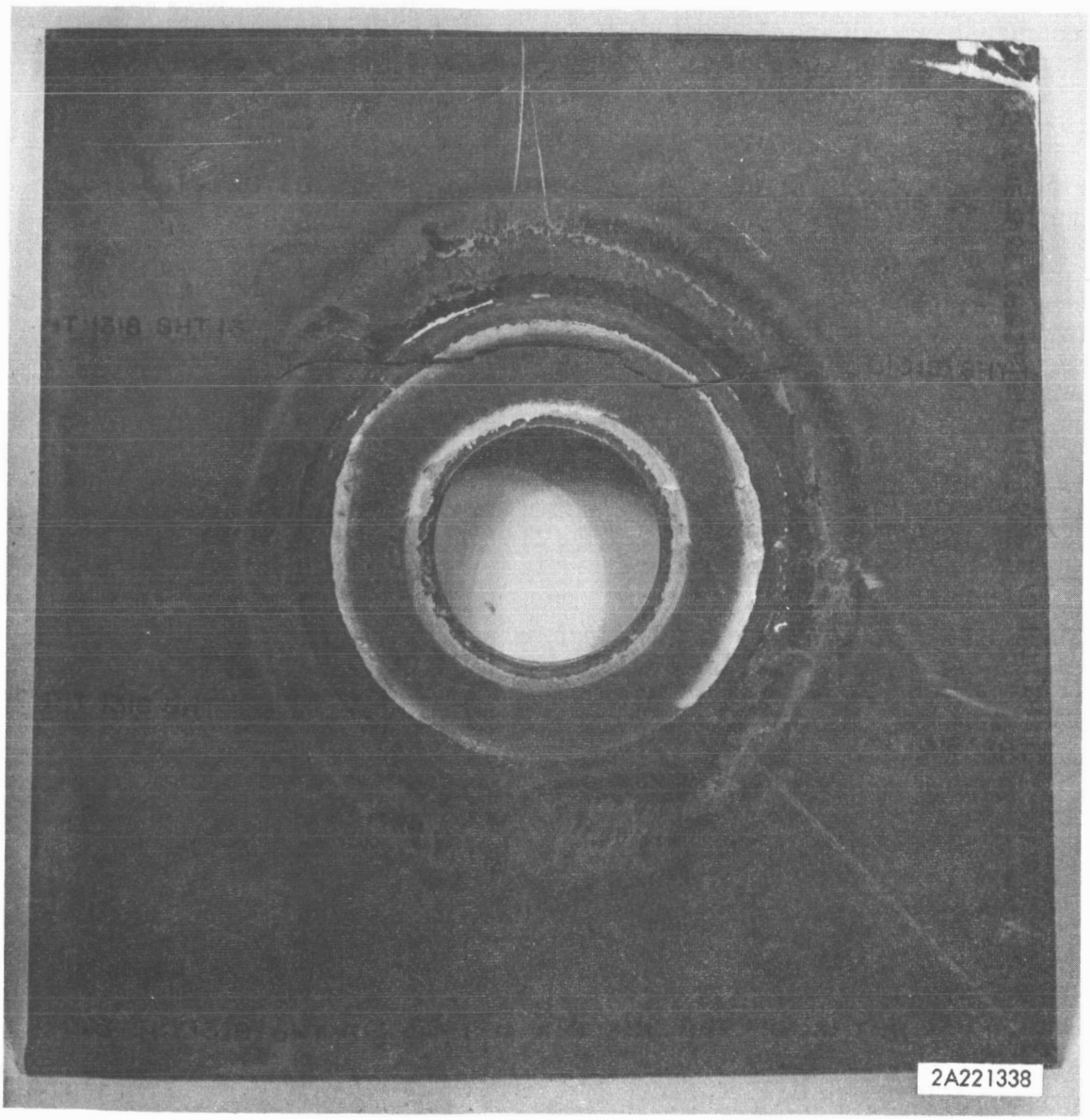



FIGURE 30

RESIDUAL STRESS CRACK IN DIFFUSION BONDED (TI) PLATE
(TEST ASSEMBLY #1)

after bonding. The crack occurred in the same relative location as the crack in the first plate, although it extended away from the ring toward only one edge of the plate. Sections from this bond showed less edge void but only intermittent bonding of the ring to the plate.

As a result of cracking of two successive assemblies, and inconsistent bond quality in the first six assemblies, a review of bonding procedures and conditions was conducted. Cracking of the two plates was attributed to the combination of high compression load and thermal stress produced by the extreme temperature gradient resulting from localized heating. Inconsistent bond quality was attributed to lack of intimate contact resulting from surface finish variation. Measures selected to eliminate these problems were to reduce the temperature gradient by application of insulation, thereby reducing heat loss from plate surfaces away from the bonding area; and to increase initial bonding pressure to overcome surface variations and achieve improved interface contact.

Subsequently, for Test No. 7, 24- by 24-inch assembly, a change was made in the bonding pressure schedule. A pressure of 3000 psi was applied at room temperature and maintained until bond area temperature reached 1500°F, at which time pressure was reduced to 600 psi. Pressure was again reduced when temperature reached 1800°F, to 400 psi, which was maintained for the remainder of the heat cycle. Insulation was added to completely cover both surfaces of the plate, to reduce the temperature gradient from the heated bond area to the plate edges. On completion of the bonding cycle, the assembly was allowed to cool with pressure relieved. Figure 31 is a plot of the time, temperatures, and pressures for Part No. 002, and illustrates the cycle used for bonding Tests 7 through 12, and the three full size parts.

For Tests No. 8, 9, and 10, 24- by 24-inch assemblies were bonded following the same procedures as those used for the third 24-inch square assembly. These were also tested ultrasonically for bond voids. Except for lack of bond within the excess allowed at the ring edges, no voids were indicated in assemblies four and five. However, ultrasonic test indicated an area of extensive voiding in the bond of the sixth assembly. This area was sectioned extensively through the indicated voids and examined at magnifications up to 500 diameters. No voids were detected at the bondline, although numerous voids were evident in the plate metal. Typical bondline and voids in the base metal are shown in the (100X) photomicrographs, Figures 32 and 33.

Test No. 8 assembly was also sectioned at 90-degree intervals around the ring and examined metallographically. Complete bonding was evident except at the ring edges where lack of bond was confined to the excess provided to accomodate it.

Test No. 9, 24- by 24-inch assembly was used for forming tests and therefore was not sectioned. No indication of bond failure or plate cracking was observed during tests with this assembly. Test No. 10, bonded assembly was also good.

As a result of this series of tests, the procedure for bonding the reinforcing ring around the port hole in the gore skin was finalized with the same procedure used for the last four assemblies of this series.

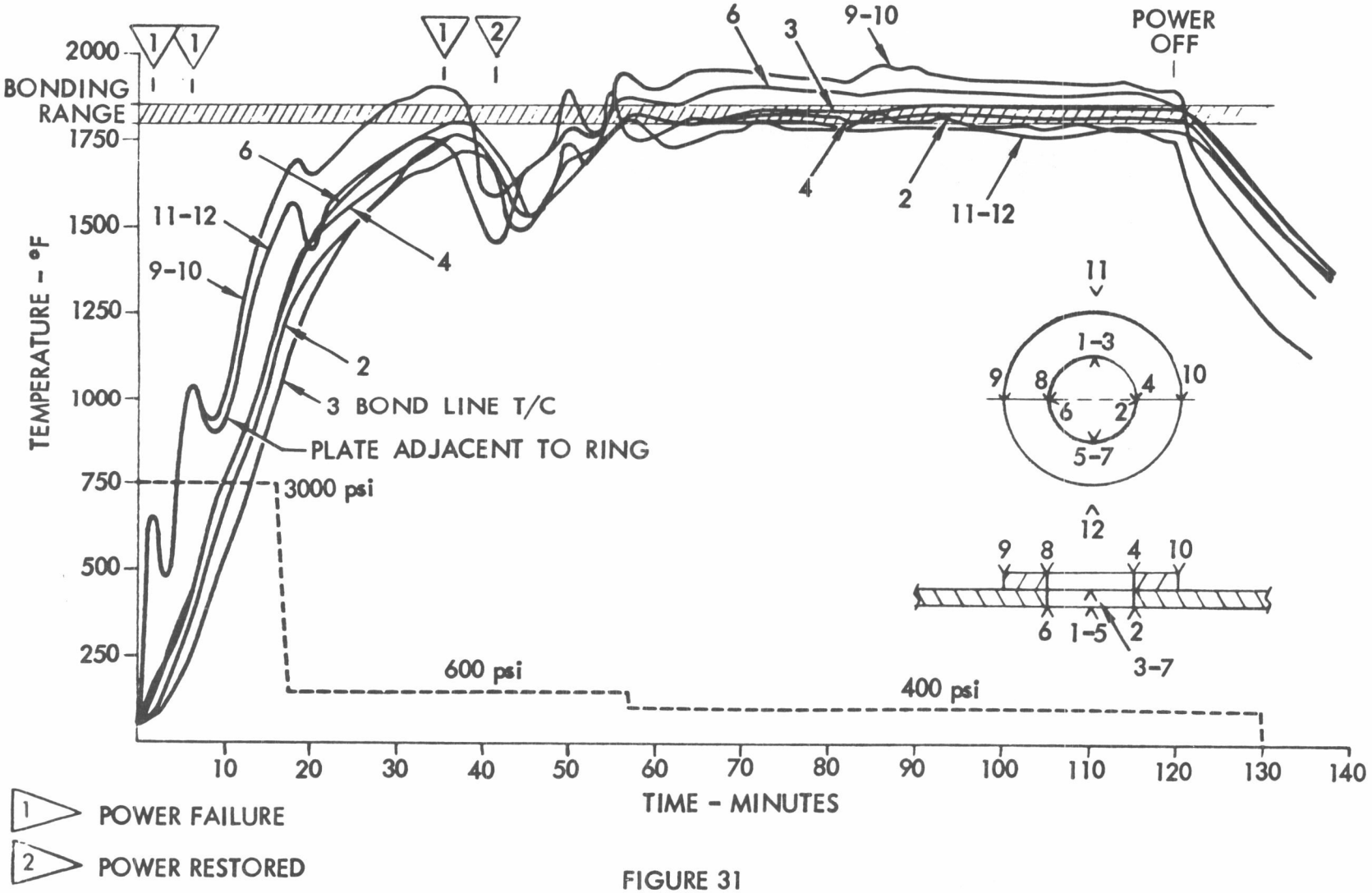



FIGURE 31

TYPICAL DIFF. BONDING CYCLE NO. 7, 8, 9, 10, 11 & 12 + 3 FULL SIZE GORE SEG.

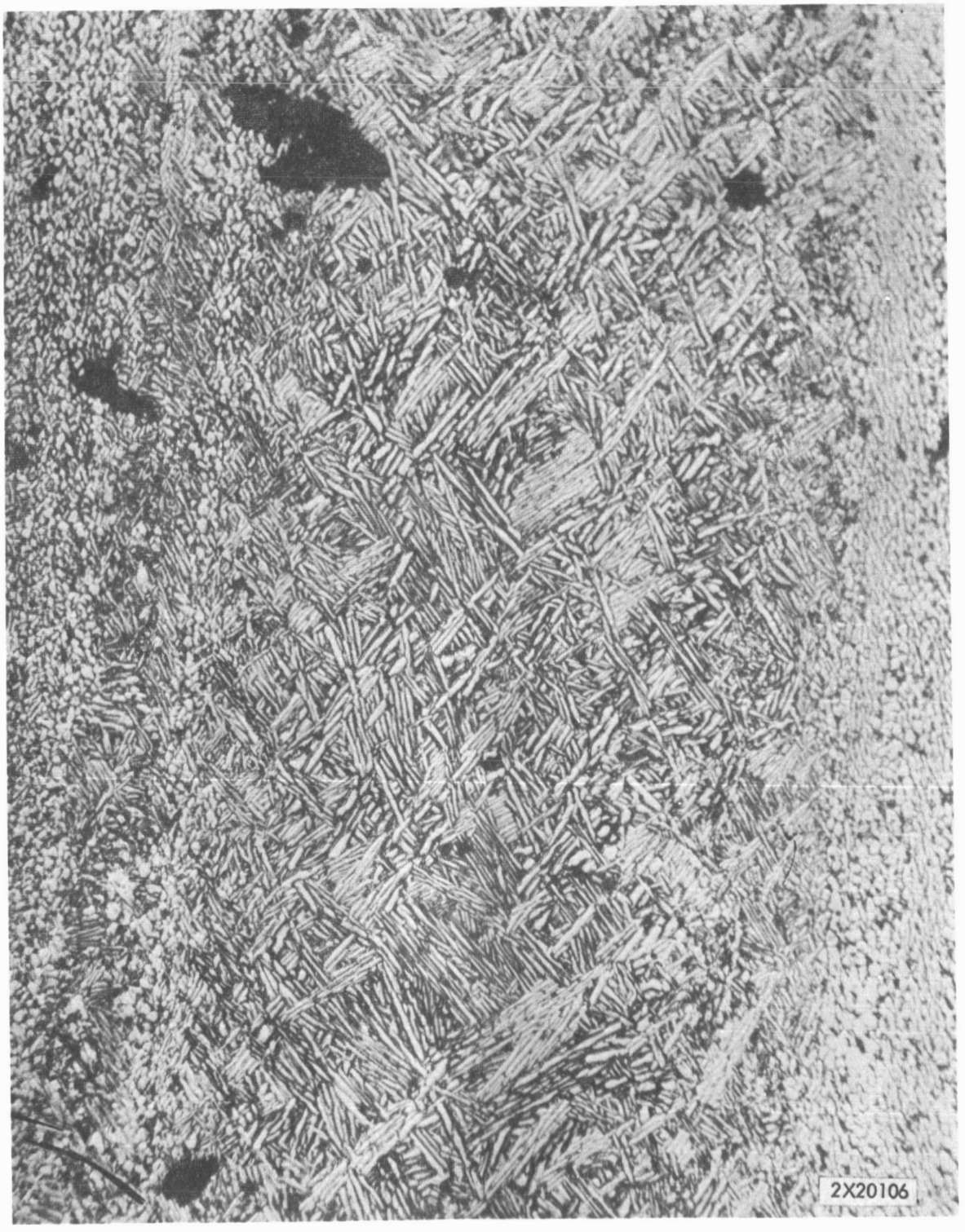



FIGURE 32

VOIDS IN BASE METAL-BONDLINE VISIBLE AT LEFT EDGE OF PHOTO - 100X (ENLARGED APPROXIMATELY 1-3/4 TIMES) (TEST ASSEMBLY #6)

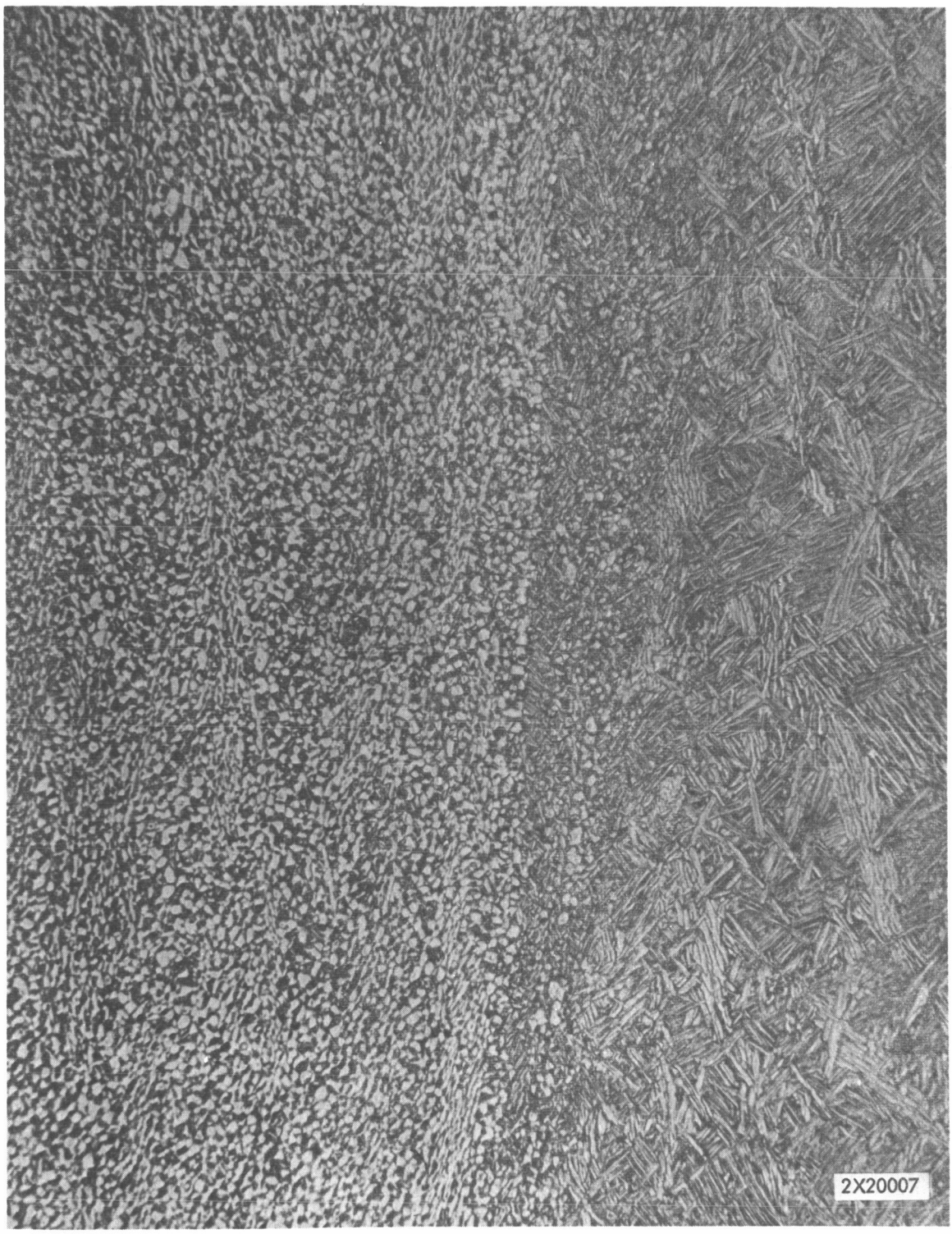



FIGURE 33

BONDLINE - 100X (ENLARGED APPROXIMATELY 1-3/4 TIMES)
(TEST ASSEMBLY #6)

6.1.4 Large Size Verification Tests

Procedures for assembling and bonding the reinforcing rings to the two 4- by 10-foot plates were the same as used for the previous smaller assemblies, with the exception of handling methods. The plates were placed on supports on each side of the hydraulic cylinder which was shifted to align with the port hole. With the insulating rings positioned on the anvil blocks, the cylinder was raised with the leveling jacks to contact the lower plate surface. These are bonded Tests No. 11 and 12 shown in Table I and the Time-Temperature-Pressure Curve shown in Figure 31 is typical for these assemblies.

Thermocouples were located in and adjacent to the bond area to monitor temperatures during bonding. Insulating blankets of 1/2-inch thick felted "Micro-Quartz" were placed on both plate surfaces covering an area approximately 4- by 6-feet surrounding the heated zone.

Distortion of the plates due to the localized heating during the bonding cycle, was observed to raise the hydraulic pressure tool three to four inches above the floor. Distortion remaining after cool down took the form of a wave of approximately 2-inch amplitude. Figures 34 and 35 are photographs of the plate before and after bonding, giving an indication of the distortion resulting from the bonding operation.

After bonding, the first assembly was alkaline cleaned and chemically etched in a nitric-hydrofluoric solution. After cleaning, a severe crack in the plate adjacent to the ring was observed. Figure 36 is a photograph showing the crack from the surface opposite the ring. It was concluded that the cracking was caused by accelerated stress corrosion during the etching operation. This conclusion was arrived at as a result of the following facts: approximately 60 hours had elapsed from completion of bonding to start of the cleaning operation. During this period numerous individuals had examined the assembly and had observed no indication of cracking. The crack was first observed during withdrawal from the nitric-hydrofluoric acid etching solution, at which time it was quite extensive and readily apparent on casual observation.

High residual stress resulting from localized heating during bonding, coupled with exposure to the corrosive etching solution provided the necessary conditions for stress corrosion. It was then decided that a furnace stress relieving operation should be conducted as soon as possible following the bonding operation, prior to chemical cleaning. The second 4- by 10-foot panel was bonded and then stress relieved in an air atmosphere furnace at 1200°F for two hours. No cracks developed in this panel and it was concluded that stress relieving had eliminated the problem.

6.1.5 Diffusion Bonding Full Size Base Gore Segments

Bonding procedures for the full size gore segment were the same as those established during the final process development tests and utilized for the 4- by 10-foot panels. Handling procedures and supporting equipment were the only items differing from the earlier bonding tests. A temporary work table, 8 by 12 feet, was erected to support the titanium plates in the horizontal position and permit access from below for the hydraulic cylinder. The aluminum plates used for the support table were thermally insulated from the gore segment by a one-inch

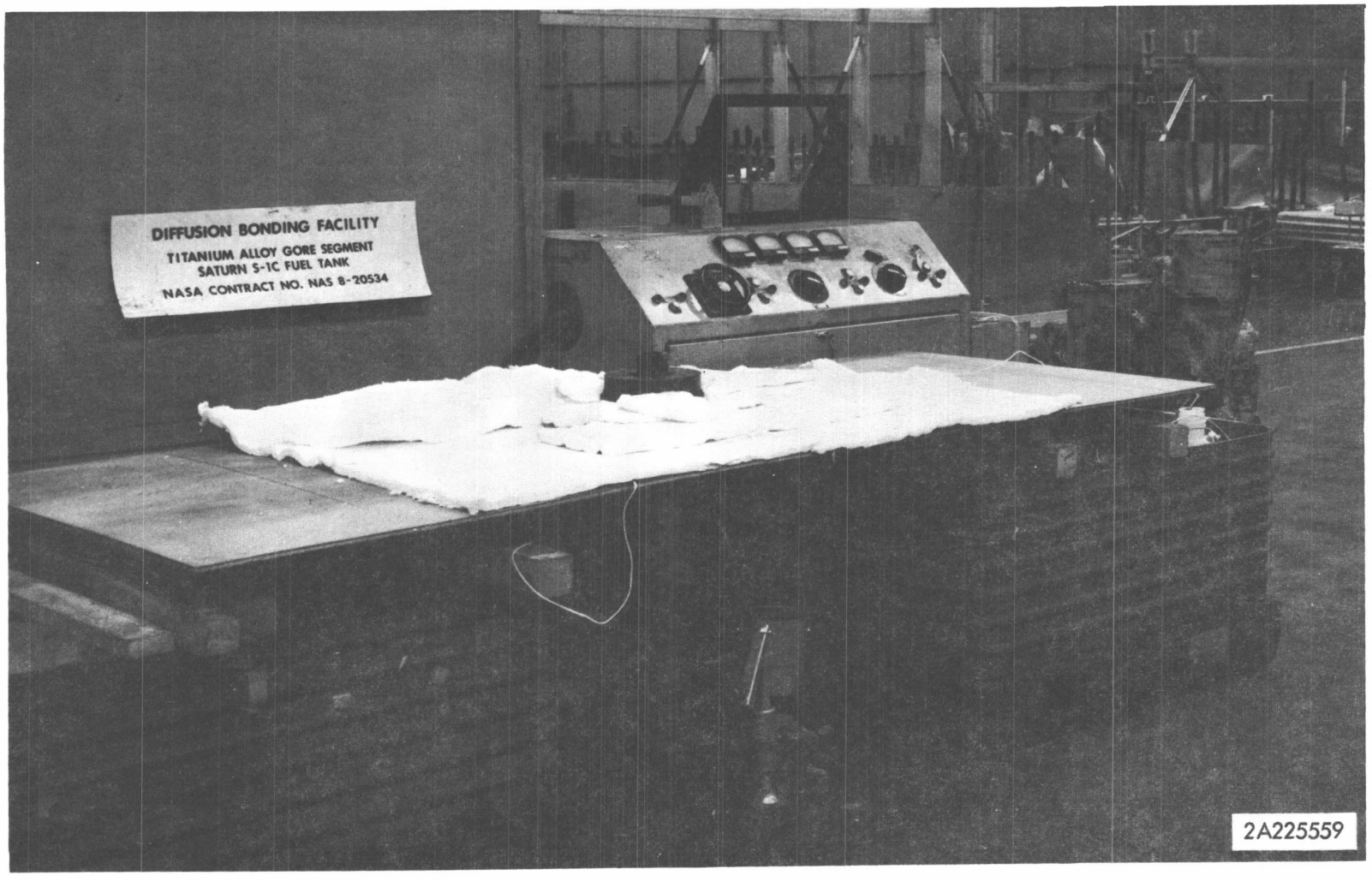



FIGURE 34

DIFFUSION BONDING OF (Ti) RING TO 4 X 10 FT. (Ti) PANEL
(HEATING CYCLE)

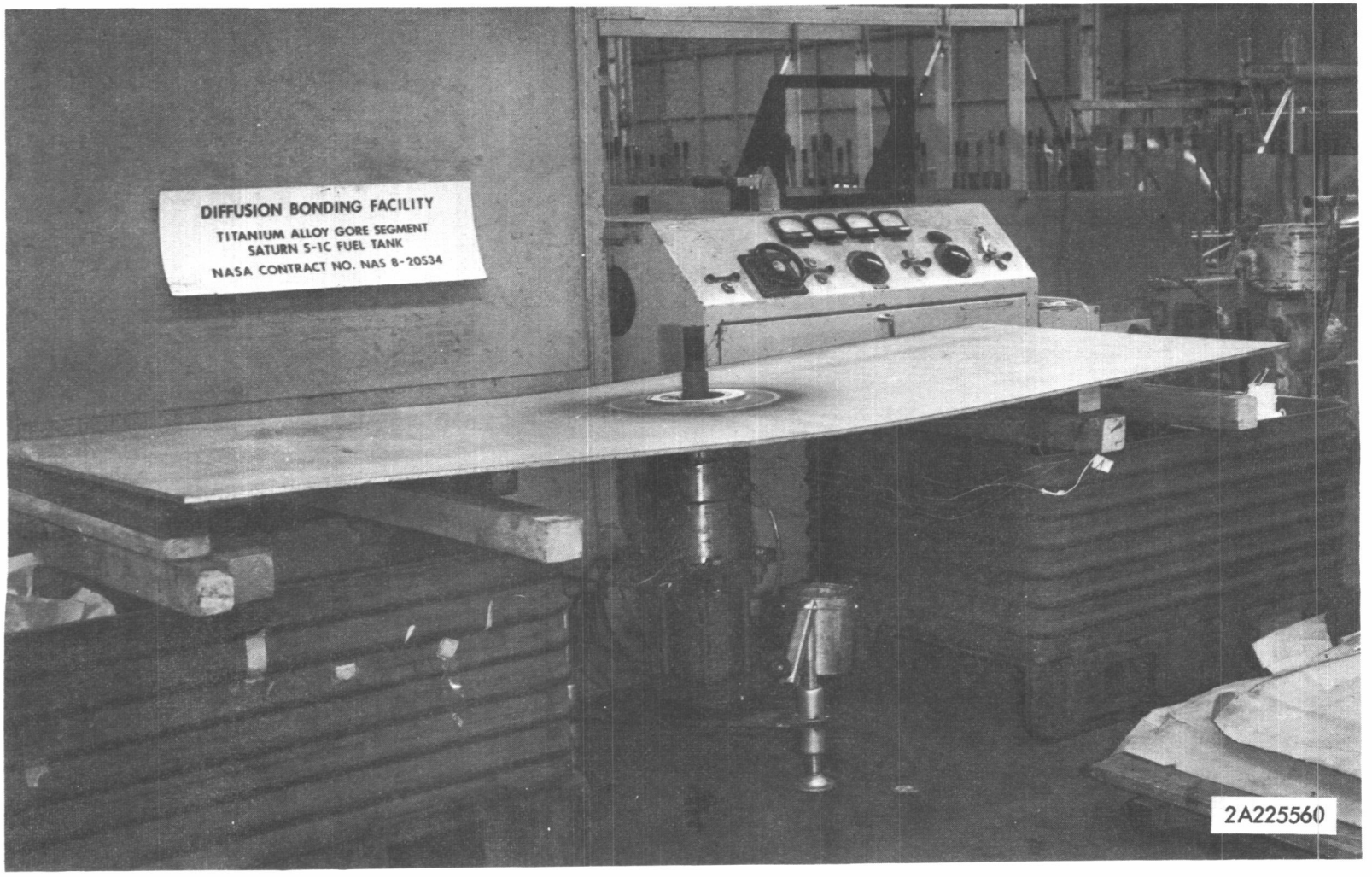



FIGURE 35

DIFFUSION BONDED 4 FT. BY 10 FT. BY 1/2-INCH TITANIUM PANEL, AFTER BONDING

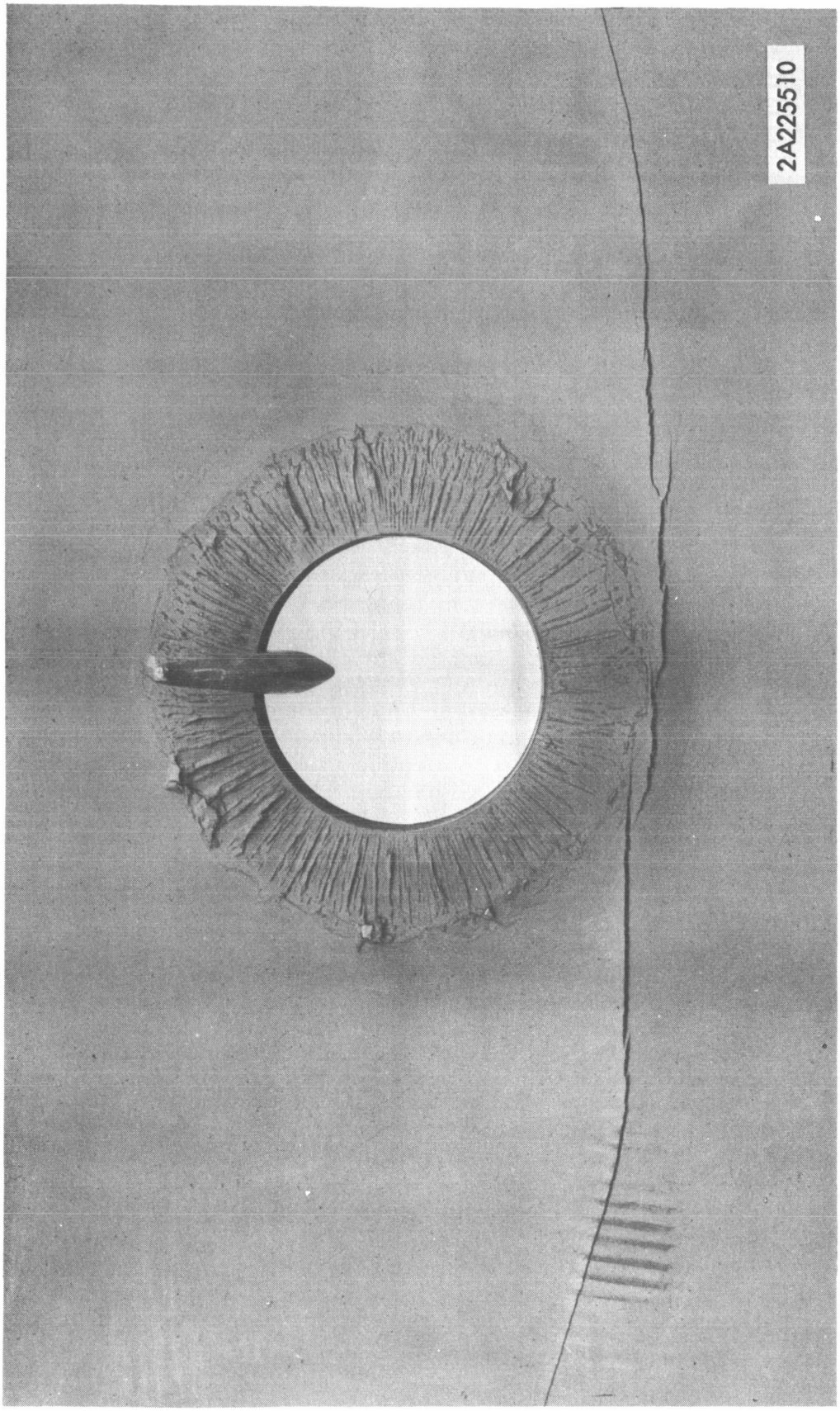



FIGURE 36
RESIDUAL STRESS CRACK IN DIFFUSION BONDED (Ti) PLATE
(4 X 10 FT. TEST)

thickness of "Molten Metal Maranite." After assembly of the ring and tooling shown in Photos of Figures 37, 38, and 39 additional "Micro-Quartz" insulating blankets were used to cover approximately the center half of the plate, as shown in Figure 40.

Thermocouples were located in and adjacent to the bond area during assembly, to monitor temperature during the bonding cycles for the three gore segments. Temperatures were recorded at one minute intervals using a Brown "Elektronic" multipoint recording potentiometer. Curves of temperatures versus time were plotted from the recording. The plot for Part No. 002 is shown in Figure 31. Bonding pressure versus temperature and time is also shown.

The first two parts bonded were units No. 002 and 003, which were not machined, except for the spotfaced surface around the port hole. The third assembly bonded was Part No. 001, which, to accommodate N/C machine schedules, had been sculptured prior to bonding. Machining of pockets and ribs was complete except in an area approximately 20 by 36 inches around the port hole as shown in the photo, Figure 41. Pockets adjacent to this area were filled with steel shims prior to bonding, in an attempt to compensate for the reduced mass around the heated zone. However, this was ineffective in preventing substantial warpage of the pocket webs as indicated in the photo of Figure 42.

Before the stress relief cycle could be accomplished on Part No. 002, a crack in the plate around the edge of the ring doubler was observed. This crack extended approximately 270 degrees around the edge of the ring, but did not appear to penetrate the plate completely. Cause of the crack was attributed to thermal stress resulting from the extreme temperature gradient from the heated zone to the cold surrounding area of the plate. To overcome this problem for the second and third bonding operations (Part No's. 003 and 001), an additional one-inch thickness of felted "Micro-Quartz" insulation was placed between the plate and the "Maranite" insulation on the support table. No cracks occurred in the two subsequent parts.

See Table II for Diffusion Bonding Cycle for full size gores.

6.1.6 Conclusions:

The diffusion bonding procedures arrived at late in this program produced good parts; however the process does not have a large margin of safety. Development should be conducted to improve this margin of safety. Heating a local area of a large plate and subjecting that area to "Upsetting" forces causes high local stresses in the heat affected zone. Reducing this stress or improving the stress relief after bonding will add an additional factor of safety to the process.

Variation of insulation techniques during bonding and stress relieving cycles after bonding were explored during this program. Further work is recommended in addition to considering a higher die forming temperature for better stress relief.

TABLE II

DIFFUSION BONDING - FULL SIZE GORES

| Test No. | Test Panel Size | Bonding Cycle: Elapsed Cycle Time - Min | Bonding Cycle: Temp. - °F | Bonding Cycle: Press - PSI | Comment |
|---|---|---|---|---|---|
| 13 | Gore Unit #2 | Start - 0<br>15<br>57*<br>120 | R.T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond - plate cracked |
| 14 | Gore Unit #3 | Start - 0<br>15<br>35<br>110* | R.T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond |
| 15 | Gore Unit #1 | Start - 0<br>15<br>27<br>113* | R.T.<br>1500<br>1800<br>1800 - 1850 | 3000<br>600<br>400<br>400 | Good bond |

* Power interruption caused by drop in transformer cooling water pressure.

## 6.2 MACHINING DEVELOPMENT

Machining of 8-1-1 titanium was an area that required little or no development since parameters for machining had previously been established on other Company research programs. This program served to verify that these parameters were valid. It pointed up that rigidity of both machine and part have a direct effect on part tolerances and machining costs. Throughout the course of this program improvements were made to achieve additional part rigidity. Wherever this was achieved tolerances were improved and material removal rates increased.

### 6.2.1 Large Size Verification Hardware

Pocketed parts such as the titanium gore segment can be produced by either of two basic machining methods, chemical milling or conventional milling. The large size verification tests of the 8- by 10-foot panel presented the opportunity to determine which method of metal removal would best support this type program.

For producing the pocket pattern, by chemical milling, calculations showed that 10 cubic inches of metal per minute could be removed, compared to 2.5 cubic inches per minute by profile milling.




FIGURE 37

DIFFUSION BONDING-FULL SIZE GORE #002
(DETAIL PARTS BEFORE BONDING)

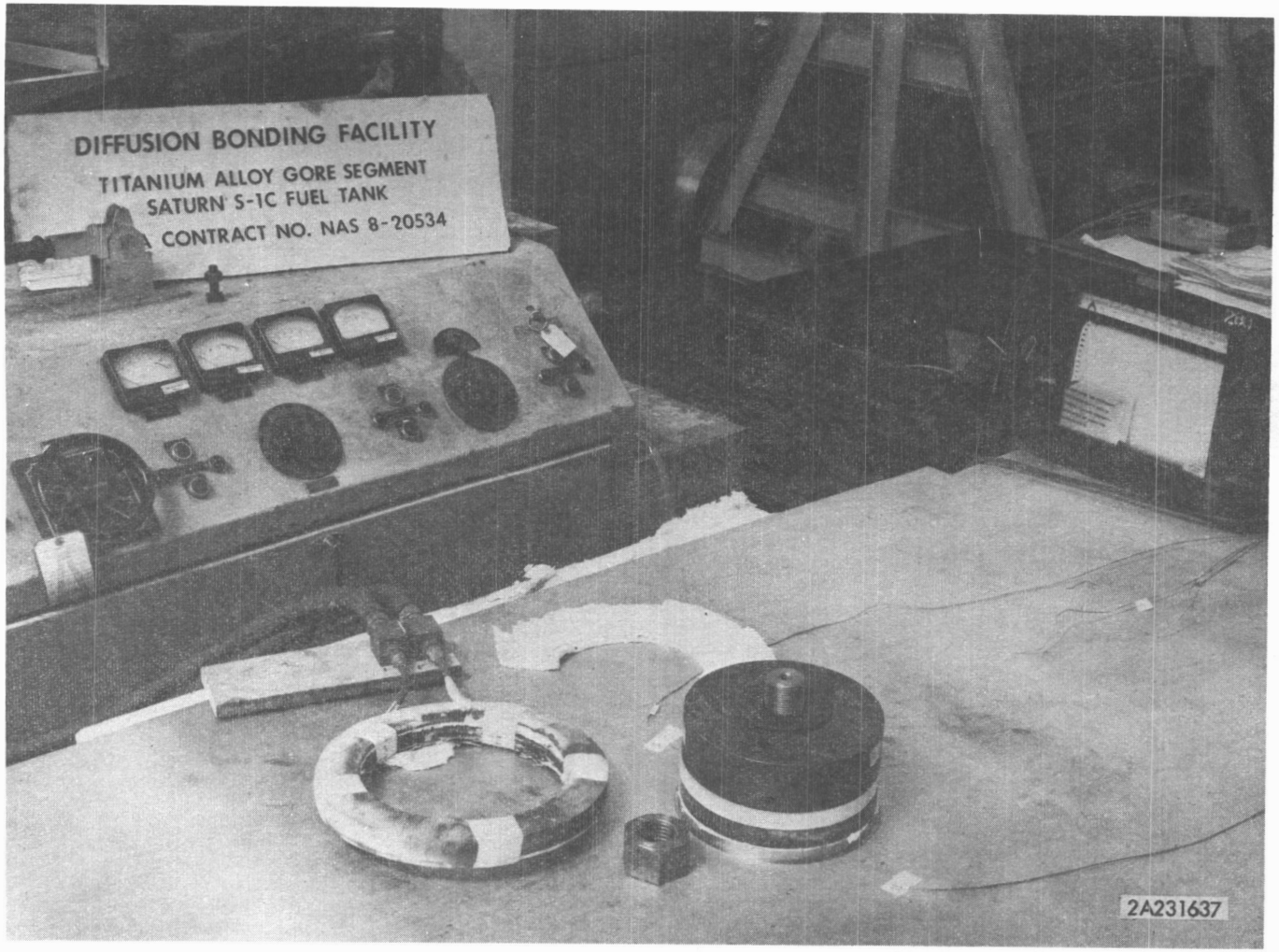



FIGURE 38

DIFFUSION BONDING-FULL SIZE GORE #002-
PARTIAL ASSEMBLY BEFORE BONDING

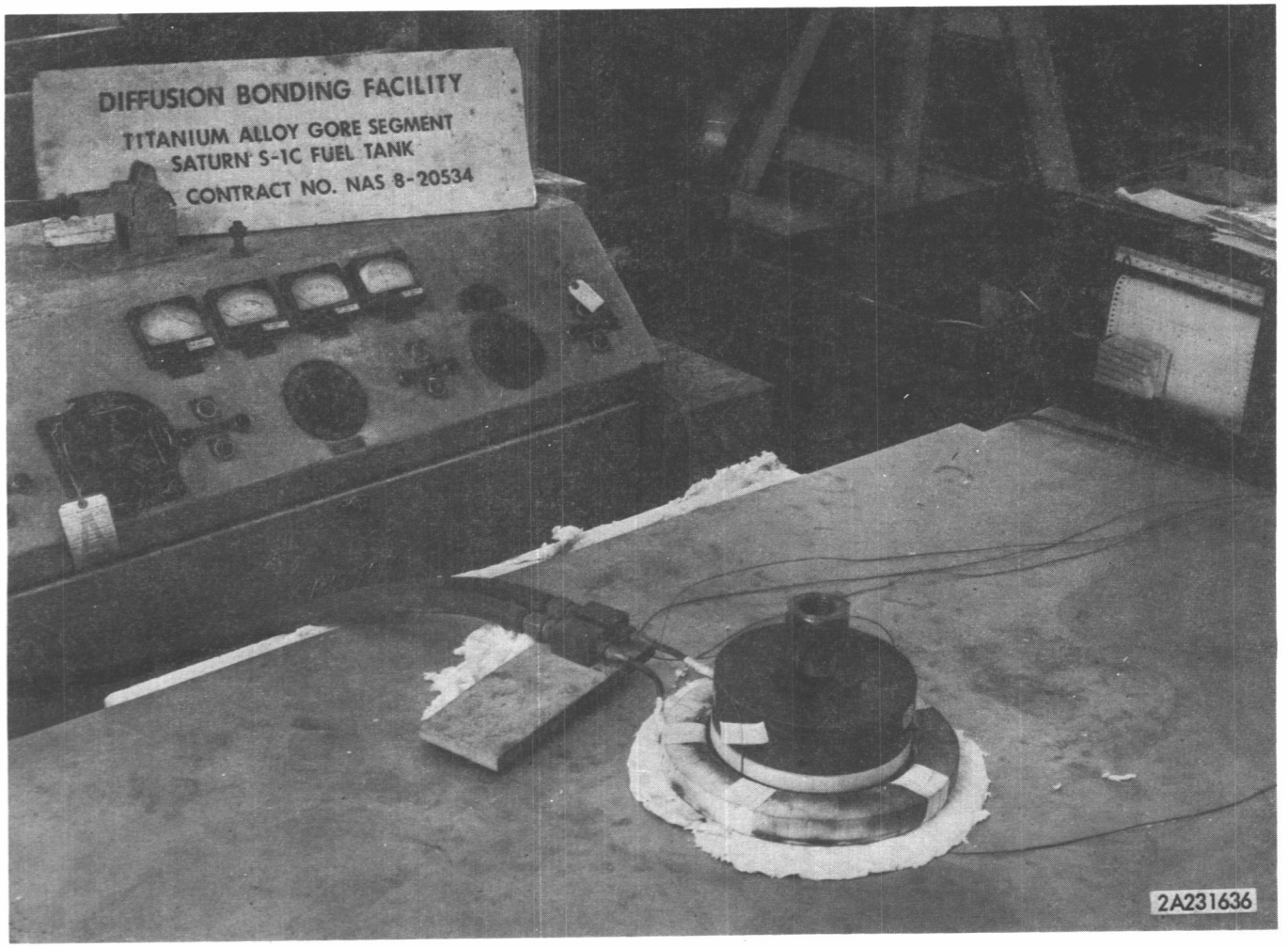



FIGURE 39

DIFFUSION BONDING-FULL SIZE GORE #002-
BEFORE BONDING

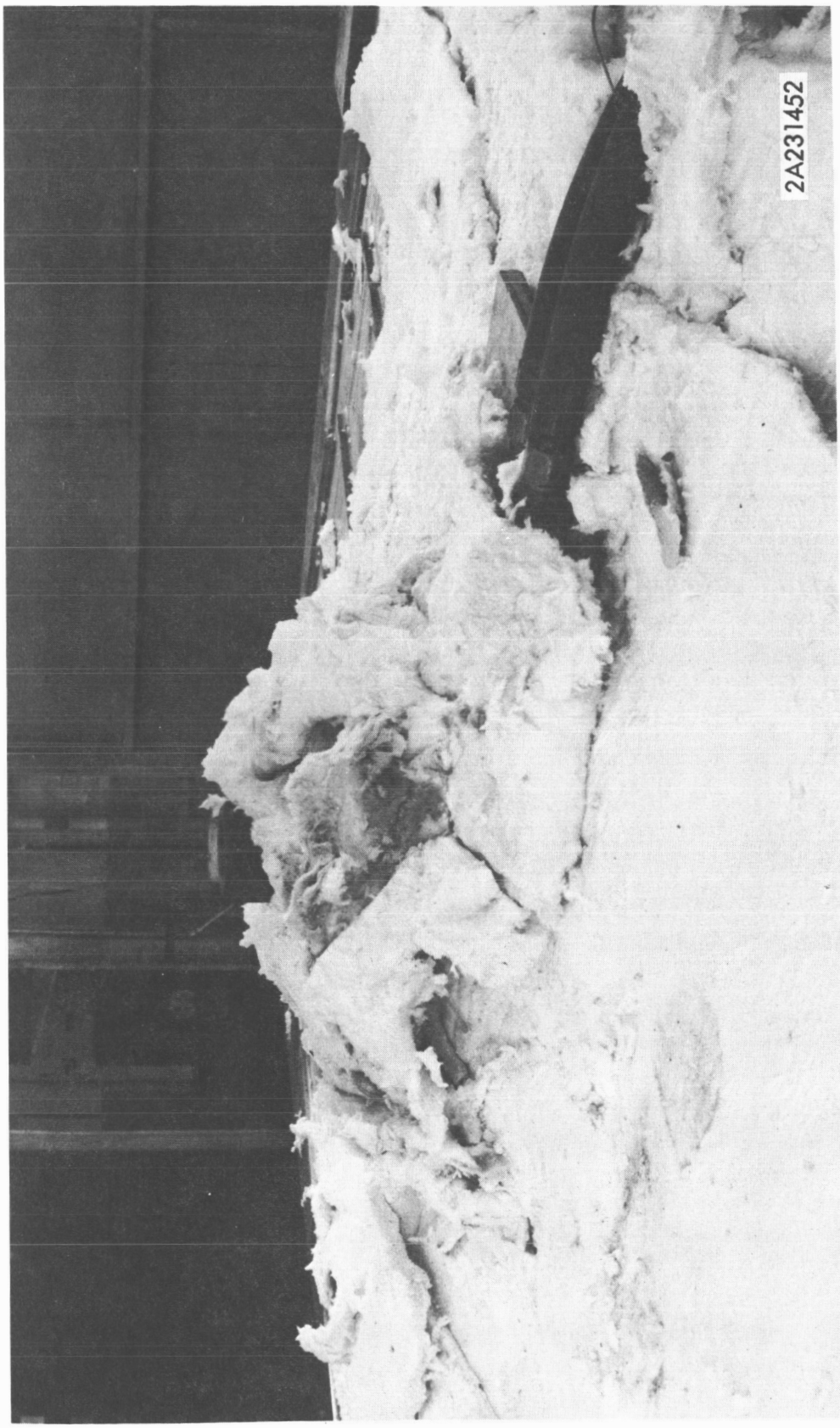



FIGURE 40

DIFFUSION BONDING-FULL SIZE GORE #001-
DURING BONDING

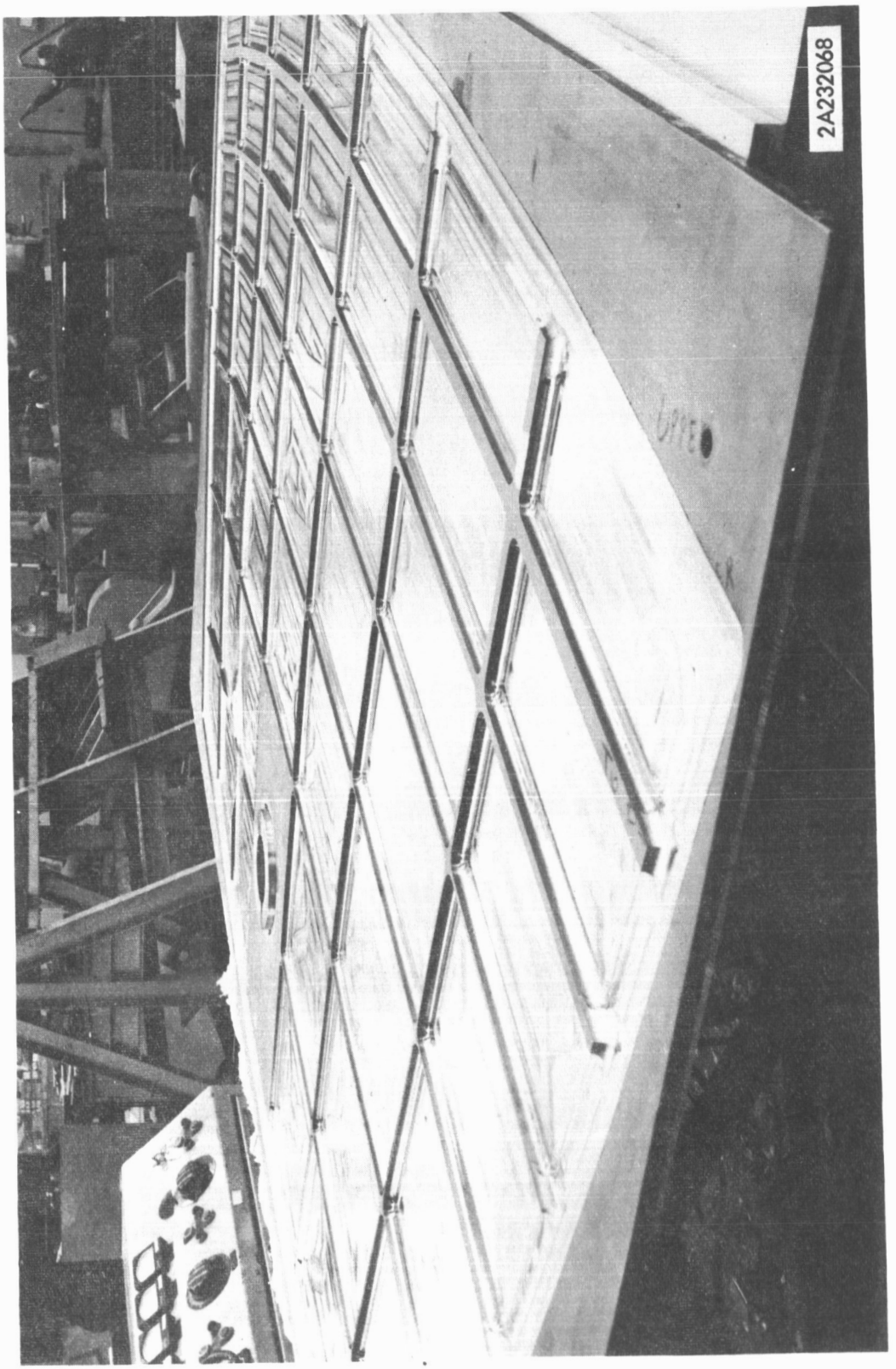



FIGURE 41
DIFFUSION BONDING - FULL SIZE GORE #001 -
BEFORE BONDING




FIGURE 42
DIFFUSION BONDING - FULL SIZE GORE #001 - AFTER BONDING

Actual removal rates were less by both methods. Chemical milling was slower because the tank was not deep enough to immerse the entire panel (Figure 43) and because the solution had to be cooled for 2 hours after each 1/2-hour of milling. Overall metal removal rate was about 1 cubic inch per minute. The web thickness after chemical milling was about 0.2 ±0.02 inch. (See Figure 44).

6.2.1.1 Conventional Milling

A numerical control program had been written for the machining of this panel, but higher priority work prevented the use of numerical control machines. Therefore, a sheet metal template was made so that the pocket pattern could be finished to final tolerances on a Keller tracer mill. The machining operation is shown in Figures 45 and 46.

To save time and money, only the cracked half of the panel was finish machined. Web thickness was about 0.090 ±0.010 inch. Approximately 0.120 inch was removed in 250 hours overall machining time, at an average of 0.030 cubic inch per minute. The low metal removal rate was due to the fact that finish cuts were being made and extra care was taken to hold tolerances.

6.2.2 Preparation For Gore Machining

Prior to gore machining two facts had to be determined: first, if chemical milling would be a more economical process; and second, what would the flat pattern of the part be to produce a formed part to design tolerances.

From the full size verification test results, it was determined that equipment in the size required for chemical milling was not available in-plant. Also, that chemical milling could not meet thickness tolerances of ±0.008 inch unless the plate was machined on both sides prior to chemical processing. Consequently, the decision was made to mill the pockets of the gore by profile milling.

6.2.2.1 Gore Flat Pattern Development

While no machining development was required in terms of feeds, speeds, cutter geometries, and lubricants it was necessary to convert the design configuration to a flat pattern.

Flat machining patterns of aluminum gores now in production were developed empirically some time ago. Prints of these patterns were obtained and studied. The aluminum gores are hydraulically bulge formed, whereas the titanium gores are vacuum creep formed. During bulge forming, the entire part stretches, while essentially no material flow results from vacuum creep forming. This difference in forming methods meant the earlier flat pattern work was not applicable.

Since the contract did not provide for the time or material to develop a new empirical flat pattern, analytical methods for applying subscale test results were worked out. The following discussion describes this analytical flat pattern development.

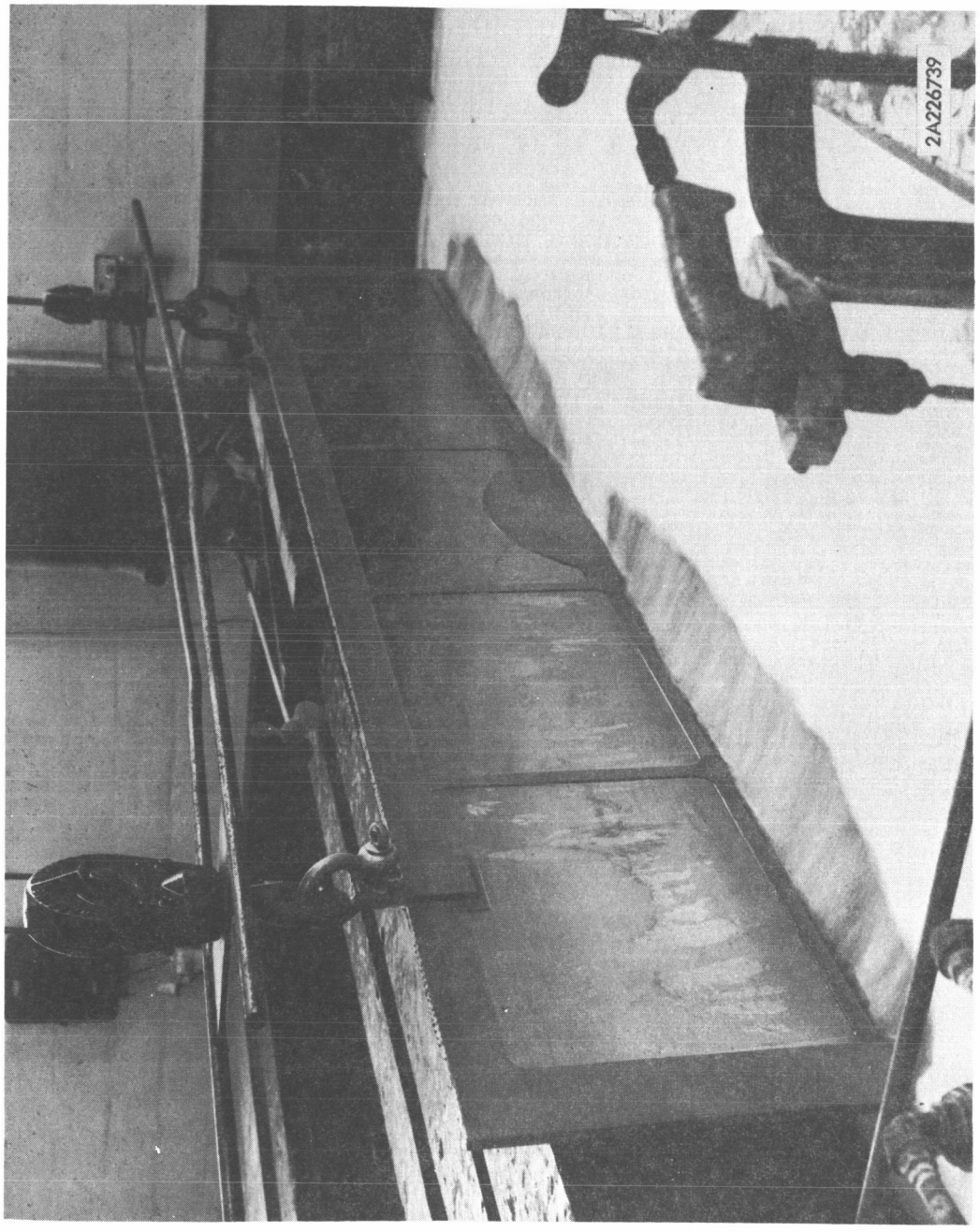



FIGURE 43
WELDED TITANIUM PANEL BEING CHEM MILLED

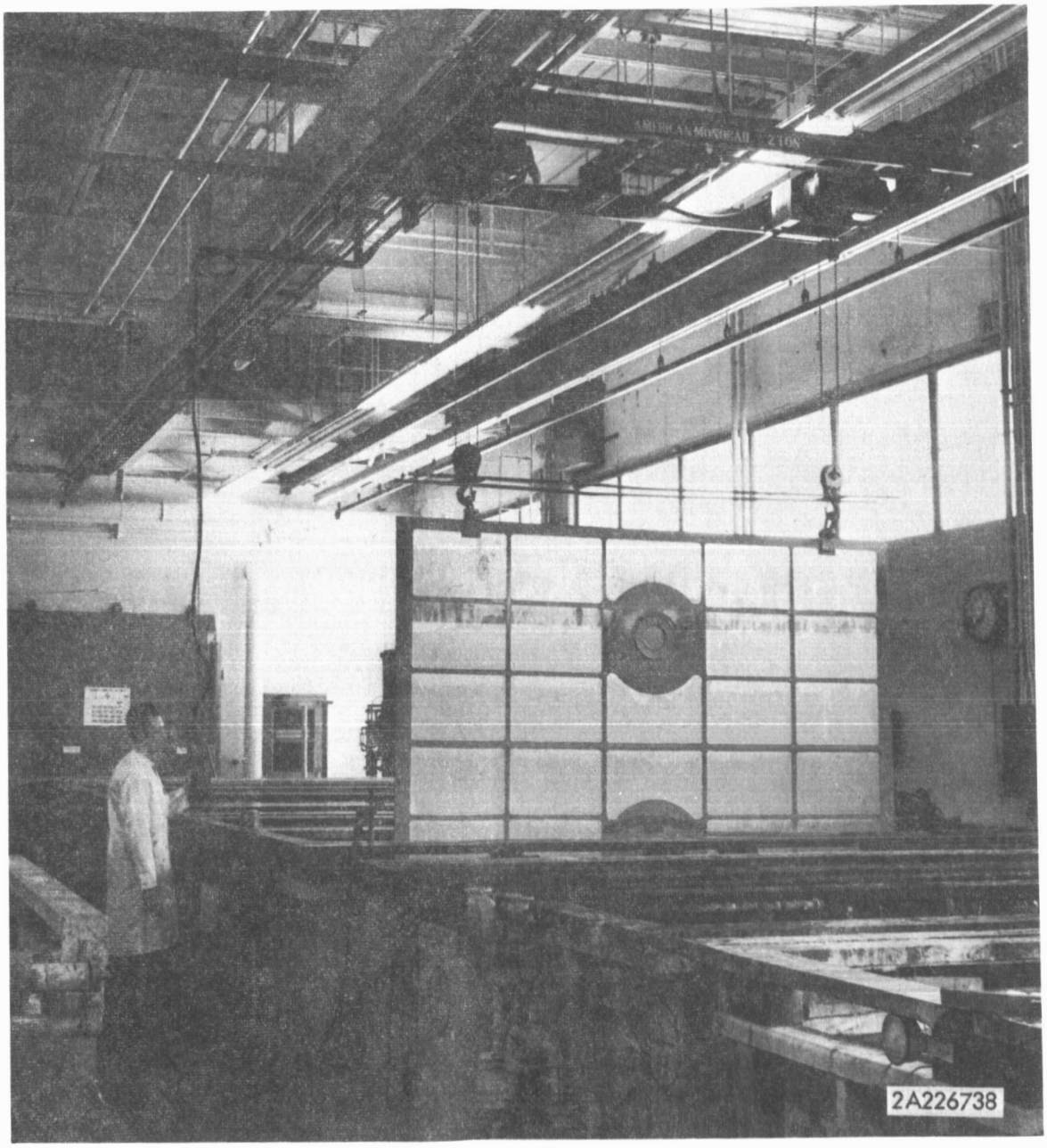



FIGURE 44

CHEM MILLING FACILITY AND WELDED TITANIUM PANEL

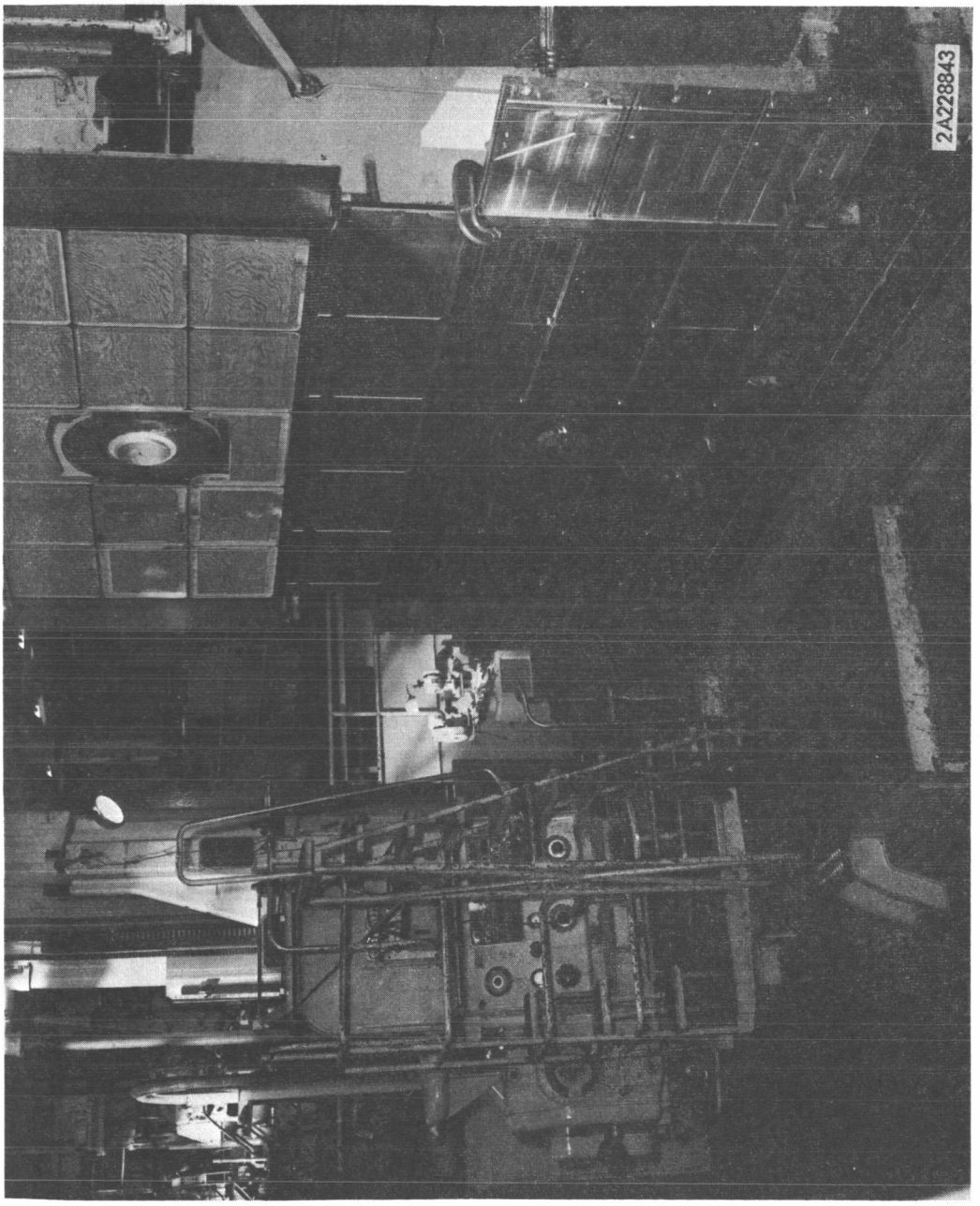



FIGURE 45

SHEET METAL TEMPLATE FOR MACHINING OF WELDED GORE

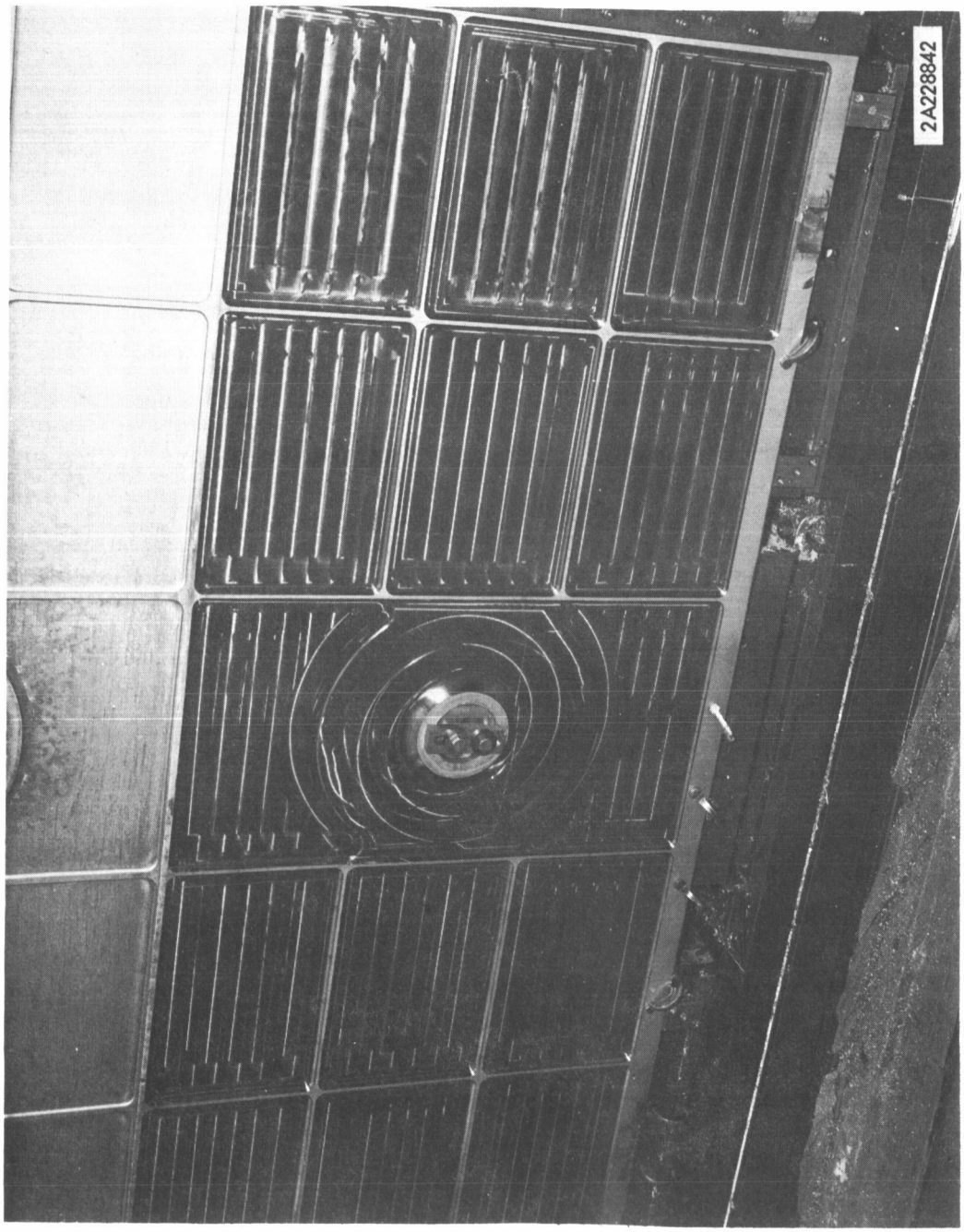



FIGURE 46

MACHINED HALF OF WELDED GORE

Subscale Tests

A subscale part nominally 24 by 36 by 1/8 inch was cut into the approximate expected shape of the flat pattern. It was scribed with a 1-inch grid on the side which was to be convex. The accuracy of the grid was about ±0.001 inch.

Prior to forming (in the same die used for the full-thickness subscale forming tests), the part was leveled in the die and its edges were projected down onto the die surface. A pencil mark was made connecting projected points. After forming, the edge of the part was traced onto the die, and rough measurements were made between the two lines. These measurements are shown in Figure 47 around the edge of the part, the accompanying arrows indicating the approximate direction of motion. Other figures on the sketch represent measurements between selected points on the formed part. These measurements were made using a flexible steel scale along the curved part surface. Their accuracy is about ±0.0025 inch.

The following conclusions can be drawn from these data:

1) The part moved down unsymmetrically, but not enough to materially affect curve tolerances.
2) Points along the centerline of symmetry moved essentially straight down; i.e., points originally in the centerplane of part symmetry remained in that plane, or nearly so, during the forming process.
3) Similarly, points essentially along the perpendicular bisector of the centerline of symmetry moved straight down, or nearly so.
4) Lines near the center of the part grew slightly.
5) Lines near the edge of the part shrank slightly.

Within the measuring tolerances of ±0.0025 inch, the amounts of growth and shrink exhibited by the subscale part could be expected to occur in the full-scale part. Further, since no major dislocation of grid lines occurred, the distances between rib intersections on the flat, milled blank must equal the arc lengths between rib intersections on the formed part. These arc lengths were determined analytically and modified by scaling up the growth and shrink factors observed in the subscale test.

Rib and Edge Intersections In Space

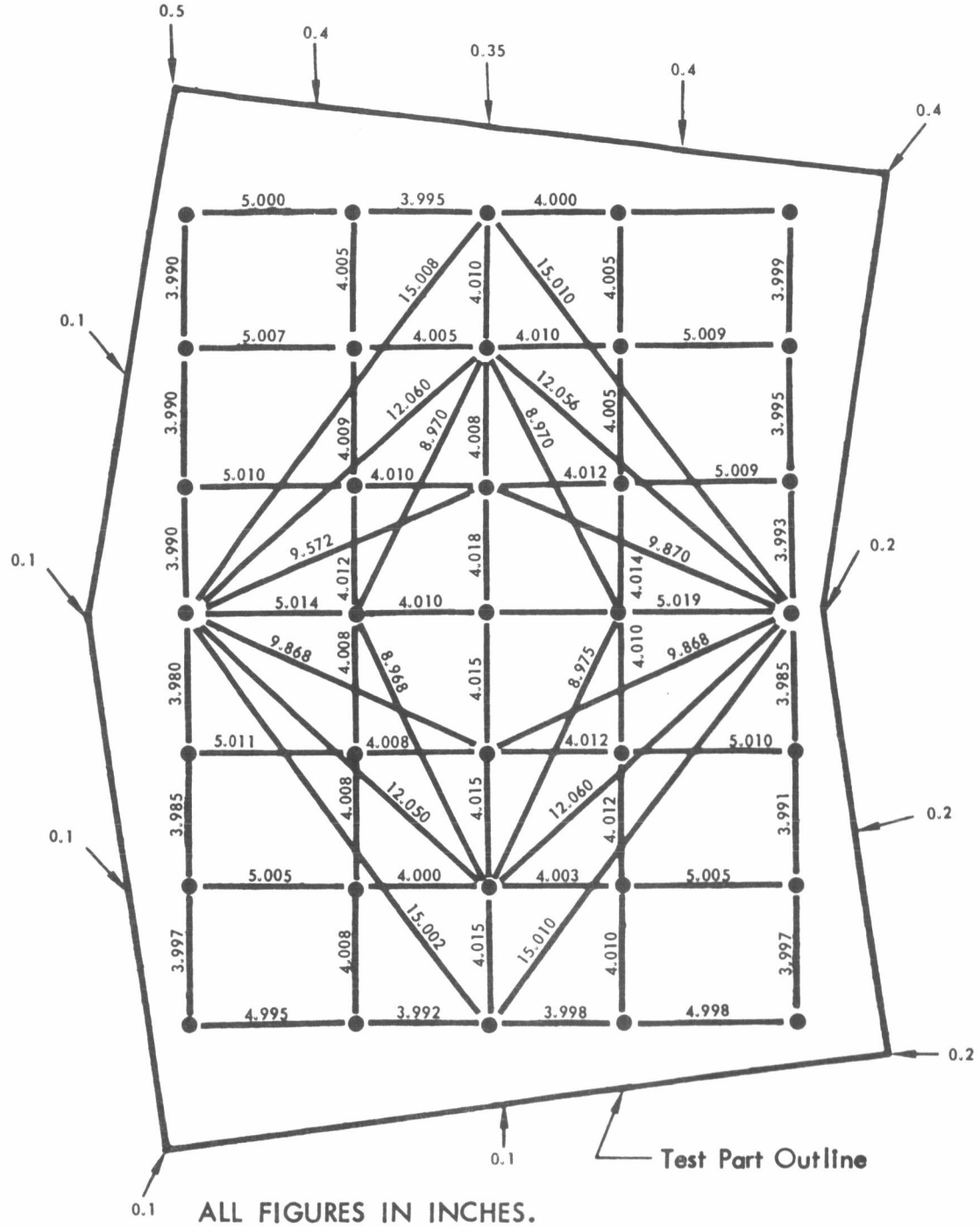
Drawing SK-PI-1165 Rev. B calls out a gore surface generated by rotating the ellipse

$$X^2 + 2Y^2 = 198^2$$

around the Y-axis. The equation of the surface thus generated is

$$X^2 + 2Y^2 + Z^2 = 198^2$$

At this point, it was convenient to establish a coordinate system which would minimize later calculations. A basic missile coordinate system was used; this




ALL FIGURES IN INCHES.

ALL MEASUREMENTS TAKEN ALONG COMPOUND CONTOURED SURFACE

FIGURE 47

SUBSCALE TEST RESULTS

is opposite from that furnished on the part drawing. Positive Y was forward on the missile, and the origin of the system was at the intersection of the major axis of the elliptical head and the Y axis. (This origin coincides with that of the drawing.) The Y-Z plane was taken as the part centerplane, so that final rotation to the die plan view resulted in a simple X-Y system. Figures 48 and 49 clarify the orientation of the part for these calculations.

Figure 48 shows the X-Y plane projection of the part and of eight planes establishing the upper part edge, six horizontal ribs, and the vertical location of the two bosses. The part lies on the far side of the ellipsoid in this view. The equations of seven of these planes are the Y values taken from the drawing and multiplied by (-1) to put them in the new coordinate system. The eighth plane (locating the two bosses vertically) is determined from the plan view radius of 160 inches given on the drawing and the ellipse formula

$$x^2 + 2y^2 = 198^2$$

$$160^2 + 2y^2 = 198^2$$

$$y = \frac{198^2 - 160^2}{2} = \pm 82.4742$$

These planes are tabulated below.

| Plane | Equation | Nomenclature |
|---|---|---|
| 1 | Y = -26.600 | Upper part edge |
| 2 | y = -34.400 | First rib centerline |
| 3 | y = -42.600 | Second rib centerline |
| 4 | y = -51.100 | Third rib centerline |
| 5 | y = -60.900 | Fourth rib centerline |
| 6 | y = -72.200 | Fifth rib centerline |
| 7 | y - -82.4742 | Boss plane |
| 8 | y = -83.600 | Sixth rib centerline |

The ninth plane is skewed and intersects the ellipsoid surface along the lower (shorter) part edge. This plane, shown as Plane 9 in Figure 49, can be described analytically as a plane containing the line of positive Y-Z slope (Tan 52°-30') passing through the point (0, -96.094, -144.000) and rotated about the line just described 1.00 degree counter-clockwise (looking towards the origin from the part).

The equation for Plane 9 was developed as follows:

Plane 9 contains the line

$$Y = 96.064 = (1.3032)\ (Z + 144)$$

or $Z - 0.76733Y = -70.264$. This will be called Line 9.

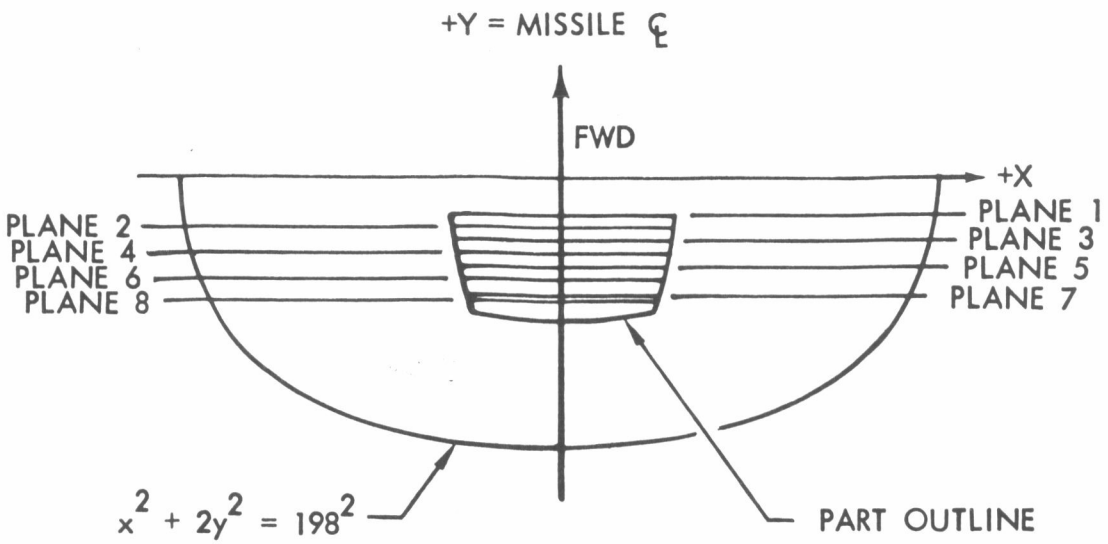
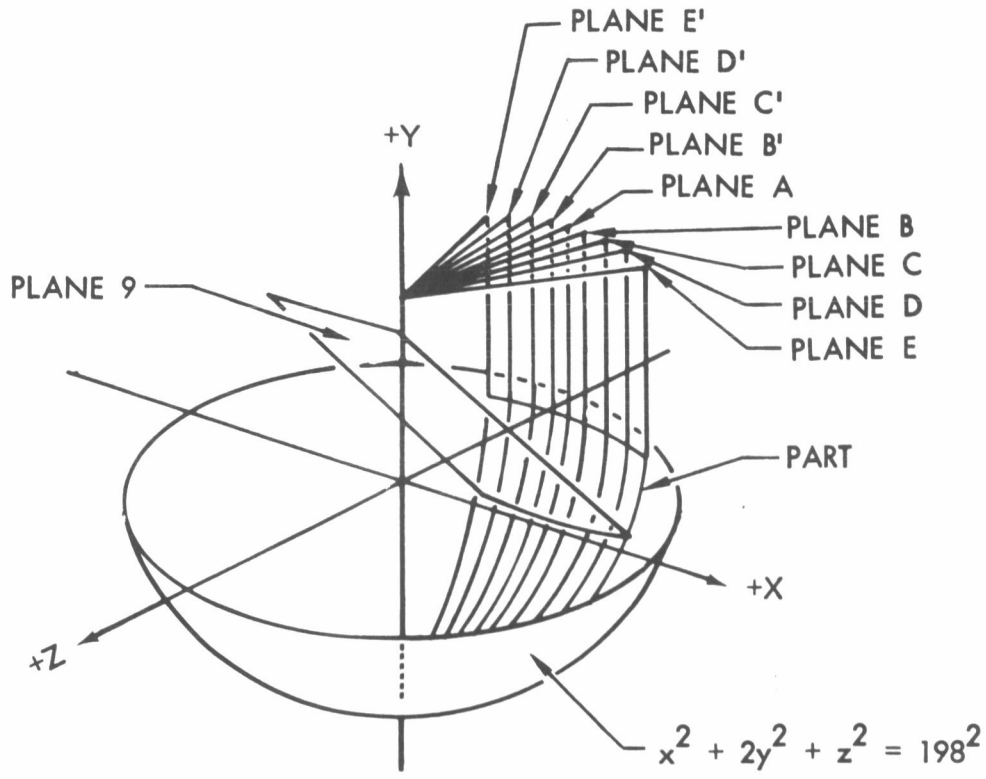



FIGURE 48




X-Z

FIGURE 49
GORE SECTION LOCATION ELLIPSOIDAL SURFACE

The intercept of Line 9 on the Y-axis occurs when Z = 0 and

$$Y = \frac{70.264}{0.76733} = 91.609.$$

The intercept of Line 9 on the Z-axis occurs when Y - 0 and

$$Z = -70.264.$$

These two points lie in Plane 9, since Plane 9 contains Line 9.

Consider next an auxiliary Plane 9a also containing Line 9 but whose intersection on both the X-Y and X-Z planes is parallel to the X axis. Plane 9a will become Plane 9 when rotated 1.00 degree counter-clockwise (looking from the part toward the coordinate system origin). Plane 9a coincides with Line 9 in Figure 50. In Figure 50, the plane of the paper is taken to be X = 10. Plane Q is another auxiliary plane, perpendicular to Line 9 and passing through the intersection of Line 9 and the Z axis.

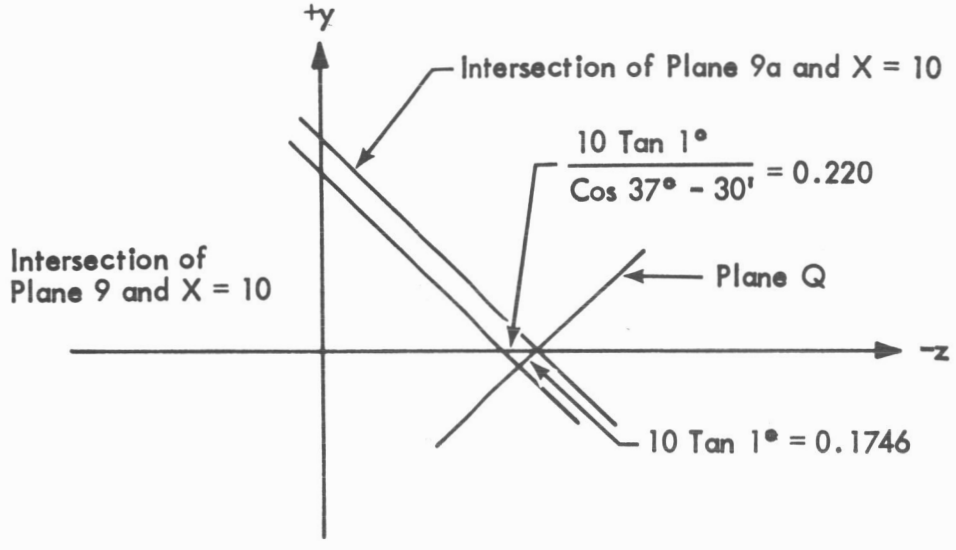



FIGURE 50
SKEWED PLANE

The point of intersection of Plane 9a, Plane Q, and the Plane X = 10 (the plane of the paper (is (10, 0, -70.264).

After rotation, the intersections moves down Plane Q in Figure 51 to a point

$$10(\text{Tan } 1°) = 0.1746$$

lower as measured along Plane Q. Plane 9a has been rotated to become Plane 9, and the element of Plane 9 marking the intersection with Plane X = 10 intersects the X-Z plane at a point

$$\frac{10(\text{Tan } 1°)}{\text{Cos } 37° - 30'} = \frac{0.1746}{0.79335} = 0.220$$

toward the origin from -70.264. This point is contained in Plane 9, and is (10, 0, -70.044).

Collecting the three points locating Plane 9:

Point 1 (0, 91.609, 0)

Point 2 (0, 0, -70.264)

Point 3 (10, 0, -70.044)

The standard equation of a plane can be written as

$$rx + sy + tz + 1 = 0.$$

Substituting the nine values just obtained and solving:

$$0\ r + 91.609\ x + 0\ t + 1 = 0$$
$$0\ r + 0\ s - 70.264\ t + 1 = 0$$
$$10\ r + 0\ s - 70.044\ t + 1 = 0$$

r = -0.00031310, s = 0.0109160, t = 0.0142320.

The Plane 9 equation can be written directly as

$$-0.00031310\ x - 0.0109160\ y + 0.0142320\ z + 1 = 0$$

or, more conveniently

$$3.131\ x + 109.160\ y - 142.300\ z = 10,000$$

The part is contained in a 45-degree segment of the plan view of the missile and contains six radial ribs equally spaced. The centerlines of these ribs are the intersections of the ellipsoid and planes radiating from the y axis as shown in Figure 49. Plane A is the y-z plane, so its intersection with the basic surface is the part centerline. The angle from Plane A to Plane B (in the x-z plane) is 45/14 = 3.214 degrees. Subsequent intervals are 6.429 degrees, so angles from Plane A can be tabulated and planar equations developed.

Planes B and B', C and C', etc., differ only in the sign of the slope. Plane F' (not shown in Figure 49 for clarity) locates the small boss on the ellipsoid by its intersection with Plane 7. Plane F' has a positive x-z slope of (Tan 10°) or 0.17633.

Letter designated planes are tabulated below.

| Plane | Rotation from y-z Plane (Degrees) | Slope in x-z Plane | Equation (X = mz) |
|---|---|---|---|
| A | 0 | | x = 0 |
| B | - 3.214 | -0.05616 | x = -0.05616 z |
| B' | 3.214 | 0.05616 | x = 0.05616 z |
| C | - 9.643 | -0.16991 | x = -0.16991 z |
| C' | 9.634 | 0.16991 | x = 0.16991 z |
| D | -16.071 | -0.28809 | x = -0.28809 z |
| D' | 16.071 | 0.28809 | x = 0.28809 z |
| E | -22.500 | -0.41421 | x = -0.41421 z |
| E' | 22.500 | 0.41421 | x = 0.41421 z |
| F' | 10.000 | 0.17633 | x = 0.17633 z |

Solving the lettered and numbered planes simultaneously with the ellipsoidal surface results in the space coordinates of significant intersections of the part. Thus, Point 1A is the center of the upper part edge, Points 1E and 1E' the upper corners, Point 7A the large boss center, etc.

These solutions were found with the aid of the computer and are listed in Table I in x, y, and z for checking purposes.

From the results of the subscale forming tests, it was determined that two lines intersecting essentially at the center of the part would move straight down into the die. Plane A is one of those lines, and Rib 4 (Plane 5) was selected as the line most nearly approaching the required transverse centerline.

Intersections of these two lines were rotated 36 degrees to match the angle of the forming tool relative to the missile centerline. Figure 51 shows schematically the relative position of the die, as determined by Tool Design.

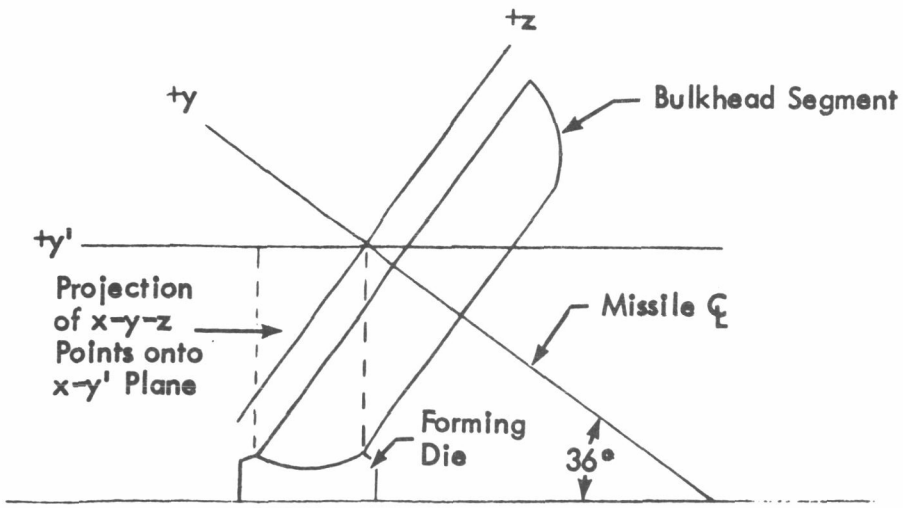



FIGURE 51
PLANE ROTATION

Projecting the points onto a horizontal x-y' plane results in new points in a new (and final) coordinate system. X-values will not change, and y'-values can be calculated by the equation:

$$y' - (\text{Cos } 36°)\ (y) - (\text{Sin } 36°)\ (z)$$

These y' values are listed in the far right column of Table III.

Arc lengths from point to point in the formed part were computed for horizontal cuts by dividing the circumference of the resulting circles by 56 and 112. These whole numbers are the fractions of full circles contained between lettered planes.

Arc lengths of lines representing vertical ribs were somewhat more difficult to obtain. The curve $x^2 + 2y^2 = 198^2$ could have been integrated to obtain length between known points, but the integral is not a simple one and the chance for error was high. A close approximation, providing for simple and, therefore, more accurate calculations, was to erect the perpendicular bisector to the straight line between two points of interest on the curve and compute the x-y intersection of the curve and the perpendicular. This third point, lying on the curve essentially half way between the two points of interest, was used to define a circle passing through the three points. Once the center of this circle was determined, the angle between the lines from the center to the two points of interest were computed and the length of arc calculated by the equation:

$$\int = (2\pi r)\left(\frac{\alpha}{360}\right).$$

The procedure provided arc lengths very nearly equal to the true length from point to point along the ellipse. True lengths between points along the lower edge (Plane 9) were calculated using the same process in three dimensions. All these calculations were performed by the computer with the output shown in Table IV under the "Computed True Length" column. Figures in the second column are multipliers to take into account the growth and shrink observed in the subscale test. These figures were obtained by interpolating between averaged test results. The final column in Table IV shows "Weighted True Lengths," or the computed lengths times the growth-shrink factor.

These lengths were used to expand to the part centerline in the die plan view to its true length, starting from Point 5A and working in both directions to establish new Points 4A, 6A, 3A, 7A, 2A, 8A, 1A, and 9A. Points along the Plane 5 projection were established similarly, except the process was slightly more difficult since the subscale test indicated no y deflection of points. This meant each point on the Plane 5 projection would maintain its y' value and move only in x. Solution of a simple quadratic yielded the new x-y' coordinates of the flat pattern Plane 5 points.

Once all Plane A and Plane 5 points were located on the flat pattern layout, remaining points were determined by striking arcs from known points of radii equal to weighted true lengths. Arc intersections represent new flat pattern points as shown in Figure 52.

TABLE III

SPACE COORDINATES OF SIGNIFICANT POINTS ON OUTER GORE SURFACE

| Point | Nomenclature (From Missile ℄) | X | Y | Z | Y' |
|---|---|---|---|---|---|
| 1E' | Upper Left Corner | -74.39116 | -26.600 | -179.5963 | |
| 1D' | | -53.81501 | ↕ | -186.7962 | |
| 1C' | | -32.56211 | ↕ | -191.6470 | |
| 1B' | | -10.89973 | ↕ | -194.0878 | |
| 1A | Upper Edge | 0.000 | -26.600 | -194.3936 | 92.74269 |
| 1B | | 10.89973 | ↕ | -194.0878 | |
| 1C | | 32.56211 | ↕ | -191.6470 | |
| 1D | | 53.81501 | ↕ | -186.7962 | |
| 1E | Upper Right Corner | 74.39116 | -26.600 | -179.5963 | |
| 2E' | | -73.44853 | -34.400 | -177.3206 | |
| 2D' | | -53.13311 | ↕ | -184.4293 | |
| 2C' | | -32.14951 | ↕ | -189.2186 | |
| 2B' | | -10.76162 | ↕ | -191.6285 | |
| 2A | First Rib | 0.000 | -34.400 | -191.9304 | 84.98448 |
| 2B | | 10.76162 | ↕ | -191.6285 | |
| 2C | | 32.14951 | ↕ | -189.2186 | |
| 2D | | 53.13311 | ↕ | -184.4293 | |
| 2E | | 73.44853 | -34.400 | -177.3206 | |
| 3E' | | -72.17862 | -42.600 | -174.2548 | |
| 3D' | | -52.21445 | ↕ | -181.2405 | |
| 3C' | | -31.59365 | ↕ | -185.9471 | |
| 3B' | | -10.57555 | ↕ | -188.3153 | |
| 3A | Second Rib | 0.000 | -42.600 | -188.6120 | 76.39998 |
| 3B | | 10.57555 | ↕ | -188.3153 | |
| 3C | | 31.59365 | ↕ | -185.9471 | |
| 3D | | 52.21445 | ↕ | -181.2405 | |
| 3E | | 72.17862 | -42.600 | -174.2548 | |
| 4E' | | -70.54416 | -51.100 | -170.3088 | |
| 4D' | | -51.03207 | ↕ | -177.1364 | |
| 4C' | | -30.87823 | ↕ | -181.7364 | |
| 4B' | | -10.33607 | ↕ | -184.0509 | |
| 4A | Third Rib | 0.000 | -51.100 | -184.3409 | 67.01283 |
| 4B | | 10.33607 | ↕ | -184.0509 | |
| 4C | | 30.87823 | ↕ | -181.7364 | |
| 4D | | 51.03207 | ↕ | -177.1364 | |
| 4E | | 70.54416 | -51.100 | -170.3088 | |

TABLE III (Cont.)

| Point | Nomenclature (From Missile ℄) | X | Y | Z | Y' |
|---|---|---|---|---|---|
| 5E' | | -68.22756 | -60.900 | -164.7161 | 47.54913 |
| 5D' | | -49.35623 | ↑ | -171.3194 | 51.43052 |
| 5C' | | -29.86421 | ↕ | -175.7683 | 54.04555 |
| 5B' | | - 9.996643 | ↓ | -178.0069 | 55.36134 |
| 5A | Fourth Rib | 0.000 | -60.900 | -178.2874 | 55.52620 |
| 5B | | 9.996643 | ↑ | -178.0069 | 55.36134 |
| 5C | | 29.86421 | ↕ | -175.7683 | 54.04555 |
| 5D | | 49.35623 | ↓ | -171.3194 | 51.43052 |
| 5E | | 68.22756 | -60.900 | -164.7161 | 47.54913 |
| 6E' | | -64.91903 | -72.200 | -156.7286 | |
| 6D' | | -46.96282 | ↑ | -163.0117 | |
| 6C' | | -28.41602 | ↕ | -167.2449 | |
| 6B' | | - 9.51188 | ↓ | -169.3749 | |
| 6A | Fifth Rib | 0.000 | -72.200 | -169.6417 | 41.30247 |
| 6B | | 9.51188 | ↑ | -169.3749 | |
| 6C | | 28.41602 | ↕ | -167.2449 | |
| 6D | | 46.96282 | ↓ | -163.0117 | |
| 6E | | 64.91903 | -72.200 | -156.7286 | |
| 5F' | Construction Point | -30.95979 | -60.900 | -175.5787 | |
| 6F' | Construction Point | -29.45847 | -72.200 | -167.0644 | |
| 7A | Large Boss | 0.000 | -82.4742 | -160.000 | 27.32263 |
| 7B' | Construction Point | - 8.97147 | -82.4742 | -159.7483 | |
| 7C' | Construction Point | -26.80149 | -82.4742 | -157.7393 | |
| 7F' | Small Boss | -27.78418 | -82.4742 | -157.5692 | |
| 8F' | Construction Point | -27.58051 | -83.600 | -156.4142 | |
| 8E' | | -60.78049 | -83.600 | -146.7372 | |
| 8D' | | -43.96897 | ↑ | -152.6198 | |
| 8C' | | -26.60452 | ↕ | -156.5831 | |
| 8B' | | - 8.90550 | ↓ | -158.5773 | |
| 8A | Sixth Rib | 0.000 | -83.600 | -158.8272 | 25.72297 |
| 8B | | 8.90550 | ↑ | -158.5773 | |
| 8C | | 26.60452 | ↕ | -156.5831 | |
| 8D | | 43.96897 | ↓ | -152.6198 | |
| 8E | | 60.78049 | -83.600 | -146.7372 | |
| 9E' | Lower Left Corner | -58.15697 | -89.74331 | -140.4035 | |
| 9D' | | -41.02656 | -92.84489 | -142.4065 | |
| 9C' | | -24.39505 | -94.85004 | -143.5791 | |
| 9B' | | - 8.088363 | -95.90103 | -144.0268 | |
| 9A | Lower Edge | 0.000 | -96.09389 | -143.9968 | 6.898025 |
| 9B | | 8.075703 | -96.07061 | -143.8013 | |
| 9C | | 24.28094 | -95.37040 | -142.9075 | |
| 9D | | 40.70908 | -93.75220 | -141.3045 | |
| 9E | Lower Right Corner | 57.53469 | -91.10250 | -138.9012 | |

TABLE IV

TRUE LENGTH DATA

| From Point | To Point | Computed True Length | Growth-Shrink Factor | Weighted True Length |
|---|---|---|---|---|
| 1A | 1B | 10.9055 | 1.0100 | 11.0146 |
| 1B | 1C | 21.8109 | 1.0080 | 21.9854 |
| 1C | 1D | 21.8109 | 1.0038 | 21.8938 |
| 1D | 1E | 21.8109 | 0.9976 | 21.7586 |
| 2A | 1A | 8.1832 | 1.0013 | 8.1938 |
| 2A | 2B | 10.7673 | 1.0048 | 10.8190 |
| 2B | 1B | 8.1832 | 1.0020 | 8.1996 |
| 2B | 2C | 21.5346 | 1.0033 | 21.6057 |
| 2C | 1C | 8.1832 | 0.9972 | 8.1603 |
| 2C | 2D | 21.5346 | 1.0013 | 21.5626 |
| 2D | 1D | 8.1832 | 1.0000 | 8.1832 |
| 2D | 2E | 21.5346 | 0.9994 | 21.5217 |
| 2E | 1E | 8.1832 | 1.0091 | 8.2577 |
| 3A | 2A | 8.8502 | 0.9998 | 8.8484 |
| 3A | 3B | 10.5811 | 1.0010 | 10.5917 |
| 3B | 2B | 8.8502 | 1.0000 | 8.8502 |
| 3B | 3C | 21.1623 | 1.0004 | 21.1708 |
| 3C | 2C | 8.8502 | 0.9982 | 8.8343 |
| 3C | 3D | 21.1623 | 0.9998 | 21.1581 |
| 3D | 2D | 8.8502 | 1.0015 | 8.8635 |
| 3D | 3E | 21.1623 | 1.0005 | 21.1729 |
| 3E | 2E | 8.8502 | 1.0082 | 8.9228 |
| 4A | 3A | 9.5174 | 0.9982 | 9.5003 |
| 4A | 4B | 10.3415 | 0.9986 | 10.3270 |
| 4B | 3B | 9.5174 | 0.9980 | 9.4984 |
| 4B | 4C | 20.6830 | 0.9982 | 20.6458 |
| 4C | 3C | 9.5174 | 0.9989 | 9.5069 |
| 4C | 4D | 20.6830 | 0.9987 | 20.6561 |
| 4D | 3D | 9.5174 | 1.0019 | 9.5355 |
| 4D | 4E | 20.6830 | 1.0010 | 20.7037 |
| 4E | 3E | 9.5174 | 1.0078 | 9.5916 |
| 5A | 4A | 11.5262 | 0.9974 | 11.4962 |
| 5A | 5B | 10.0019 | 0.9976 | 9.9779 |
| 5A | 5B' | 10.0019 | 0.9976 | 9.9779 |
| 5A | 6A | 14.2397 | 0.9974 | 14.2027 |
| 5B | 4B | 11.5262 | 0.9970 | 11.4916 |
| 5B | 5C | 20.0038 | 0.9967 | 19.9378 |
| 5B | 6B | 14.2397 | 0.9970 | 14.1970 |
| 5B' | 5C' | 20.0038 | 0.9967 | 19.9378 |
| 5B' | 6B' | 14.2397 | 0.9970 | 14.1970 |
| 5C | 4C | 11.5262 | 0.9990 | 11.5147 |
| 5C | 5D | 20.0038 | 0.9979 | 19.9618 |
| 5C | 6C | 14.2397 | 0.9983 | 14.2155 |
| 5C' | 5D' | 20.0038 | 0.9979 | 19.9618 |
| 5C' | 5F' | 1.1113 | 0.9979 | 1.1090 |

TABLE IV (Cont.)

| From Point | To Point | Computed True Length | Growth-Shrink Factor | Weighted True Length |
|---|---|---|---|---|
| 5C' | 6C' | 14.2397 | 0.9983 | 14.2155 |
| 5D | 4D | 11.5262 | 1.0021 | 11.5504 |
| 5D | 5E | 20.0038 | 1.0008 | 20.0198 |
| 5D | 6D | 14.2397 | 1.0010 | 14.2539 |
| 5D' | 5E' | 20.0038 | 1.0008 | 20.0198 |
| 5D' | 6D' | 14.2397 | 1.0010 | 14.2539 |
| 5E | 4E | 11.5262 | 1.0075 | 11.6126 |
| 5E | 6E | 14.2397 | 1.0052 | 14.3137 |
| 5E' | 6E' | 14.2397 | 1.0052 | 14.3137 |
| 5F' | 6F' | 14.2397 | 0.9983 | 14.2155 |
| 6A | 6B | 9.5169 | 0.9986 | 9.5036 |
| 6A | 6B' | 9.5169 | 0.9986 | 9.5036 |
| 6A | 7A | 14.1007 | 0.9977 | 14.0683 |
| 6B | 6C | 19.0038 | 0.9969 | 18.9449 |
| 6B | 8B | 14.7264 | 0.9974 | 15.6855 |
| 6B' | 6C' | 19.0038 | 0.9969 | 18.9449 |
| 6B' | 8B' | 15.7264 | 0.9974 | 15.6855 |
| 6C | 6D | 19.0038 | 0.9978 | 18.9620 |
| 6C | 8C | 15.7264 | 0.9980 | 15.6949 |
| 6C' | 6D' | 19.0038 | 0.9978 | 18.9620 |
| 6C' | 6F' | 1.0874 | 0.9974 | 1.0846 |
| 6C' | 8C' | 15.7264 | 0.9980 | 15.6949 |
| 6D | 6E | 19.0038 | 0.9997 | 18.9981 |
| 6D | 8D | 15.7264 | 1.0002 | 15.7295 |
| 6D' | 6E' | 19.0038 | 0.9997 | 18.9981 |
| 6D' | 8D' | 15.7264 | 1.0002 | 15.7295 |
| 6E | 8E | 15.7264 | 1.0036 | 15.7830 |
| 6E' | 8E' | 15.7264 | 1.0036 | 15.7830 |
| 6F' | 8F' | 15.7264 | 0.9980 | 15.6949 |
| 7A | 7B' | 8.9760 | 1.0005 | 8.9805 |
| 7A | 8A | 1.6257 | 0.9982 | 1.6228 |
| 7B' | 7C' | 17.9520 | 0.9994 | 17.9412 |
| 7C' | 7F' | 0.9972 | 0.9994 | 0.9966 |
| 8A | 8B | 8.9102 | 1.0006 | 8.9155 |
| 8A | 8B' | 8.9102 | 1.0006 | 8.9155 |
| 8A | 9A | 19.4086 | 0.9984 | 19.3775 |
| 8B | 8C | 17.8204 | 0.9995 | 17.8115 |
| 8B | 9B | 19.3698 | 0.9984 | 19.3775 |
| 8B' | 7B' | 1.6257 | 0.9974 | 1.6215 |
| 8B' | 8C' | 17.8204 | 0.9995 | 17.8115 |
| 8B' | 9B' | 19.0870 | 0.9984 | 19.0565 |
| 8C | 8D | 17.8204 | 0.9994 | 17.8097 |
| 8C | 9C | 18.2062 | 0.9988 | 18.1844 |
| 8C' | 7C' | 1.6257 | 0.9980 | 1.6224 |
| 8C' | 8D' | 17.8204 | 0.9994 | 17.8097 |

TABLE IV (Cont.)

| From Point | To Point | Computed True Length | Growth-Shrink Factor | Weighted True Length |
|---|---|---|---|---|
| 8C' | 8F' | 0.9900 | 0.9994 | 0.9894 |
| 8C' | 9C' | 17.3480 | 0.9988 | 17.3272 |
| 8D | 8E | 17.8204 | 0.9997 | 17.8151 |
| 8D | 9D | 15.5556 | 1.0001 | 15.5572 |
| 8D' | 8E' | 17.8204 | 0.9997 | 17.8151 |
| 8D' | 9D' | 14.0921 | 1.0001 | 14.0935 |
| 8E | 9E | 11.3255 | 1.0043 | 11.3742 |
| 8E' | 9E' | 9.2054 | 1.0043 | 9.2450 |
| 8F' | 7F' | 1.6257 | 0.9980 | 1.6224 |
| 9A | 9B | 8.0785 | 1.0040 | 8.1108 |
| 9A | 9B' | 8.0911 | 1.0040 | 8.1235 |
| 9B | 9C | 16.2481 | 1.0040 | 16.3131 |
| 9B' | 9C' | 16.3499 | 1.0040 | 16.4153 |
| 9C | 9D | 16.5887 | 1.0025 | 16.6302 |
| 9C' | 9D' | 16.7965 | 1.0025 | 16.8385 |
| 9D | 9E | 17.2056 | 1.0003 | 17.2108 |
| 9D' | 9E' | 17.5280 | 1.0003 | 17.5333 |

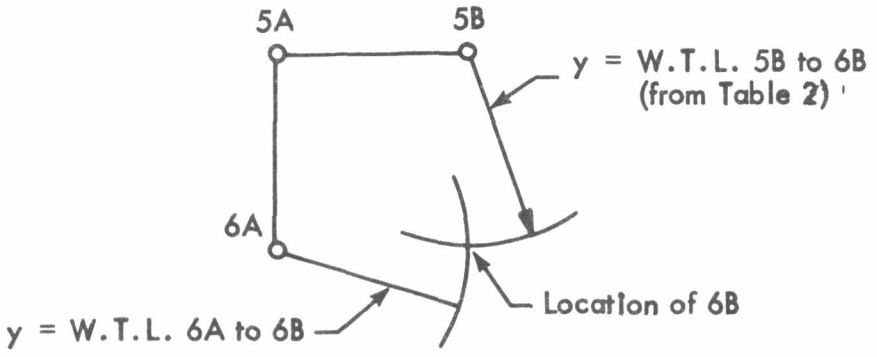



FIGURE 52

FLAT PATTERN LAYOUT PROCEDURE

This results in straight lines from point to point instead of the gentle curves actually required. The loss of accuracy is not significant.

Final flat pattern "x" - "y" points were obtained from an APT* computer run. (APT contains a geometry subroutine ideally suited to this particular computation.)

The APT printout is shown in Table V, and the flat pattern layout is shown in Figure 53. Excess allowances, rib widths, and web thicknesses are included to make the flat pattern layout complete.

From this information the part was programmed, tapes were made (14 files), and the Numerical Control Operators Document was prepared.

Pocket Pattern Inspection

There were two primary reasons to determine the accuracy of location of the stiffening ribs on the interior gore surface. First, of course, it was necessary to compare the finished product to the drawing tolerances. Of equal importance, however, was a check on the method used to predict the flat pattern geometry.

The gore section was located on a wooden frame and supported by four plywood headers cut to the inside shape of the gore per the drawing. A fifth plywood template established the OML of the lower edge of the gore in the inspection fixture. A 1-second, direct reading theodolite was set up with its center at the theoretical missile centerline. Drawing dimensions from Points 2A, 2D, and 2D' were used to establish this point. Elevation coordination was established from the same points. The entire fixture was tilted to establish the correct dimension between Point 7A and the theoretical vertical centerline. This positioned the gore section as closely as possible to its true space orientation relative to the theodolite. This inspection set-up is shown in Figure 54.

*APT (automatically programmed tools) is a nationally accepted specialized computer language which was developed for programming numerically controlled machine tools.

# TABLE V

## X-Y' COORDINATES OF FLAT PATTERN

| Point | X | Y' | Point | X | Y' |
|---|---|---|---|---|---|
| 1A | 0 | 93.5649 | 5A | 0 | 55.5262 |
| 1B | 11.0132 | 93.3869 | 5B | 9.9765 | 55.3613 |
| 1B' | -11.0132 | 93.3869 | 5B' | - 9.9765 | 55.3613 |
| 1C | 32.9506 | 91.9355 | 5C | 29.8708 | 54.0456 |
| 1C' | -32.9506 | 91.9355 | 5C' | -29.8708 | 54.0456 |
| 1D | 54.6762 | 89.2269 | 5D | 49.6606 | 51.4305 |
| 1D' | -54.6762 | 89.2269 | 5D' | -49.6606 | 51.4305 |
| 1E | 76.0805 | 85.3161 | 5E | 69.3005 | 47.5491 |
| 1E' | -76.0805 | 85.3161 | 5E' | -69.3005 | 47.4391 |
| 2A | 0 | 85.2711 | 6A | 0 | 41.3235 |
| 2B | 10.8187 | 85.1896 | 6B | 9.5024 | 41.1722 |
| 2B' | -10.8187 | 85.1896 | 6B' | - 9.5024 | 41.1722 |
| 2C | 32.3794 | 83.7952 | 6C | 28.4049 | 39.9059 |
| 2C' | -32.3794 | 83.7952 | 6C' | -28.4049 | 39.9059 |
| 2D | 53.7721 | 81.0938 | 6D | 47.1994 | 37.3907 |
| 2D' | -53.7721 | 81.0938 | 6D' | -47.1994 | 37.3907 |
| 2E | 74.9273 | 77.1393 | 6E | 65.8282 | 33.6630 |
| 2E' | -74.9273 | 77.1393 | 6E' | -65.8282 | 33.6630 |
| 3A | 0 | 76.5227 | 7A | 0 | 27.2552 |
| 3B | 10.5902 | 76.3423 | 7F' | -27.8719 | 25.8163 |
| 3B' | -10.5902 | 76.3423 | | | |
| 3C | 31.7175 | 74.8957 | 8A | 0 | 25.6324 |
| 3C' | -31.7175 | 74.8957 | 8B | 8.9145 | 25.4977 |
| 3D | 52.7038 | 72.2950 | 8B' | - 8.9145 | 25.4977 |
| 3D' | -52.7038 | 72.2950 | 8C | 26.6860 | 24.3054 |
| 3E | 73.5023 | 68.3310 | 8C' | -26.6860 | 24.3054 |
| 3E' | -73.5023 | 68.3310 | 8D | 44.3358 | 21.9241 |
| | | | 8D' | -44.3358 | 21.9241 |
| 4A | 0 | 67.0224 | 8E | 61.7994 | 18.4028 |
| 4B | 10.3255 | 66.8476 | 8E' | -61.7994 | 18.4028 |
| 4B' | -10.3255 | 66.8476 | | | |
| 4C | 30.9281 | 65.5117 | 9A | 0 | 6.2549 |
| 4C' | -30.9281 | 65.5117 | 9B | 8.1099 | 6.1369 |
| 4D | 51.4116 | 62.8474 | 9B' | - 8.1210 | 6.4578 |
| 4D' | -51.4116 | 62.8474 | 9C | 24.4226 | 6.2624 |
| 4E | 71.7362 | 58.9034 | 9C' | -24.5232 | 7.1137 |
| 4E' | -71.7362 | 58.9034 | 9D | 41.0465 | 6.7186 |
| | | | 9D' | -41.3294 | 8.1549 |
| | | | 9E | 58.2346 | 7.6017 |
| | | | 9E' | -58.7981 | 9.6585 |




FIGURE 53
FLAT PATTERN LAYOUT

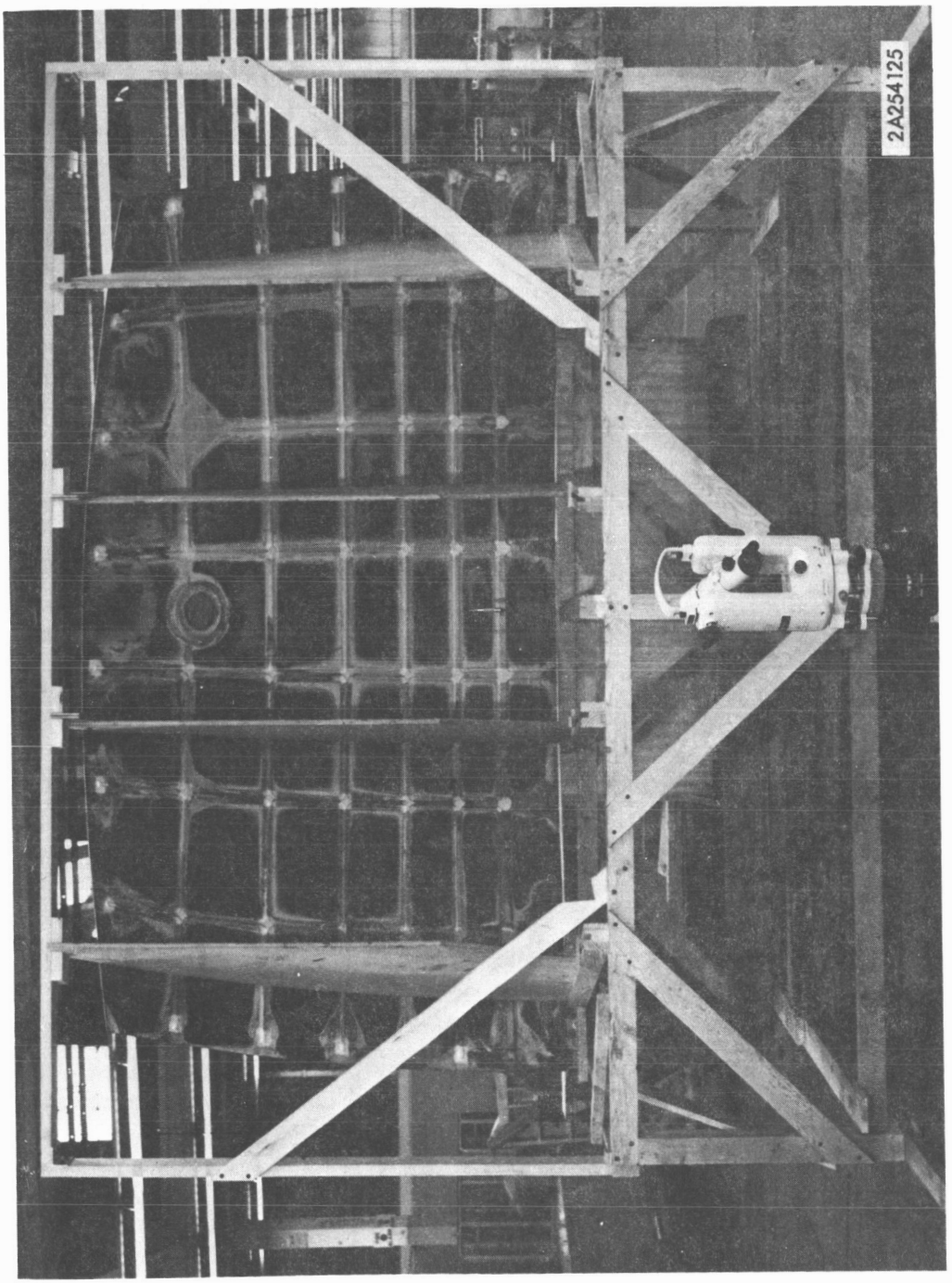



FIGURE 54
POCKET PATTERN INSPECTION

Theodolite readings were taken in azimuth and elevation at each point which could be located (points around the part exterior, on Plane "A", and Point 8C' could not be physically established) and angular data were tabulated. About 20 additional readings taken at random checked to the original readings within ±5 arc seconds, or about ±0.005 inch at the average range involved.

Because the drawing was dimensioned to the exterior of the part while the points to be inspected lay on the interior of the part, it was necessary to transfer dimensions through each rib intersection. Interior values were obtained by establishing the tangent to the defining parabola at each theoretical horizontal rib elevation, then using trigonometric relationships to calculate the new rib centerline elevations on the inside of the part. Actual rib centerline intersections were established by bisecting each rib, then drawing intersections on the part using drafting instruments.

Angular data resulting from the optical inspection were converted to linear x and y deviations through further trigonometric calculations which included compensation for the distance from the instrument to each point on the part. These deviations were plotted and statistically corrected for obvious y and rotational biases (no x bias was apparent). The resulting "best fit" data were then replotted and are shown in Figure 55. Points on planes E, E', 1, and 9 were extrapolated from interior points, since direct readings could not be obtained. (Accuracy of these data, due to the multiple calculations and bias removal, is no better than ±0.010 inch.)

Accuracy of the finished gore contained deviations ranging up to 1.5 inch in x and 0.61 inch in y. Tolerances on horizontal ribs were shown on the drawing at ±0.200 inch. Tolerances on vertical ribs were given at ±0°-5' which converted to about ±0.240 to ±0.280 inch, depending on the elevation involved.

The pattern of deviations, however, leaves no doubt that almost all error was due to incorrect prediction of material movement during forming and can be corrected. All deviations were outward from the part center. The direction and magnitude of the deviations fit a uniform pattern except in rare instances.

Table VI contains a corrected set of x-y' values based on the results of the inspection. These values were obtained by adding or subtracting averaged deviations from the values shown in Table V. Since the corrections are only accurate to ±0.010 inch, three significant decimals are carried in Table VI instead of the four decimals carried in Table V. Table VI supersedes Table V in the event another titanium gore should be fabricated.

### 6.2.3 Gore Machining

Several changes were made in the original machining processing to accommodate machine work load problems. Originally it was planned to machine these parts completely on the numerical control profiler. Numerical control profilers were reserved for machining these parts but had to be given up when the parts were only rough machined to make way for prior machine commitments. The late arrival of titanium material caused the work load conflict. Also, several changes in processing were made to recover from situations created by using titanium material that was out of specification.

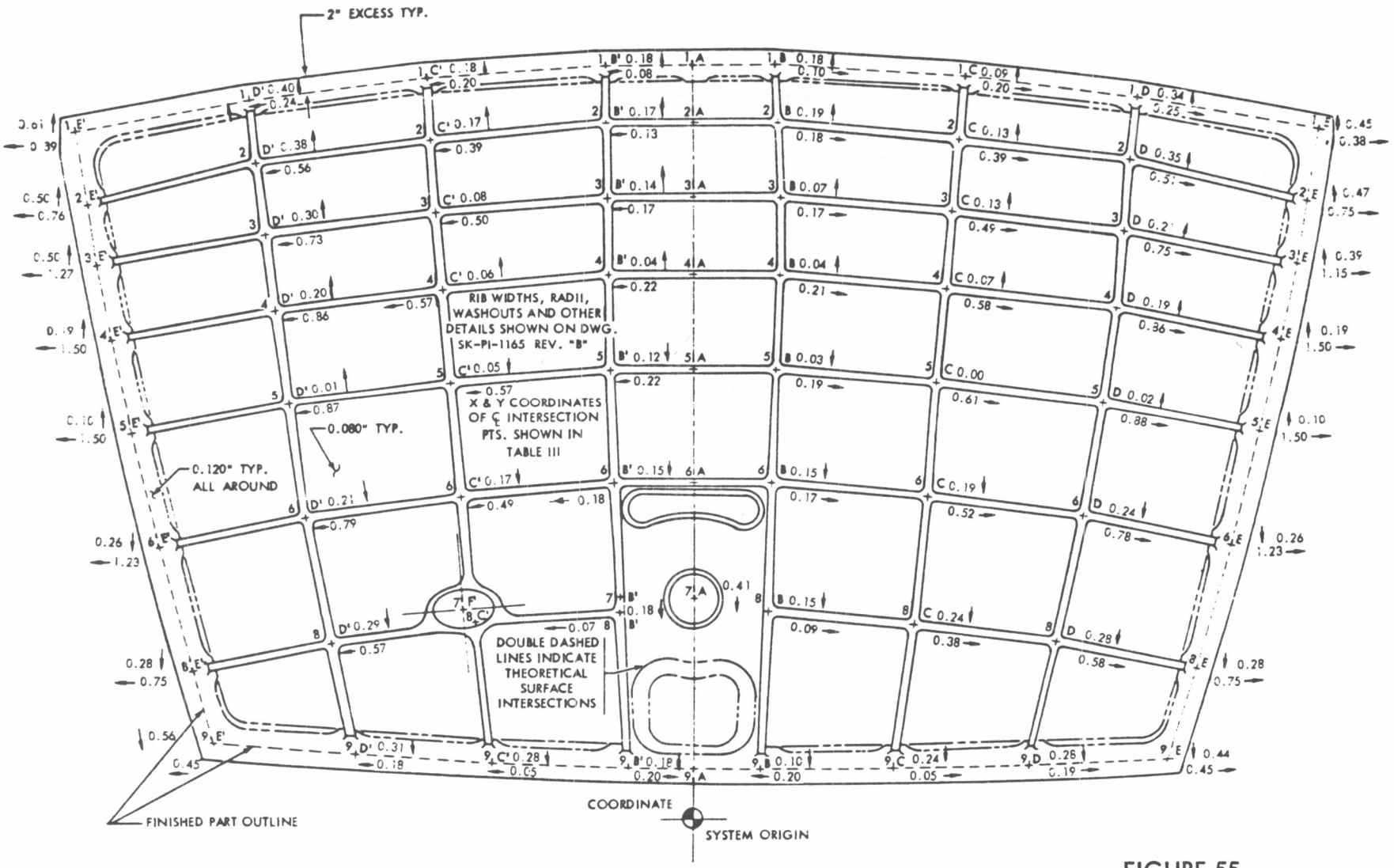



FIGURE 55

BEST FIT DATA

TABLE VI

CORRECTED X-Y' COORDINATES OF FLAT PATTERN

| Point | X | Y' | Point | X | Y' |
|---|---|---|---|---|---|
| 1A | 0 | 93.415 | 5A | 0 | 55.466 |
| 1B | 10.923 | 93.207 | 5B | 9.767 | 55.441 |
| 1B' | -10.923 | 93.207 | 5B' | - 9.767 | 55.441 |
| 1C | 32.751 | 91.796 | 5C | 29.281 | 54.076 |
| 1C' | -32.751 | 91.796 | 5C' | -29.281 | 54.076 |
| 1D | 54.426 | 88.857 | 5D | 48.781 | 51.411 |
| 1D' | -54.426 | 88.857 | 5D' | -48.781 | 51.411 |
| 1E | 75.691 | 84.786 | 5E | 67.801 | 47.449 |
| 1E' | -75.691 | 84.786 | 5E' | -67.801 | 47.449 |
| 2A | 0 | 85.121 | 6A | 0 | 41.444 |
| 2B | 10.659 | 85.001 | 6B | 9.322 | 41.322 |
| 2B' | -10.659 | 85.001 | 6B' | - 9.322 | 41.322 |
| 2C | 31.989 | 83.645 | 6C | 27.895 | 40.086 |
| 2C' | -31.989 | 83.645 | 6C' | -27.895 | 40.086 |
| 2D | 53.232 | 80.724 | 6D | 46.409 | 37.621 |
| 2D' | -53.232 | 80.724 | 6D' | -46.409 | 37.621 |
| 2E | 74.167 | 76.659 | 6E | 64.598 | 33.923 |
| 2E' | -74.167 | 76.659 | 6E' | -64.598 | 33.923 |
| 3A | 0 | 76.433 | 7A | 0 | 27.405 |
| 3B | 10.420 | 76.252 | 7F' | -27.492 | 26.056 |
| 3B' | -10.420 | 76.252 | | | |
| 3C | 31.218 | 74.786 | 8B | 8.835 | 25.668 |
| 3C' | -31.218 | 74.786 | 8B' | - 8.835 | 25.668 |
| 3D | 51.964 | 72.035 | 8C | 26.306 | 24.545 |
| 3D' | -51.964 | 72.035 | 8C' | -26.306 | 24.545 |
| 3E | 72.292 | 67.891 | 8D | 43.756 | 22.214 |
| 3E' | -72.292 | 67.891 | 8D' | -43.756 | 22.214 |
| | | | 8E | 61.049 | 18.683 |
| 4A | 0 | 67.002 | 8E' | -61.049 | 18.683 |
| 4B | 10.106 | 66.808 | | | |
| 4B' | -10.106 | 66.808 | 9A | 0 | 6.375 |
| 4C | 30.358 | 65.452 | 9B | 8.310 | 6.277 |
| 4C' | -30.358 | 65.452 | 9B' | - 8.321 | 6.598 |
| 4D | 50.552 | 62.647 | 9C | 24.373 | 6.522 |
| 4D' | -50.552 | 62.647 | 9C' | -24.473 | 7.374 |
| 4E | 70.236 | 58.713 | 9D | 40.857 | 7.019 |
| 4E' | -70.236 | 58.713 | 9D' | -41.139 | 8.455 |
| | | | 9E | 57.785 | 8.102 |
| | | | 9E' | -58.348 | 10.159 |

The complete machining processing of each gore (No. 001 and No. 002) is discussed in the next section.

6.2.3.1 Profile Milling of Gore No. 001

Due to the late arrival of the sheets from the supplier, revisions were necessary in scheduling in order to take advantage of available time on the Kearney-Trecker N.C. mill.

Tape tryout machining tests had been run prior to material arrival and had proven acceptable. A full-size sheet of aluminum was sculptured to the gore configuration for this test.

To accommodate the N C. machine schedules, Part No. 001 was put on the mill immediately after receiving inspection. This meant a by-pass of diffusion bonding of the doubler ring at this time. The pockets and the ribs were machined except in the area which would be diffusion bonded.

Due to a y axis, or vertical travel, capacity limit of 4 feet, the gore section was machined one half at a time.

The vacuum chucks were set up on the mill and the gore section positioned relative to the chucks with set points and tooling and indexing holes. The upper half of the section which contains the fitting hole was machined first.

The decision was made not take a clean up cut on the outside skin surface prior to sculpturing the inside of the gore section. The section was then secured with clamps and vacuum to the chucks.

The original planwas to make one roughing pass and one finish pass, per pocket, to the required membrane thickness of 0.080-inch thickness. However, as the machining of the pockets commenced it was found that excessive vibrations were set up and cutter chatter would not allow the full depth of cut. Investigation showed that the surface pits and gouges on the chuck side of the sheet prevented the material from nesting firmly to the vacuum chuck for machining.

Cuts to a depth of 0.100-inch were made while maintaining a chip load of 0.005-inch per tooth of cutter. Surface feet per minute was held at approximately 40 feet. These light cuts enabled the vacuum pressure to gradually pull the locally gouged material down to the chuck for uniform thickness machining. A flood of soluble oil coolant was used.

Since diffusion bonding of this part would take place after this initial machining, only boring and spotfacing of the flange itself was done in the center fitting area. All other pocket areas were machined to a membrane thickness of 0.130 ±0.050 inch. This material excess was left for machining, after the doubler ring bonding cycle, as previous tests had shown that a certain amount of distortion would result in the areas surrounding the fitting.

After the top section of the gore was sculptured, to the dimension listed above, the part was turned over and repositioned on the vacuum chuck and the bottom half was machined to match. The initial machining of Part No. 001 was complete.

This part was then processed through the diffusion bonding, "Hot" flattening and cleaning cycles prior to being returned for final pocket milling. Also, during this time the N.C. profilers became loaded and the part had to be completed on a Keller tracer mill.

The vacuum chucks were set up on the Keller mill and the gore section positioned on the chucks as before. The full size aluminum section that was made during the N.C. tape tryout was used as a template for the tracer head. The size of the titanium section and the aluminum template did pose somewhat of a set-up problem. Again only one-half of the gore section could be machined at a time due to "Y" axis travel limitations of the Keller tracer mill. This "Y" travel limitation made it possible to overlay the aluminum template on the titanium gore section and thus have a workable overall height. See Figure 56.

The gore section was clamped to the vacuum chucks and the pumps turned on to pull 25 inches Hg, during the machining operation. Again the upper half of the section was machined first. The transition area around the fitting hole was machined and the port hole was spotfaced and bored before any of the pockets were finish machined. The upper half was now carefully checked to be sure that all areas of the gore section were being held flat and tight to the vacuum chucks. Each pocket was then indicated for high points and checked for thickness with a vidigage and the dimensions recorded. The drawing tolerance of 0.080 inch ±0.007 inch was the target for membrane thickness in all the pockets. Again the uneven skin surface made it extremely difficult to machine and hold tolerances. It became apparent that with this surface condition, ±0.007 inch could not be held, so the nominal was still set at 0.080 inch with a ±0.010-inch tolerance. To improve the holding power of the vacuum chucks, extra grooves were machined in the chuck to give a pattern of 4-inch squares on the chuck face. New rubber was installed in all the grooves. The chuck was now capable of exerting and maintaining a greater vacuum force on the part. Since one of the main objectives of the program was weight saving, the average of all the pocket web thicknesses was to be 0.080 inch. It took at least two passes per pocket to bring the part within this new tolerance goal. When all pockets were finish machined the rib height was then taken down to 0.50 ±0.050 inch. This was made necessary by the plate being out of gage tolerance. The transition from membrane thickness to weld land thickness was final machined as was the weld land itself. The part was then repositioned and the same operation repeated on the bottom half of the section.

At this point, work on the contract was suspended, and the No. 001 gore section was taken from the Keller tracer mill and put in storage.

Operations yet to be done on this part are:

1) An ultrasonic inspection of the diffusion bonded doubler ring.
2) Vacuum forming cycle.
3) Final machining of the port hole fitting after the forming operation.
4) Final part trim.

Since Part No. 002 was the one finished under the renegotiated contract, Part No. 001 was returned to MSFC without being processed completely.

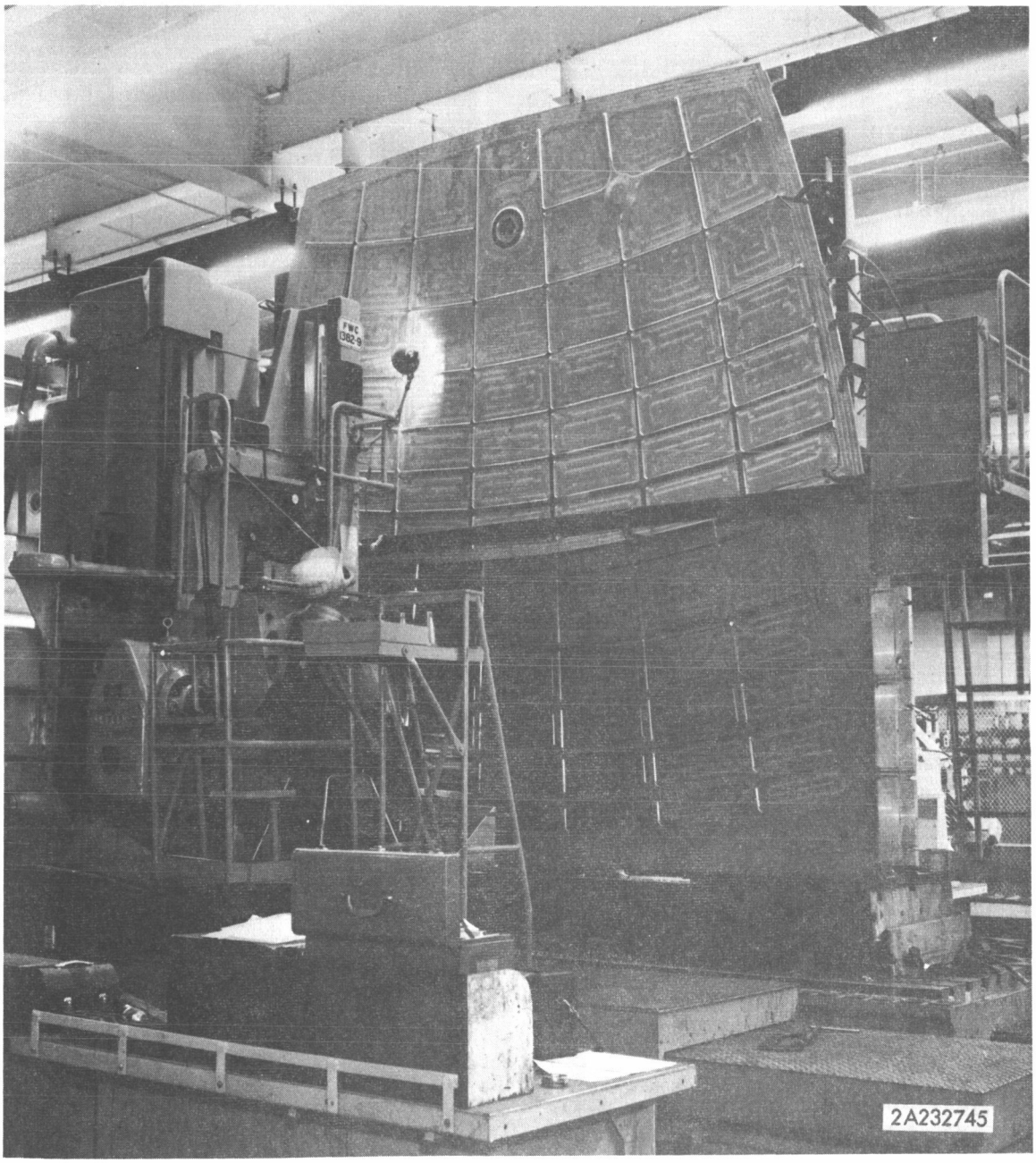



FIGURE 56

TRACER TEMPLATE OVERLAYED ON
THE GORE SECTION OF THE KELLER MILL

6.2.3.2 Profile Milling of Gore No. 002

This part was machined in the previously planned sequence. That is, it was pocket milled after diffusion bonding, hot flattening and cleaning; in contrast to, Part No. 001 which was rough milled before bonding (due to machine load) and finish milled after bonding.

Part No. 002 was scheduled for the Kearney-Trecker profile N.C. Mill as soon as Part No. 001 came off the machine. At this time a crack in the plate around the edge of the ring doubler was observed. This crack extended approximately 270 degrees around the edge of the ring, but did not appear to penetrate the plate completely. Cause of the crack was attributed to thermal stress resulting from the extreme temperature gradient from the heated zone to the cold surrounding area of the plate, during diffusion bonding. A decision as to the disposition of the crack would be made upon further investigation during machining. (Figure 104.)

As soon as Part No. 001 came off the K&T N.C. mill, Part No. 002 went on. It was positioned on the vacuum chucks in the same manner as Part No. 001. The time allotted to the contract on this N.C. mill was running out, and it was obvious it could not be machined completely before the deadline. Arrangements had been made to utilize the tape tryout aluminum part, as a template, for a Keller, tracer, profile mill in another shop. Since the part would have to be moved in the midst of the machining operation, the target for the membrane thickness in the pockets would be 0.130 inch. This would then leave material for resetup on the Keller profile mill.

The upper half of the section which contained the fitting hole was machined first. A plunge cut to depth was used with a 3-inch diameter by 0.375-inch radius, four flute cobalt end mill. SFM was held at 40 and chip load per tooth was 0.005 inch. A flood of soluble oil was used as coolant. Vibrations were again set up and the cutter had to be backed out 0.150 inch before the cutter chatter stopped. It was felt that the vacuum chucks were not holding the part solid enough and allowing it to vibrate. This led to work hardening of the titanium and dulled the cutters very quickly. With the cut backed off to the 0.280-inch thickness the machining went very smoothly. (The average depth of cut was from 0.200 to 0.250 inch, taking into account the variation in gage of the plate.)

A weld prep of the crack had been thought of for this time, but it was decided to continue with the sculpturing of the part until the schedule forced the section off the N.C. mill. The upper half was completed and the part turned over and machining was underway on the bottom half before the move had to be made.

When the move to the Keller profile mill was made, vacuum chucks, vacuum pumps, angle plates and associated plumbing were taken and utilized for setup duplication on the tracer machine.

Experience, gained on the machining run on the K&T N.C. mill, made it imperative that the setup provide the greatest possible holding power from vacuum chuck to part. The angle plates that would hold the vacuum chucks were indicated true to the "X" and "Y" axis. The vacuum chuck which had been builtup for the contract was 4 by 14 feet and was not attached to the trued-in angle plates. When the vacuum chuck had been securely bolted in place, a cut across the face of the

chuck was taken to true the chuck to the angle plates and the machine travel. Two 6-1/4 by 6-1/4 by 5 inch Chicago pneumatic vacuum pumps driven by 5 hp electric motors were used to provide the vacuum for the chucks. One pump was hooked to each section of the chuck.

The part was now positioned on the chucks, as before, with the bottom half of the section in place for machining and the vacuum was turned on. The aluminum template was put in place and secured over the top of the part (Figure 56). A 1-5/8-inch diameter by 0.375-inch radius, four flute end mill was used to make cuts to print depth around the perimeter of each pocket. The SFM of the cutter was held at about 45, and chip load per tooth was kept at about 0.005 inch. After all pockets were cut on the periphery to depth, a 2-1/2-inch diameter end mill was used to machine the center of the pockets to a target thickness of web of 0.130 inch. Each pocket was then vidigaged (Figure 57), cut again to print tolerance of 0.080 inch. A final vidigage operation was undertaken and the dimensions recorded. The dimensional tolerance was 0.080 +0.045/-0.032 inch. The transition area from pocket bottom to weld land was machined as well as the weld land itself. The part was trimmed to remove excess on the periphery, and then turned over and the top half was machined to match. The gage of the sheet varied to such a degree (0.200 inch) that the ribs had to be machined to a nominal height of 0.500 inch.

After machining was completed, the repair to the crack around the bonded doubler ring was undertaken. Since the crack did not extend through the plate it was decided to prepare the crack for welding by end milling. The fractured area of crack was removed to present clean metal for the weld operation. A 3/8-inch diameter, ball nose, end mill was used for the milling. The end mill was plunged to a depth of 0.120 inch, which left a web thickness of 0.060 inch at the bottom of the weld prep.

The part was then processed to completion according to the Manufacturing Plan. A discussion of the remaining machining operations involved in the plan follows.

As indicated in previous discussions on forming process development, one of the major problems of forming the gore segment was edge buckling. Tests had indicated that this buckling could be minimized by welding a framework to the periphery of the part. After the forming operation, this framework had to be removed and the part trimmed to a net part trim line.

The formed gore section was removed from the form die and placed on the "Egg Crate" trimming fixture for removal of the welded picture frame.

The original plan was to use a skate attachment for the final trim of the part. However, tests involving friction sawing with a "Skil-Saw" proved quicker and more economical, so this method was used. A portable Black Decker, 6-inch "Skil-Saw" with 4500 rpm was used for the trimming. A metal cutting, high speed steel, solid tooth, circular saw blade was used. The saw blade was 6-inch diameter, 150-tooth by 1/16-inch wide. An air-spray mix of TJ-73 coolant was directed on the blade during the cutting cycle to control blade heating, (see Figure 58 for application of coolant). The entire 42 feet of peripheral trimming was done with two saw blades, each sharpened once. No difficulty was encountered in following the layout line of the straight-edge in removing the excess titanium.

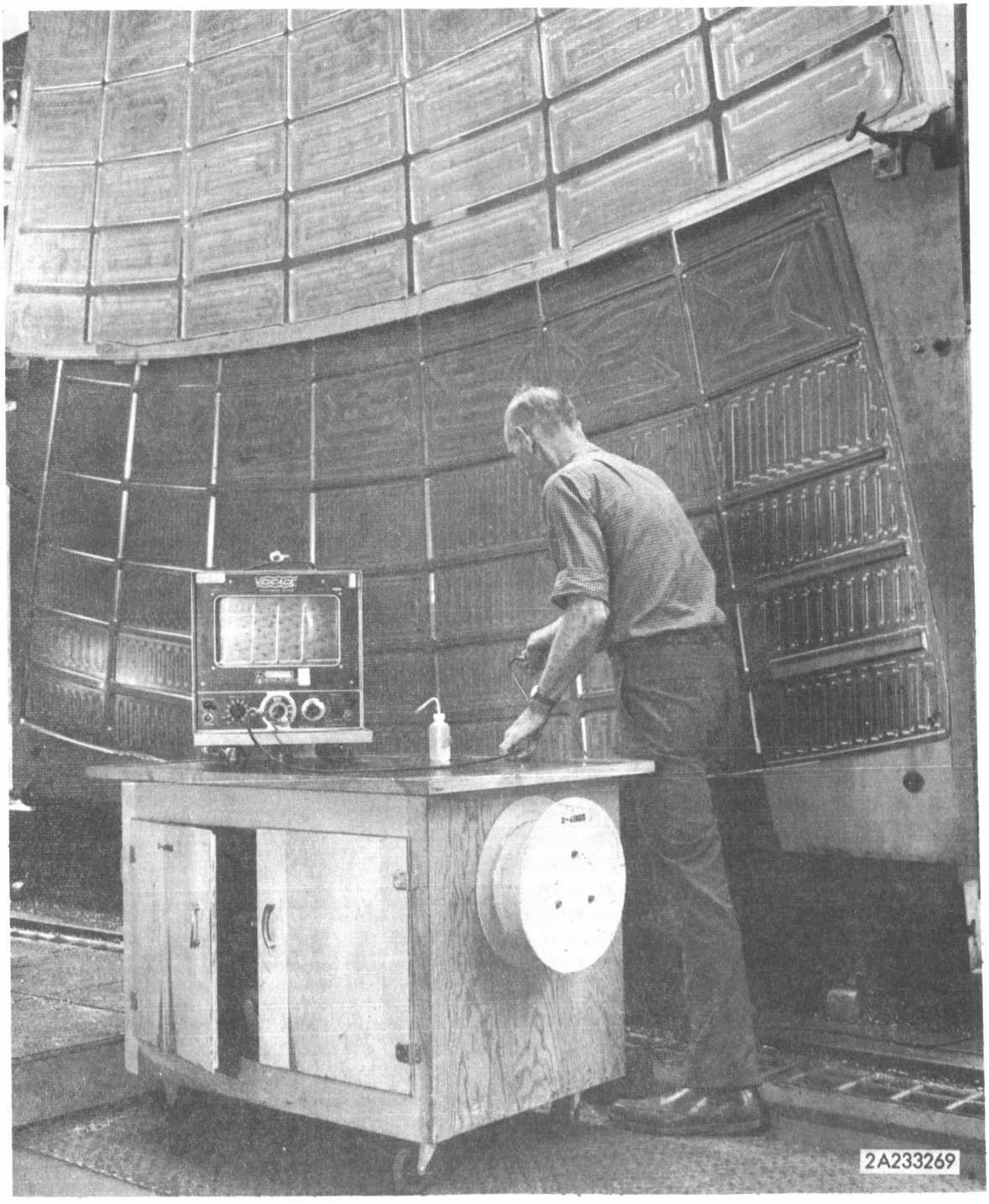



FIGURE 57

VIDIGAGING THE MACHINED POCKETED AREA
TO DETERMINE THE THICKNESS OF THE WEB AREA

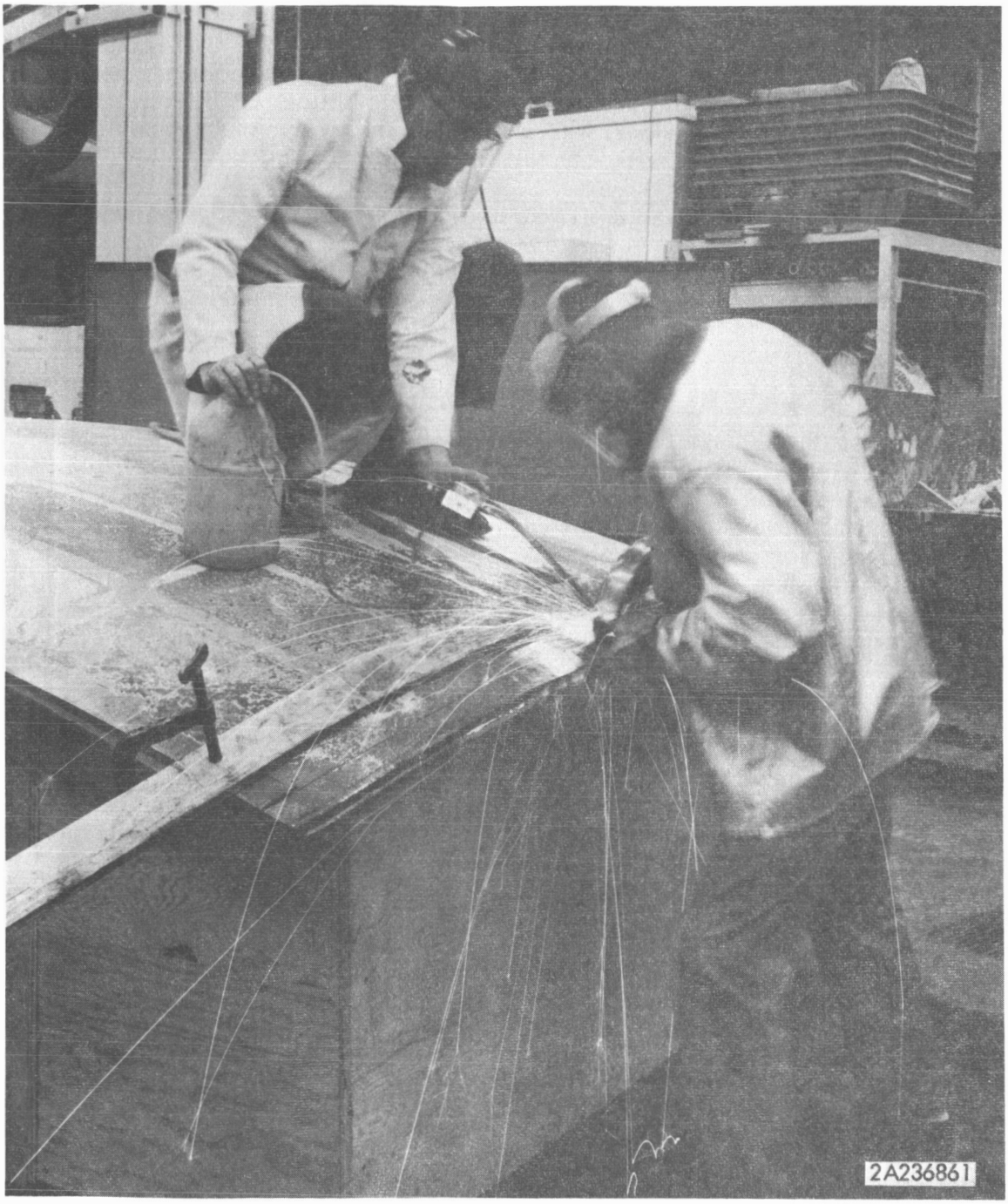



FIGURE 58

TRIMMING FRAMEWORK FROM GORE SECTION
WITH SKILL SAW AND SPRAY MIST COOLANT

Final machining of the fitting hole area (with Keller profile mill) was the last operation to be accomplished. To locate the gore on the Keller, a holding fixture was fabricated by making a plaster splash of an area two feet on each side of the fitting hole and extending the full eight feet in height of the gore. A steel reinforcing bar was added for structural strength and 6-inch "I" beams were used for the base legs. The cast was a duplicate of the gore contour and was used to nest the gore for mounting on the Keller angle plates. The fixture was bolted to the machine and the part was clamped to the fixture and secured for machining (Figure 59).

A single point carbide tool bit was used in a Wholhaupter boring head (Figure 60) The spotface to thickness was fly-cut by using the positive feed capacity of the head. The bore of the fitting hole and the back chamfer on the inside were then set and finish machined. This machining itself presented no problems, however part handling did because of size.

### 6.2.4 Conclusions

Cutters, cutting conditions, coolant and machine rigidity are important considerations whenever titanium is machined. This program further verified that cobalt cutters have a 4-to-1 life advantage over regular high speed steel cutters; that cutting conditions should be increased or decreased around a basic starting point of 40 SFM for cobalt cutters and 0.005 inch per tooth chip load; that a flood of water soluble oil is a satisfactory coolant (sulphurized or chlorinated cutting fluids should not be used with titanium because of its stress corrosion tendencies); and that machine rigidity is essential to minimizing machining costs and machining tolerances.

## 6.3 FORMING PROCESS DEVELOPMENT

Process development consisted of a series of tests which evolved as results of previous tests were analyzed. Subscale tests were initially planned to establish process parameters and tool design criteria. After these parameters and criteria were determined, the final step was to be full size die design and forming of a gore segment. However, results were not according to plan. Subscale blanks were successfully formed, but there was some apprehension regarding direct scaleup to a full size gore segment. A large size verification test indicated that unforeseen problems existed. Further testing, both full scale and subscale, was necessary to solve wrinkling problems. An outline of the forming test sequence is shown in Figure 61.

### 6.3.1 Subscale Tests

Preliminary subscale tests were designed to determine the feasibility of vacuum forming a 1/2- by 24- by 36-inch titanium plate. A saddleback die, with contour severity greater than that of the gore was used because of its ready availability (Figure 62). The plate conformed to the die contour after being formed at 1450°F, using 29 inches of Hg to supply the forming forces. The resultant contoured blank is shown in Figure 63.

A second subscale test was run on a small vacuum die with contour simulating that of the full scale gore. The 8-1-1 titanium blank had sculptured pockets of gages approximating those of the gore segment. The blank was formed at 1450°F

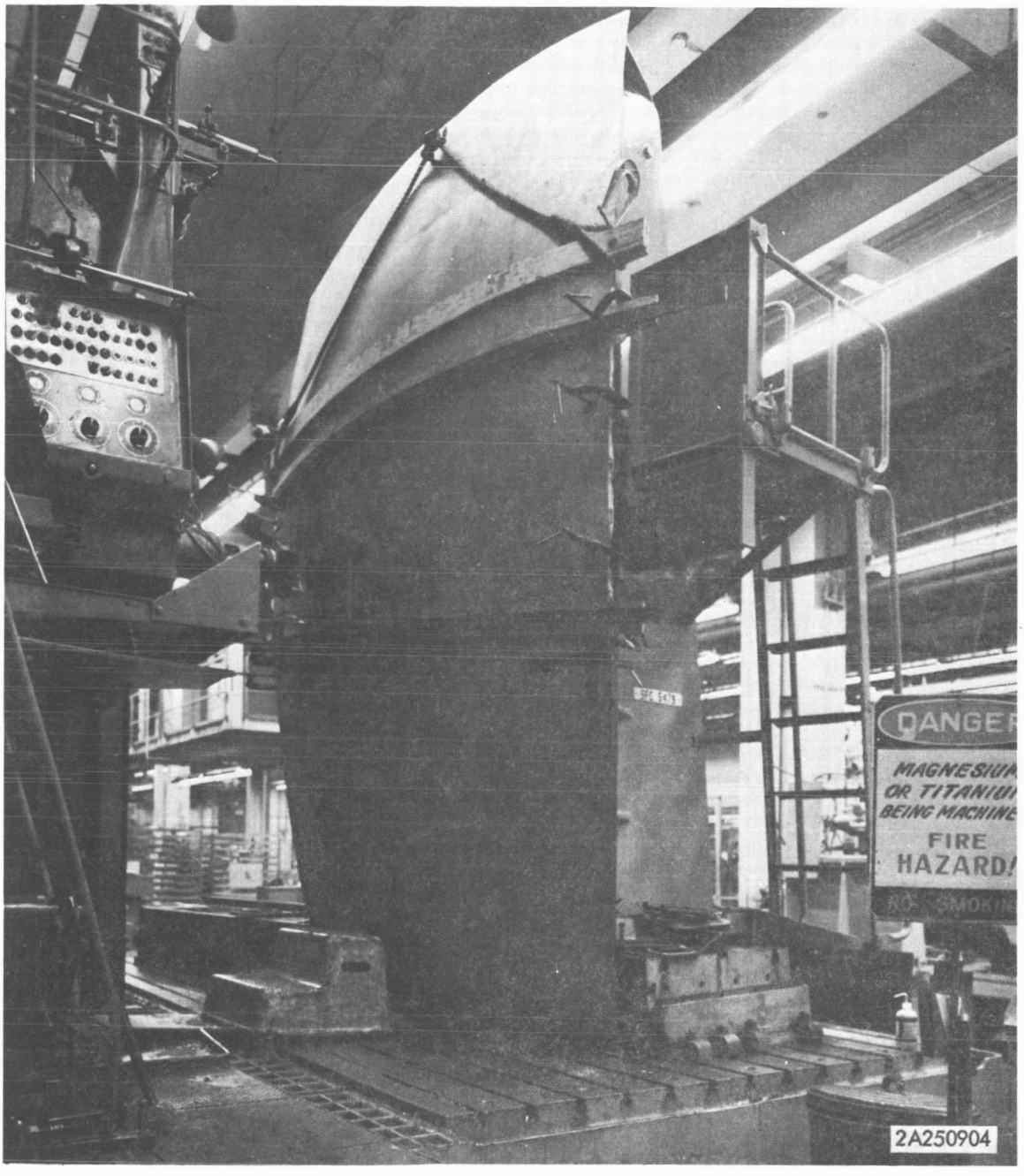



FIGURE 59

FORMED SECTION IN PLACE FOR FINAL MACHINING ON KELLER MILL

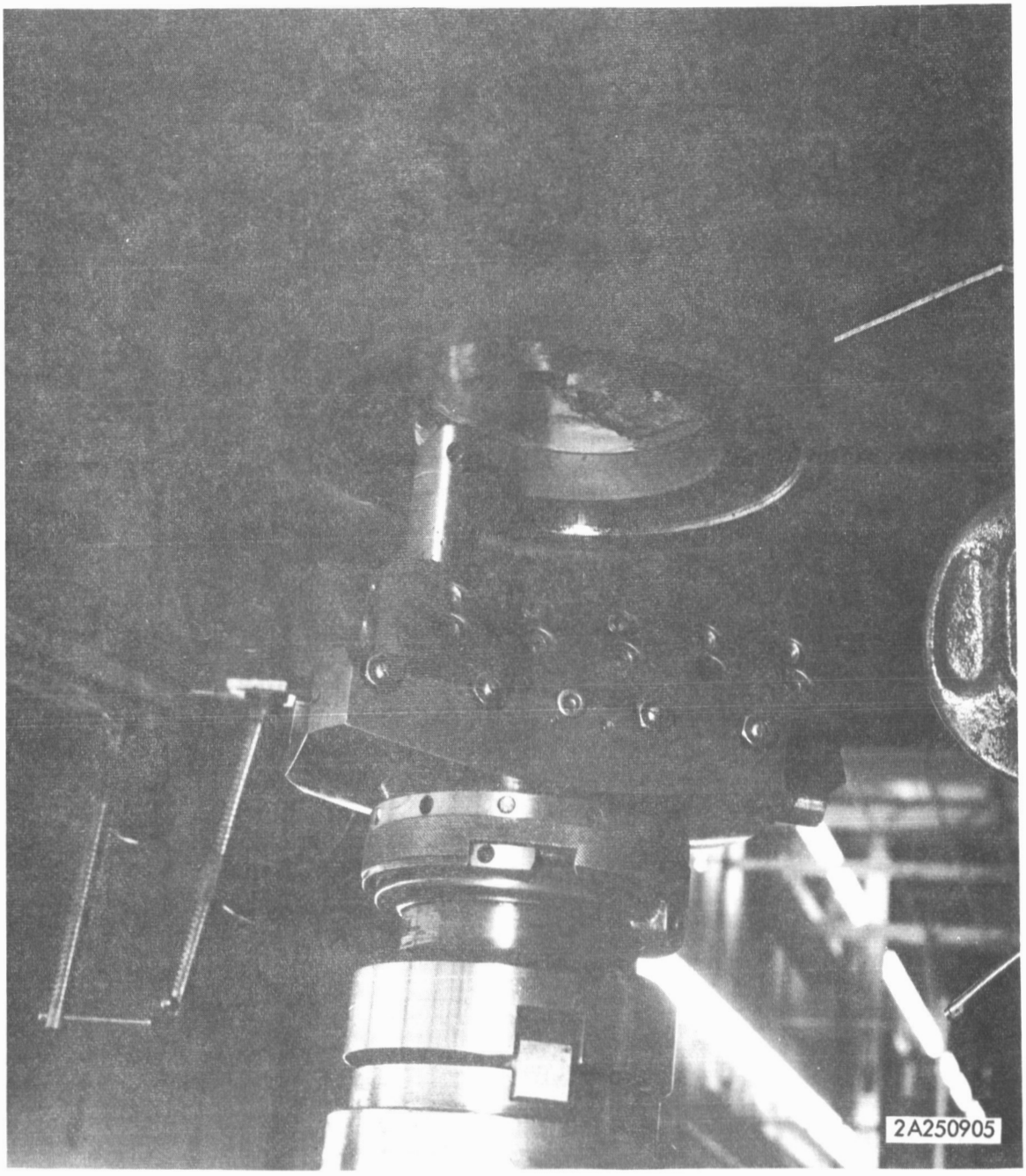



FIGURE 60

BORING HEAD FOR SPOTFACING AND FINAL BORING

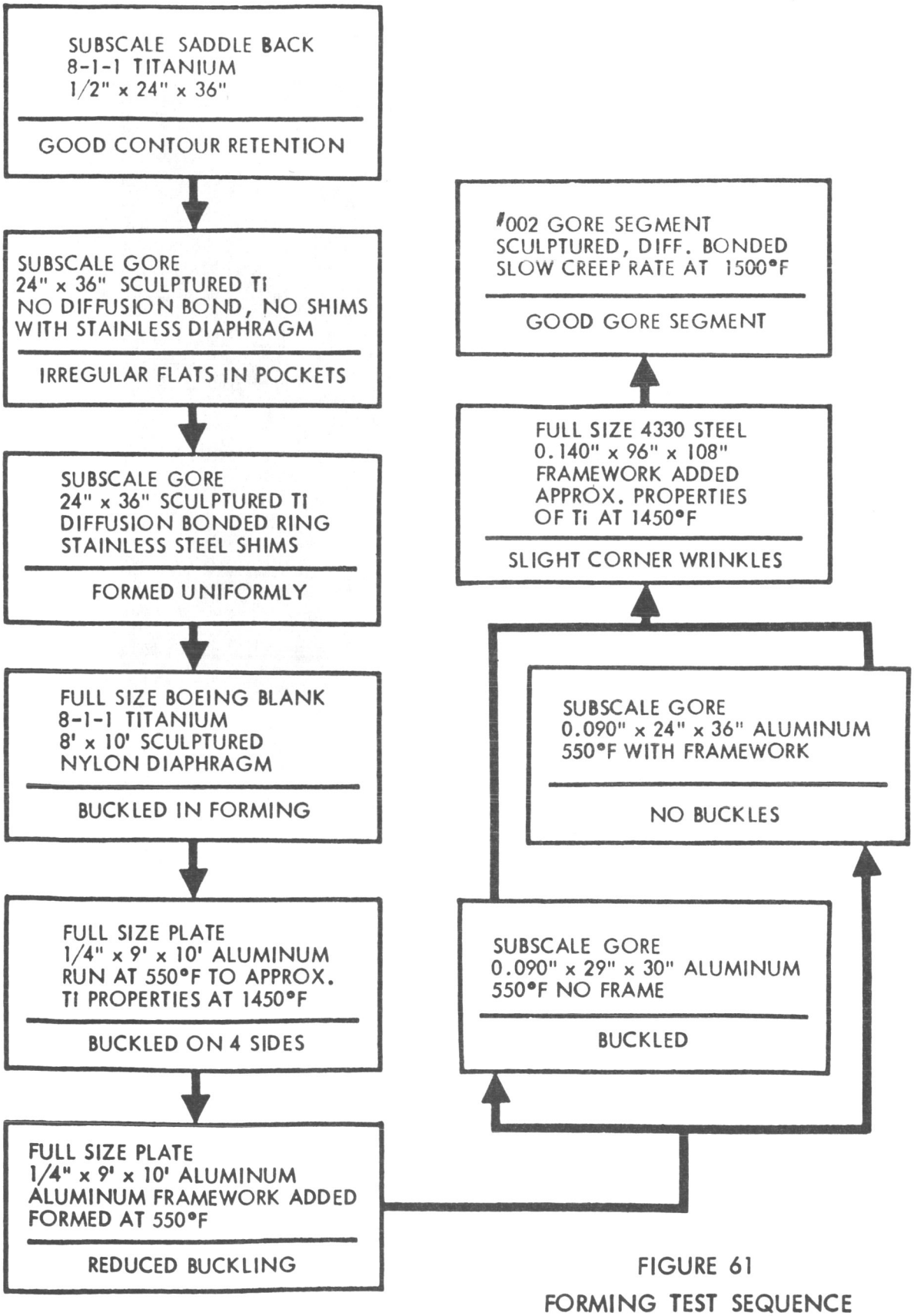



FIGURE 61
FORMING TEST SEQUENCE

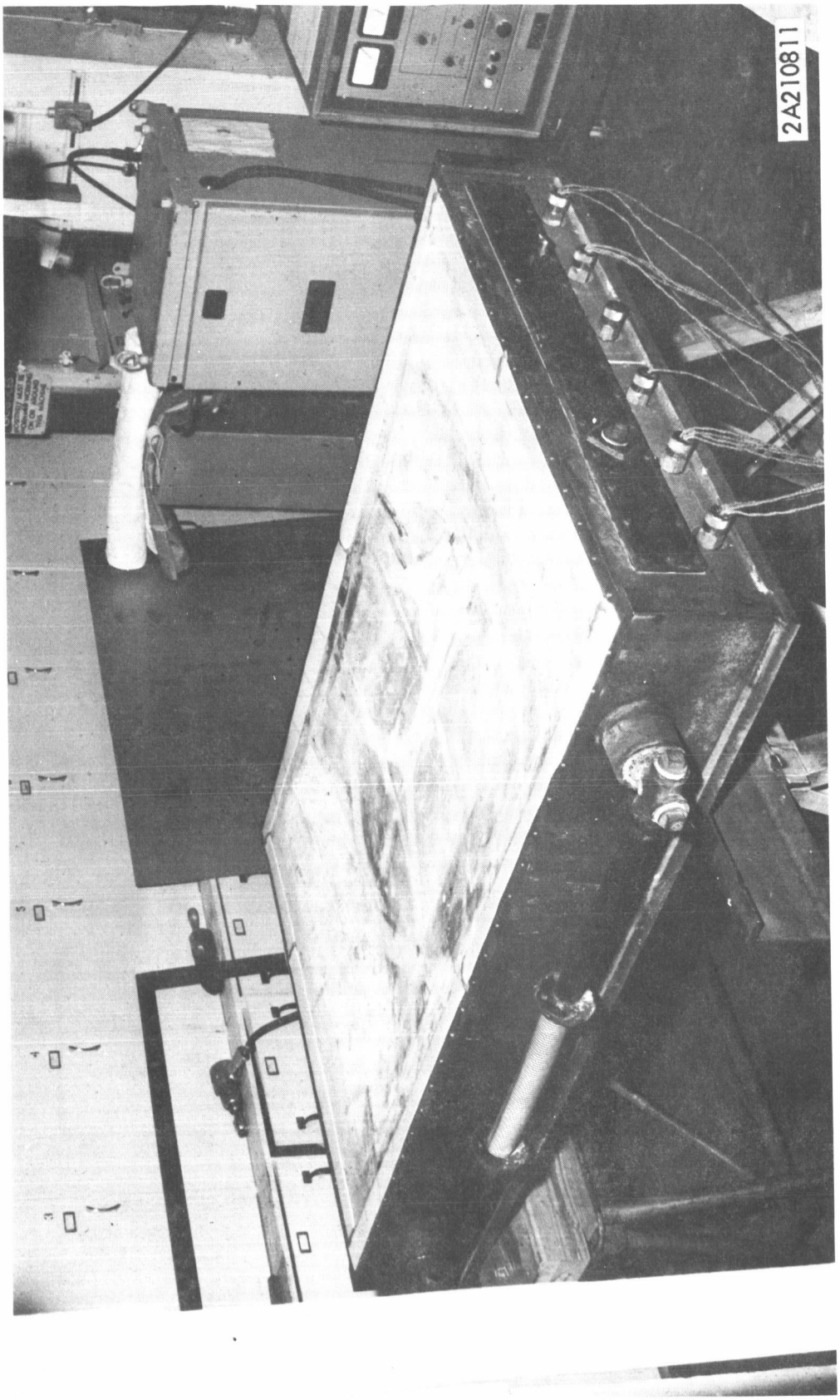



FIGURE 62

SADDLEBACK HOT VACUUM FORMING CERAMIC DIE

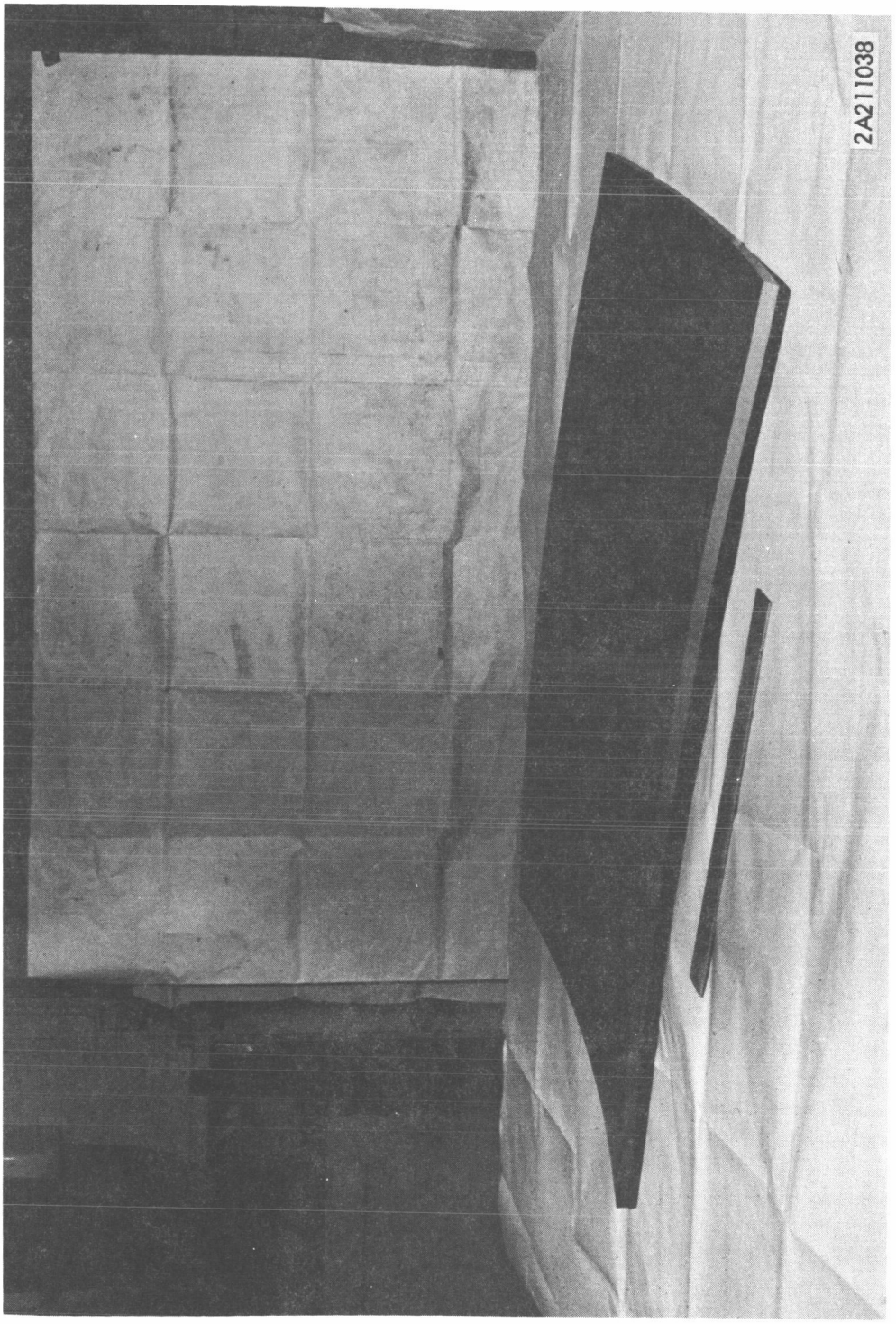



FIGURE 63

ONE-HALF INCH THICK PLATE FORMED IN SADDLEBACK DIE

using 22 to 26 inches of Hg (Figure 64). Bridging by the stainless steel vacuum diaphragm caused the pockets to form irregularly. Figure 65 depicts bridging and the corresponding uneven pressure distribution. Figure 66 illustrates the shimming technique proposed to correct this problem.

The next subscale test incorporated both shims and the diffusion bonded ring. Stainless steel shims were used in the sculptured pockets and alumina sand was used to fill the irregular pattern around the diffusion bonded ring. This approach provided equalized pressure distribution and the blank formed uniformly using 1450°F and 25 inches of Hg. The formed part is shown in Figure 67.

Before the first full size forming test was run, a major change in the vacuum forming operation was made. The stainless steel diaphragm was deleted because of wrinkling and sealing problems encountered during tool tryout testing. The advancement of insulation capability was adequate to permit substitution of a nylon diaphragm capable of withstanding 400°F. This new diaphragm offered ease of handling and sealing.

### 6.3.2 Large Size Verification Test

The first full scale test was run on an 8-1-1 titanium blank which consisted of two 4- by 10-foot sheets welded to an 8- by 10-foot configuration. The blank was partially machined, partially chemically milled; had a crack resulting from diffusion bonding (Figure 36), and had two lifting holes along one edge.

The blank was cleaned, coated with phosphate-fluoride and Everlube T-50, then placed in the die. Four 6- by 6- by 0.063-inch pieces of stainless steel protected the die face at the corners of the blank. Stainless steel shims were coated with Everlube T-50, then placed in the pockets. This brought the shimmed pockets level with the ribs, permitting equal pressure transmission to all areas of the blank.

A 0.020-inch stainless steel skirt was placed around the perimeter of the panel, preventing the vacuum blanket from forcing insulation underneath the part. Figure 68 shows the test setup nearing this point. Thirty-six inch wide strips were used to skirt the ends, while 18-inch strips sufficiently bridged the gaps along the sides. The panel was insulated with two 1/2-inch layers of quartz fiber (Figure 69), a fiberglass blanket (Figure 70), a 5-inch depth of Vermiculite, another fiberglass blanket, and then the nylon diaphragm (Figure 71). This 0.005-inch diaphragm was sealed using tape and Duxseal.

Due to thermocouple problems (discussed in Section 6.3.3) encountered during the initial stage of heating, the actual temperature of the blank was not precisely known after 1000°F was passed. Calculations made after the test indicated vacuum was probably applied prematurely when the part was in the 1000-1300°F range. Heating of the part continued until the part was in the 1300-1450°F range. The part was then soaked for 1-1/2 hours.

The required cooldown rate of less than 100°F/hour was maintained to 900°F, then the insulation was removed and the part examined. The formed 8- by 10-foot blank is shown in Figure 72. Two large wrinkles extend radially inward from the lift holes, but not into the doubler area. The remainder of the panel formed satisfactorily with slight springback.




FIGURE 64
SCULPTURED SIDE OF A 1/2-INCH THICK GORE THAT HAS BEEN HOT VACUUMED FORMED, IN SUBSCALE DIE

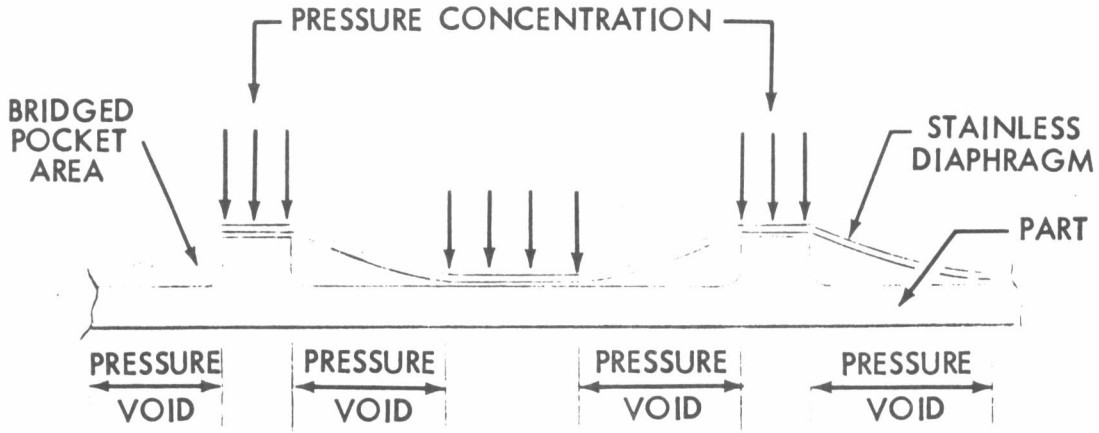



FIGURE 65
UNEVEN PRESSURE DISTRIBUTION

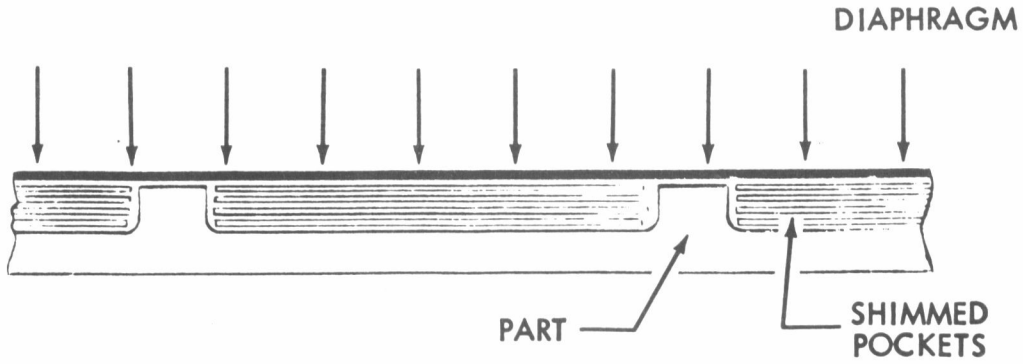



FIGURE 66
EQUALIZED PRESSURE DISTRIBUTION

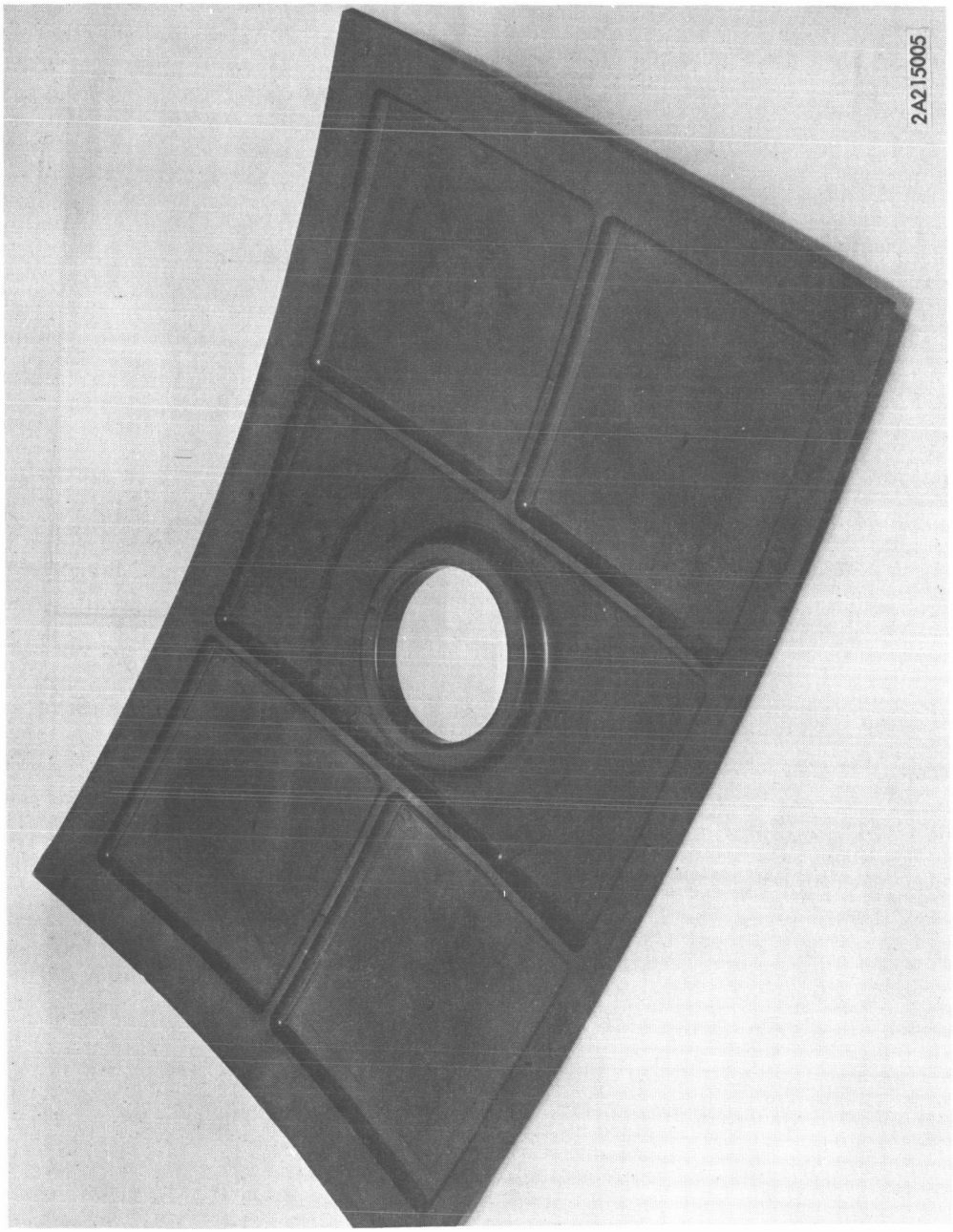



FIGURE 67
PLATE SCULPTURED WITH DIFFUSION BONDED
RING FORMED IN SUBSCALE DIE

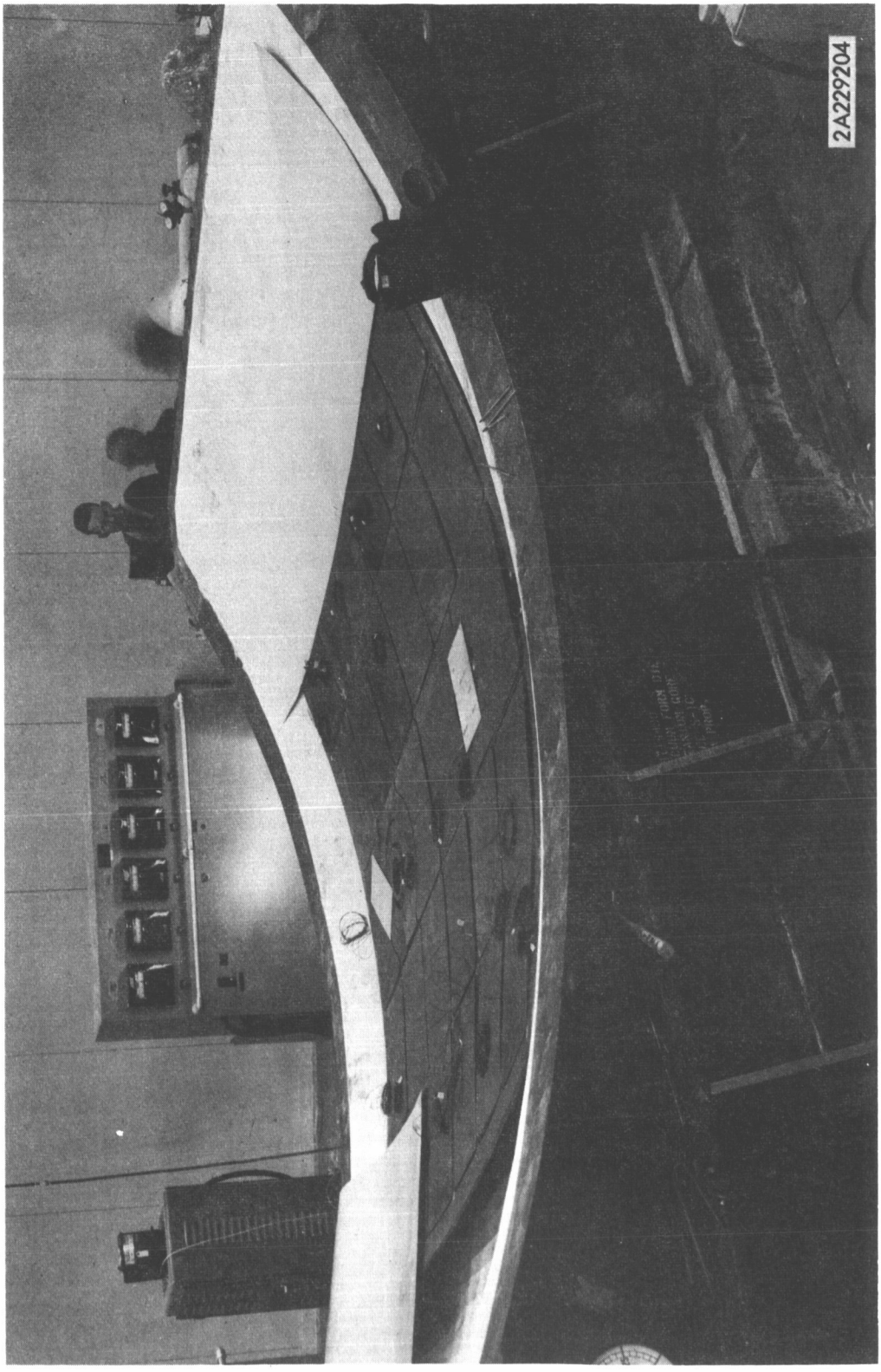



FIGURE 68
EIGHT BY TEN FOOT SECTION BEING PREPARED
FOR FORMING

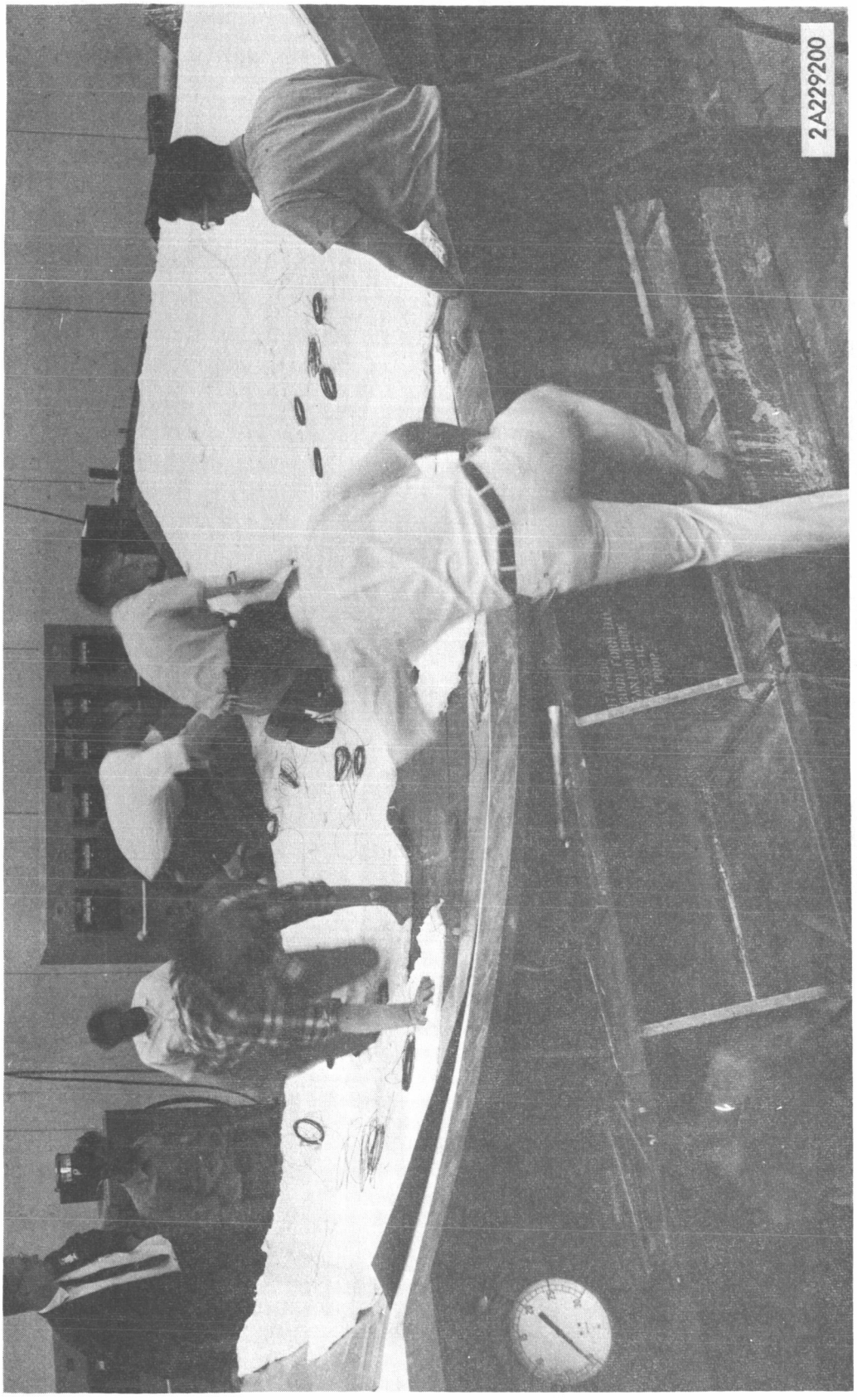



FIGURE 69
INSULATION BEING APPLIED TO THE 8 X 10-FOOT SECTION

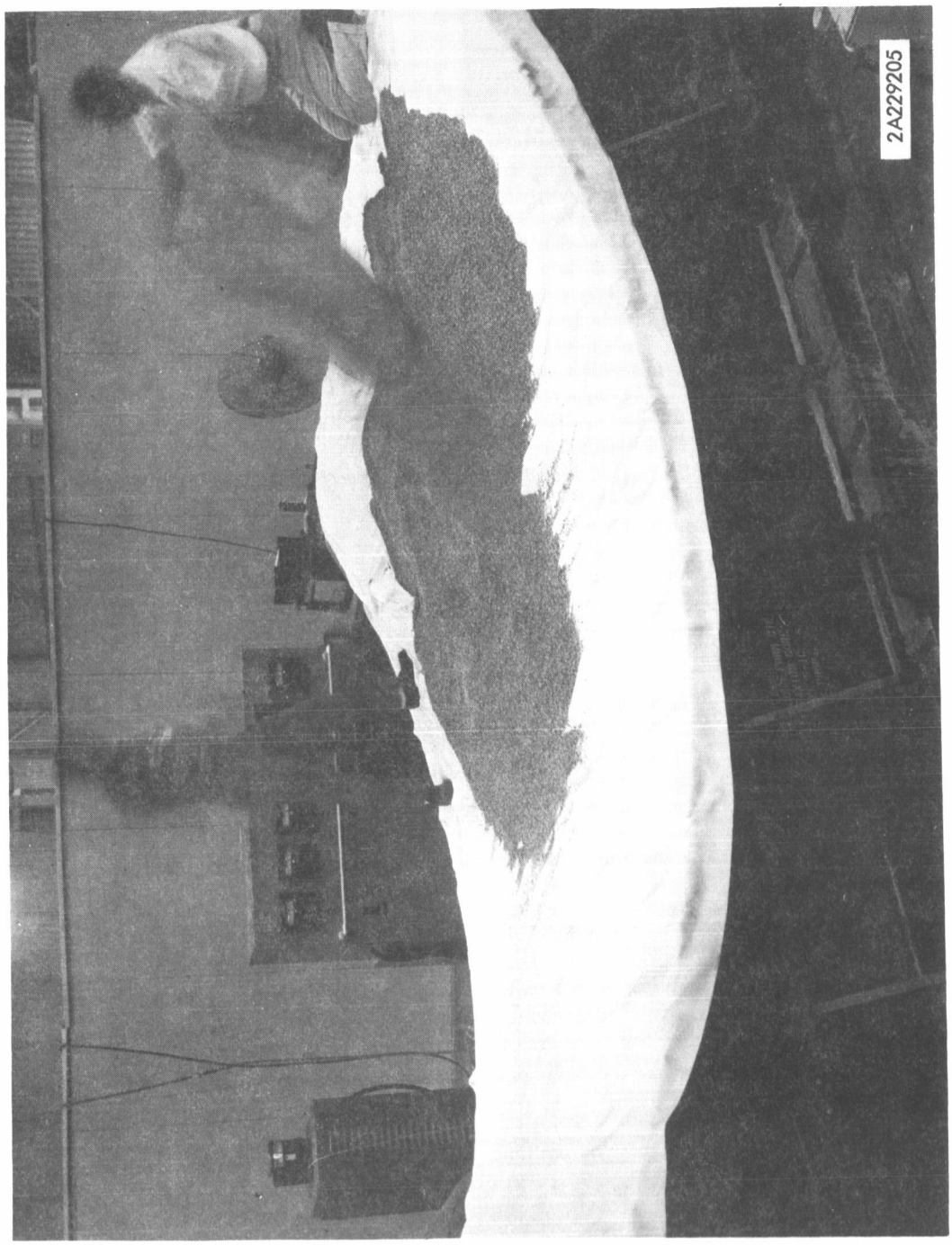



FIGURE 70
VERMICULITE BEING APPLIED OVER THE FIBERGLASS BLANKET

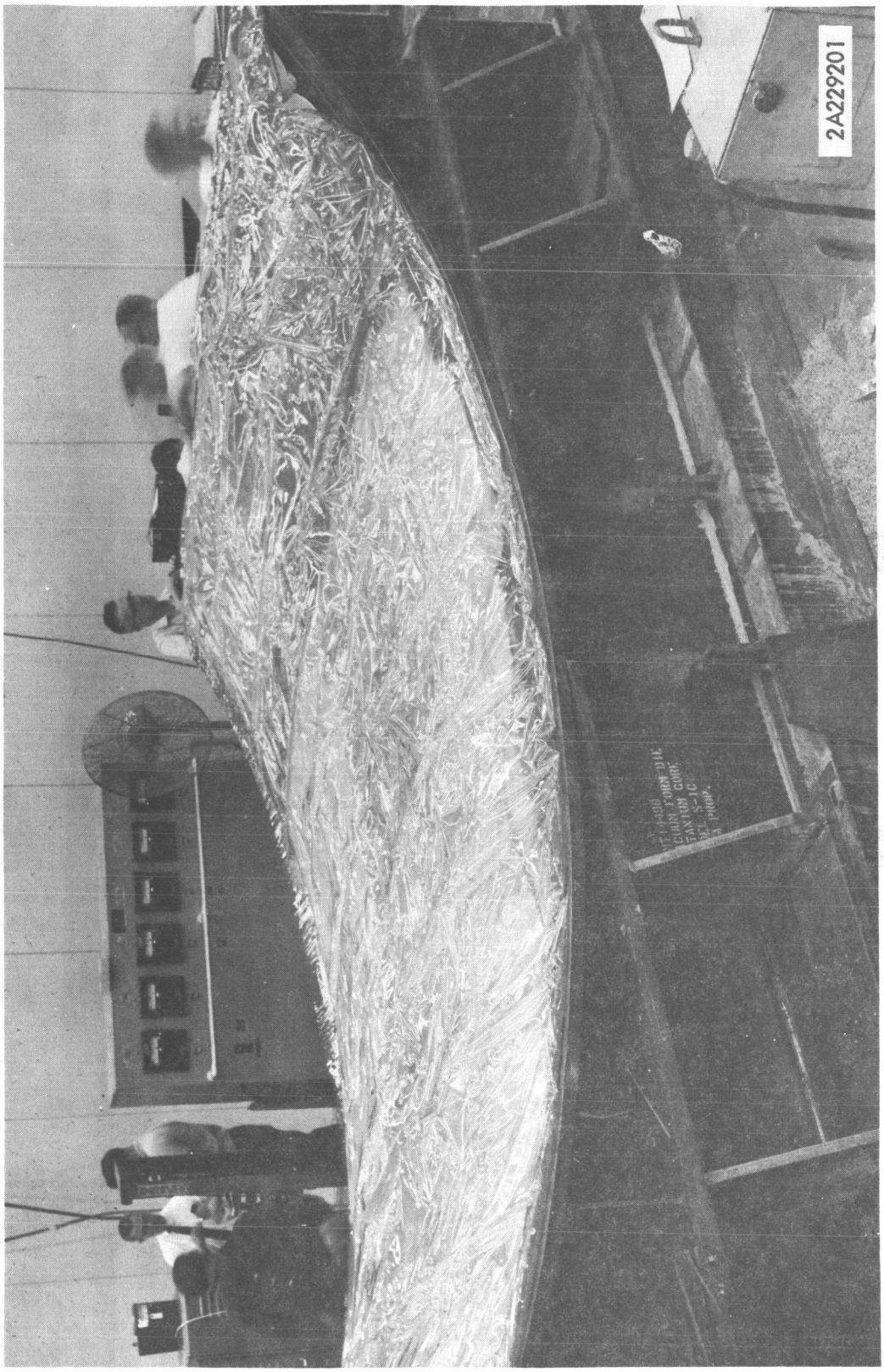



FIGURE 71

0.005-INCH NYLON DIAPHRAGM COVERING SECTION AND DIE

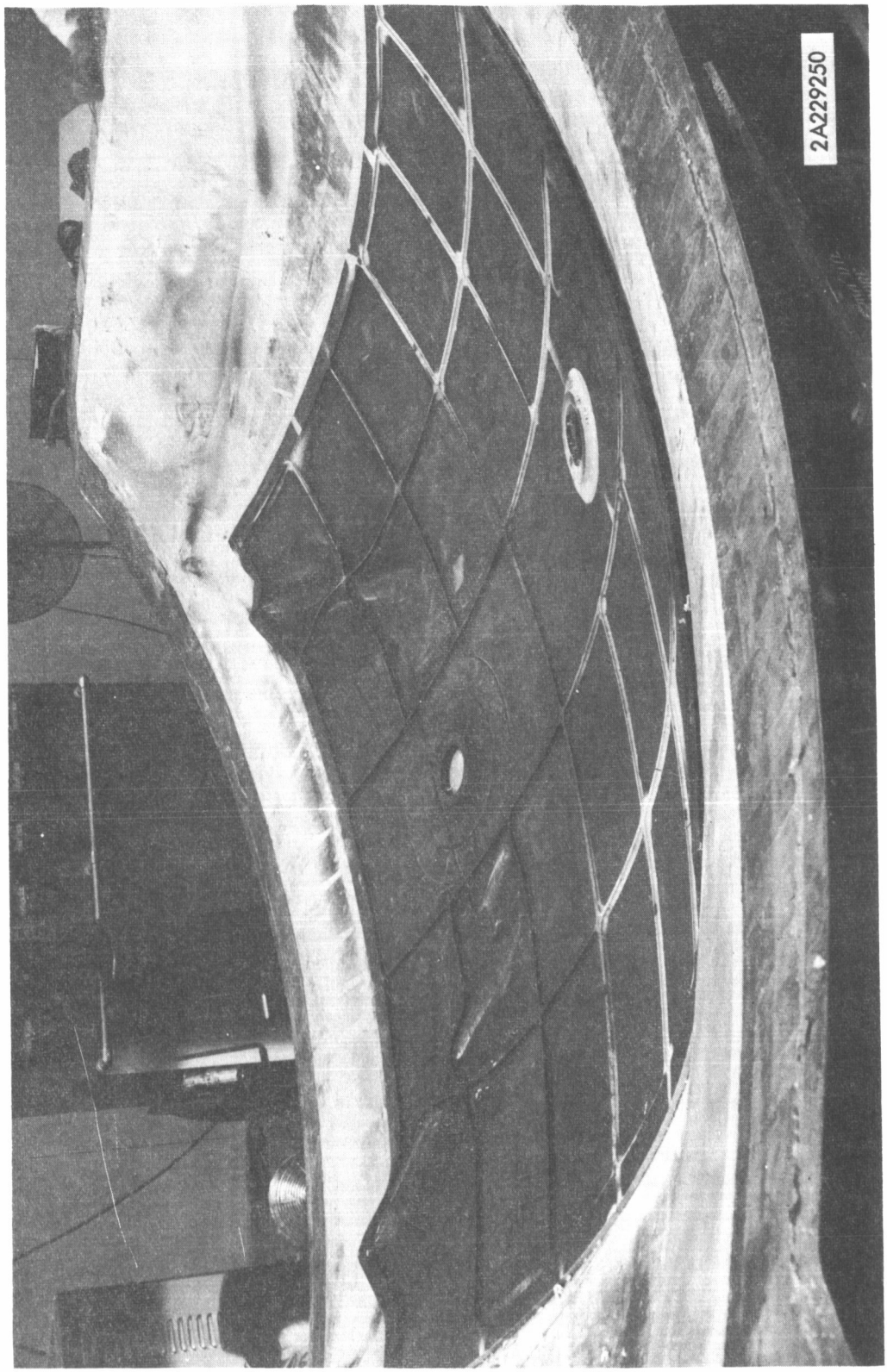



FIGURE 72
8 X 10-FOOT TITANIUM VACU-FORM TEST
(WRINKLE FAILURES)

The unexpected wrinkling problem was attributed to premature introduction of vacuum (at less than 1450°F), weakening of border area in the vicinity of lift holes, and uneven stress distribution due to the diffusion bonding crack.

### 6.3.3 Thermocouple Problem

Two major thermocoupling problems were solved using the results of this test. The thermocouples were found broken at the transition zone between the part and die. This break was made as the blank moved down into the die cavity. To correct this a 1-1/2-inch diameter by 4-foot flexible steel tube was used as a bridge from the periphery of the tool to approximate center of the part. By doubling back the thermocouple wires inside the tube, the wires were allowed to move with the part during forming. A secondary thermocoupling problem concerned burning of insulation near the junction (causing shorts), and connection of the thermocouples to the part. The utilization of ceramic insulators in uninsulated zones and the attachment of thermocouples to stainless steel tabs (placed on the sculptured ribs) remedied this situation.

### 6.3.4 Wrinkle Prevention Tests

Further forming development tests were then planned to determine the causes of wrinkling and/or to develop corrective measures. Since the first NASA gore segment to be formed would be valued at approximately $17,000 in the machined condition, further development work was deemed necessary to improve chances of success.

A 1/4-inch, 9- by 10-foot aluminum plate was obtained for forming tests in a temperature range of approximately 550°F where yield strength and elongation would approximate that of the 8-1-1 titanium gore segment. Due to the lower temperature requirement, a thinner layer of insulation was used, allowing operators to observe the contour as the part formed. A gentler application of pressure was attempted in order to reduce buckling tendencies. The plate buckled on each edge, midway through the forming cycle and the test was terminated.

The aluminum plate was then rolled to remove the buckles, and a 1/2-inch thick by 2-inch wide framework was tack welded around the perimeter of the part. The forming test was rerun, and buckling occurred only on the most severely contoured edge where a break in the weld also occurred. The framework reduced buckling, but did not eliminate it (Figure 73).

Further tests were then planned to investigate heavier frameworks and the effects of forming rate variation. Two subscale tests were run to further demonstrate the advantage of forming with a welded framework. The material was 6061 aluminum (0.090 by 24 by 36 inches), and the forming temperature was 550°F. The 0.090-inch gage was chosen because it probably would buckle.

The first sheet buckled at the edges as anticipated (Figure 74). A 1/4-inch thick by 1-inch wide framework was welded around the periphery of the second sheet. It was subjected to an identical forming cycle and formed free of buckling or wrinkling (Figure 75).

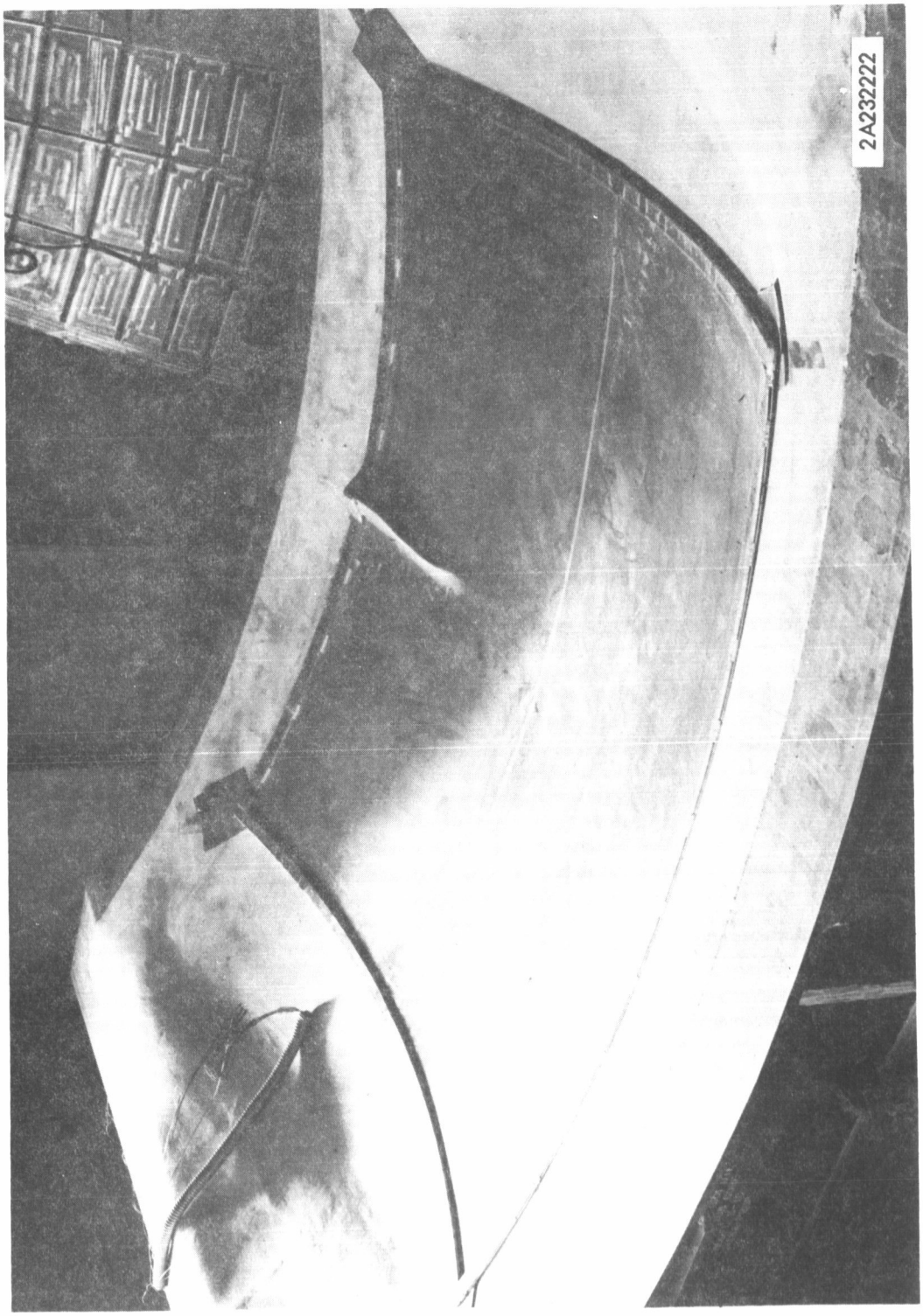



FIGURE 73
ALUMINUM TEST PART WITH 1/2 X 2-INCH PICTURE FRAME




FIGURE 74
24 X 36 X 0.090-INCH ALUMINUM TEST PART

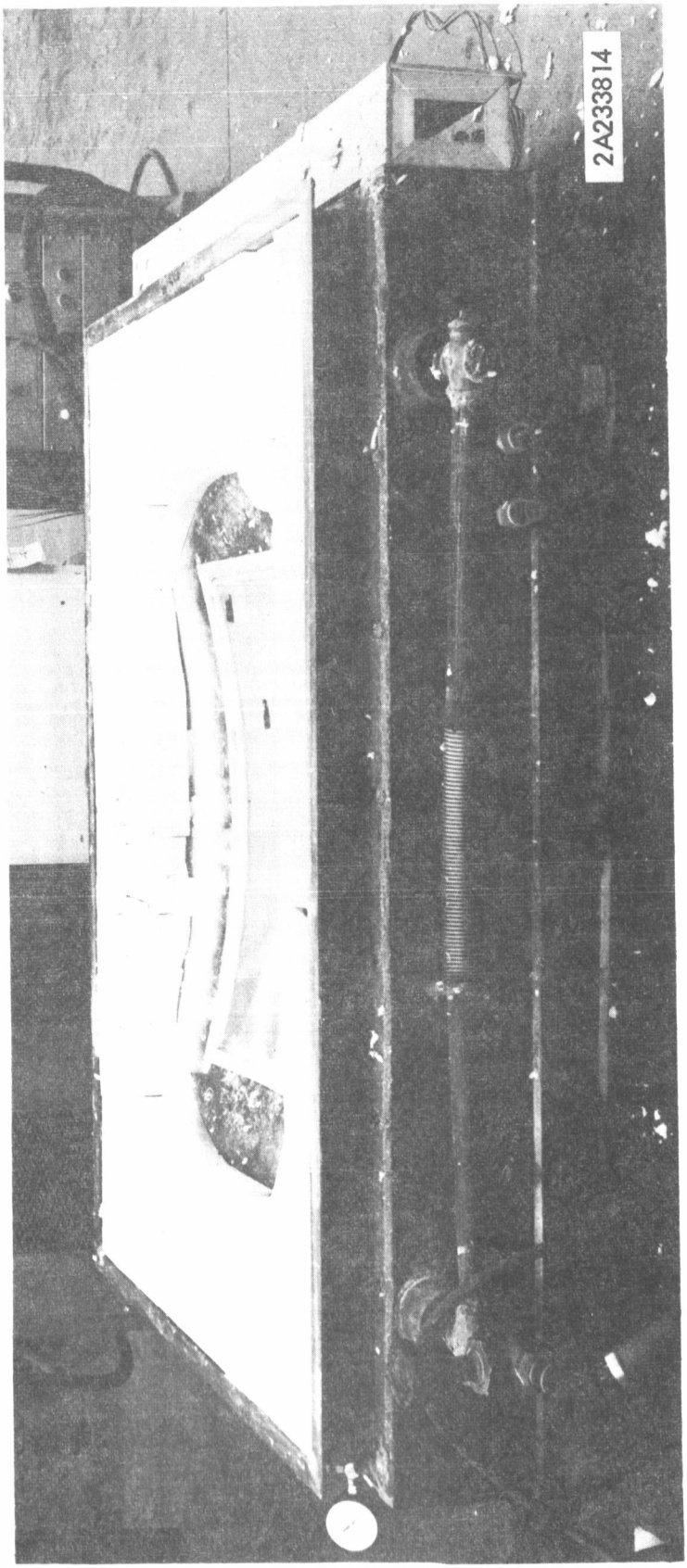



FIGURE 75
SUB-SCALE VACU-FORM DIE WITH ALUMINUM TEST PART

Based upon these results, another full scale test was conducted. This test blank consisted of 2 sheets of 0.140- by 48- by 108-inch 4330 steel plate, welded to a 0.140- by 96- by 108-inch configuration. A 4330 framework, 0.75-inch thick by 2-inches wide, was attached by welding both inside and out using continuous beads. The part was placed in the full size die and insulated. The nylon diaphragm was placed over the part and the insulation and was sealed with tape.

The effect of introducing an inert atmosphere into the system was also evaluated in this test. Three argon bottles were used to facilitate argon flow through the chamber. To prevent pressure build-up a vacuum level of less than 1/2 inch of Hg was held during heat up. A mass spectrometer was incorporated into the system to obtain data on the atmosphere within the die. *

The part was heated to 1450°F in 2-1/2 hours; then temperature was maintained for 12-1/2 hours. The temperature was held over this long period to allow the occurrence of as much creep forming as possible. During 80 percent of the soak period, a vacuum level of 1/2 to 4 inches of Hg was maintained. When the part was within 1 inch of the die at the center, the vacuum was increased from 4 to 25 inches and held there through completion of the test. (Note: The creep forming approach used in this test marked the first successful attempt to control the forming rate by controlled vacuum.)

After the center of the blank was net to contour, the heat and vacuum were turned off, and the part was allowed to cool. Photos of the formed part are shown in Figures 76 and 77. As the illustrations show, there was slight waviness in the corners of the part, and slight springback occurred. The combination of framework and creep forming technique definitely minimized the buckling problem. Figure 78 shows the part in the die after the framework was trimmed.

### 6.3.5 Forming the Gore No. 002

At this point, machining of the No. 002 gore blank was nearing completion. Previous full scale and subscale testing had indicated that a heavy framework coupled with a slow creep forming cycle, at maximum allowable temperature, should produce a wrinkle free part. Thermocoupling, insulation, and diaphragm improvements had been made during previous tests, resulting in greater confidence in the control of the critical variables. The blank was relatively free from defects, with the major imperfection being the weld repair of the crack around the diffusion bonded area.

Gore segment No. 002 was prepared with a 1/2-inch thick by 2-inch wide framework welded with a continuous bead inside and out. It was then cleaned, phosphate-fluoride coated, then sprayed with Everlube T-50 lubricant. The die face was coated with boron nitride lubricant and stainless steel shims were used under the corners of the blank to protect the die. Figure 79 shows the gore resting in place before the application of insulation. A 0.020-inch thick stainless steel skirt was then used to close the gaps between the part and die. Pocket shimming

* The result of the argon atmosphere test was inconclusive. The inert atmosphere was extremely difficult to maintain, and the detection procedure was costly, further efforts to investigate inert conditions were suspended.

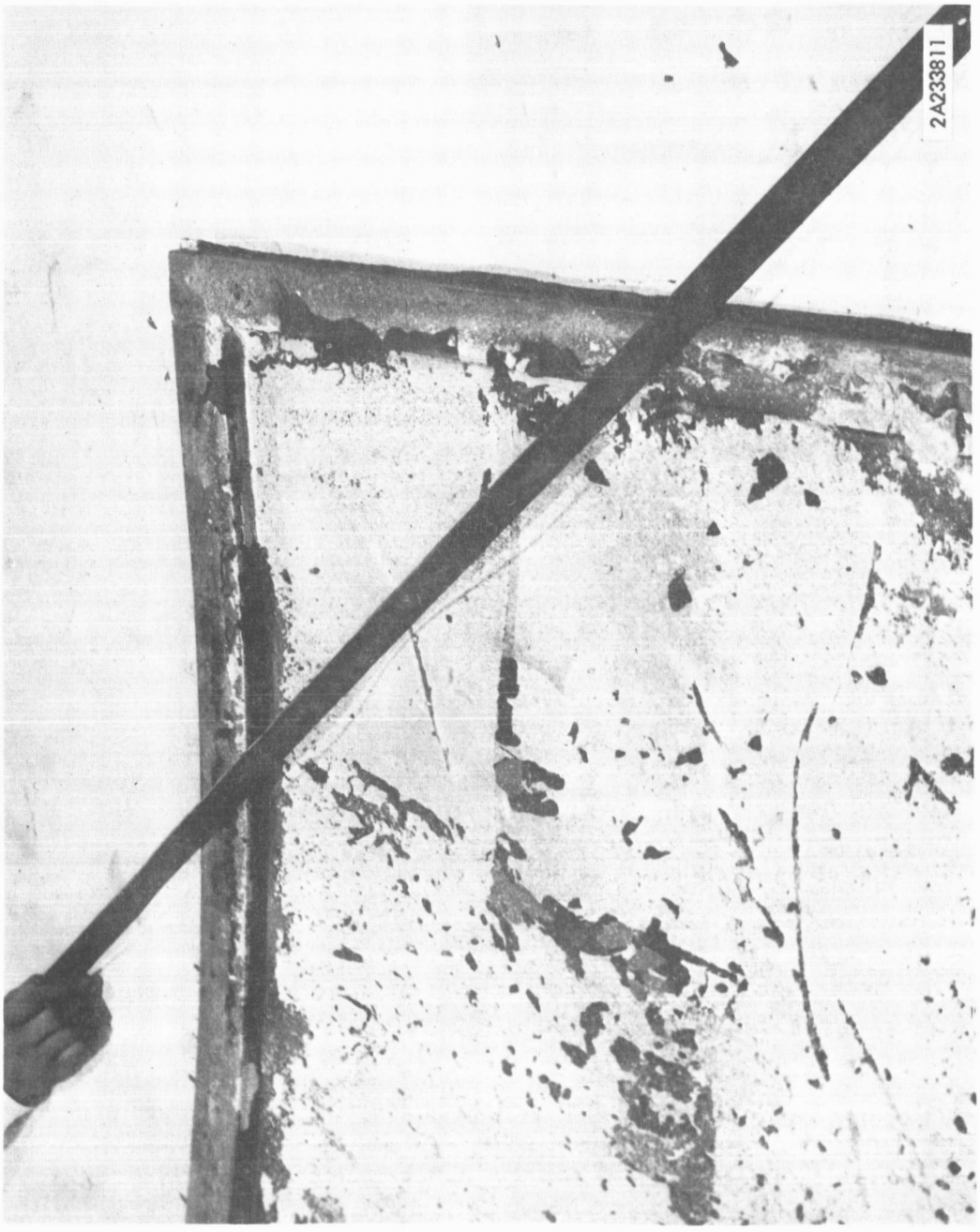



FIGURE 76
4330 STEEL TEST PART AFTER HOT VACU-FORMING




FIGURE 77

4330 STEEL PART AFTER FORMING (WITH PICTURE FRAME)

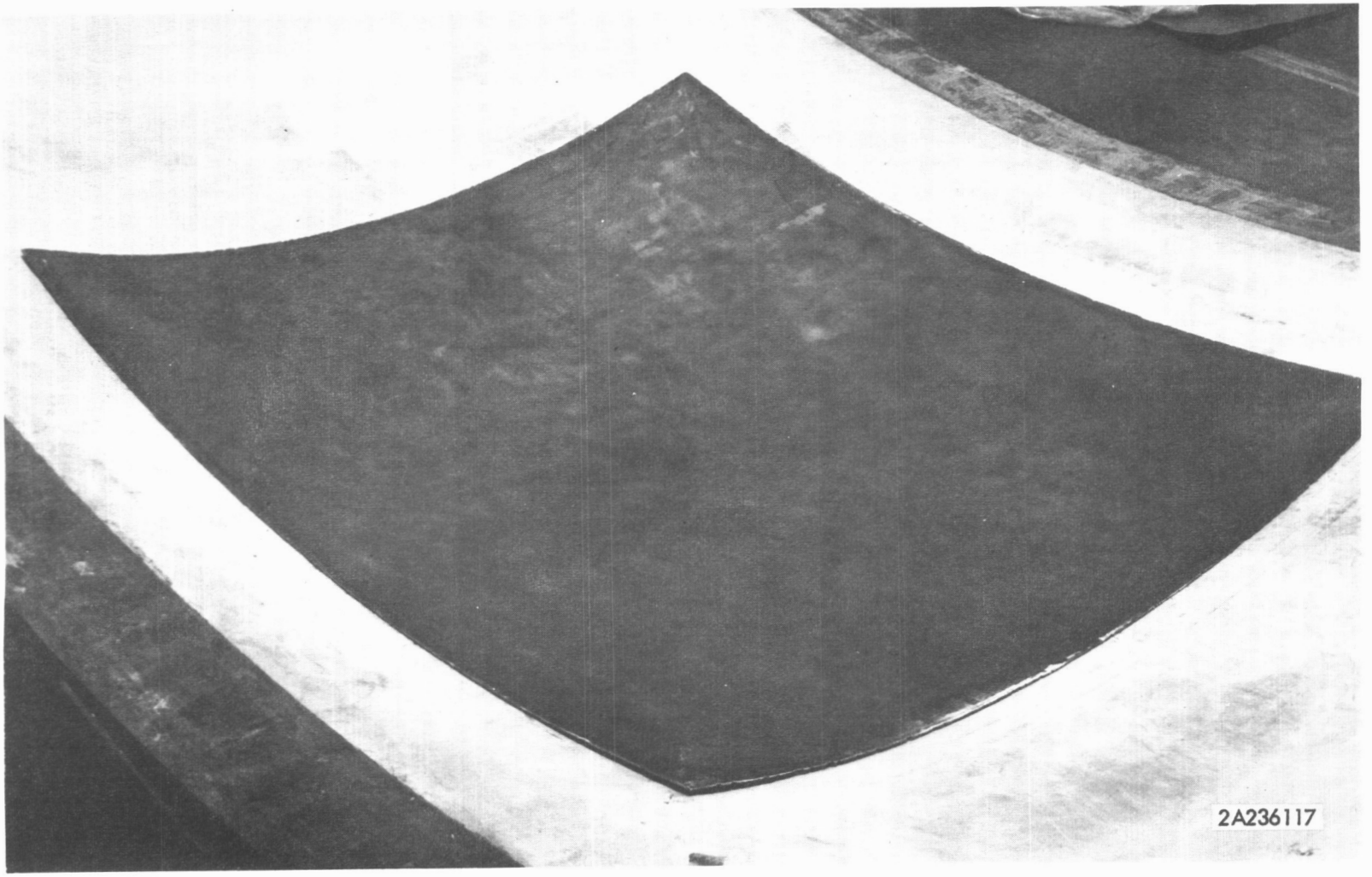



FIGURE 78

4330 STEEL PART AFTER FORMING (WITHOUT PICTURE FRAME)

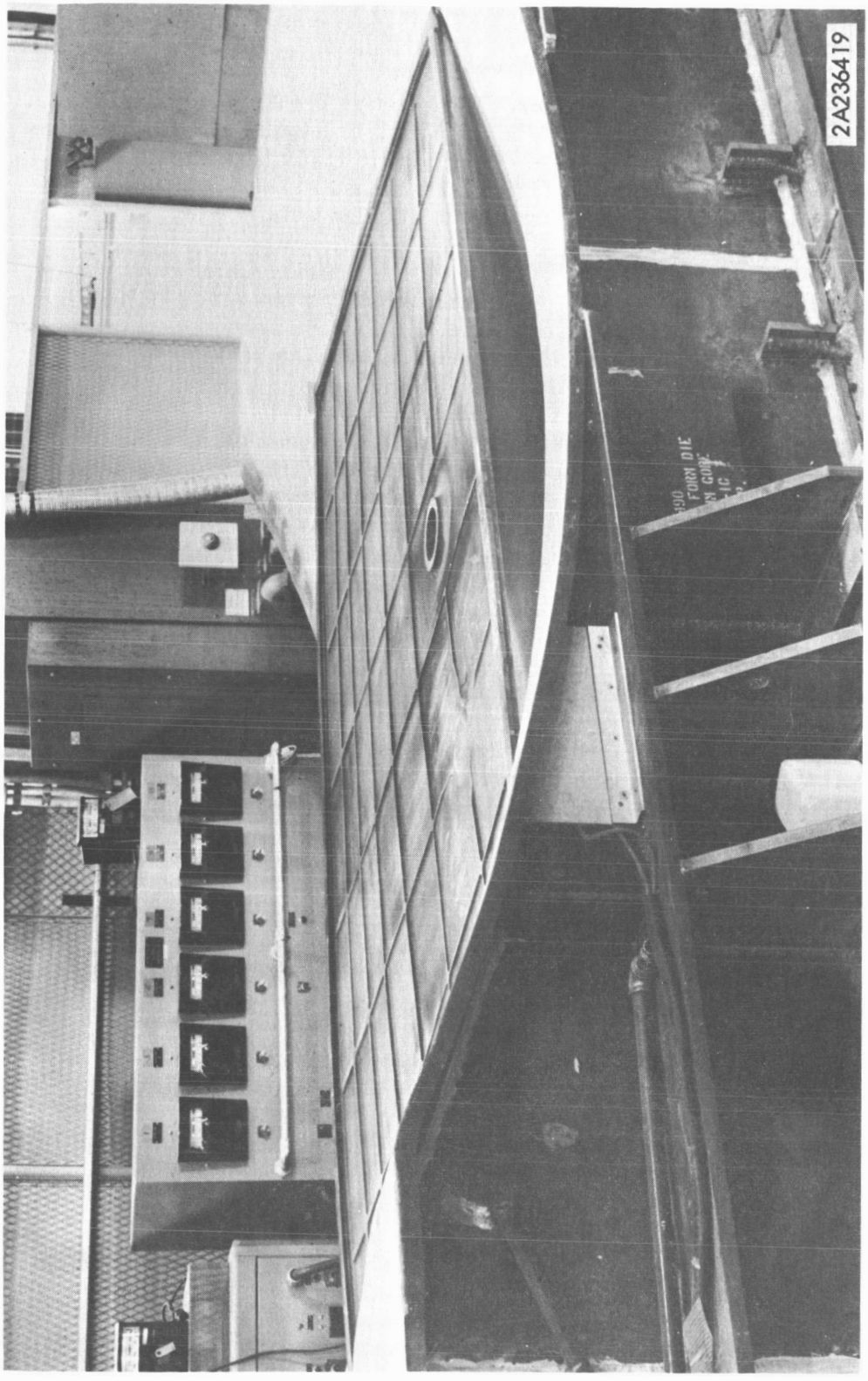



FIGURE 79

TITANIUM GORE #002 IN DIE (BEFORE FORMING)

did not appear necessary because the nylon diaphragm eliminated the bridging effect encountered with the stainless steel diaphragm. However, approximately two-thirds of the shims had been previously fabricated, and because of the slight uncertainty which still remained, they were used.

Two 1/2-inch thick layers of Kaowool insulating blankets were applied covering the part and all heated areas of the die. A 0.030-inch thick fiberglass cloth was laid over the Kaowool insulation. Vermiculite insulation was poured onto the fiberglass blanket to an overall depth of 5 inches. The 0.005-inch thick nylon diaphragm covered the insulation and was sealed with tape.

The part was heated to 1450°F in 4-3/4 hours, during which time a vacuum of 1/8 inch of Hg was held, as shown in Figure 80, to prevent a ballooning tendency caused by expansion of gases in the die chamber. Figure 81 shows relevant time, temperature, pressure, and deflection data. During heat-up the part partially formed, due to the influence of its own weight.

After cooling, the gore segment was examined for conformity to die contour. It was a maximum of 0.125 inch off the die in the diffusion bonded ring area (Figure 82). In the central area the part to die deviation was less than 0.10 inch. Waves appeared in the corner pocket areas (Figure 83) but were considered insignificant in light of the success observed over the remainder of the part. The largest wave was approximately 4 inches wide, 10 inches long, and 0.25 inch deep. The corner pocket waves are barely visible in the photographs due to the grey surface and poor lighting. The gore segment was net to the die on all four sides, with exception of the corners where shims had been placed to protect the die. Figure 84 shows the formed part, nearly net to the die contour.

The formed gore segment was removed from the die and placed on its trimming fixture. A metal cutting, high speed, steel, solid tooth, circular saw blade was used in a 4500 rpm "Skil-Saw." Trimming was completed satisfactorily using only two saw blades.

### 6.3.6 Wrinkle Removal Tests

After trimming, an attempt was made to remove the waves which had occurred in the corner pockets. Initial testing was performed on the subscale gore die, using a severely wrinkled test blank (Figure 85). A ceramic block was cast to the die contour for use as a straightening fixture. The blank was insulated, then heated to 1450°F with a 40 psi pressure being applied (see setup in Figure 86). Approximately 90 percent of the severe buckle was removed (Figure 87). Full scale wrinkle removal plans were then made with the intention of removing the slight wrinkles in the No. 002 gore segment.

A complication arose when full scale testing was conducted. Uneven heating, due to the cooling effect of the cast ceramic straightening fixture, caused an "oil canning" effect along one edge and toward the central region of the part. Figure 88 shows the full scale test apparatus. These tests concluded the heated vacuum forming development effort.

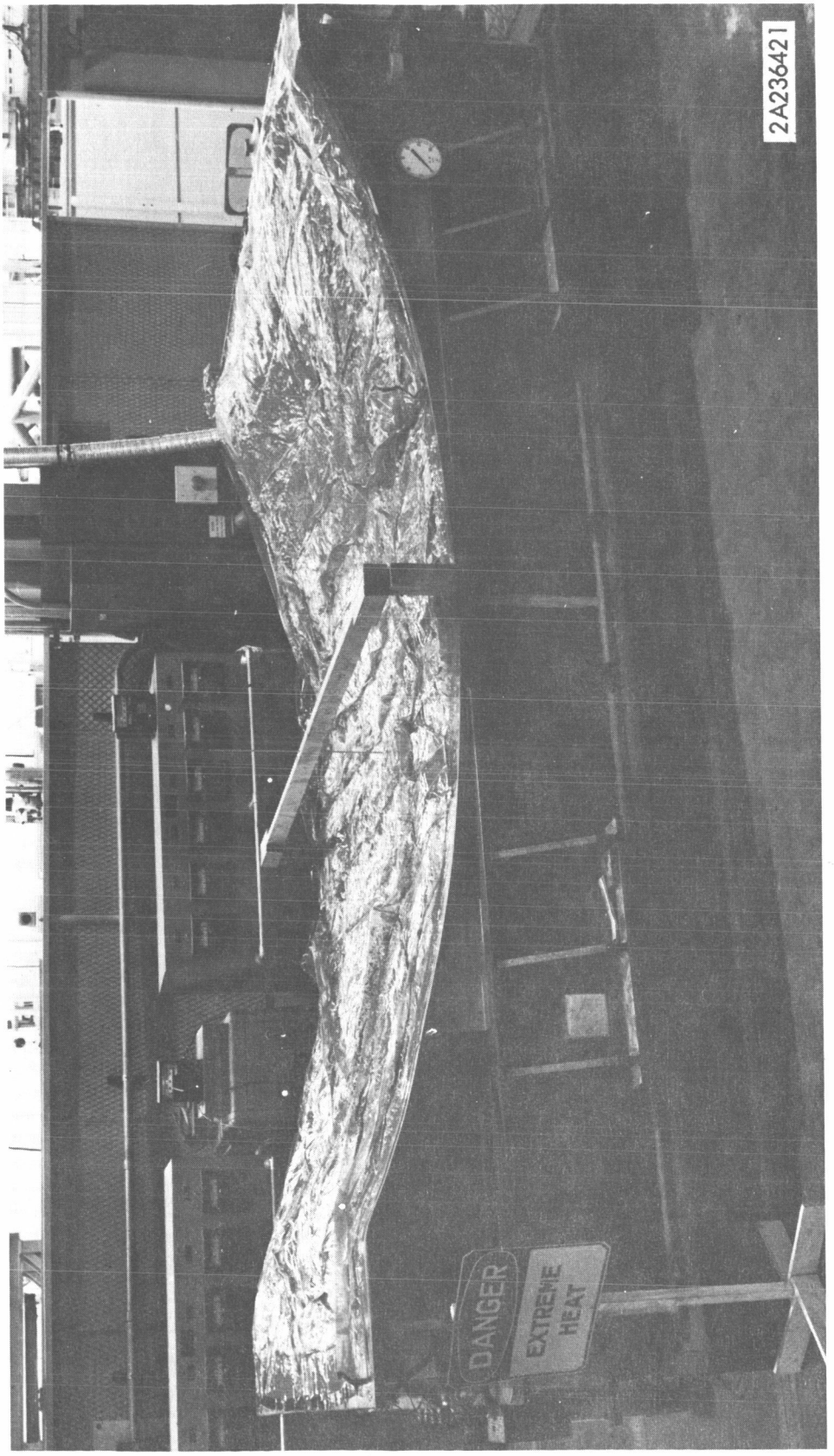



FIGURE 80

TITANIUM GORE #002 IN DIE (DURING FORMING)

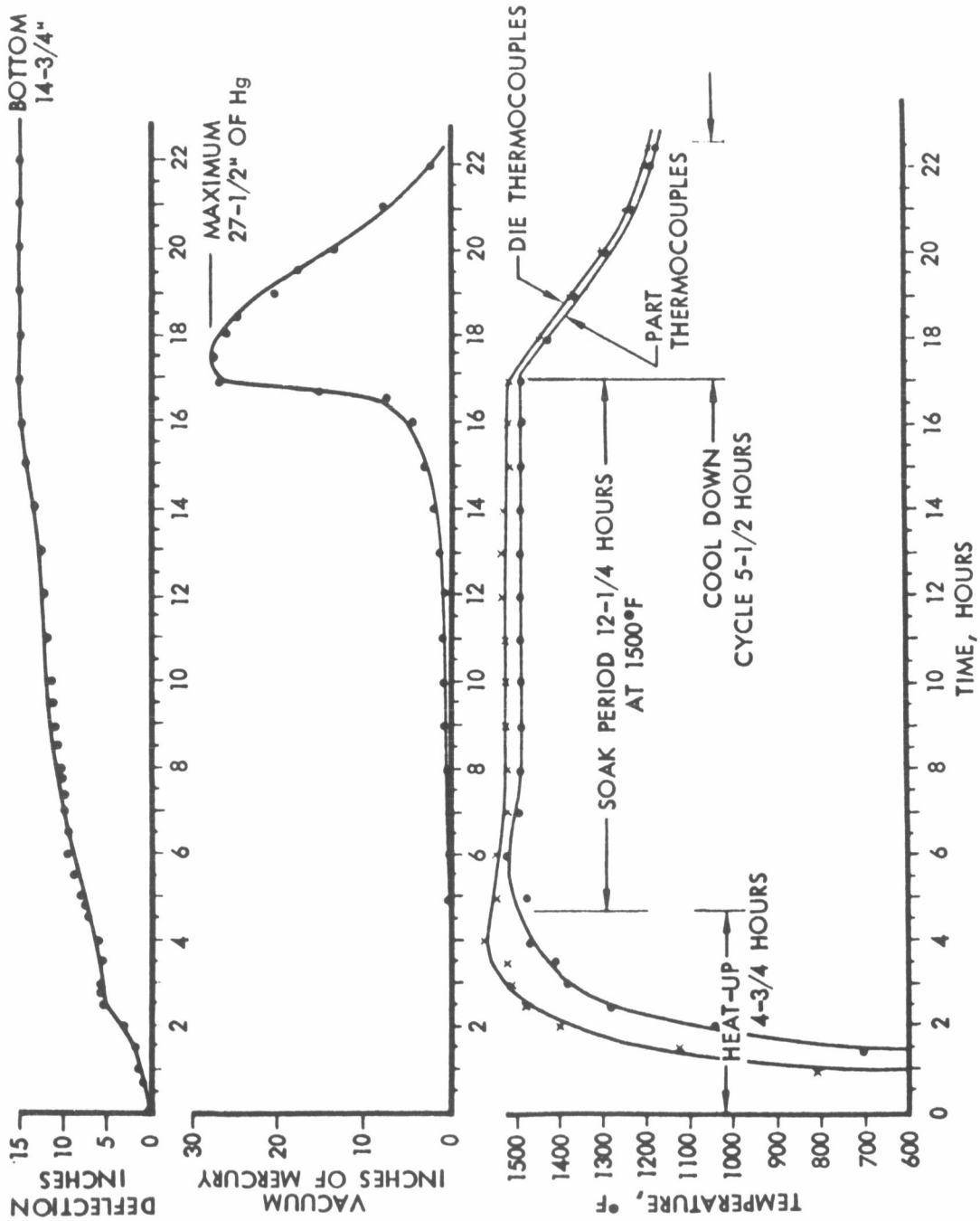



FIGURE 81

NASA GORE DIE TEST SCULPTURED 8-1-1 TITANIUM PART TIME VS. TEMP., VACUUM, & DEFLECTION AUGUST 12, 1966 t = 0 4 AM




FIGURE 82

TITANIUM GORE #002 IN DIE (AFTER FORMING)

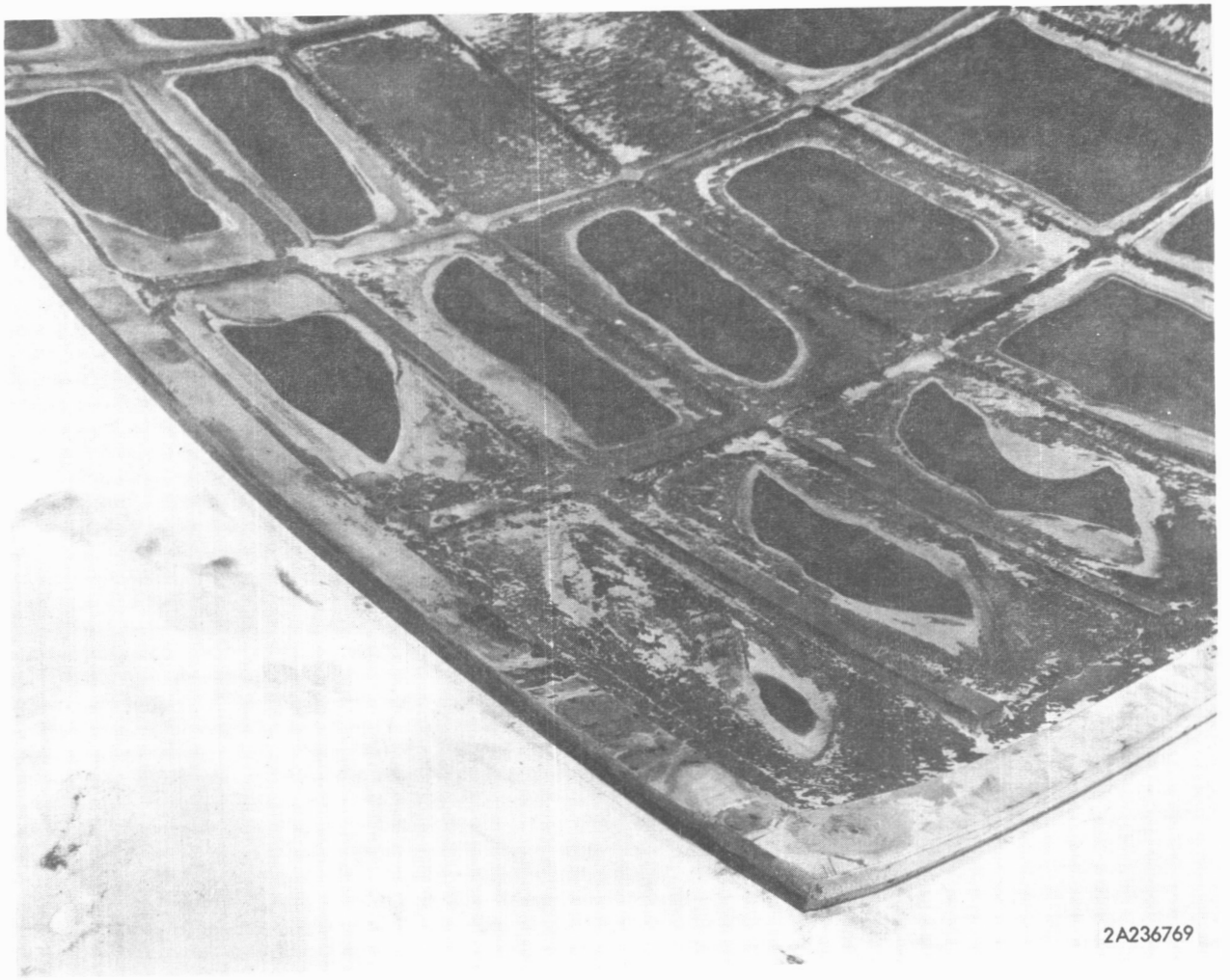



FIGURE 83

TITANIUM GORE #002 IN DIE (AFTER FORMING)

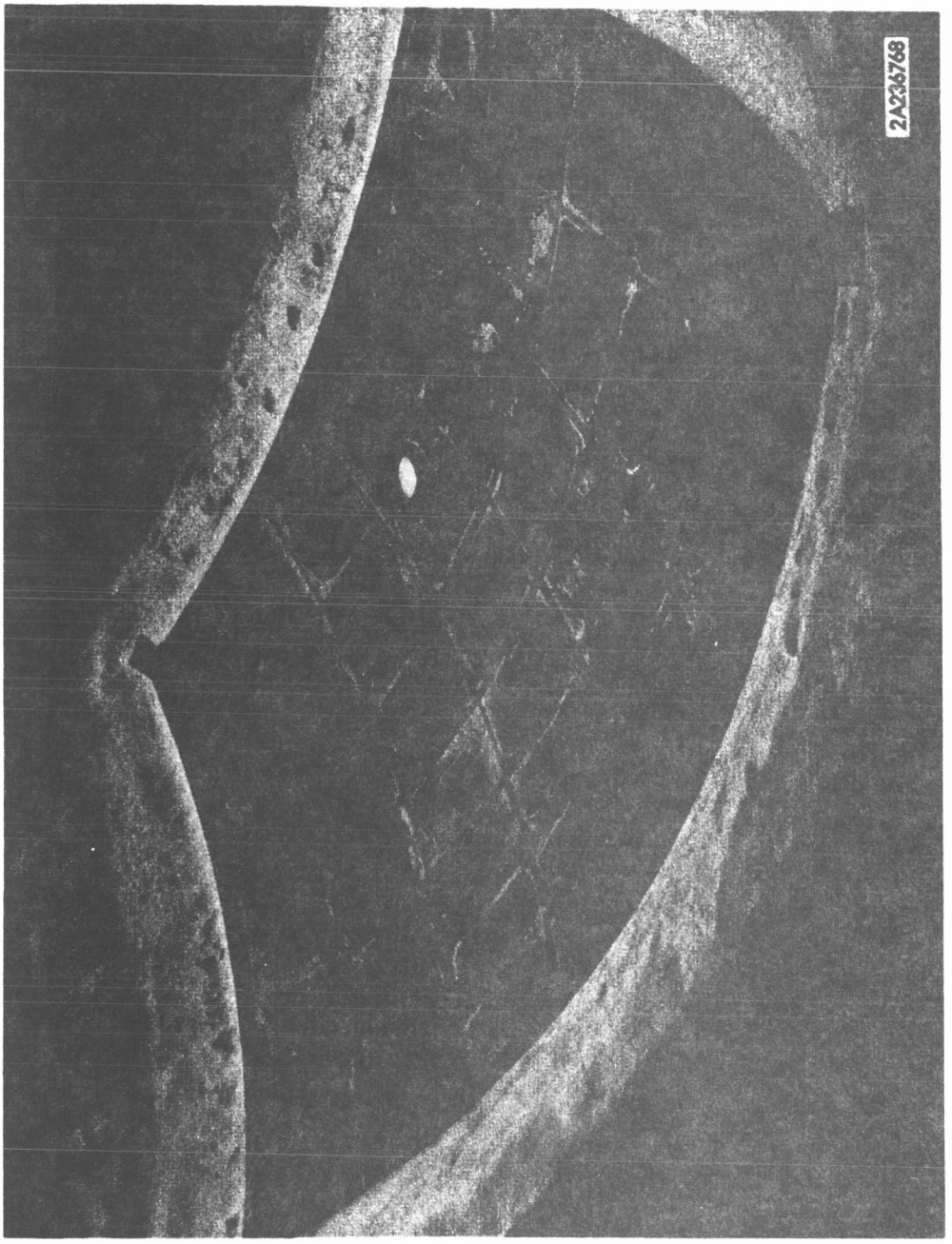



FIGURE 84

TITANIUM GORE #002 IN DIE (AFTER FORMING)

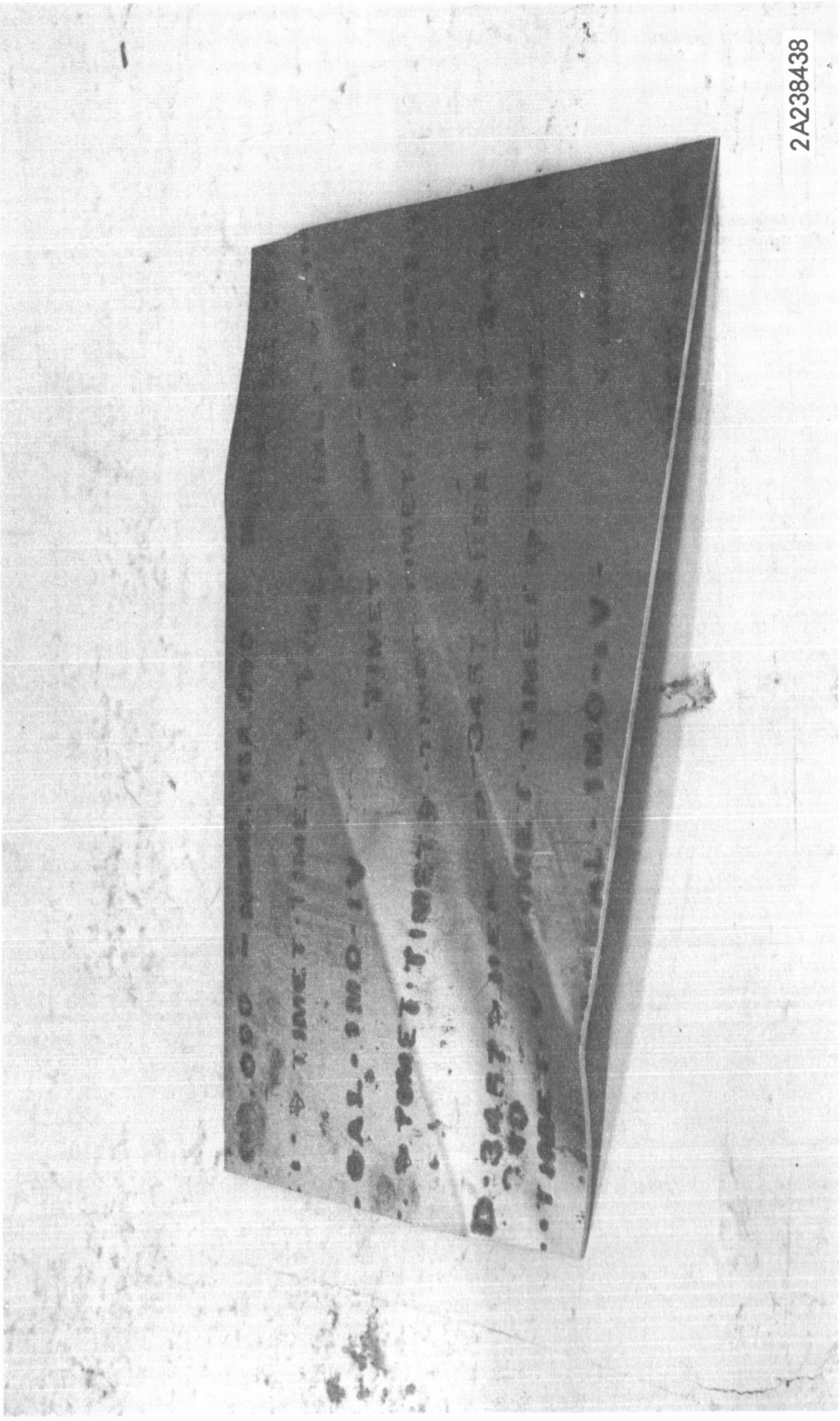



FIGURE 85

TITANIUM WRINKLE TEST PART (BEFORE HEATING)

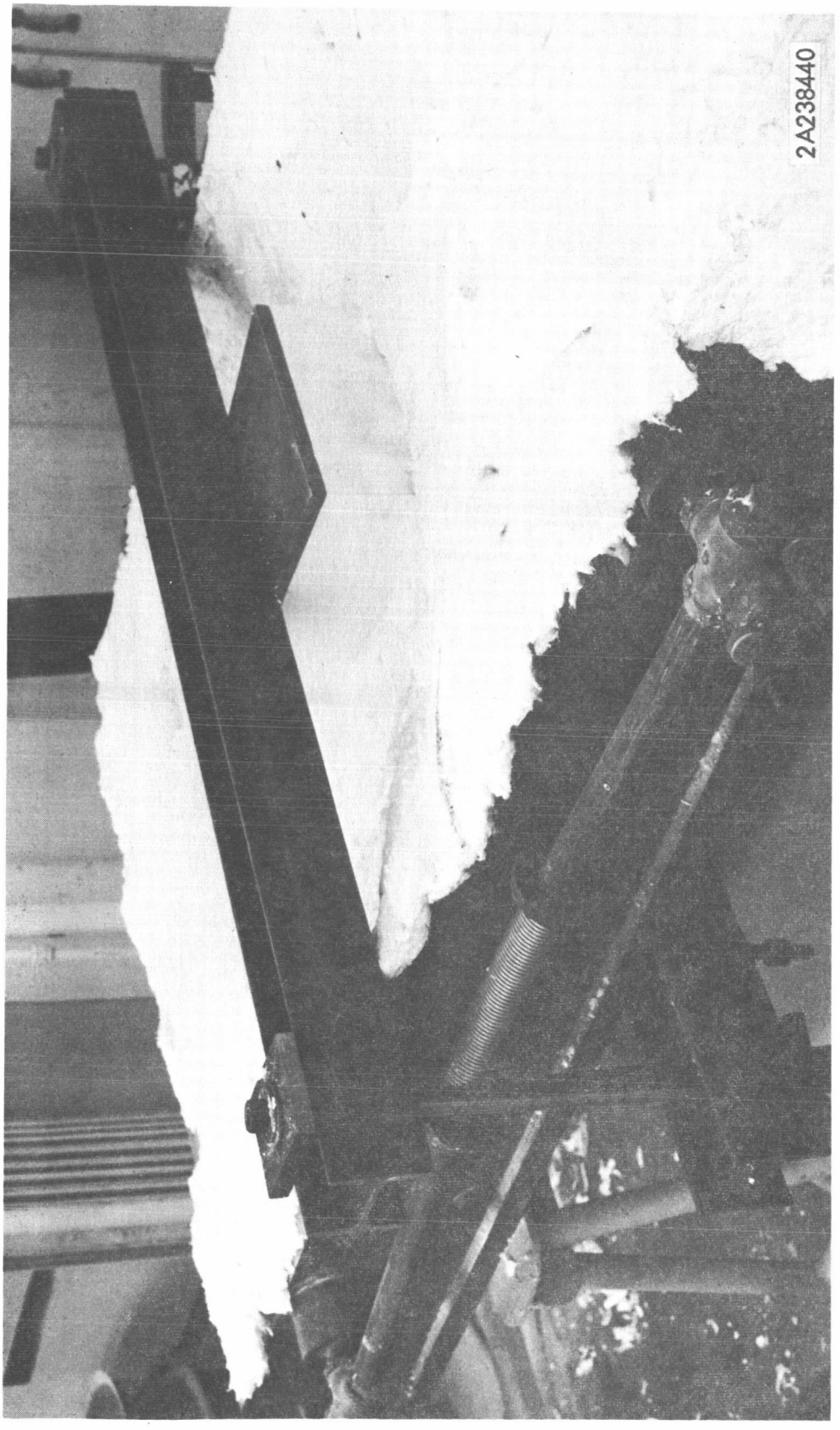



FIGURE 86

SUB-SCALE WRINKLE REMOVAL SET-UP




FIGURE 87

TITANIUM WRINKLE TEST PART (AFTER HEATING)

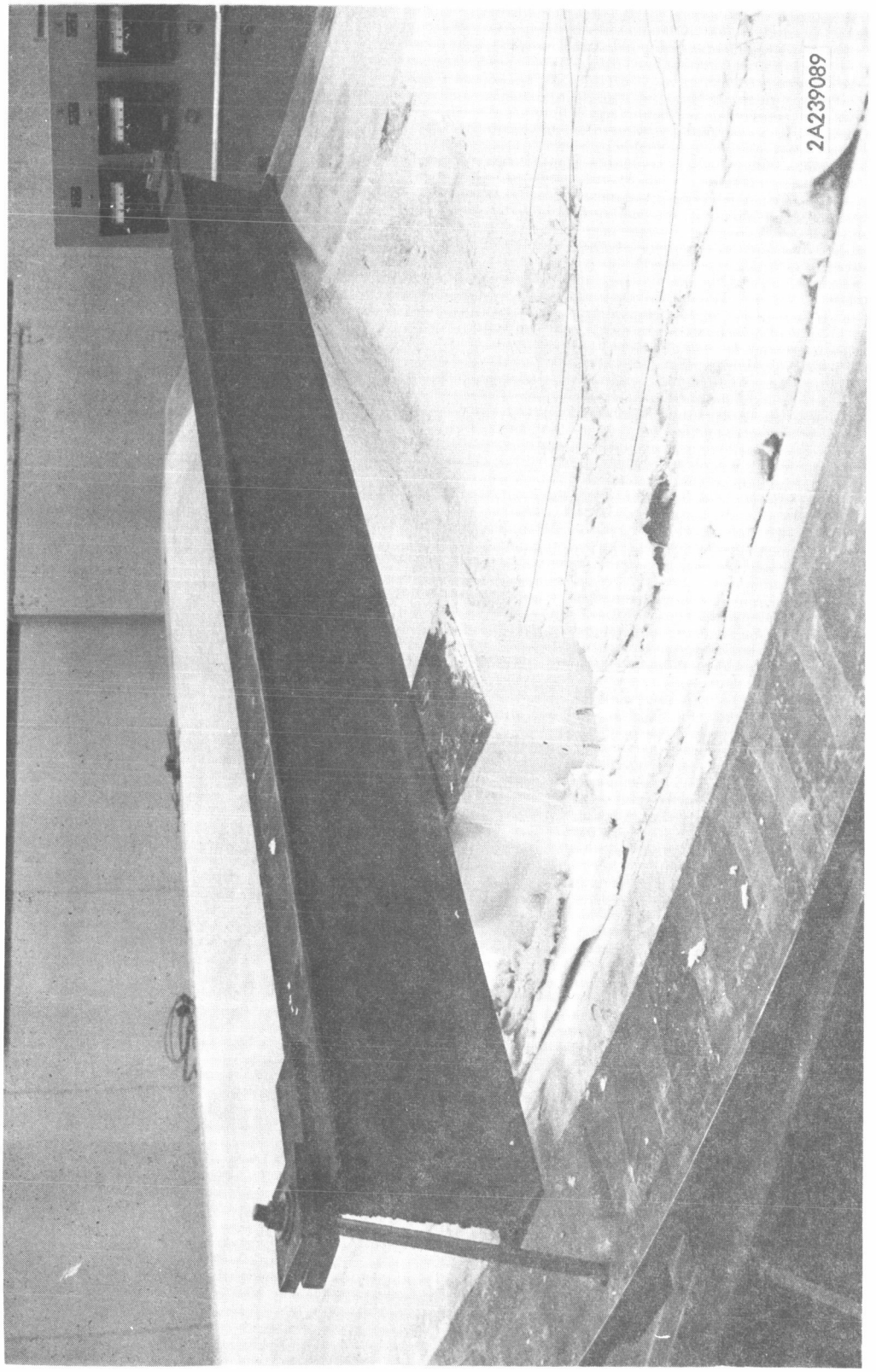



FIGURE 88
WRINKLE REMOVAL TEST ON TITANIUM GORE #002
(TEST SET-UP)

### 6.3.7 Final Processing of Gore No. 002

Sandblasting was used to remove the tough scale which remained on the part. Next came an alkaline cleaning followed by a water rinse and a nitric-hydrofluoric acid pickle. Another water rinse, followed by a hot air drying completed the cleaning and left the part ready for final inspection.

Figure 89 shows the formed gore segment in position on the die, after wrinkle removal tests, ready for final contour inspection. The examination indicated that the part was within 1/4 inch of being net to the die contour, with the exception of the two corners where the waves were 0.320-inch off the die face. Figures 90 and 91 show the part being transported outside of the die.

Both an ultrasonic and visual penetrant inspection were then conducted. Ultrasonic inspection indicated possible separations in two areas on the diffusion bonded ring. This separation indicated a weak diffusion bond, suggesting that forming forces may have weakened the joint; however, verification would have to be established by destructive test. Visual and penetrant inspection of the entire gore segment revealed a 0.5-inch long crack on the inside or pocketed surface of the repair weld bead. Two 0.75-inch cracks were discovered on the outside surface of the repair weld bead. These cracks were attributed to the continuation, during forming, of minute cracks assumed present prior to forming.

The gore segment was then trimmed to the net trim line and placed on the Keller profile mill for final machining. Boring and spotfacing were completed. The part was then packaged and shipped to MSFC.

### 6.3.8 Conclusions and Recommendations

Delivery of the part ended a phase in the development of a production process for fabricating a full size S-IC titanium gore. The delivered part represents significant advancement in the development of a hot vacuforming process.

The advancements made in this process during the program and the recommendations for follow-on work to make the processes production ready, are given below. The titanium gore completed on this program is impressive by its size, its reasonably smooth contour and its light weight. As a production part it almost meets requirements. Close inspection of the part reveals it to possess panel waviness, web thickness, and rib location variations exceeding drawing tolerances; besides, an unsatisfactory surface condition on the unmachined (outside) surface. However, as a result of this program, the causes of these conditions are well understood and can be largely eliminated in any subsequent program. To eliminate the objectionable panel waviness due to the forming, the following process approaches should be analyzed when processing of future titanium gores is being considered.

Titanium part forming restraining devices and techniques must be explored more fully to control the compression and tensile strain. This will prevent the generation of waviness in the part during forming. Other approaches, such as, using a higher forming temperature and a different creep forming cycle, should be considered.

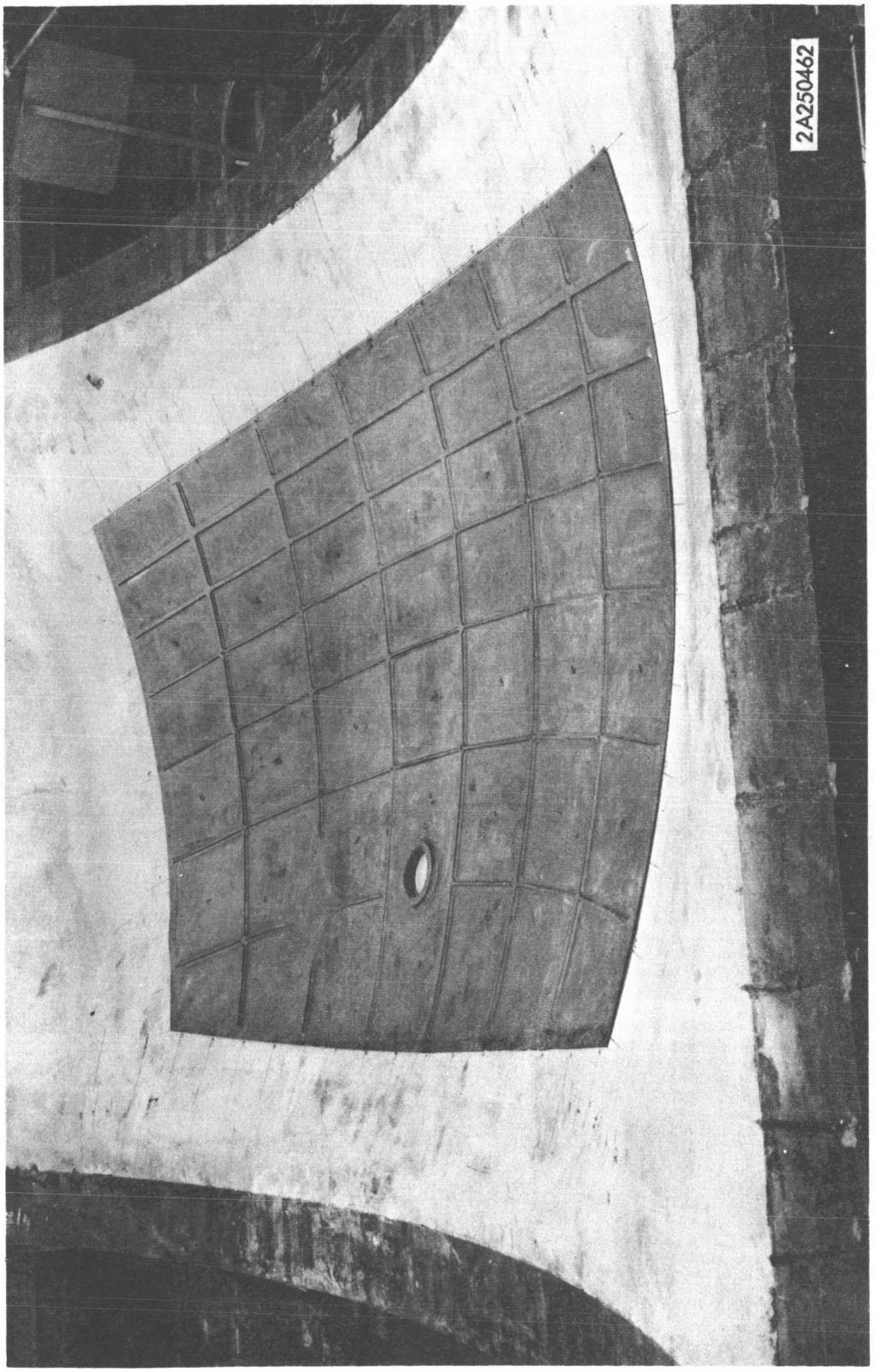



FIGURE 89

TITANIUM GORE #002 IN FORM DIE (WITHOUT PICTURE FRAME)

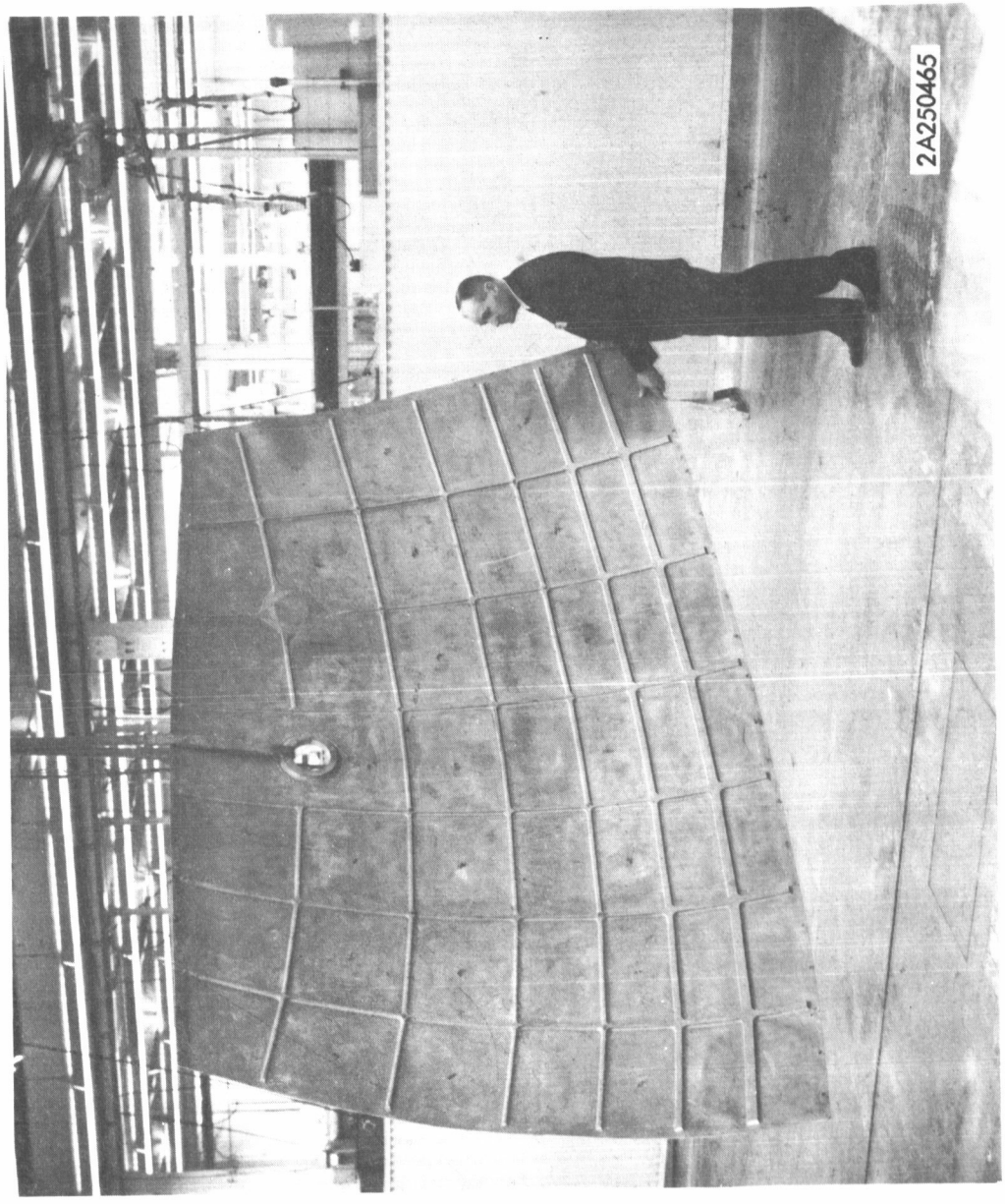



FIGURE 90

TITANIUM GORE #002

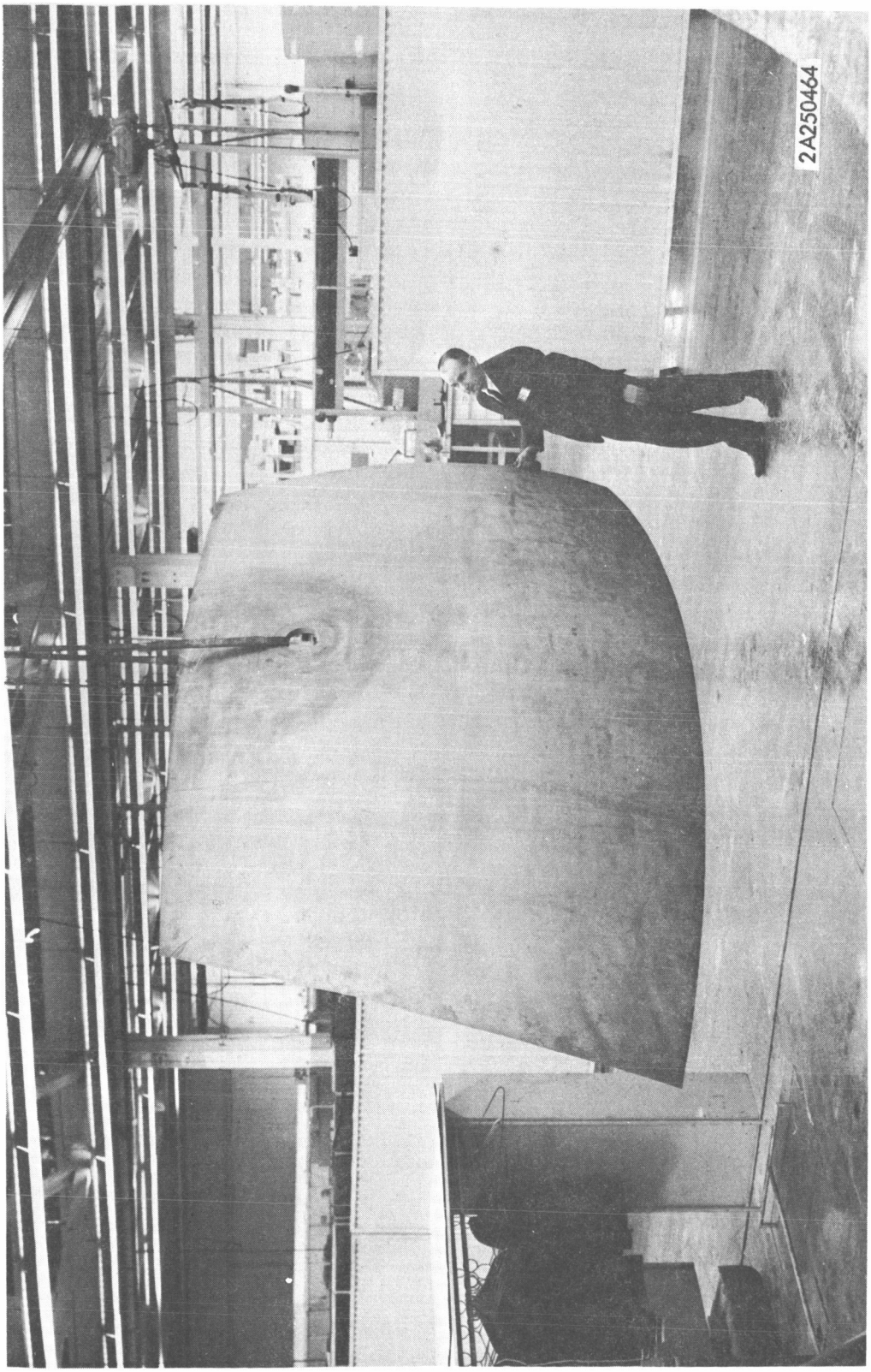



FIGURE 91
TITANIUM GORE #002

Improvement in part restraint can be obtained by attaching edges of the part to the die framework (steel). During forming, the part deforms into the die and additional edge restraint would provide additional process control. Another method would be to revise the design of the presently used picture frame to vary part restraint.

Waviness is an indication of compression failure so any approach that will render the material more ductile for forming will probably enhance the process. Forming temperatures as high as 1800°F can be used, so far as the material is concerned; but, Figure 92 would indicate 1400°F to 1600°F to be the best range. At these temperatures the material is more plastic and easier to form than at the 1450°F used here. However, the real limitation is the operational limit of the forming tool. This forming tool can be heated to approximately 1800°F by itself; but, the practical limit would probably be about 1600-1700°F if it were to be used for an extended period of time.

Creep forming, as applied in this program, consisted of forming the part at a rate of approximately 1 inch per hour deformation until the part midpoint contacted the die. The part was held at a temperature of 1450°F and vacuum was used to control the deformation. This creep rate could be decreased and thereby decrease the part wrinkling tendencies. Less vacuum would be used and forming would require a longer time cycle.

Development should be conducted to investigate additional waviness removal techniques. Presently magnetic forming is being used to remove waviness in Saturn aluminum gores. Titanium material is tougher than aluminum and techniques considered practical for aluminum have not worked for titanium. Reheating and localized pressure techniques were tried on the titanium part in this program, but, these proved more detrimental than helpful for reducing waviness.

Even with a production qualified process that produces parts without waviness, the fact that there might be an occasional part with waviness dictates the need for means to remove the waviness. Also, welding of parts together caused part distortion which must be removed or redistributed by a yet unknown method; another reason for waviness removal development.

The large web thickness variation contained in the test part, can be corrected in the future by: machining the outside surface prior to inside pocketing; by extra care in the design and use of the vacuum chuck; and careful set-up in the final machining pass.

Stiffening ribs in future part can be located within drawing tolerances if the corrected x-y' coordinates for the flat pattern (Table VI) are used instead of the coordinates used in this test program.

## 6.4 ULTRASONIC INSPECTION OF DIFFUSION BONDS

Quality Control investigations conducted during the subscale process development portion of this program included both X-ray and ultrasonic inspections. The use of X-ray was dropped as a potential production inspection method after several comparisons between the two methods indicated a necessity of extensive angle shots to resolve conditions at the bond line. Ultrasonic Pulse-Echo inspection techniques were selected as the most promising nondestructive test method because of the inherently greater sensitivity to voids and inclusions.

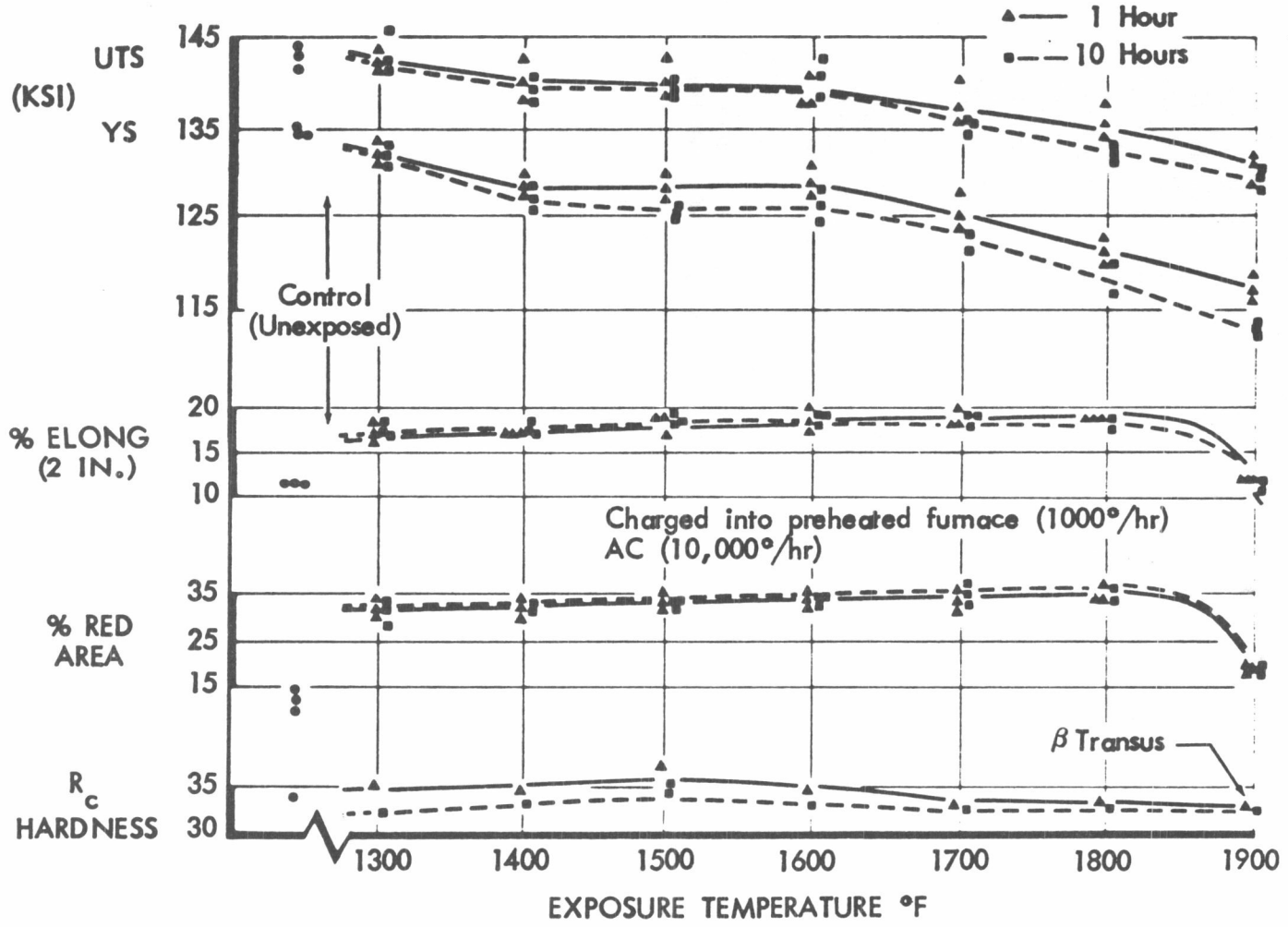



FIGURE 92

EFFECT OF EXPOSURE TEMPERATURE ON THE ROOM-TEMPERATURE MECHANICAL PROPERTIES OF MILL-ANNEALED Ti-8Al-1Mo-1V ALLOY EXPOSED 1 OR 10 HOURS AT TEMPERATURE AND AIR COOLED

6.4.1 Initial Processing

During the process development phase utilizing 20- by 20-inch subscale gores, one panel had intentional voids introduced at the bond line. Two of these voids were produced by applying a layer of graphite at the interface prior to bonding. Sensitivity of the tests was originally based on the sensitivity necessary to obtain satisfactory reflection from these intentional voids.

Subsequent to inspection, the part containing the graphite induced voids was machined. During the machining operation it was found that several large, unbonded areas had not been detected. The indicated need for improved sensitivity was obtained by fabricating standards for senstivity by drilling flat bottomed holes (fbh) into a segment of diffusion bonded ring so that the bottom of the hole approximated the plane of the bond line. These holes were of 1/8-inch diameter, and 3/64-inch diameter. This segment was then examined at several different sensitivities ranging from the sensitivity necessary to obtain a relative 100 percent indication from the 1/8-inch diameter hole to that required for 100 percent indication from a 3/64-inch hole. This response was based on interpolation due to extreme difficulty encountered attempting to drill the 3/64-inch hole in titanium with available drills. Figures 93 and 94 illustrate the difference in sensitivity involved. Class B sensitivity shown in Figure 93 is equivalent to a 100 percent indication from the 1/8-inch fbh. Class A'A sensitivity shown in Figure 94 is equivalent to a 100 percent indication from a 3/64-inch fbh.

As a check on the adequacy of the various sensitivities in defining bond quality the segment of bonded ring shown in Figures 93 and 94 was sectioned at two locations and examined at approximately 50X magnification. By locating on the ultrasonic plot of bond line quality the approximate location of the sections and comparing this with the cross section under the microscope it was determined that sensitivity equivalent to Class AA was ample for the present inspection. The sections, shown in Figures 95 and 96, were selected as representing Type A bond line void condition, and Type B scattered void.

6.4.2 Final Processing

The ultrasonic equipment for the subscale gore testing scanned a fully immersed part. However, the large verification parts and the full scale gore were too large for total immersion. A modification of this set up was evolved which consisted of placing an 18-inch square frame, 3 inches high around the ring and sealing with a water tight clay at the base of the frame; then covering the access hole from the opposite side, and filling this "coffer dam" with sufficient water to provide the ultrasonic coupling medium. The equipment set up for the large verification part tests is illustrated in Figure 97. A close up of the "coffer dam" immersion technique is illustrated in Figure 98. The results of this verification test are shown in Figures 99 and 100. The dark areas in each case represent poor bond conditions. The ring shown in Figure 99 is unacceptable, while that in Figure 100 is considered of acceptable quality.

Full scale gores No. 001 and No. 002 were inspected during their manufacture. A set-up typical of the inspection is illustrated in Figure 101. Gore No. 001, the unformed part, contained no evidence of poor bond. Gore No. 002, the formed part, did contain three areas of poor bond, illustrated in Figure 102. The condition occurring between 12 o'clock and 3 o'clock is basically bondline void, that

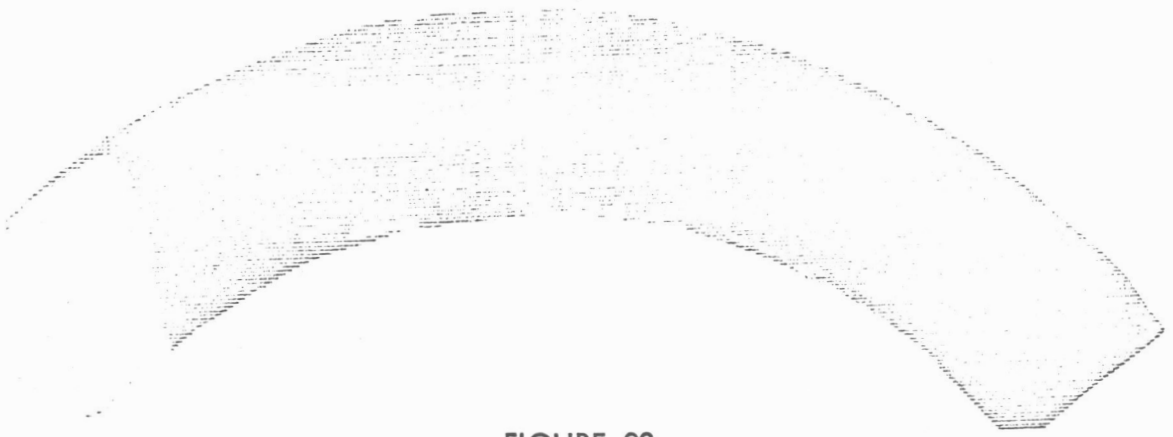
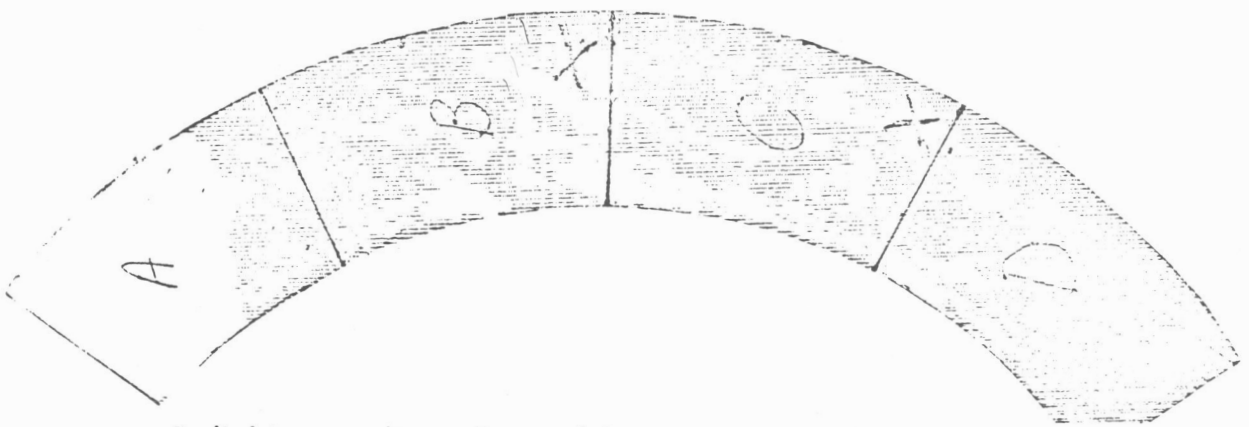


FIGURE 93
MACHINED SEGMENT SCAN AT CLASS B SENSITIVITY




Radial Lines Indicate Proposed Sections for Type A Failure (C) and Type B Failure (B)

FIGURE 94
REPEAT SCAN AT CLASS AA SENSITIVITY

TYPES OF DIFFUSION BOND FAILURE

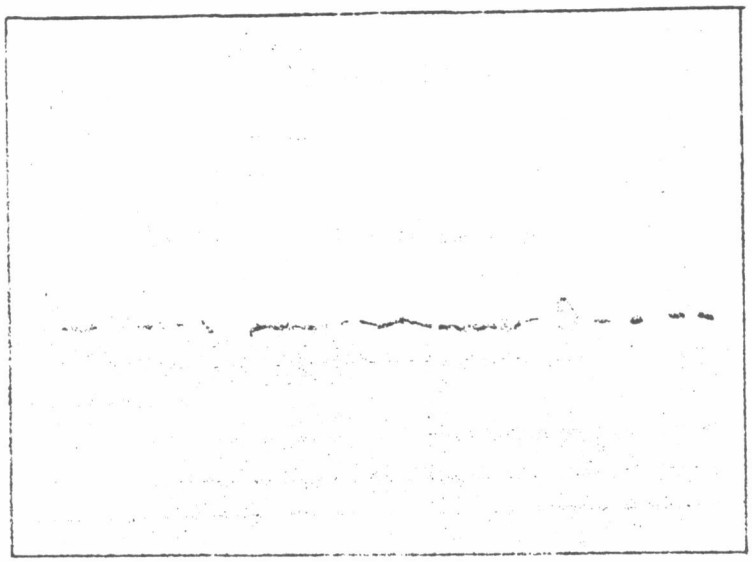


FIGURE 95

TYPE A FAILURE APPEARANCE IN SKETCH FROM PHOTOMICROGRAPH AT APPROXIMATELY 50X

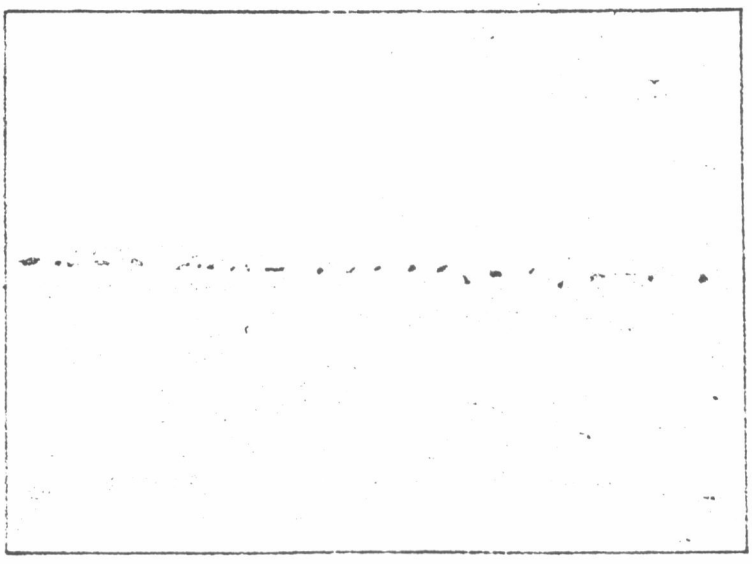


FIGURE 96

TYPE B FAILURE APPEARANCE IN SKETCH FROM PHOTOMICROGRAPH AT APPROXIMATELY 50X

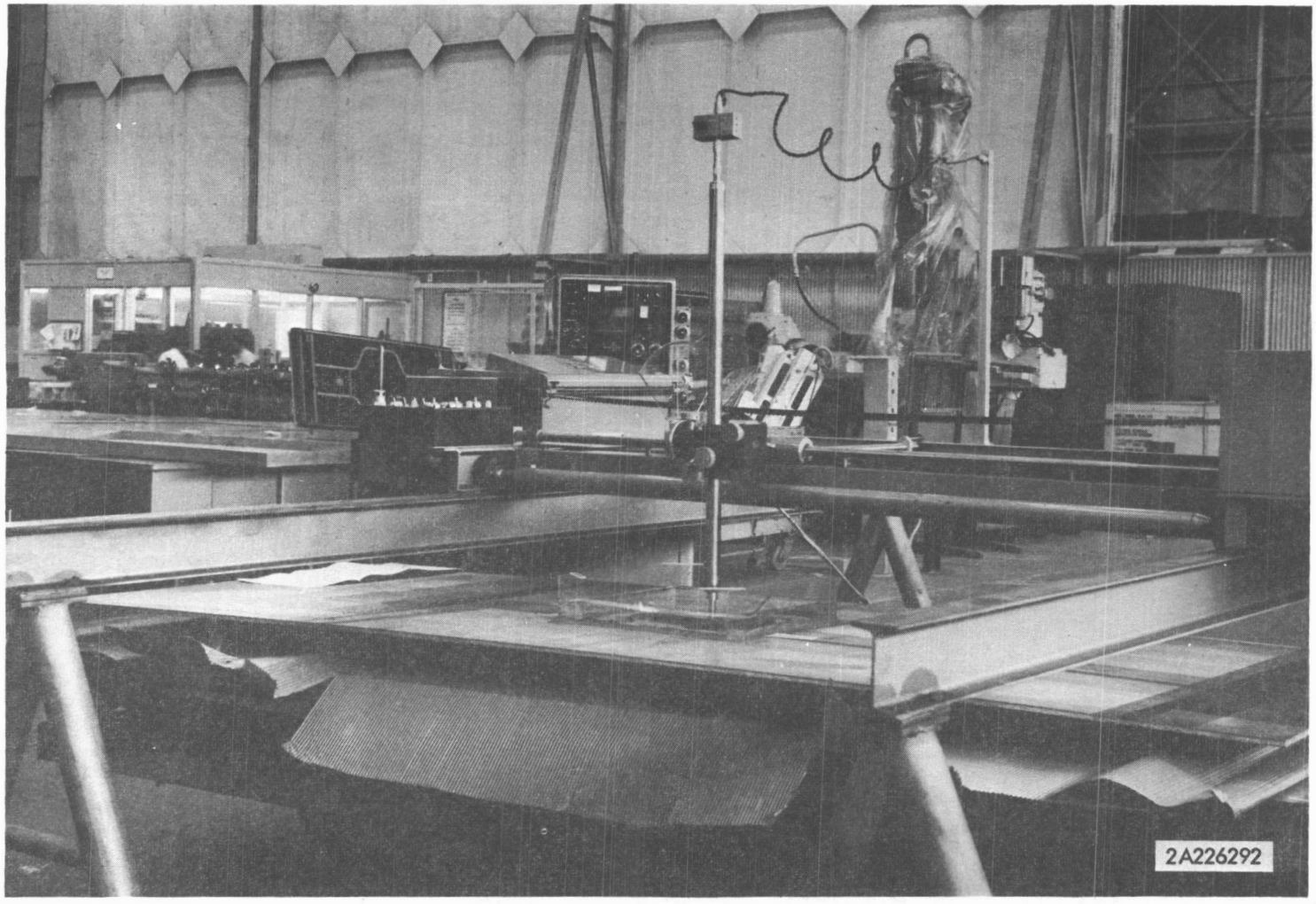



FIGURE 97

"C"-SCAN BRIDGE SET-UP TO USE "I" BEAM SUPPORTS
AND COFFER DAM IMMERSION TECHNIQUE

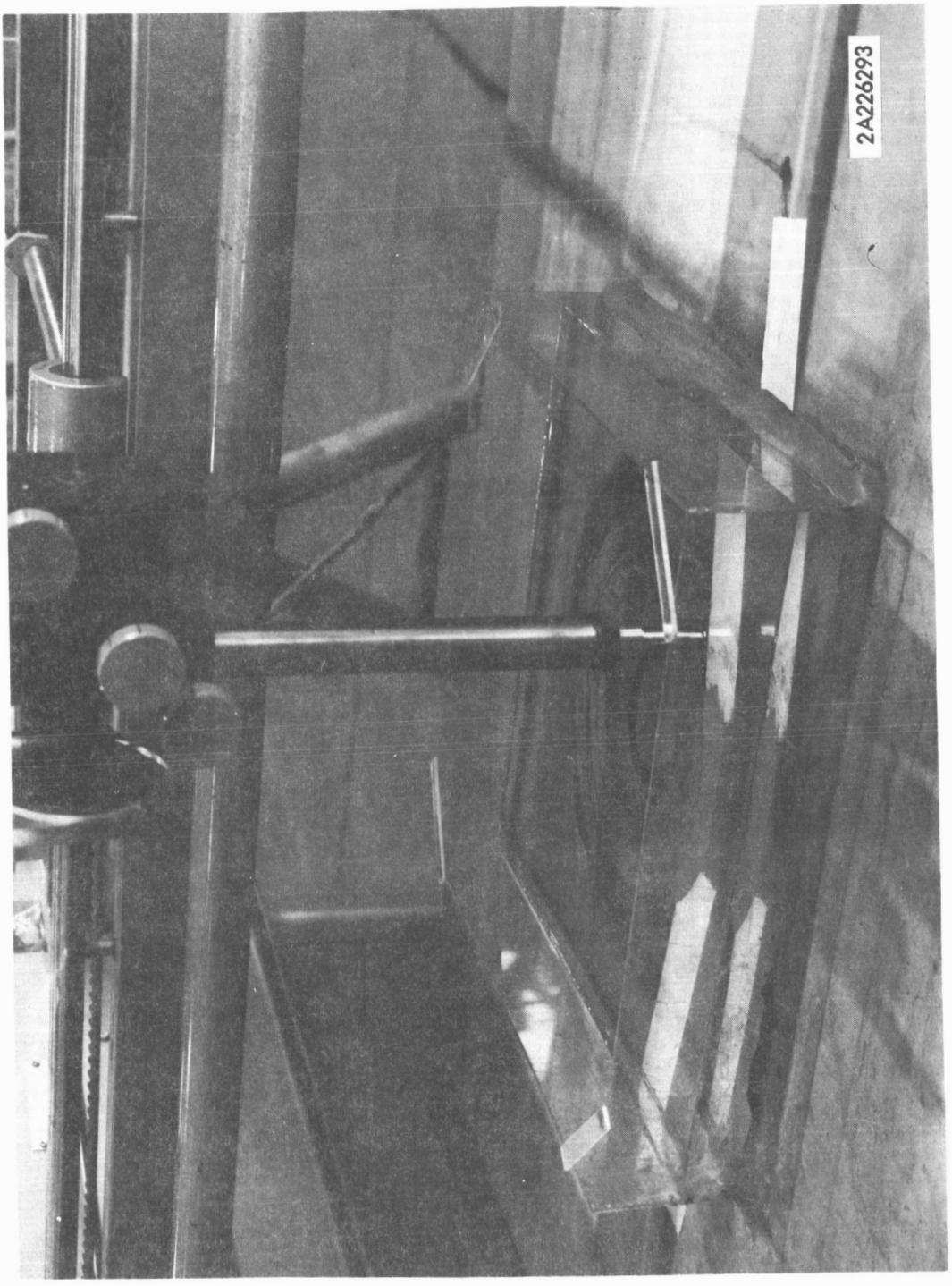



FIGURE 98
COFFER DAM TECHNIQUE DETAIL

Sheet No. 1

Echoes of relative amplitude greater than 50%

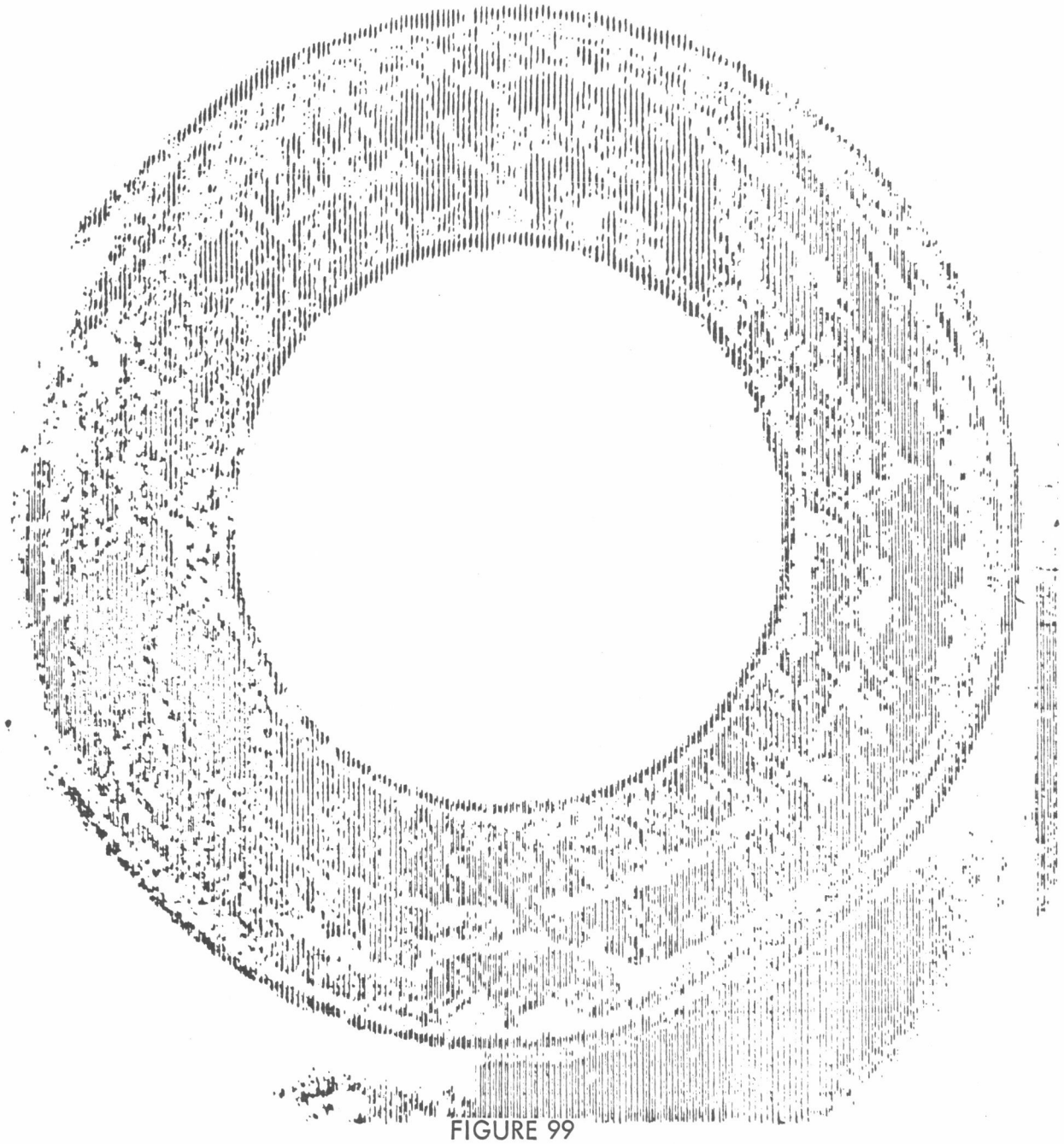


FIGURE 99

RECORD OF ULTRASONIC TESTING OF THE DIFFUSION BONDED RING ON THE CRACKED PANEL. DARK AREAS REPRESENT FLAWS, POROSITY, OR OTHER DISCONTINUITIES. THIS DENSITY IS CONSIDERED UNACCEPTABLE BY QUALITY CONTROL.

Sheet No. 2

Echoes of relative amplitude greater than 50%

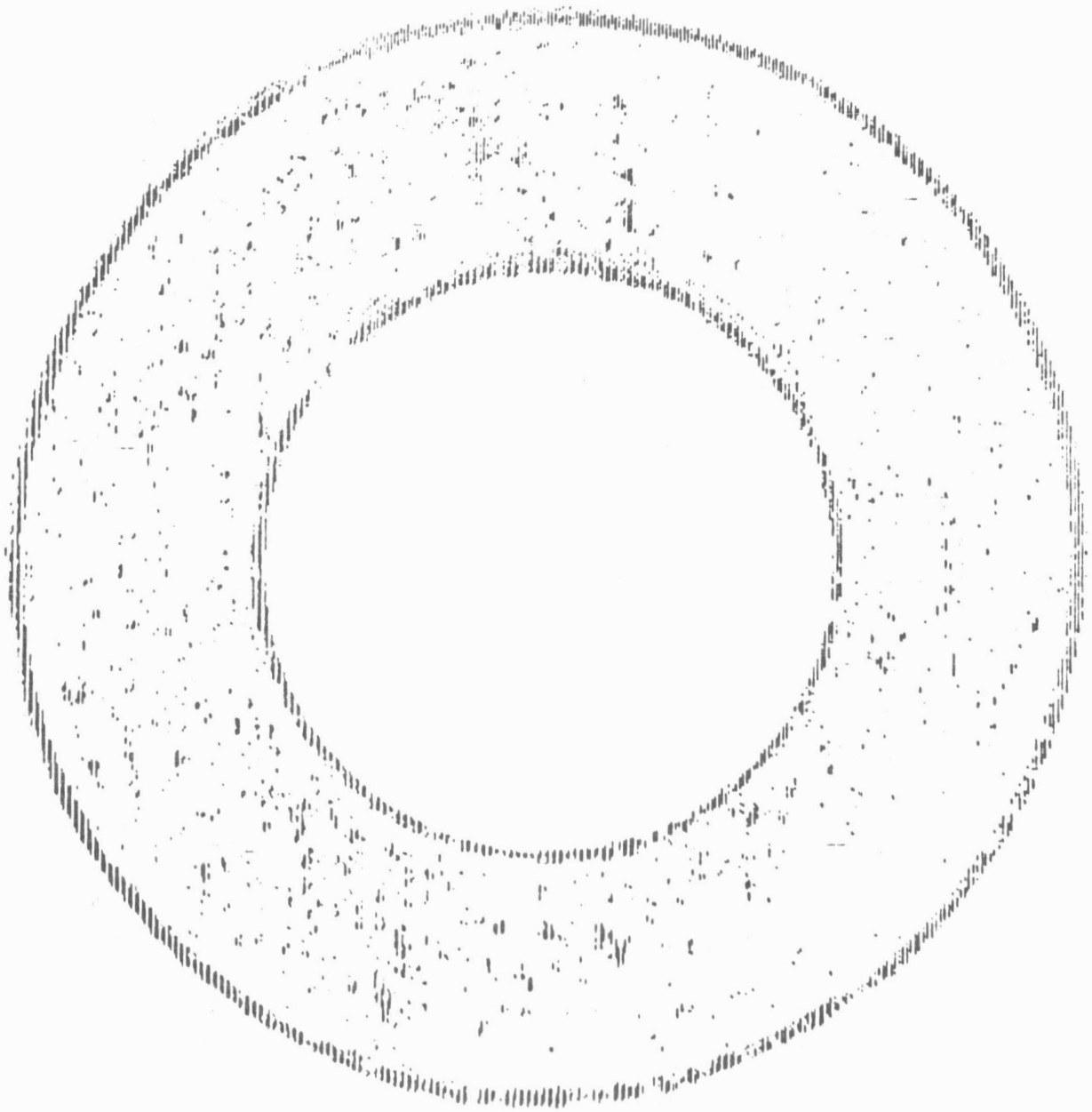


FIGURE 100

RECORD OF ULTRASONIC TESTING OF THE DIFFUSION BONDED RING ON THE SECOND (UNCRACKED) PANEL. THIS DENSITY OF FLAWS IS CONSIDERED ACCEPTABLE.

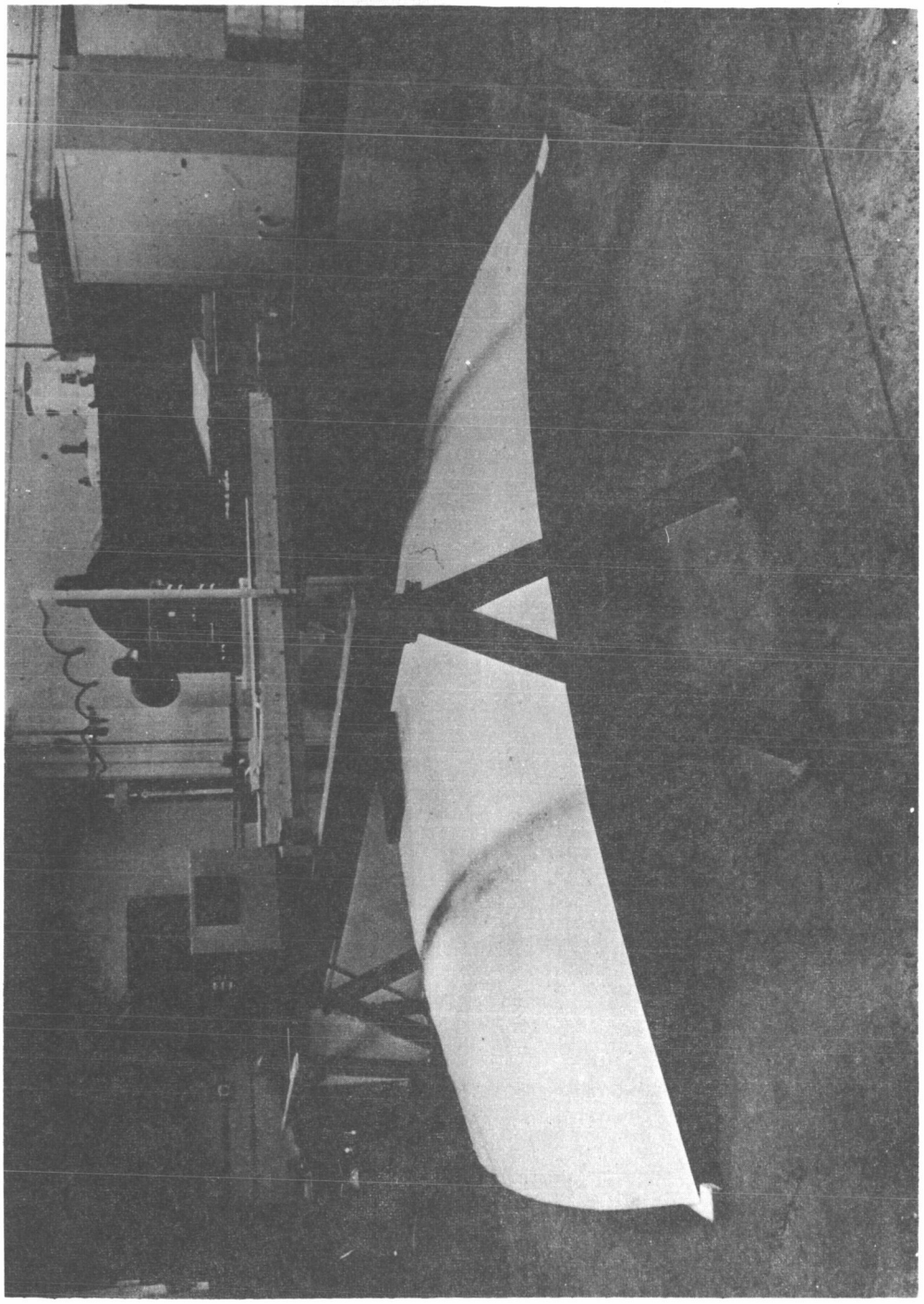


FIGURE 101
ULTRASONIC INSPECTION TITANIUM GORE #002

Type A Failure is Relatively Continuous Bond Line Void

Type B Failure Represents Sprinkled Discontinuities of Average Spherical Diameter Greater Than 0.015 Inch

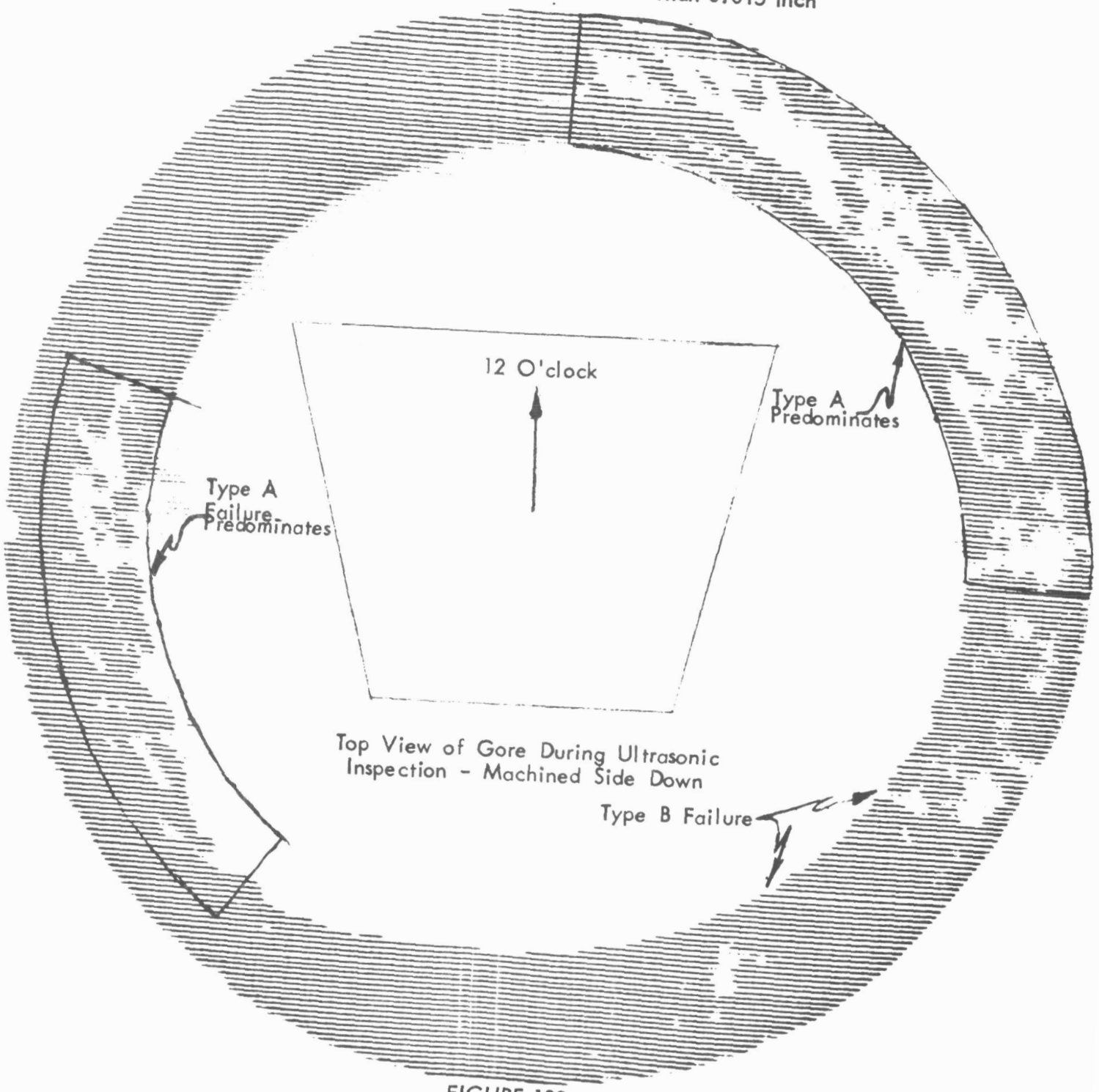



FIGURE 102

ULTRASONIC DISPLAY GORE #002

between 3 o'clock and 6 o'clock is predominantly scattered small voids with some larger planar discontinuities. Between 6 o'clock and 9 o'clock there is an area of small, scattered voids. The part is not considered acceptable, due to these three areas of poor bond.

6.4.3 Conclusions

The present ultrasonic inspection capability has several limitations which make it undesirable for production inspection. These are listed below:

1) Necessity of providing coupling medium between transducer and part.
2) Large size, difficult portability of mechanical scan system.
3) Inconsistent response from transducer to transducer.
4) Lack of fully adequate definition of acceptable criteria.
5) Heavy reliance on experience in interpreting results.
6) Limited ability to perform inspection at thickness under 1/8 inch.
7) Limited ability to use focused transducers for contoured parts.

6.4.3.1 Development effort presently in progress is aimed at negating many of these factors. Some of these programs are:

1) Development of a highly portable mechanical scan system incorporating automatic contour aligning means, and remote recording capability with provision for varying the scale factor between part and recording over the range 1/10:1 to 10:1.
2) Development of complete and standardized transducer specifications for guidance in purchasing, and calibrating production inspection units.
3) Development of a unique broad band Ultrasonic Spectrum Analysis instrument for obtaining greatly improved resolution.

These developments are expected to contribute significantly to improved quality by providing a greater ability to test present and future materials and processes.

6.5 WELDING

It was not intended that welding be a part of the process development on this program; however, it turned out to be very essential. It was required on three separate occasions: first, to join two plates of titanium together to make a large size forming verification test part; second, to repair a stress crack that occurred in the heat affected area adjacent to the diffusion bonded ring; and third, to repair a crack near the lower edge of the part that was caused by mishandling. The experience gained from these exercises is discussed below.

6.5.1 Plate Welding

During the early phases of this program, 8-1-1 titanium material in sheets large enough for (one-part) fabrication were not available. To allow verification of the vacuum forming process on a full size part, it was necessary to join two 4- by 10-foot sheets of 8-1-1 material.

This was accomplished by machining a double "V" edge preparation on one 10-foot edge of each sheet, leaving a root of 0.150 inch. The plates were then positioned on an aluminum welding table and aligned for welding (Figure 103). Mismatch in the parts was minimized by a combination of vacuum and mechanical hold down. Gas purging of the underbead was provided by using a simple hat section of aluminum foil taped directly to the titanium sheets.

After accomplishing the best fit-up possible, the parts were manually (GTA) tacked every six inches. To complete the weld on one side, a mechanized (GTA) weld was used. The weld sequence consisted of a fusion pass and two filler passes using commercially pure titanium wire. After completing the weld on one side the part was removed from the hold downs and turned over and the weld sequence was repeated to complete the weld.

Welding from both sides minimized the distortion to the sheets and mismatch was no greater than 0.040 inch. After completion of the weld, the part was stress-relieved prior to machining.

A test part completed at the same time and manner as the described weld was subjected to destructive physical testing. Four test samples exhibited an average tensile strength to 137.7 ksi, a yield of 120.9 ksi, and elongation ranged from 5 to 7 percent.

6.5.2 Repair Welds

Welding was required later in the program when it was discovered that the developmental part had cracked around the diffusion bonded fitting, Figure 104. It was necessary to repair the fault prior to forming to keep it from propagating further and resulting in a complete fracture.

The crack was prepared for welding by using a 3/8-inch diameter, ball nose end mill. The end mill was plunged to a depth of 0.120 inch, following the crack, which left a root thickness of 0.060 inch at the bottom of the weld preparation.

Manual gas tungsten arc welding was used for the repair. Argon shielding gas was used both at the torch and on the underbead to prevent excessive oxidation. A fusion pass without wire addition fused the bottom of the grooved area. The weld was then completed by back-step* sequencing, using commercially pure titanium filler wire. Back stepping was utilized to minimize the introduction of stresses and associated distortion to the section.

When the machining fixture was being fabricated, which would hold the gore during boring, it was necessary to locate the gore in the die to make a plaster cast. During one of the lifts out of the die a fracture occurred in the part about 3 inches from the center of the "Y" ring edge, Figure 105. The edges of the crack were ragged, showed short transverse cracking and the edges overlapped a maximum of 0.070 inch.

*By this technique, a sequence of short welds starting away from and going back to each previous weld is used to minimize heat input and part distortion.

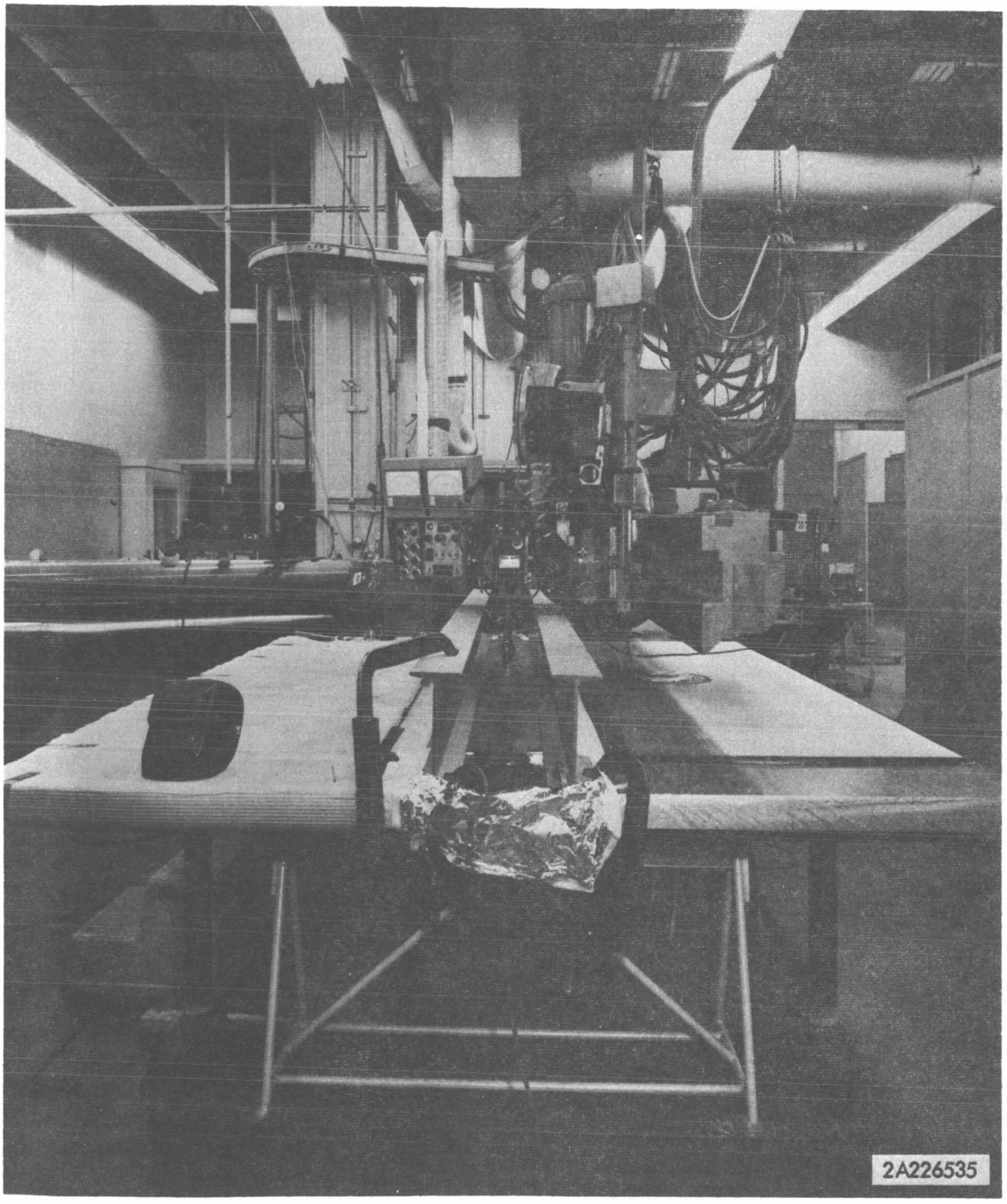



FIGURE 103

GTA WELDING TWO 4 FT. BY 10 FT. TITANIUM PANELS

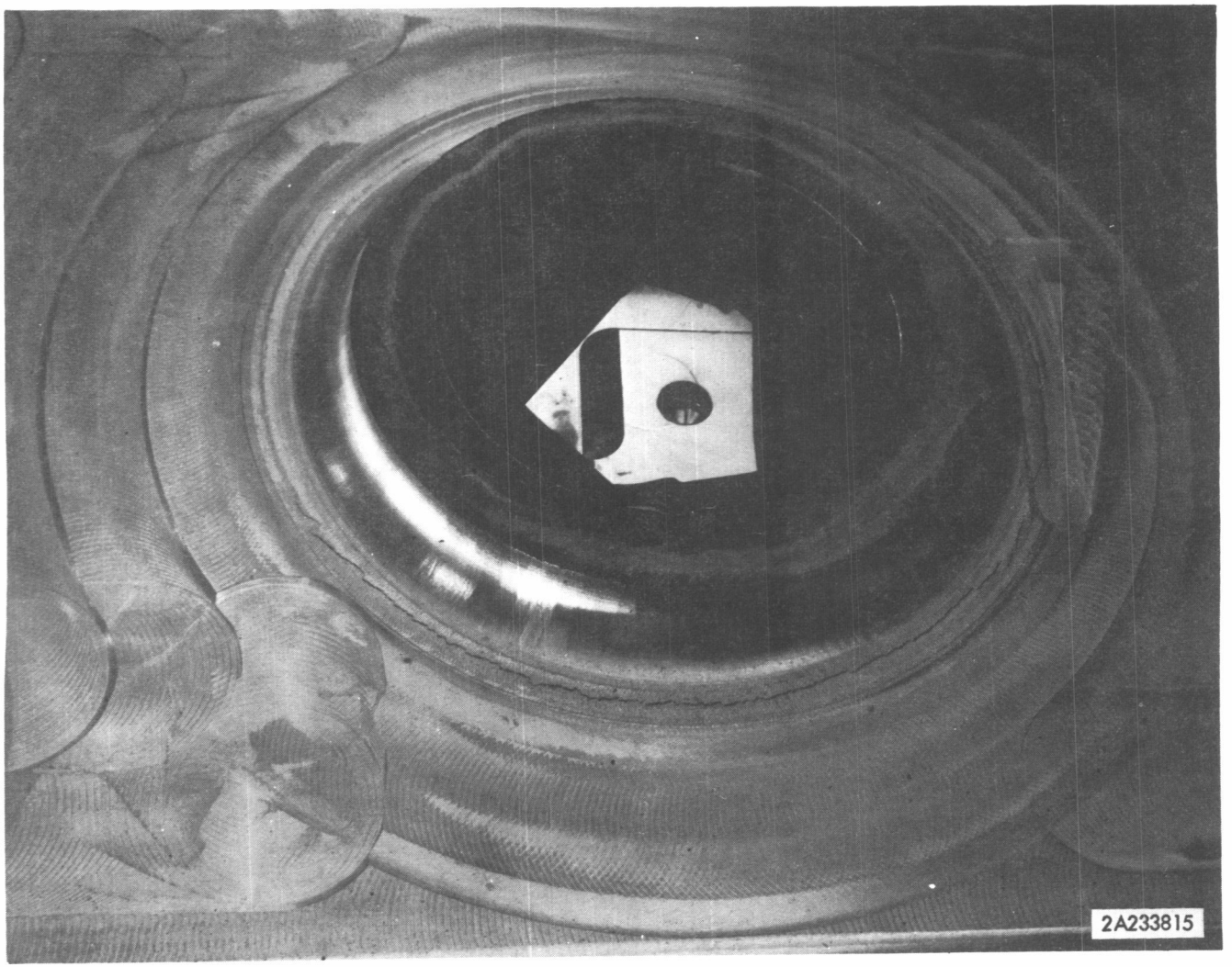



FIGURE 104

RESIDUAL STRESS CRACK IN TITANIUM GORE #002 FROM DIFFUSION BONDING

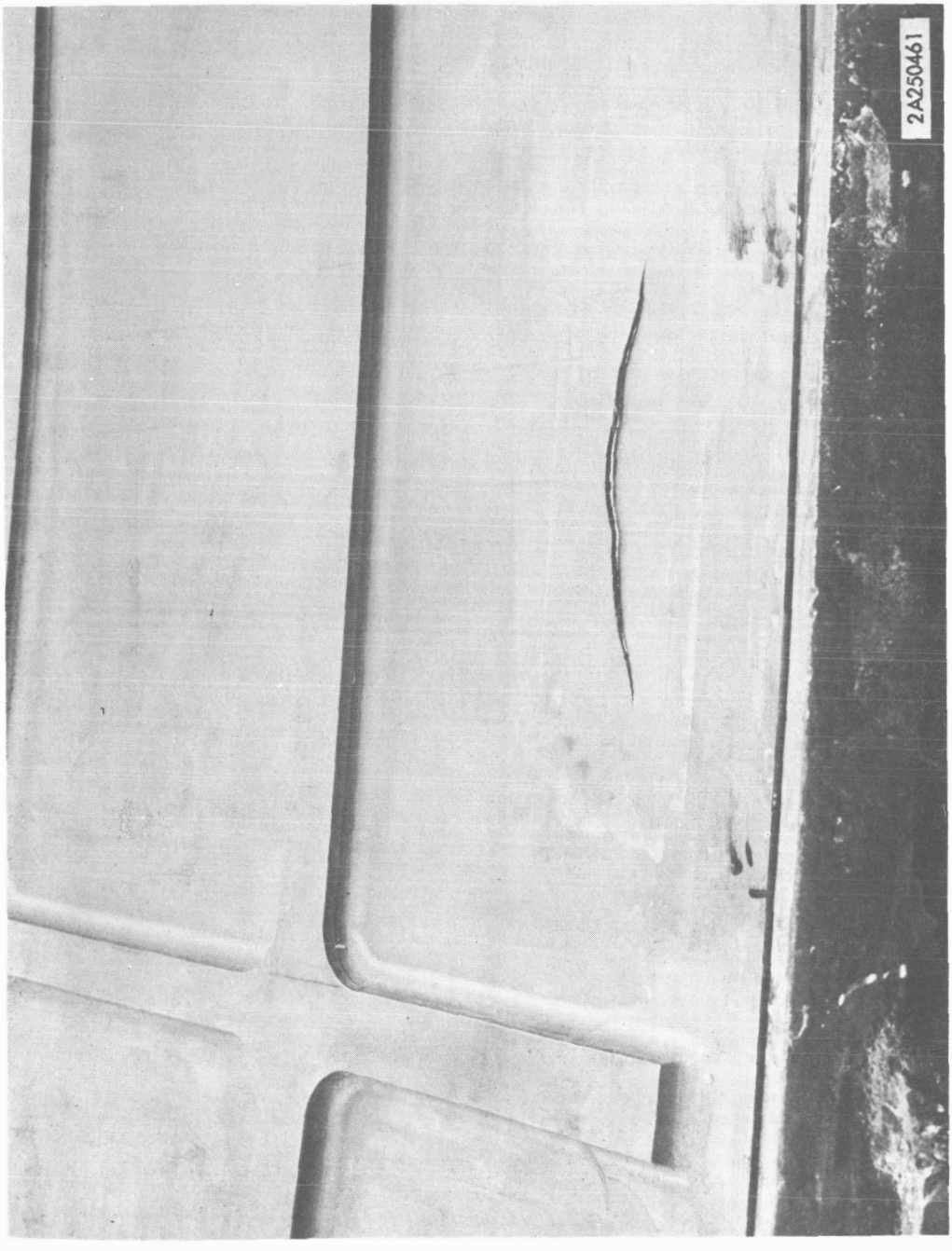



FIGURE 105
CRACK IN EDGE OF TITANIUM GORE #002
(MIS-HANDLING)

Stopper holes, 1/8 inch in diameter, were drilled using a rotary carbide burr to prevent crack propagation. The crack ends were pinpointed by applying a full length radiographic film. The part was then cleaned with MEK and wire brushing and clamped into the correct position with as little mismatch as possible. A plenum chamber for shielding gas was fabricated from aluminum foil and taped to the back side of the part. A 1/4-inch copper tube was placed in this chamber to purge with an argon flow of 12 DFM. Helium at 70 CFH and 30 psi was used as the torch shielding gas.

The weld area was then tacked at 1-1/2-inch intervals to prevent mismatch. Welding began by filling one stopper hole on the left and backstepping in 1-1/2-inch segments, finishing up by welding the right hand stopper hole. When this procedure was complete the part was turned over and the weld sequence repeated.

Heat input to the gore, due to the weld repair, created a new wave in the edge of the part adjacent to the repair. The wave was approximately 8 inches long and 0.25 inch high. Radiographic inspection of the weld showed one small crack or inclusion at the left extremity of the weld.

Although most of the welding which was accomplished during the course of this program could be classed as "state-of-the-art", it was a valuable lesson in titanium welding. Techniques for welding large size titanium parts were developed and purging devices capable of covering fairly large areas fabricated. The weld repairing on this gore section was complex and varied enough to substantially increase the confidence level in titanium welding.

## 6.6 FABRICATION COSTS

Based on the processing specified in the preceeding Section 5.0, an estimate of the cost to manufacture a part by this process is as follows:

| | | |
|---|---|---|
| Titanium Material (5/8 x 96 x 156) | | $10,000 |
| Receiving Inspection | 20 hr. | |
| Machining Details | 60 hr. | |
| Diffusion Bonding | 90 hr. | |
| Stress Relieving | 8 hr. | |
| "Hot" Flattening | 30 hr. | |
| Machining | 550 hr. | |
| Inspection of Machined Pockets | 30 hr. | |
| Fusion Weld Picture Frame | 32 hr. | |
| "Hot" Vacuum Forming | 160 hr. | |
| Trim Off Picture Frame | 8 hr. | |
| Trim, Bore and Spotface | 60 hr. | |
| Clean | 4 hr. | |
| Inspect Contour | 8 hr. | |
| Total | 1060 hrs. | |

Added to this must be the power cost of $67.00 per 8 hour shift. This new process would require about $402.00 in power cost because of the longer (48 hour) forming cycle.

These costs do not include overhead cost, do not reflect a learning curve, and do not include the extra organizational activities associated with making the first part. It is conceivable, that by the time the fifth part was produced by this process, the manhours shown would be reduced to under 600 hours. This is also predicated upon making a good part every time, the cost of the material is such that economics dictate more care in the processing to ensure the production of a good part everytime. Also, that extreme care be exercised to prevent handling damage to the part at any stage in the processing.

## 7.0 RECOMMENDATIONS

This program, conducted under the direction of the National Aeronautics and Space Agency, George C. Marshall Space Flight Center, Manufacturing Engineering Laboratories, has demonstrated the feasibility of using 8-1-1 titanium alloy material for Saturn fuel tank construction.

At the beginning of this program, industry data indicated titanium to be formable, machinable, weldable, and to have the mechanical properties desired; however, the suitability of titanium for Saturn gore fabrication had to be determined. In this program, a Saturn gore was designed for titanium, fabricated by special titanium manufacturing processes and evaluated. The evaluation showed the following:

1) Gore size titanium plate can be rolled in the 1/2- by 96- by 156-inch size.
2) Local thickening of the plate can be accomplished by diffusion bonding.
3) Plate distortion, due to rolling or local heating, can be removed by "hot" flattening.
4) Pocket machining can be readily accomplished on a profile milling machine. The flat pattern developed here (see Table IV) can be used for similar titanium gores formed by this process.
5) The titanium gore can be formed to the Saturn tank contour by hot vacuum forming in a single face resistant heated ceramic die.
6) The material properties to be unaffected by the processing.
7) The gore weight to be approximately 25 percent less than the comparable aluminum part.

According to this evaluation, feasibility has been proven but each of these factors require refinement and improvement before it can be considered a repeatable, reliable production process.

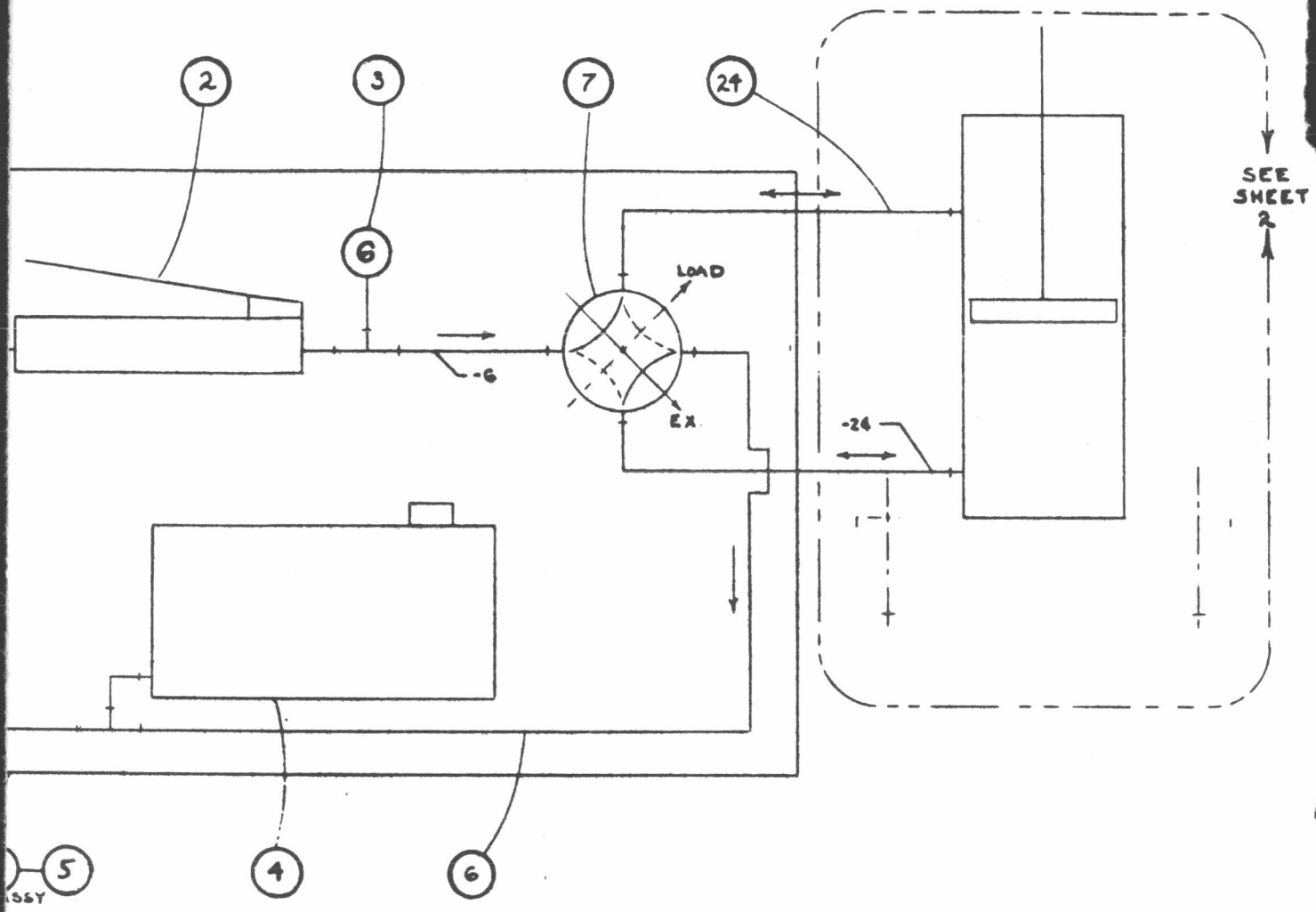
These refinements should include improvement in raw material processing at the mill, improvements in the diffusion bonding and hot flattening processing to minimize and control stress concentrations, improvements in part restraint and application of forces during the forming cycle, and in ultrasonic inspection methods to assure part integrity. Besides refinement of the processes for fabricating a gore, consideration should be given to the development of a good process for removing weld distortion after gores are welded together. Titanium material possesses two characteristics: low heat conductivity and high yield strength which makes it more susceptible to weld distortion and more difficult to remove distortion, than aluminum.

At this time it is not recommended that an overall process improvement program be initiated. Feasibility has been demonstrated and further refinements are attainable through the normal course of process implementation in a production program. Certainly sufficient time should be allowed in a production program to accomplish these refinements.

The success of a production program involving titanium gores will depend upon consistent material properties and a reliable manufacturing process. Material

properties data is lacking, especially as related to material performance after it has been processed through numerous thermal cycles. It is, therefore, recommended that a wide spectrum of materials properties test data be obtained before a decision is made to use titanium as a gore material in production.

A limited test program is also recommended to obtain important forming tool performance data before the tool is scrapped. This program should be a die life cycle testing program incorporating limited forming cycle improvement work. Up to this time the vacuum forming die has been cycled eight times to the range of 1400 to 1600°F for a total thermal cycling time of approximately 60 hours, without failure. Valuable data can be obtained for future die design by cycling at successively higher temperatures in an accelerated life cycle testing program.




PART NO TOOL PER TPS 40

TOOL NO GMT 14489 (A)

- 25 ASSY PART 1 OF 10
- 8 ASSY PART 2
- 10 DETAIL PART 3
- 11 " PART 4
PART 5 & 6 DELETED (B)
- 15 " PART 7
- 17 " PART 8
- 18 " PART 9
- 7 PART 10

DETAILS 2 THRU 6 & 24 ARE BORROWED AND ARE NOT A PERMANENT PART OF THIS TOOL

DETAIL - 13 (3)

FUNCTION OF TOOL

TO APPLY PRESSURE TO TITANIUM GORE SKIN & RING FOR DIFFUSION BONDING

NOTES

SHEET ONE - NONE SCALE DRAWING. SHEET TWO SCALE DRAWING & SCALE FOR ALL NON-CRITICAL DIMENSIONS NOT SHOWN.

BREAK ALL SHARP EDGES

SUBSTITUTION OF PARTS AND MATERIAL TO BE FUNCTIONALLY EQUIVALENT

THIS DRAWING SHOWS BORROWED EQUIPMENT USED IN THIS TOOL. SEE 1

CAUTION —

SPEE-D-COUPLERS ARE TO BE KEPT CLEAN. DUST CAPS SHALL BE INSTALLED WHEN LINES ARE REMOVED.

1 AVAILABLE AS A UNIT FROM PCA 96B STORES. SEE STAN OLSON, DEPT 2-856, PH 5-4417 FOR PERMISSION TO BORROW.

2 LOOSE PARTS. DO NOT SCREW & DOWEL.

3 THIS DETAIL CONSUMED IN USE. - QUANTITY ALLOWS FOR 1 SPARE.

4 FLAME CUT OR SAW. DO NOT FINISH EDGES.

5 GRIND SURFACES TO REMOVE MINIMUM OF MATERIAL.

6 HEAT TREAT PRIOR TO TRIMMING IN OVEN AS FOLLOWS

1. FOUR HOURS AT 250° F.
2. FOUR HOURS AT 300° F.
3. FOUR HOURS AT 400° F.
4. RAISE TEMP. UNIFORMLY TO 1000°F IN 12 HOURS (24TH HR.)
5. MAINTAIN 1000°F FOR FOUR HOURS
6. COOL GRADUALLY IN OVEN

7 CUT -23, 7 INCHES LONG. INSTALL -13 IN TOOL & COMPRESS WITH SIMULATED PROD. PARTS - WITHOUT HEAT. (COMP. LOAD ON -13 TO BE 1000 P.S.I.) RETRIM -23 TO MAINTAIN A MINIMUM CLEARANCE WITH -15 OF ¼ INCH

8 OPTIONAL TO MAKE

| | | | | | | |
|---|---|---|---|---|---|---|
| 25 | UT7131 | 1 | EYE BOLT | | -10 | |
| | 27 | 3 | RING | | FIBER FRAX | |
| | 26 | 3 | RING | | MOLTEN METAL MACHINITE 1 X 12 X 12 | |
| | 25 | 1 | STAND ASSY. | | | |
| 1 | 24 | 2 | HIGH PRESSURE HOSE 6FT. | | ENERPAC # A804 OR EQUAL | |
| | 28 | 3 | RING | | FIBER FRAX | |
| 25 | 22 | 1 | STAND | | HRS - ASTM-A7 ½ X 26 X 29 | |
| 25 | 21 | 3 | CAP SCREWS | | HEX. HD. ½-13 X 1¼ | |
| 25 | 20 | 3 | LEVELIZING JACK - BASSICK | | A-625 | |
| 25 | 19 | 2 | BUSHING 3000 PSI | | 1 TO 3/8 I.D. | |
| | 18 | 1 | WASHER | | LG. FLT. GRD. STK. ¼ X 5 X 5 | |
| | 17 | 1 | HEX NUT - FIN. | | STL. 2-12 THDS/INCH | |
| 25 | 16 | 1 | EXTENSION ROD | | C.R.S. 2½ DIA X 20 LG. | |
| | 15 | 1 | CAP | | HRS - ASTM-A7 3 X 10 X 10 | |
| | 14 | 1 | RING | | INCONEL 750 X 1 X 10 X 10 | |
| 25 | 13 | 3 | INSULATOR | | JM- MOLTEN METAL MACHINITE 3M 1 X 12 X 12 | |
| 8 | 12 | 1 | BAFFLE | | HRS - ASTM-A7 4 X 10 X 10 | |
| | 11 | 1 | BLOCK | | HRS - ASTM-A7 4 X 10 X 10 | |
| | 10 | 1 | BLOCK | | HRS - ASTM-A7 6 X 10 X 10 | |
| 25 | 9 | 1 | HYDRAULIC CYLINDER | | HANNIFIN - JB - H - 12 | |
| | 8 | 1 | BAFFLE ASSY | | | |
| | 7 | 1 | VALVE - 4 WAY (3 POSITION - SPOOL TYPE) | | BARKSDALE # G142 R3HC3 | |
| 1 | 6 | 1 | LINES | | AS REQ'D - 3000 PSI | |
| 1 | 5 | 1 | BASE | | PLYWOOD | |
| 1 | 4 | 1 | RESEVOIR | | 1½ GAL | |
| 1 | 3 | 1 | GAGE | | 3000 PSI HYD | |
| 1 | 2 | 1 | HYD PUMP | | P39 ENERPAC | |
| | 1 | 1 | HYDRAULIC ASSY | | | |

A GMT14489

ATTRIBUTE DEV 0 0

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| REV WORD ON | DETAIL NO | QUANTITY | NAME OF DETAIL | ZONE | MATERIAL | STOCK SIZE | |
| | | | | | | | |

TOOLING CHANGE ORDER

| LTR | NUMBER | DATE |
|---|---|---|
| A | | 9/30/65 |
| B | | 1-25-6 |
| C | | 5-2-6 |

SCALE NOTED

ALL DIMENSIONS IN INCHES

EXCEPT AS NOTED TOLERANCE FRACTIONAL ± DECIMAL ± ANGULAR ± MACHINE FINISH

| SHOP | CONCURRENCE | DATE |
|---|---|---|
| | | |
| | NAME | DATE |
| DESIGN BY | A. NELSEN | 7-16-65 |
| DETAIL BY | — | — |
| CHECK BY | H. MICHELS | 7-21-65 |
| APPROVED | | |
| APPROVED | | |

FINISH | COLOR OR PROTECTIVE | SIZE | MODEL | DRAWING SHEET SIZE 5

T O O L D R A W I N G

THE BOEING COMPANY DIVISION

GORE SECTION DIFFUSION BONDING TOOL

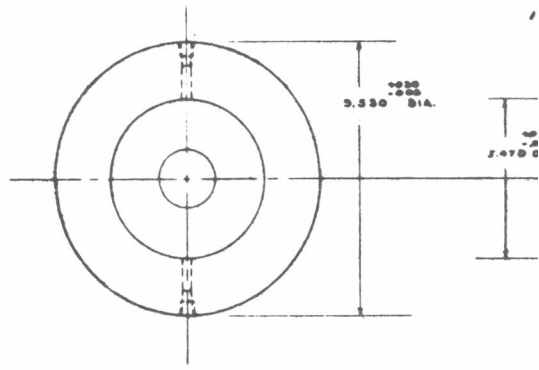
A GMT14489 SHEET 1 OF 2

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USED ON BENCH

5-72963-1801

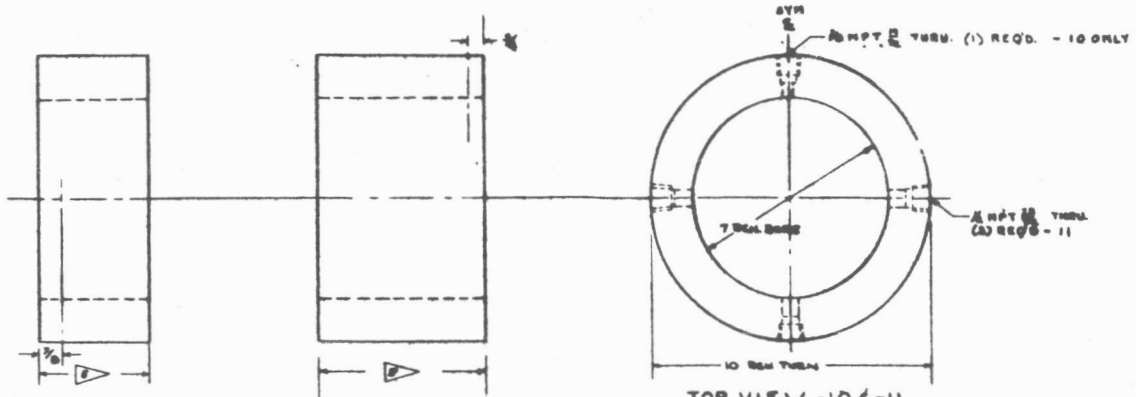
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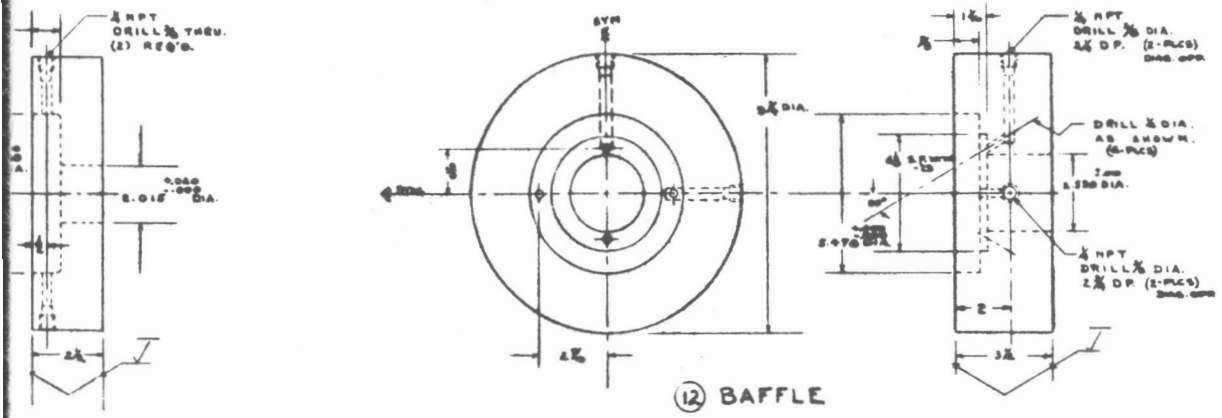

(15) CAP



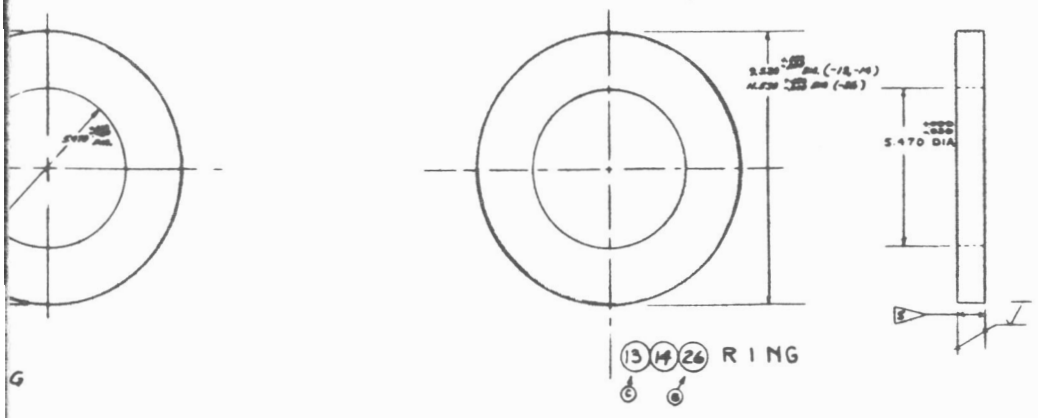
(28)(27) RIN




⑪ BLOCK ⑩ BLOCK TOP VIEW -10 & -11




⑫ BAFFLE




⑬ ⑭ ㉖ RING

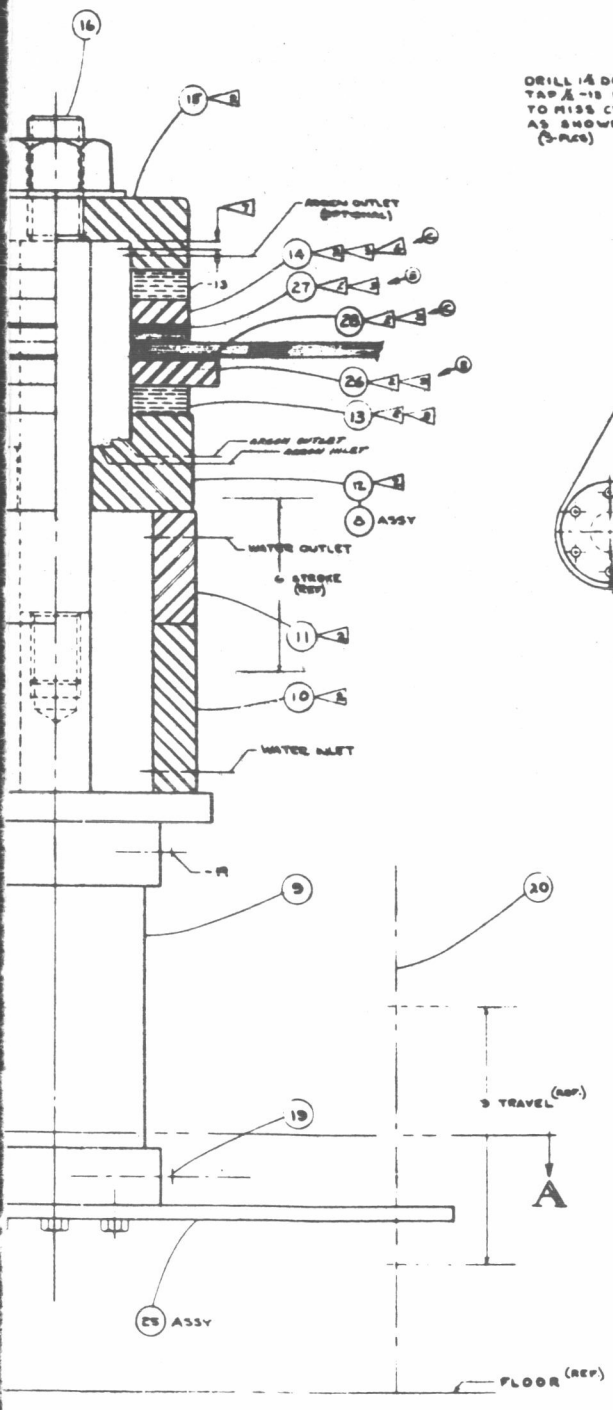



⑯ EXTENSION ROD

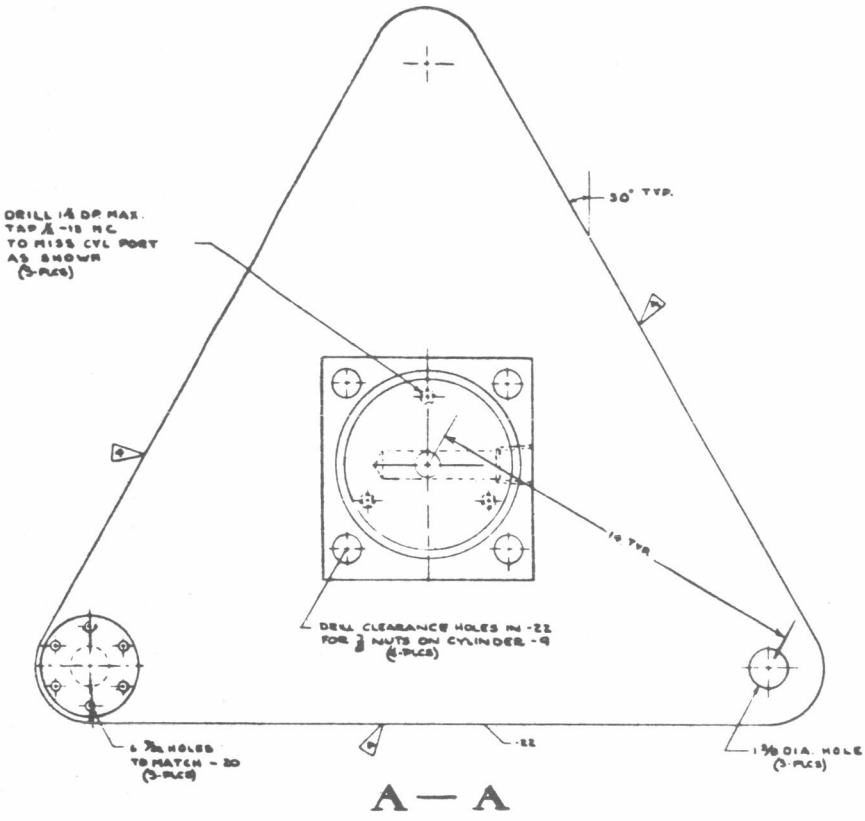



5 4 3

1-628



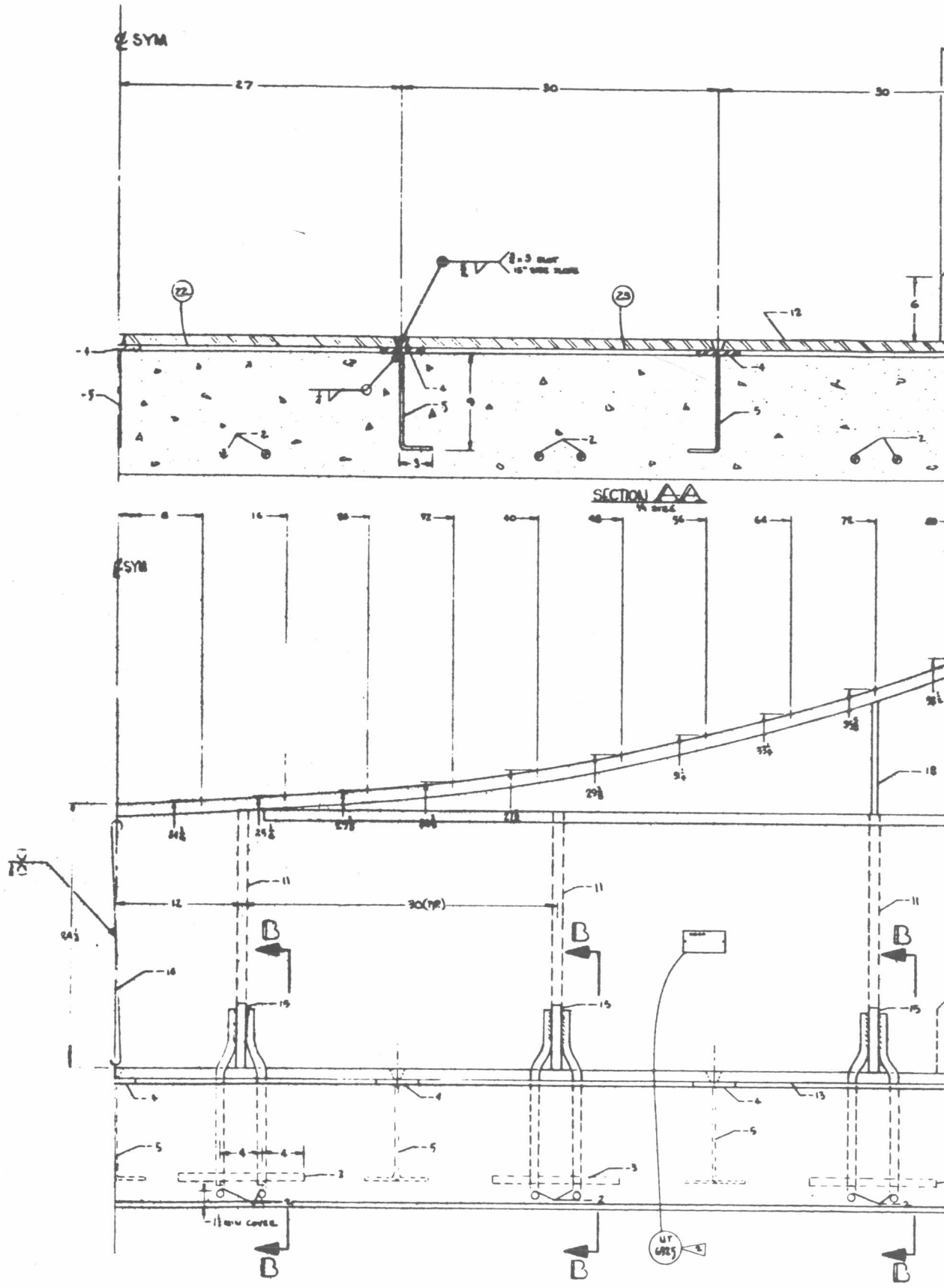

SIDE VIEW



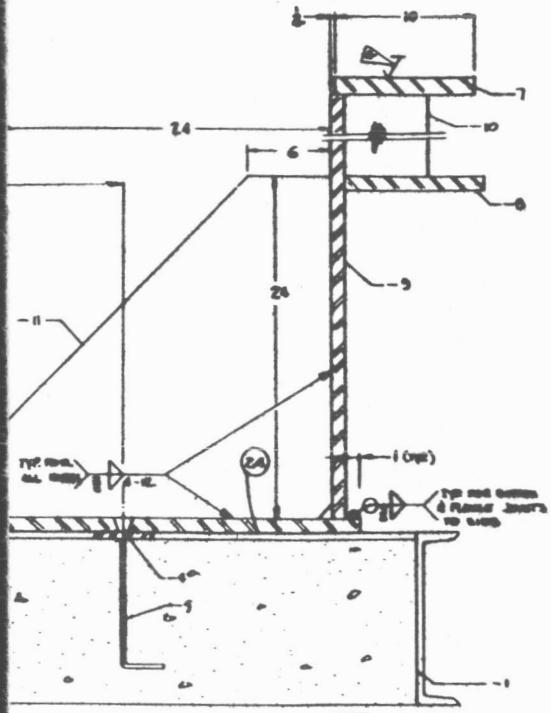

A — A

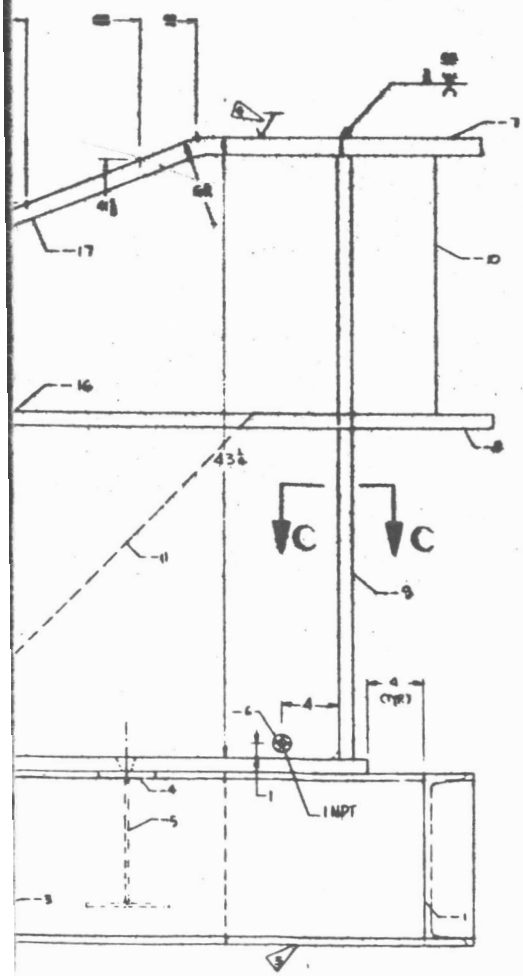
| | | | | | |
|---|---|---|---|---|---|
| | | | | SIZE | HOME |
| | | | | | TOOL DRAWING |
| | | | | | GORE SECTION DIFFUSION BONDING TOOL |
| | | | | | GMT14489 — 2 |

GMT14489 — 2



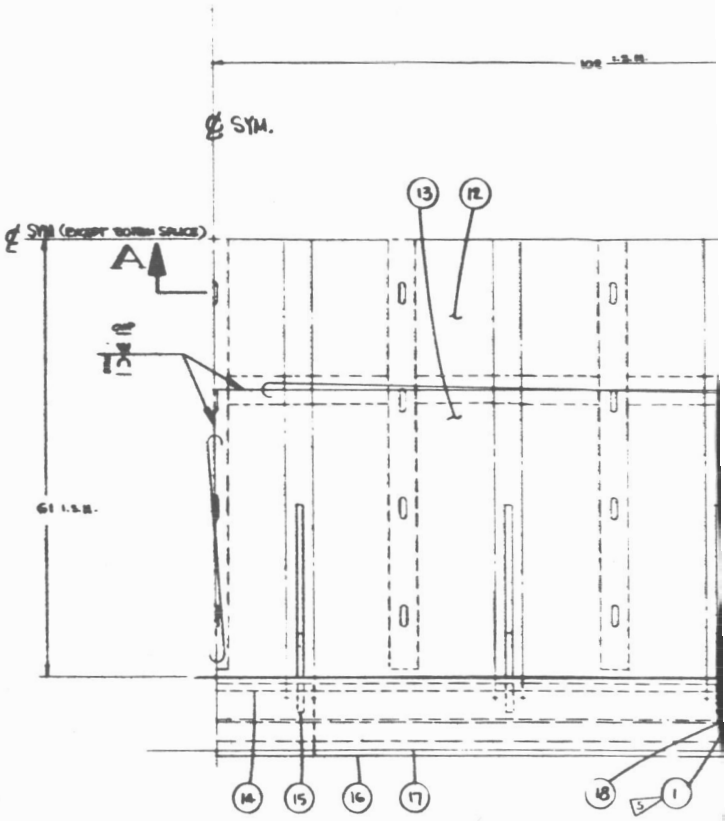

APPENDIX



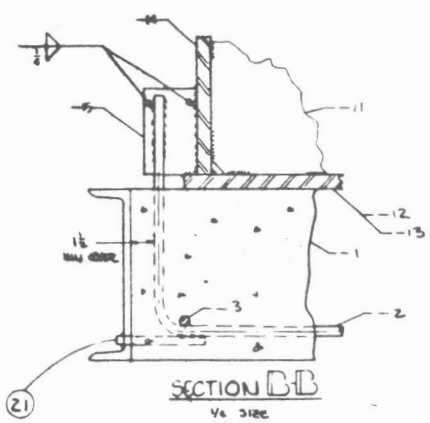





SECTION CC




QUARTER PLAN VIEW



SECTION BB



1-a64B

FUNCTION OF TOOL -

TO VACUUM FORM TITANIUM GORE SECTIONS.

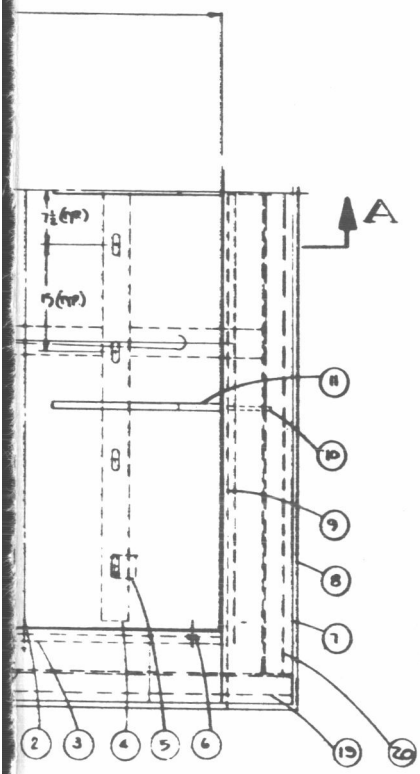
WELD PER TPS 2.8 (DO NOT STRESS RELIEVE OR SANDBLAST)

5. OPTIONAL MAT
4. PAINT FLOOR LIBERALLY WITH FORM OIL BEFORE POURING CONCRETE
3. HAND GRIND SMOOTH AND LIGHTLY OIL.
2. PAINT OUTSIDE SEMI-GLOSS WHITE, EXCEPT BOTTOM, FLANGE FACE AND EMBEDDED ITEMS.
1. IDENTIFY PER TPS 4.0
1. 7½ CU YDS. 5000 psi (28 DAY) CONCRETE ●
AGGREGATE NOT CRITICAL

SUBSTITUTION OF FUNCTIONALLY EQUIV. MAT. ALLOWED

REFERENCE:

SHEET 1 - STRUCTURAL DETAILS
SHEET 2 - CERAMIC DETAILS
SHEET 3 - WIRING AND PLUMBING DETAILS
SHEET 4 - DIAPHRAGM AND CLAMPING DETAILS




| | | | | |
|---|---|---|---|---|
| | MT 6529 | 1 | MSFC TOOL I.D. TAG | |
| 24 | 2 | PATCH PAD | HRS | ½ x 6 x 19 |
| 23 | 4 | PATCH PAD | HRS | ½ x 2 x 6 |
| 22 | 2 | PATCH PAD | HRS | ½ x 2 x 23 |
| 21 | 24 | RE-BAR | #6 x 7 | |
| 20 | 2 | END RAIL | HRS CHANNEL | 12 x 8 x 1/4 x 134 |
| 19 | 2 | SIDE RAIL | HRS CHANNEL | 12 x 8 x 1/4 x 226 |
| 18 | 4 | STIFFENER | HRS | 6 x ½ x 10½ |
| 17 | 2 | FLANGE | UHR | 10 x 1⅛ x 228 ● |
| 16 | 4 | REINFORCING R/B | UHR | 10 x 1 x 99 |
| 15 | 12 | ANCHOR PLATE | PMS | 4 x 1 x 6 |
| 14 | 4 | SIDE PLATE | PMS | 66 x 1 x 108 (MACHINED) |
| 13 | 2 | BOTTOM PLATE | PMS | 42 x 1 x 104 |
| 12 | 1 | BOTTOM PLATE | PMS | 84 x 1 x 208 |
| 11 | 1A | KNEE | PMS | 24 x 1 x 24 |
| 10 | 6 | STIFFENER | HRS | 6 x ½ x 18 |
| 9 | 2 | SIDE PLATE | PMS | 42 x 1 x 123 |
| 8 | 2 | REINFORCING R/B | UHR | 10 x 1 x 144 |
| 7 | 2 | FLANGE | UHR | 10 x 1⅛ x 142½ ● |
| 6 | 6 | PLUG, PIPE | M.P. | 1 NPT ● |
| 5 | 56 | ANCHOR | HRS | 3 x ⅜ x 12 |
| 4 | 7 | BAR | HRS | 4 x ½ x 120 |
| 3 | 12 | RE-BAR | NO. 6 | x 12 |
| 2 | 12 | RE BAR | NO. 6 | x 168 |
| 1 | 1 | CONCRETE BASE | | |

NOTED

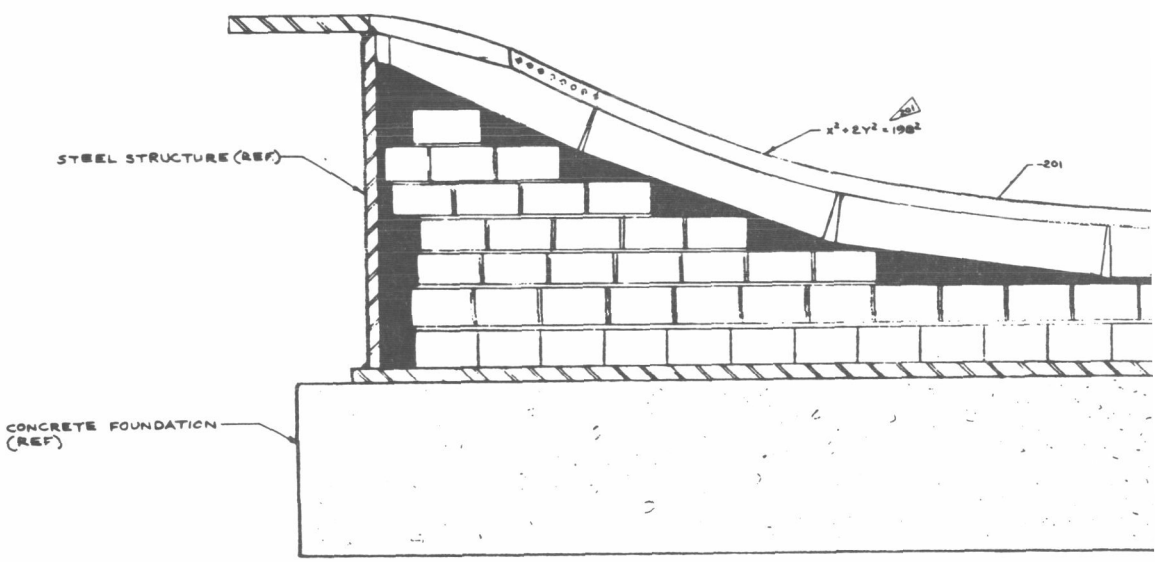
TOOL DRAWING

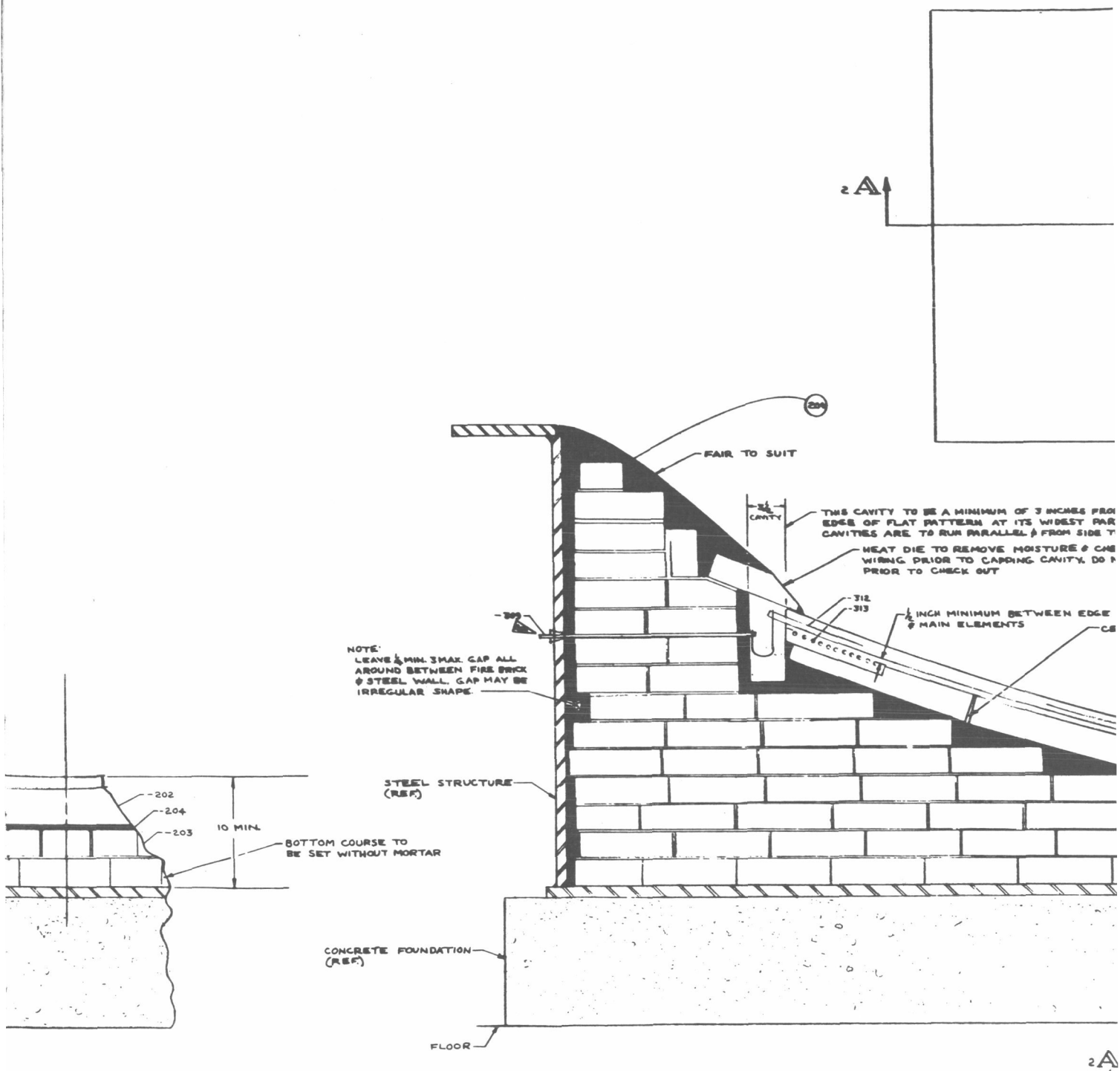
THE BENDIX CORPORATION
AEROSPACE DIVISION

VACUUM FORM DIE
TITANIUM GORE

GMT 14490 sht 1 of 4

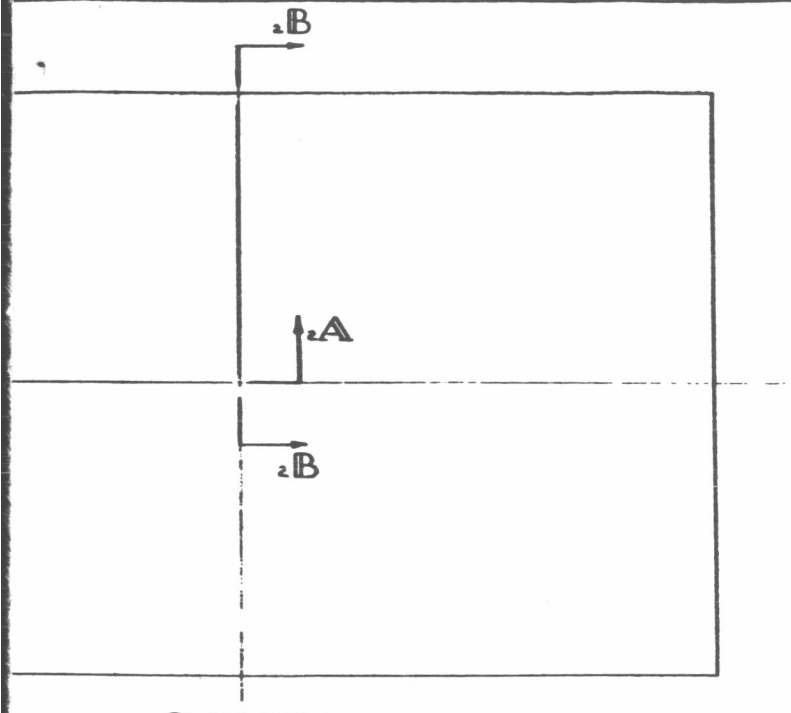
(2)


STEEL STRUCTURE (REF)
CONCRETE FOUNDATION (REF)
201
2B - 2B
½ SIZE


2 A
204
FAIR TO SUIT
¾" CAVITY
THIS CAVITY TO BE A MINIMUM OF 3 INCHES FRO
EDGE OF FLAT PATTERN AT ITS WIDEST PAR
CAVITIES ARE TO RUN PARALLEL ∅ FROM SIDE T
HEAT DIE TO REMOVE MOISTURE ∅ CAB
WIRING PRIOR TO CAPPING CAVITY. DO N
PRIOR TO CHECK OUT
312
313
½ INCH MINIMUM BETWEEN EDGE
∅ MAIN ELEMENTS
NOTE:
LEAVE ½ MIN. 3 MAX. GAP ALL
AROUND BETWEEN FIRE BRICK
∅ STEEL WALL. GAP MAY BE
IRREGULAR SHAPE.
STEEL STRUCTURE
(REF.)
202
204
203
10 MIN.
BOTTOM COURSE TO
BE SET WITHOUT MORTAR
CONCRETE FOUNDATION
(REF.)
FLOOR
2 A
4

5 4 3

1-66B




PLAN VIEW
SHOWS SECTION CUTS FOR CERAMIC LAYUP
NO SCALE
ALL DETAIL OMITTED

SHT 2 SHOWS CERAMIC LAYUP ONLY.

CENTER SCREED (EMT 12R 17266) TO OBTAIN THE MAXIMUM SWEEP IN THE STRUCTURAL CAVITY. NOTE THE 10 MIN. DIM. AT THE BOTTOM BETWEEN THE DIE FACE & STL. STRUC.

USE MORTAR FOR FAIRING OVER -309 CONNECTORS, OPTIONAL TO NOTCH OR DRILL BRICK.

MORTAR ALL FIREBRICK EXCEPT BOTTOM COURSE.

SCALE DWG FOR NON-CRIT DIMS NOT GIVEN.

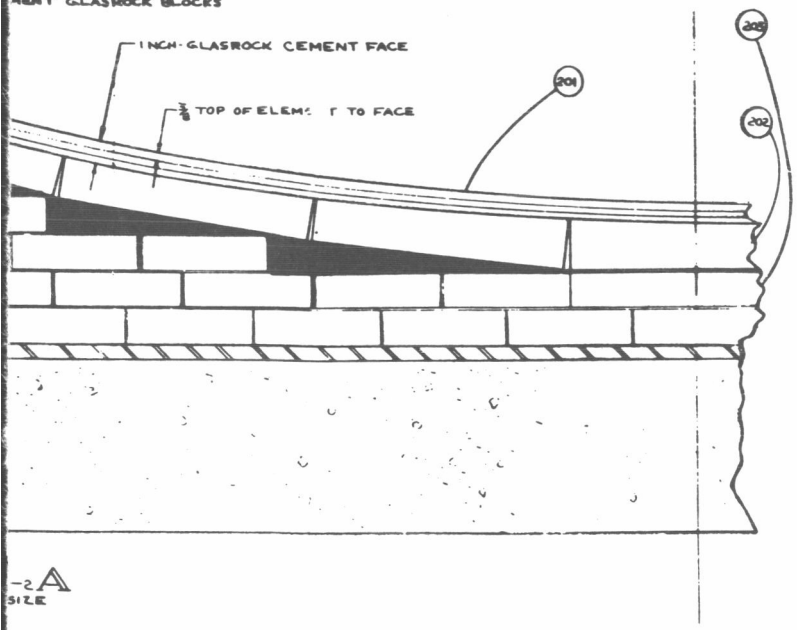
FIRE BRICK TO BE LAYED TO OBTAIN BEST UTILIZATION. IT IS NOT REQUIRED TO FOLLOW THE PATTERN SHOWN.

GLASROCK BLOCKS TO BE FACED TO ±1/64 PRIOR TO SCREEDING OF CEMENT FACE.

PROVIDE CAVITIES AS REQ'D. FOR WIRING EDGE ELEMENTS.

T &
D SIDE OF BOIL.
CK
OT COVER-309'S

MENT GLASROCK BLOCKS




-2A
SIZE

| | | | | | |
|---|---|---|---|---|---|
| 205 | 300-lb | MORTAR | 3 | SAIR SET | |
| 204 | 3000 LBS | FAIRING | 3 | H.W LITE WT CASTABLE #22 | |
| 203 | 3000 | FILLER | 2 | FIRE BRICK K20 2½x4½x9 | |
| 202 | 12.5 | INSULATION | 2 | GLASROCK BLOCKS 30LB EA | |
| 201 | 4420 LB | FACING | 2 | GLASROCK CEMENT 55 75 CON. | |

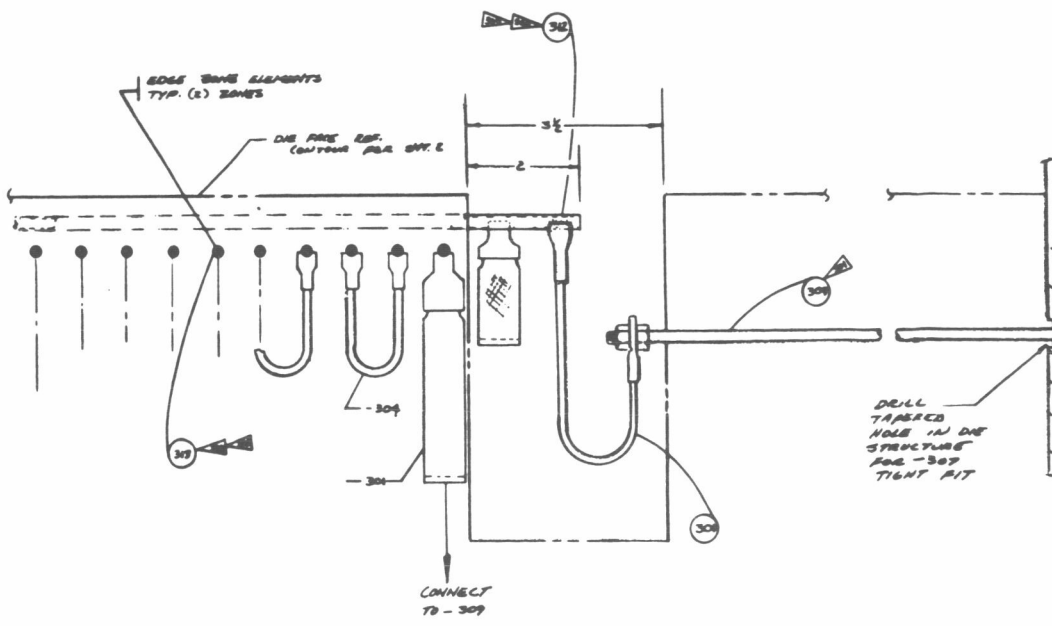
NOTED

TOOL DRAWING
AEED GRACE

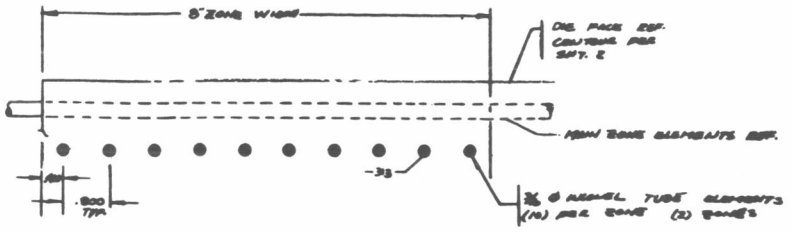
VACUUM FORM DIE
TITANIUM GORE

GMT 14490 — 2

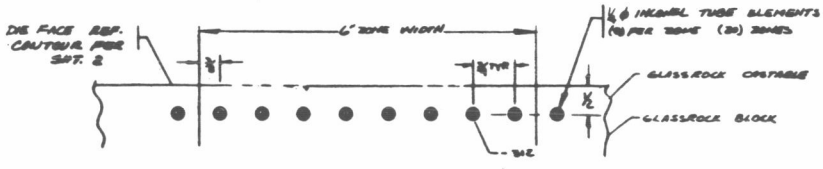
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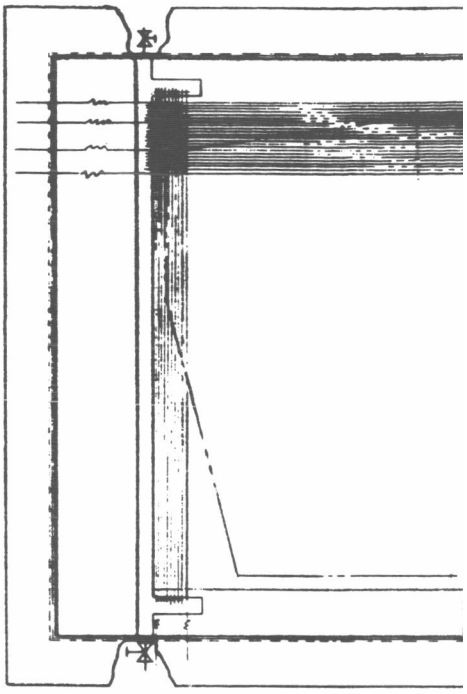

SECTION VIEW
FULL SIZE

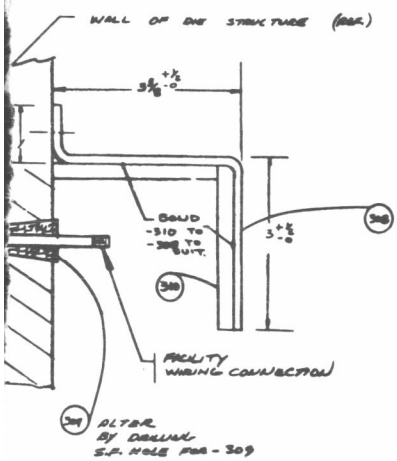


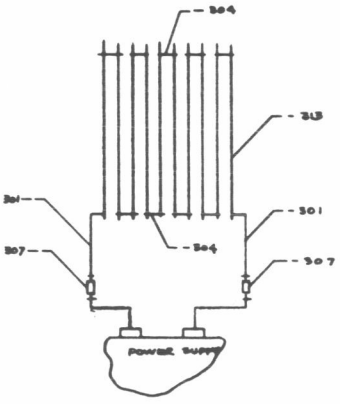

EDGE ZONE ELEMENT SPACING
(2) ZONES



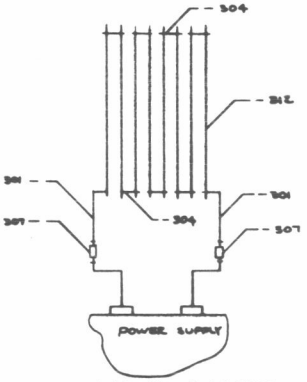

MAIN ZONE ELEMENT SPACING
(18) ZONES



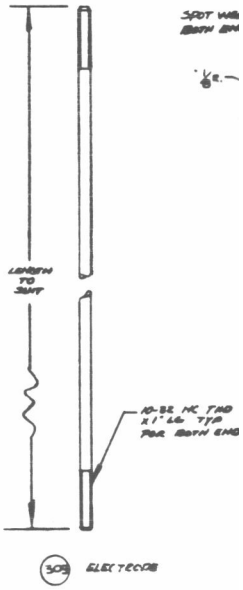


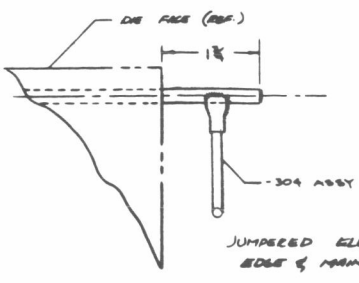




WIRING DIAGRAM
EDGE ZONES ONLY

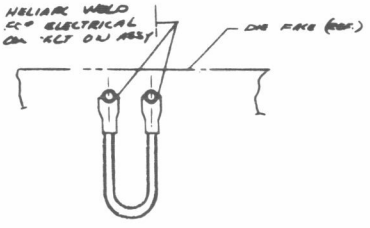



WIRING DIAGRAM
MAIN ZONE ONLY



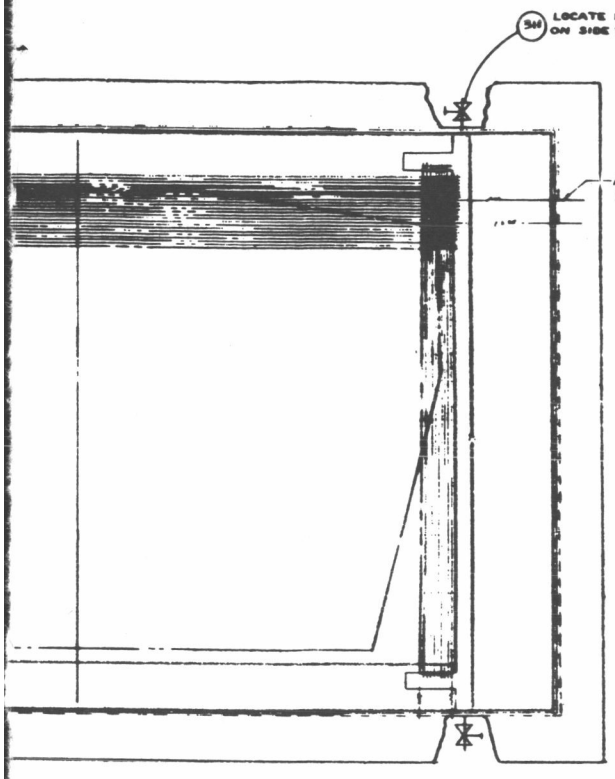




JUMPERED ELEMENTS
EDGE & MAIN ZONES






J-68 B




▶ MAY BE IN SHORT LENGTHS TO COVER ELEMENTS ONLY

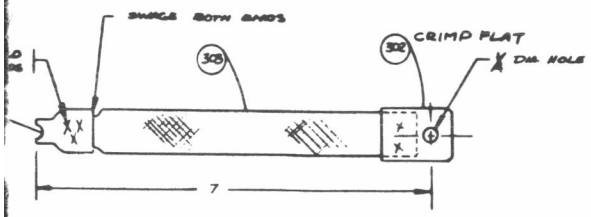
▶ CONTOUR ELEMENTS PER SHT 2

▶ POSITION ELEMENTS 4" OUTSIDE PROD. PART FLAT PATTERN AT WIDEST POINT AND CONTINUE SPACING PER DETAIL

▶ 1/16 WAX COAT ROD

1/16 WAX COAT ALL ELEMENTS PRIOR TO POURING CASTABLE

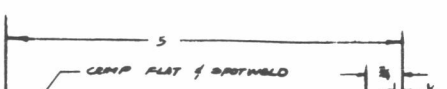
SEE SHT. I FOR GENERAL NOTES

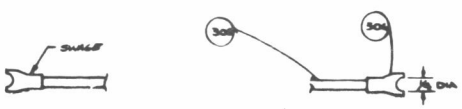






(301) CONNECTOR ASSY.

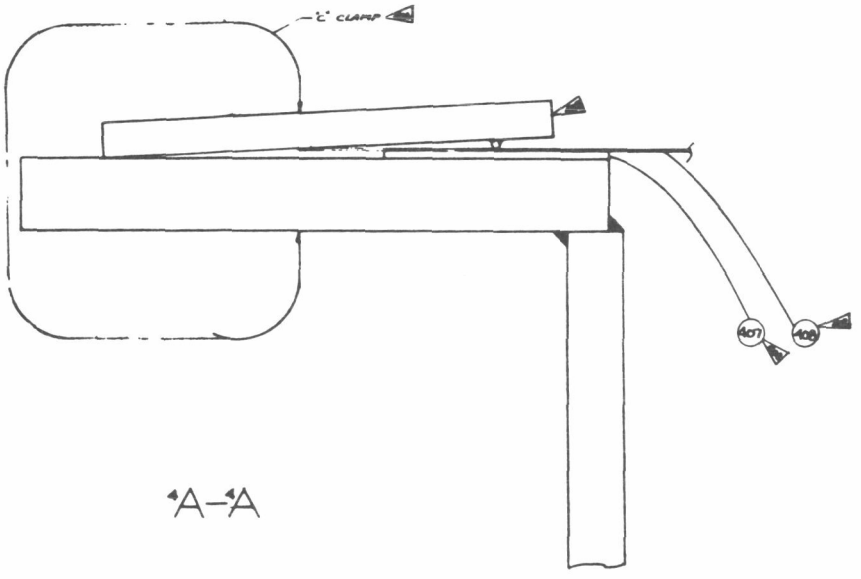


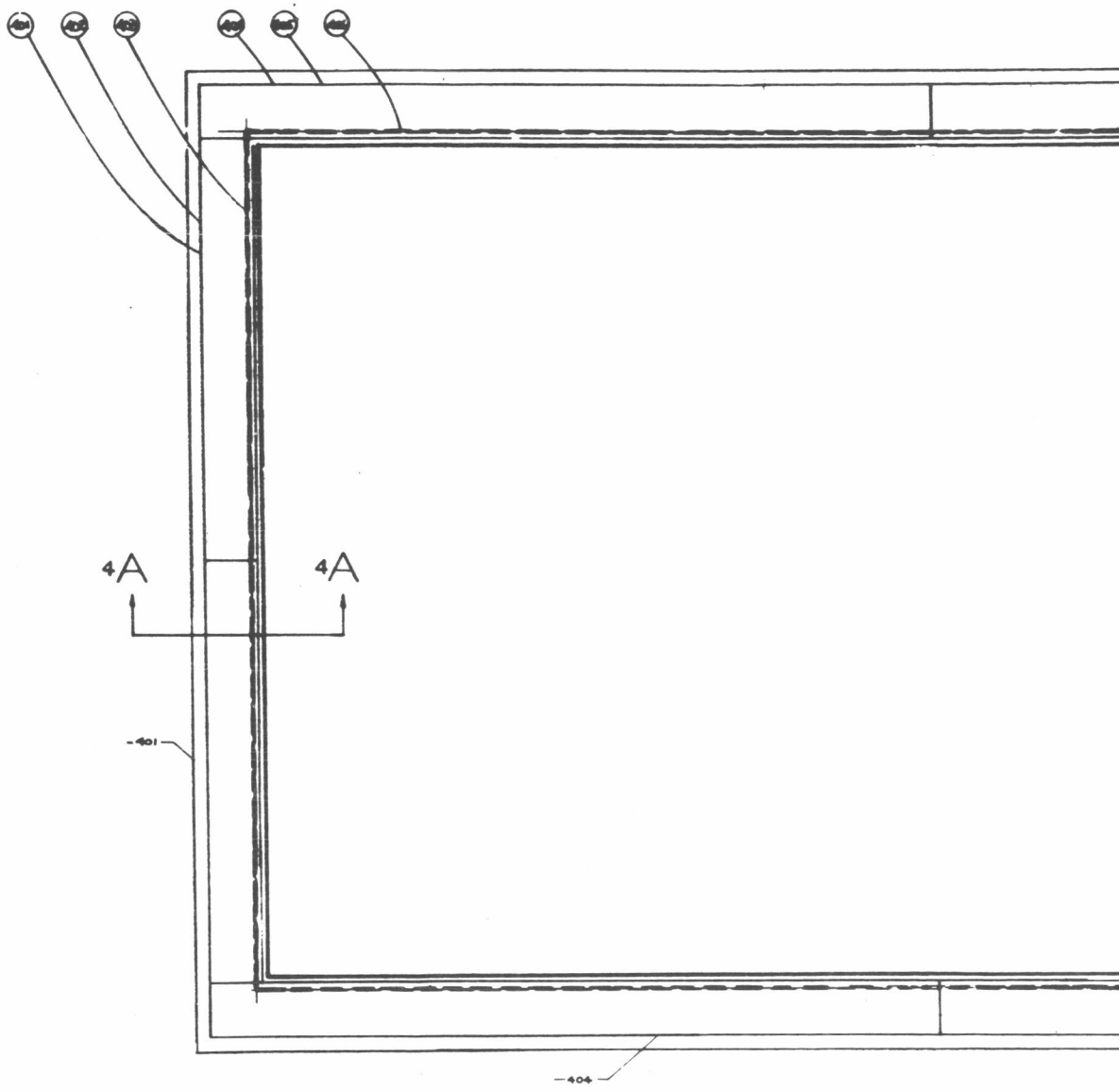

(304) CONNECTOR ASSY.

| | | | | |
|---|---|---|---|---|
| | 313 | 20 | ALIGNING LIP - BASE (CUP) | |
| | 312 | 144 | ELECTRODE - MAIN (CUP) | |
| | 311 | 4 | VALVE | |
| | 310 | 80 | INSULATION | |
| | 309 | 40 | SELECT FORM | |
| | 308 | 2 | SHIELD | |
| | 307 | 40 | LOC STOPPER | |
| 301/304 | 306 | 80/288 | TERMINAL | |
| 304 | 305 | 144 | CONNECTOR | |
| | 304 | 144 | CONNECTOR ASSY | |
| 301 | 303 | 40 | CONNECTOR | |
| 301 | 302 | 40 | TERMINAL | |
| | 301 | 40 | CONNECTOR ASSY | |

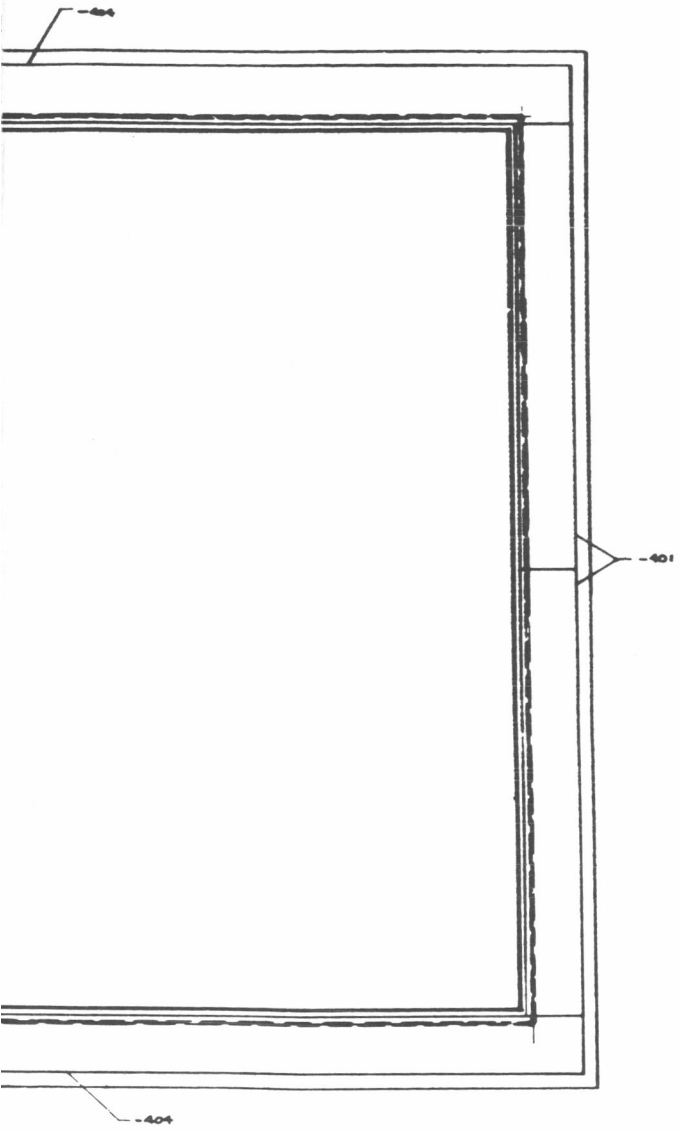
| | | | |
|---|---|---|---|
| SCALE FULL | | | |
| | | | |
| | | | |
|




4A–4A




PLAN VIEW
1/8 SIZE




SHT 4 SHOWS CLAMPING BEVEL & DIAPHRAM ONLY

▽ SHOP FINISH - 6" THROAT

▽ EXPENDABLE ITEM

▽ SAW CUT OR SHEAR EDGES. NO FINISH REQ'D - BREAK SHARP EDGES

CONTOUR TO FIT FLANGE ON STEEL STRUCTURE

| | | | |
|---|---|---|---|
| 408 | 1 | DIAPHRAM | |
| 407 | 1 | SEAL | SILICONE RUBBER |
| 406 | 4 | DEPRESSOR | AL WIRE |
| 405 | 4 | CLAMP BAR | AL6061-T651 |
| 404 | 4 | CLAMP BAR ASSY | |
| 403 | 4 | DEPRESSOR | AL WIRE |
| 402 | 4 | CLAMP BAR | AL6061-T651 |
| 401 | 4 | CLAMP BAR ASSY | |

NOTES

TOOL NUMBER

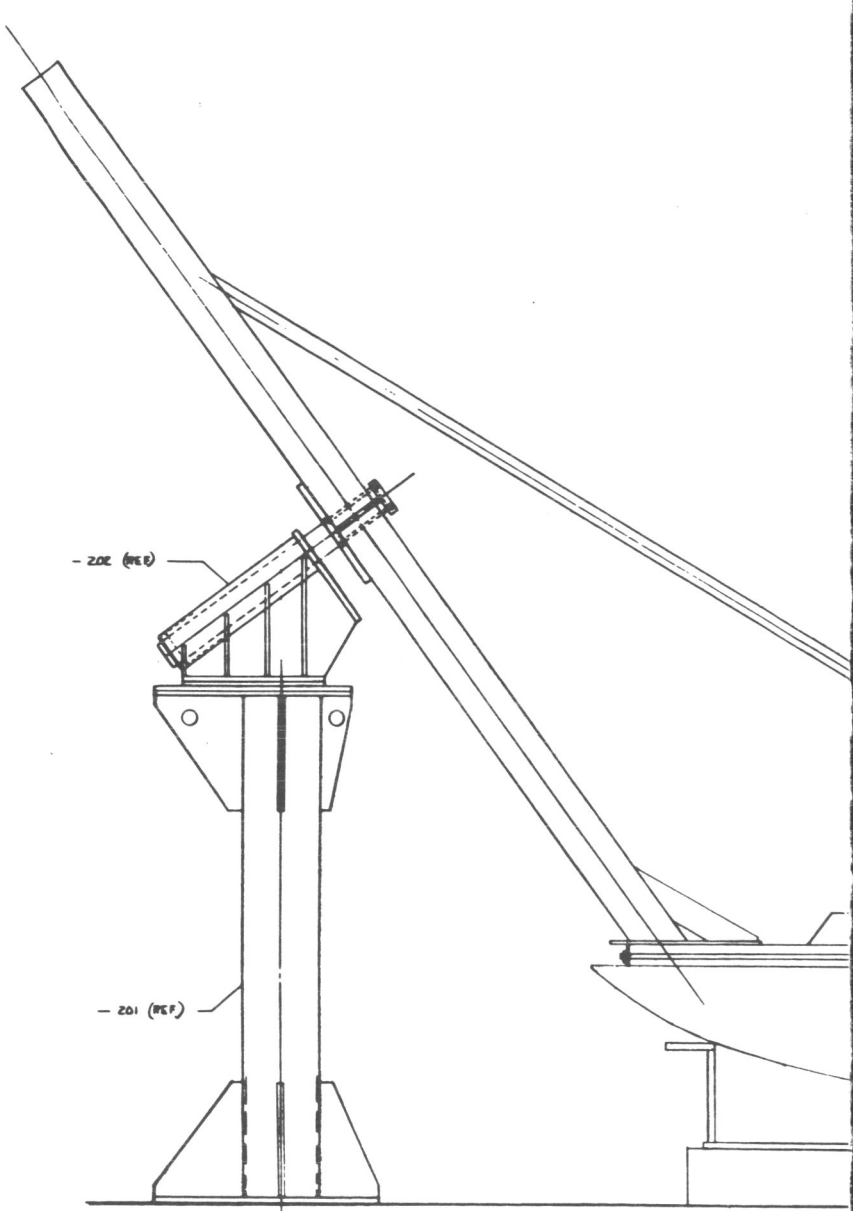
VACUUM FORM DIE

TITANIUM GORE

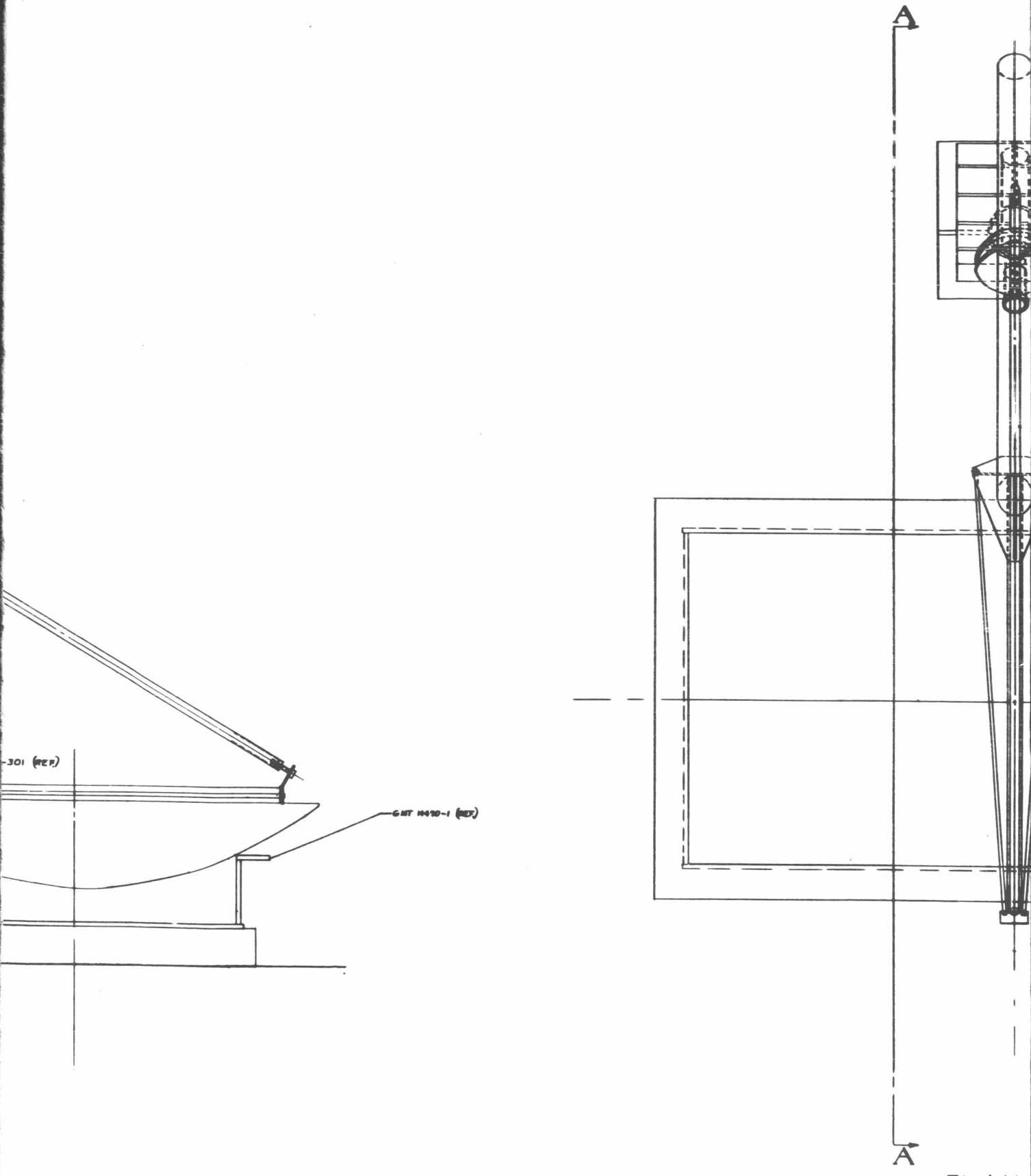
GMT14490 — 4

GMT 14490 —

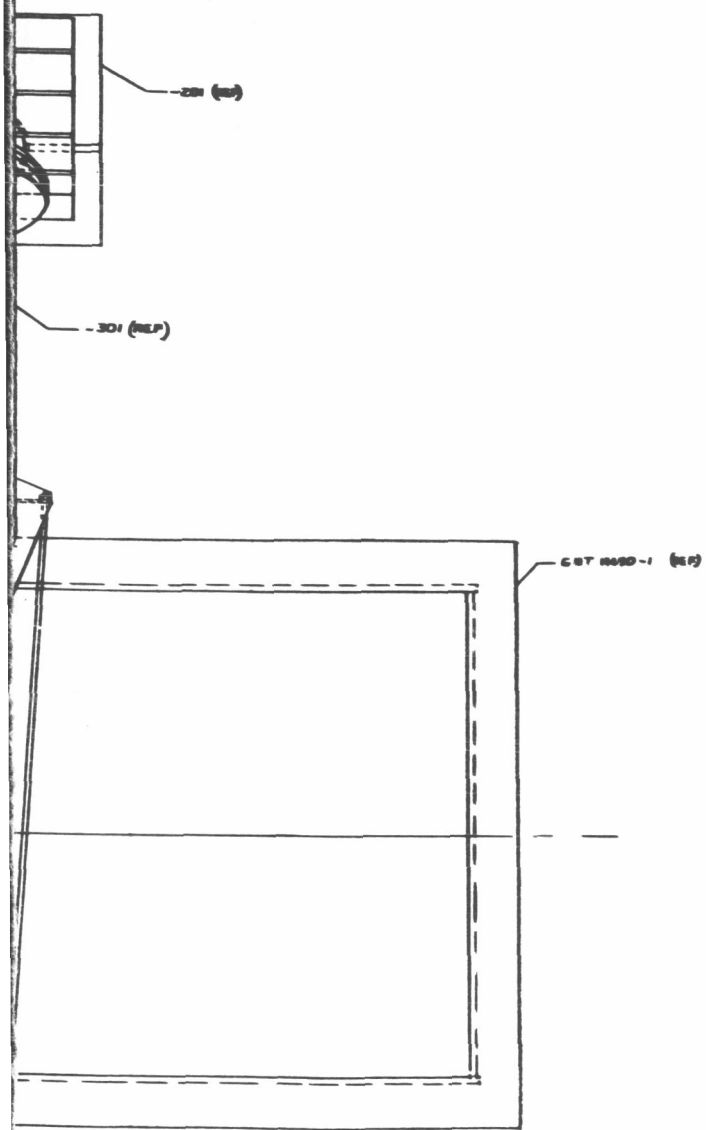
(2)




A–A


A
A
-301 (REF)
GMT 11430-1 (REF)
PLAN
5
4
3

SHT 1 SHOWS TYP SCREEDING TOOL AND DIE SETUP




INSTRUCTIONS FOR DIE CONSTRUCTION BY USE OF SCREEDING TOOL:

1. LOCATE PRODUCTION PART FLAT PATTERN IN DIE CAVITY MAINTAIN EQUAL DISTANCE OF FLAT PATTERN CORNERS FROM STEEL STRUCTURE.
2. LOCATE CORNERS OF FLAT PATTERN 1½ TO 2⅛ INCHES FROM TOP OF DIE AND SET SCREED TOOL TO THESE POINTS. SEE NOTE ON SHT 2 OF EMIT 12 R 17260 FOR ADJUSTMENT INSTRUCTIONS.
3. SET BLOCKS AS SHOWN ON SHT 2 OF 6MT 14490. SAW BLOCKS, LEAVING ACCESS SO THEY CAN BE ROUTED AS SHOWN ON SHT 4 OF EMIT 12 R 17260.
4. SET SCREED BLADES AS SHOWN ON SHT 4 OF EMIT 12 R 17260 AND SCREED IN FIRST COAT OF BUBACK CEMENT.
5. BEND TUBES AND CEMENT IN PLACE PER SHT 4 OF 6MT 14490.
6. SET SCREED BLADES AND SCREED IN ROUGH DIE FACE.
7. RESET BLADES AND SCREED IN FINAL DIE FACE.
8. WIRE AND PLUMB PER SHT 4 OF 6MT 14490.
9. PAIR IN TROUGH CAP ETC. PER SHT 2 OF 6MT 14490.
10. REMOVE SCREED BLADES AND INSTALL -403 REV OF EMIT 12 R 17260 FOR INSPECTION USE.

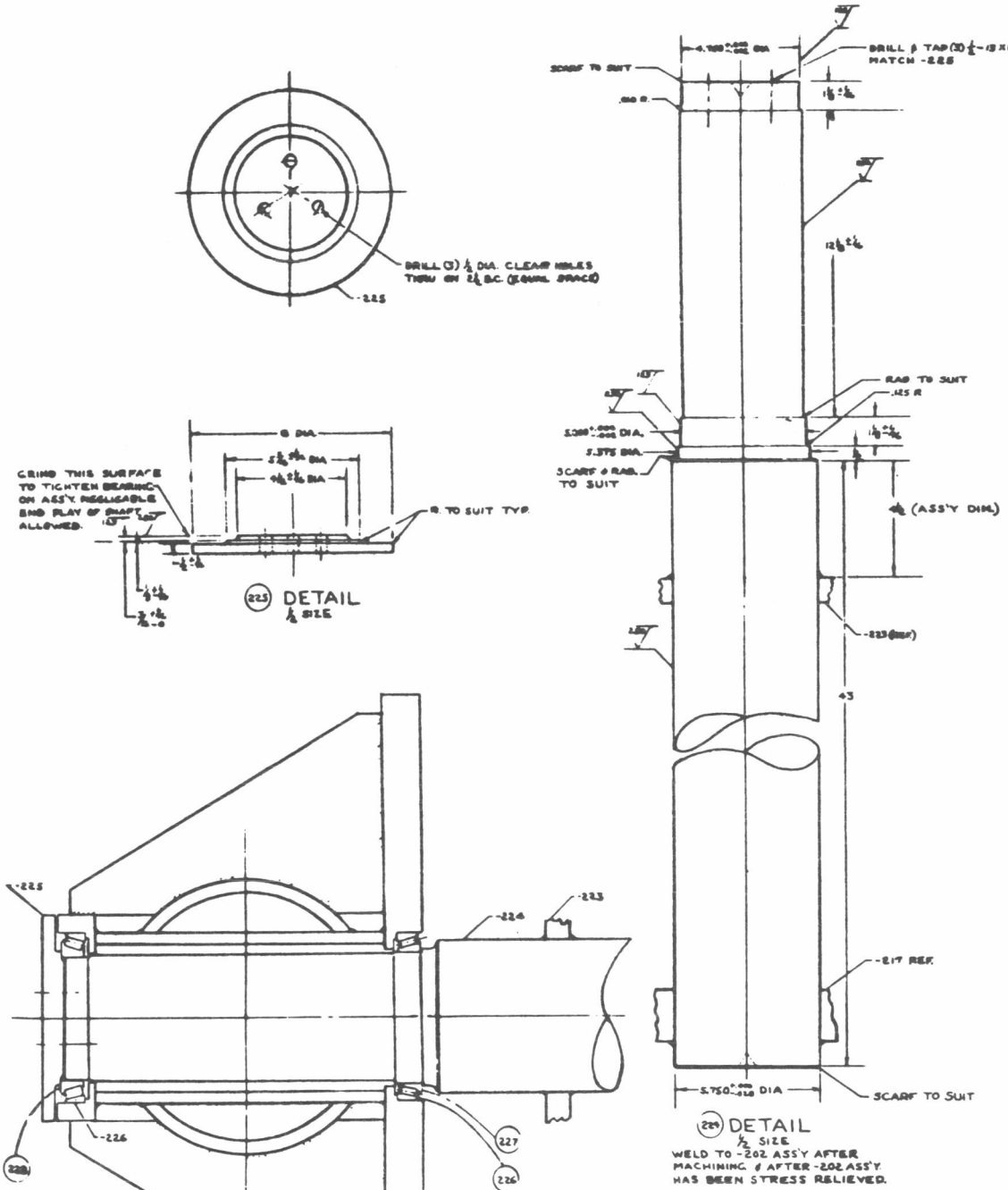
VIEW

(2)

EMIT 12 R 17260

SCREED
TITANIUM GORE

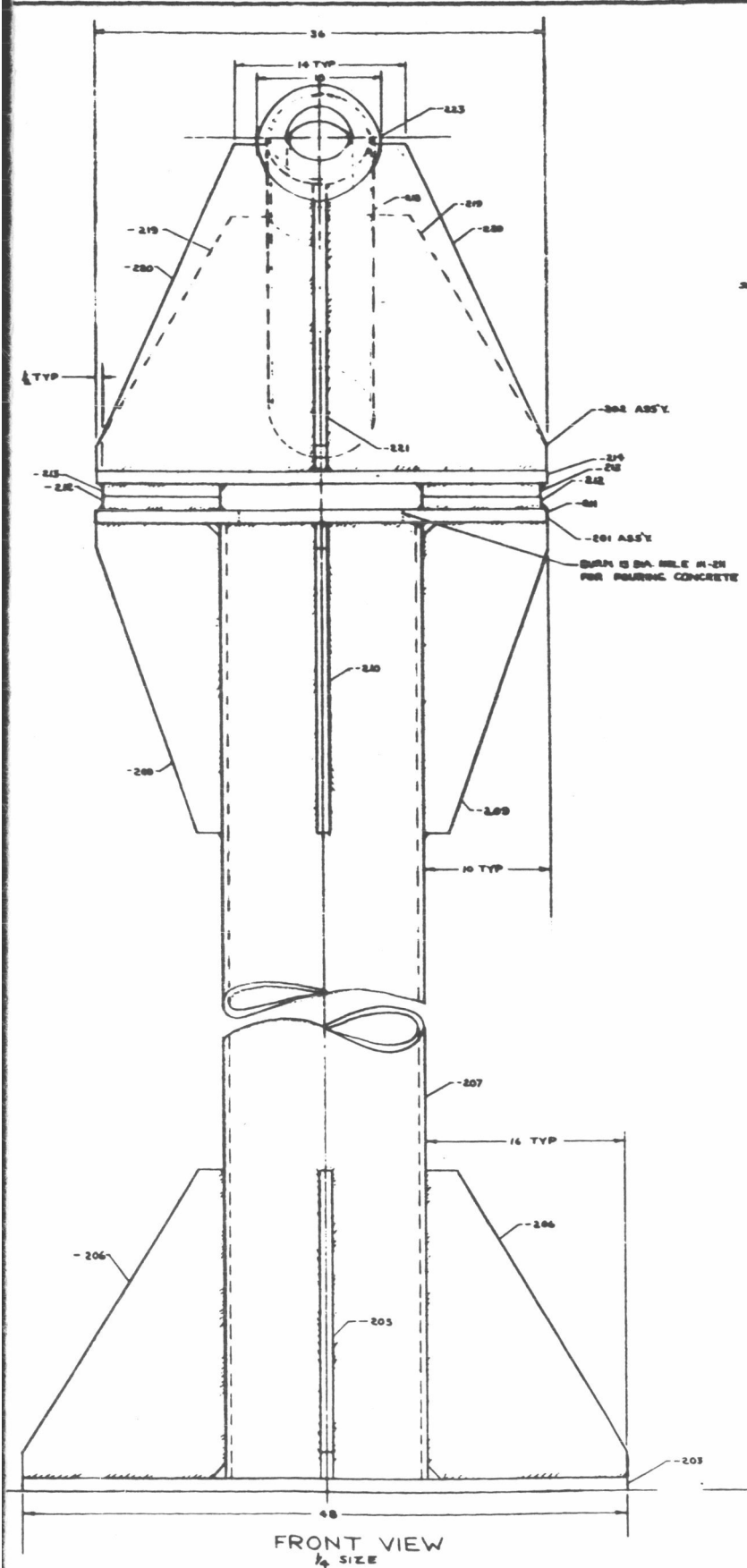
EMIT 12 R 17260 sht 1 of 4



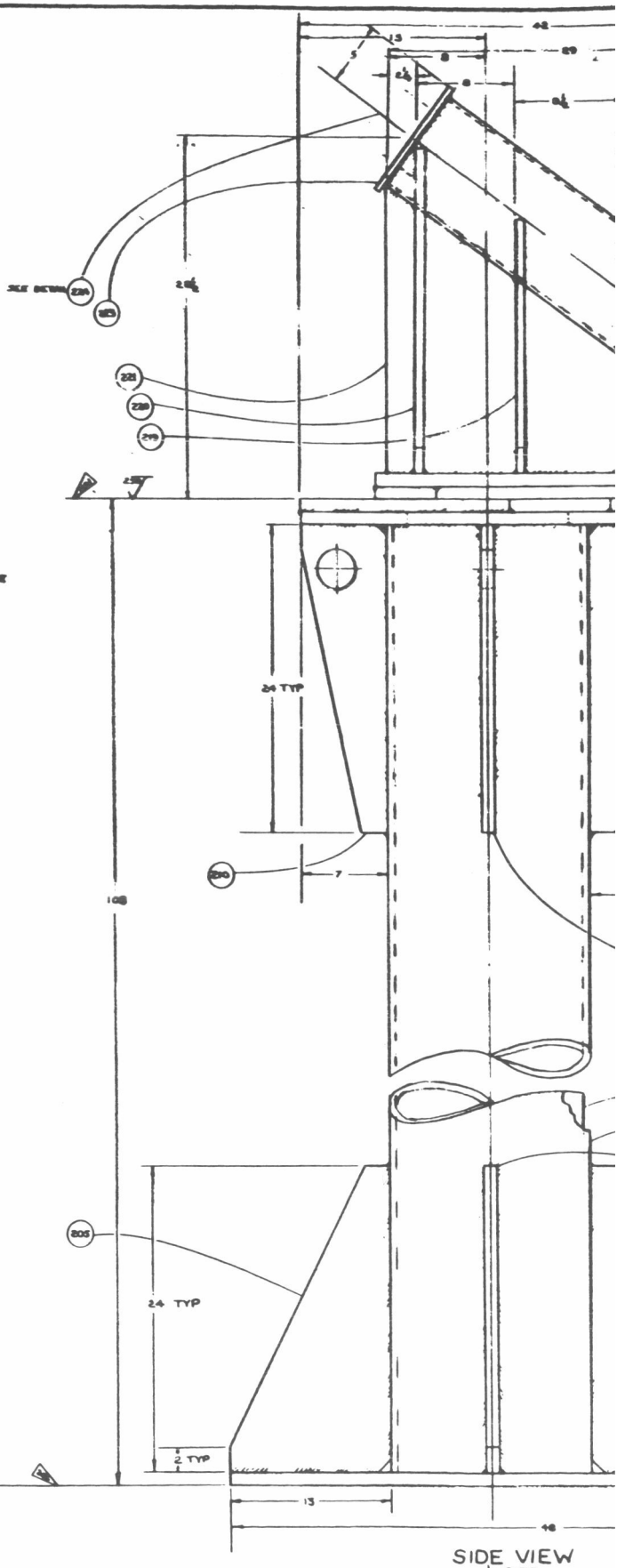

(225) DETAIL
½ SIZE

(224) DETAIL
½ SIZE
WELD TO -202 ASS'Y AFTER MACHINING & AFTER -202 ASS'Y HAS BEEN STRESS RELIEVED.

ASS'Y. DETAILS
½ SIZE



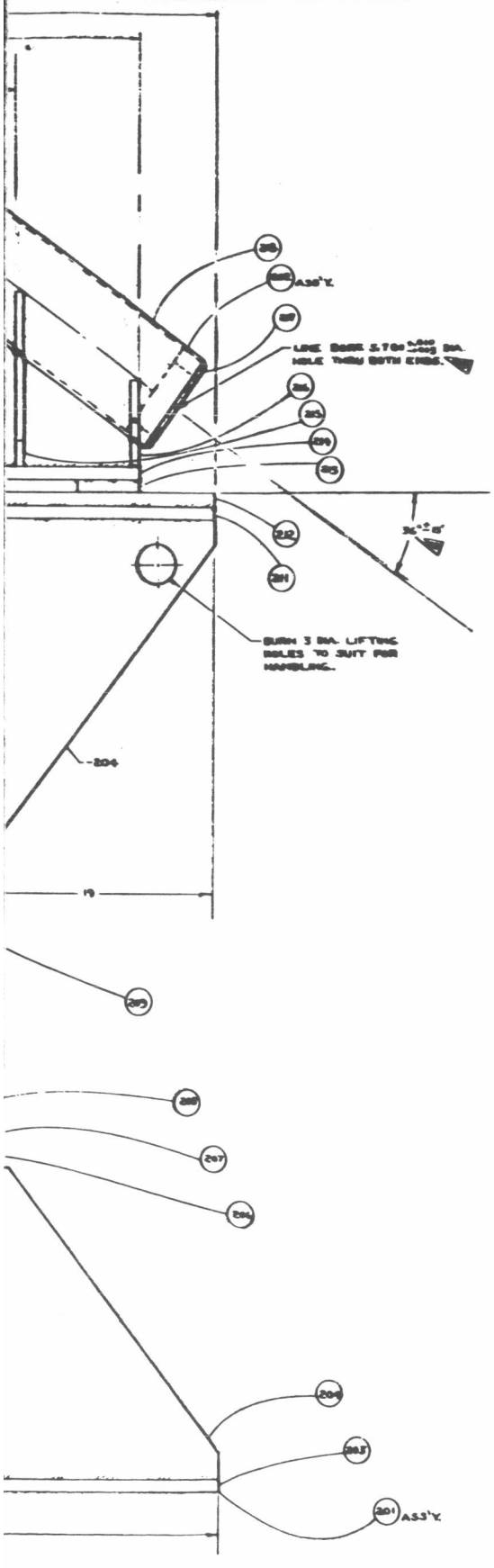

FRONT VIEW
¼ SIZE




SIDE VIEW
¼ SIZE

5 4 3

1-74B




SHT. 2 SHOWS STANCHION & HOLDER FOR SCREED ASS'Y. & ASS'Y. OF HOLDER & SCREED ASS'Y.

SHIM & MOVE -202 ASS'Y AS REQ'D. ALONG THIS LINE TO ALIGNE SCREED IN THE DIE CAVITY. THE PROPER HEIGHT WILL BE WHEN THE FLAT PROD. PART IS $1\frac{52}{64}$ INCH BELOW THE TOP OF DIE. THE PROPER VERTICAL LOCATION IS OBTAINED WHEN ALL FOUR CORNERS OF THE FLAT PROD PART ARE EQUAL DISTANCE FROM THE STEEL DIE WALL. BOLT OR WELD -202 ASS'Y. TO -201 ASS'Y. AFTER ALIGNING TO PREVENT ANY SLIPPAGE OR TILTING.

GROUT & LAG TO FLOOR SO TOP OF -201 ASS'Y IS LEVEL.

MAINT TOOLING BALLS TO SUIT FOR SETTING UP & INSPECTING ALIGNMENT.

STRESS RELIEVE WELDED STRUCTURE PRIOR TO MACHINING.

SCALE DWG. FOR NON-CRIT DIMS NOT GIVEN.

| | | | | | |
|---|---|---|---|---|---|
| | 228 | 1 | CUP | 7 | TIMKEN #L225842 |
| | 227 | 1 | CUP | 7 | TIMKEN #L225849 |
| | 226 | 2 | CONE | 7 | TIMKEN #L225810 |
| | 225 | 1 | BEARING HOLDER | 7 | HRS 8 DIA. X 1 |
| 202 | 224 | 1 | SHAFT | 4 | HRS RD 6 X 38 -01-0237-0066 |
| 202 | 223 | 1 | FACE PLT | 4 | HRS 1 X 10 X 10 |
| 202 | 221 | 1 | SUPPORT PLT | 4 | HRS 1 X 22½ X 28½ |
| 202 | 220 | 2 | GUSSET | 4 | HRS ⅜ X 17½ X 23½ |
| 202 | 219 | 2 | GUSSET | 4 | HRS ⅜ X 17½ X 20 |
| 202 | 218 | 1 | SPACER | 2 | STD BLK STL PIPE SCH 40 8 X 36 |
| 202 | 217 | 1 | PLUG | 2 | HRS 2 X 8 DIA. |
| 202 | 216 | 2 | GUSSET | 2 | HRS ⅜ X 13½ X 17½ |
| 202 | 215 | 2 | GUSSET | 2 | HRS ⅜ X 6½ X 17½ |
| 202 | 214 | 1 | BASE PLT | 2 | HRS 1 X 30 X 36 |
| 202 | 213 | 4 | MACHINE PAD | 2 | HRS 1 X 5 X 9½ |
| 201 | 212 | 4 | MACHINE PAD | 3 | HRS 1 X 9½ X 17 |
| 201 | 211 | 1 | TOP PLATE | 3 | HRS 1 X 32 X 46 |
| 201 | 210 | 1 | GUSSET | 4 | HRS ⅜ X 7 X 24 |
| 201 | 209 | 2 | GUSSET | 3 | HRS ⅜ X 10 X 24 |
| 201 | 208 | 1 | STABILIZER | 3 | CONCRETE 1/3 CU YD |
| 201 | 207 | 1 | STANCHION | 3 | 16" PIPE X 108 |
| 201 | 206 | 2 | GUSSET | 3 | HRS ⅜ X 16 X 24 |
| 201 | 205 | 1 | GUSSET | 4 | HRS ⅜ X 13 X 24 |
| 201 | 204 | 2 | GUSSET | 3 | HRS ⅜ X 19 X 24 |
| 201 | 203 | 1 | BASE PLT | 2 | HRS 1 X 48 X 48 |
| | 202 | 1 | HOLDING ASS'Y | 2 | |
| | 201 | 1 | STANCHION ASS'Y | 2 | |

NOTED

TEST

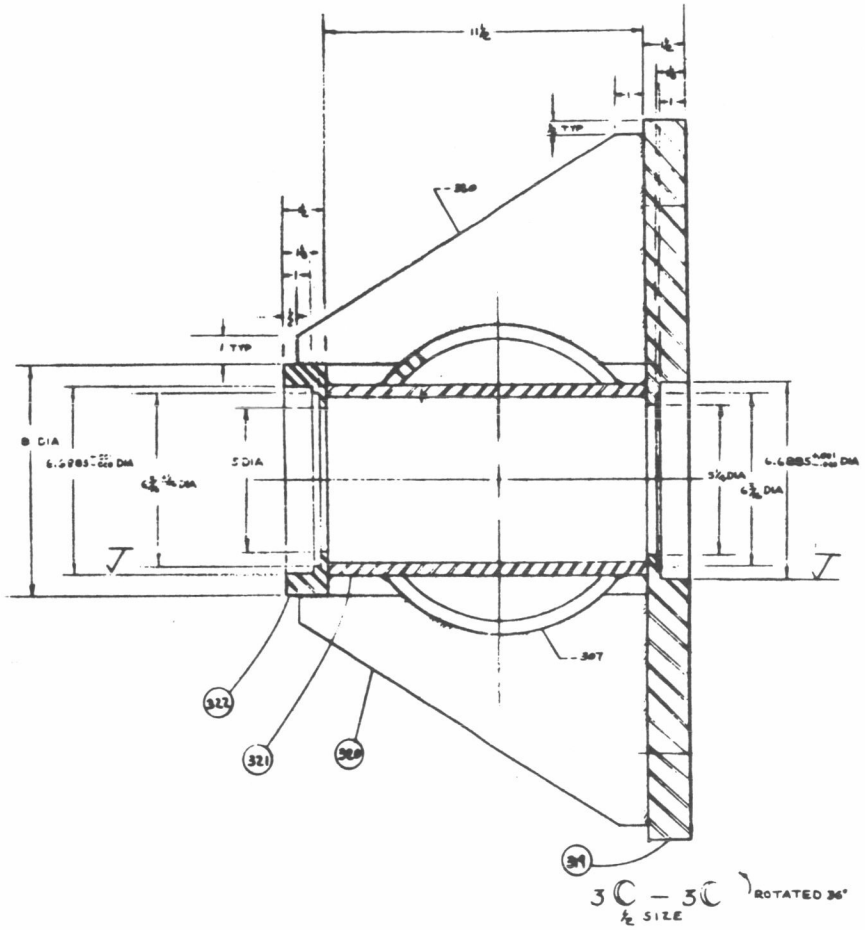
SCREED
TITANIUM GORE

EMIT 12 R 17260

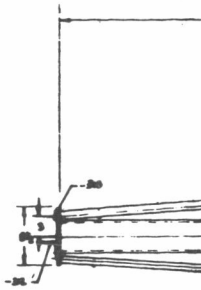
LIMIT 12 R 17260 — 2

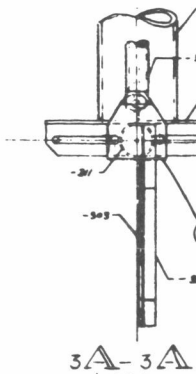
(2)

STANCHION ASS'Y

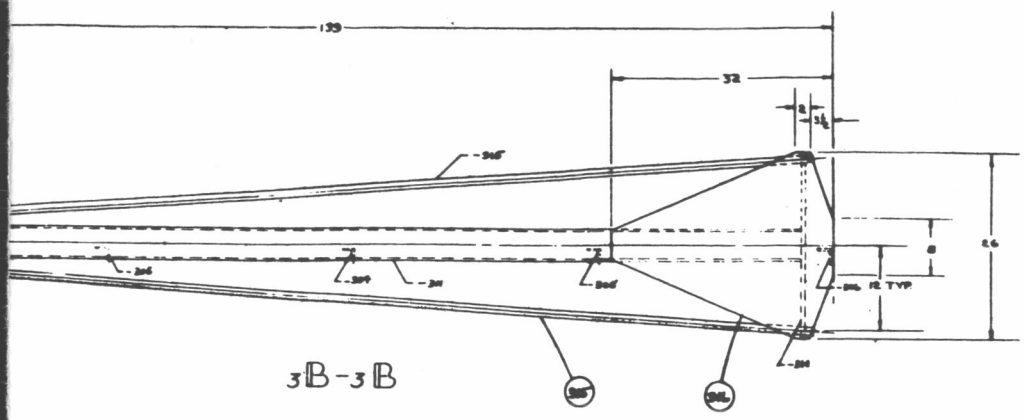


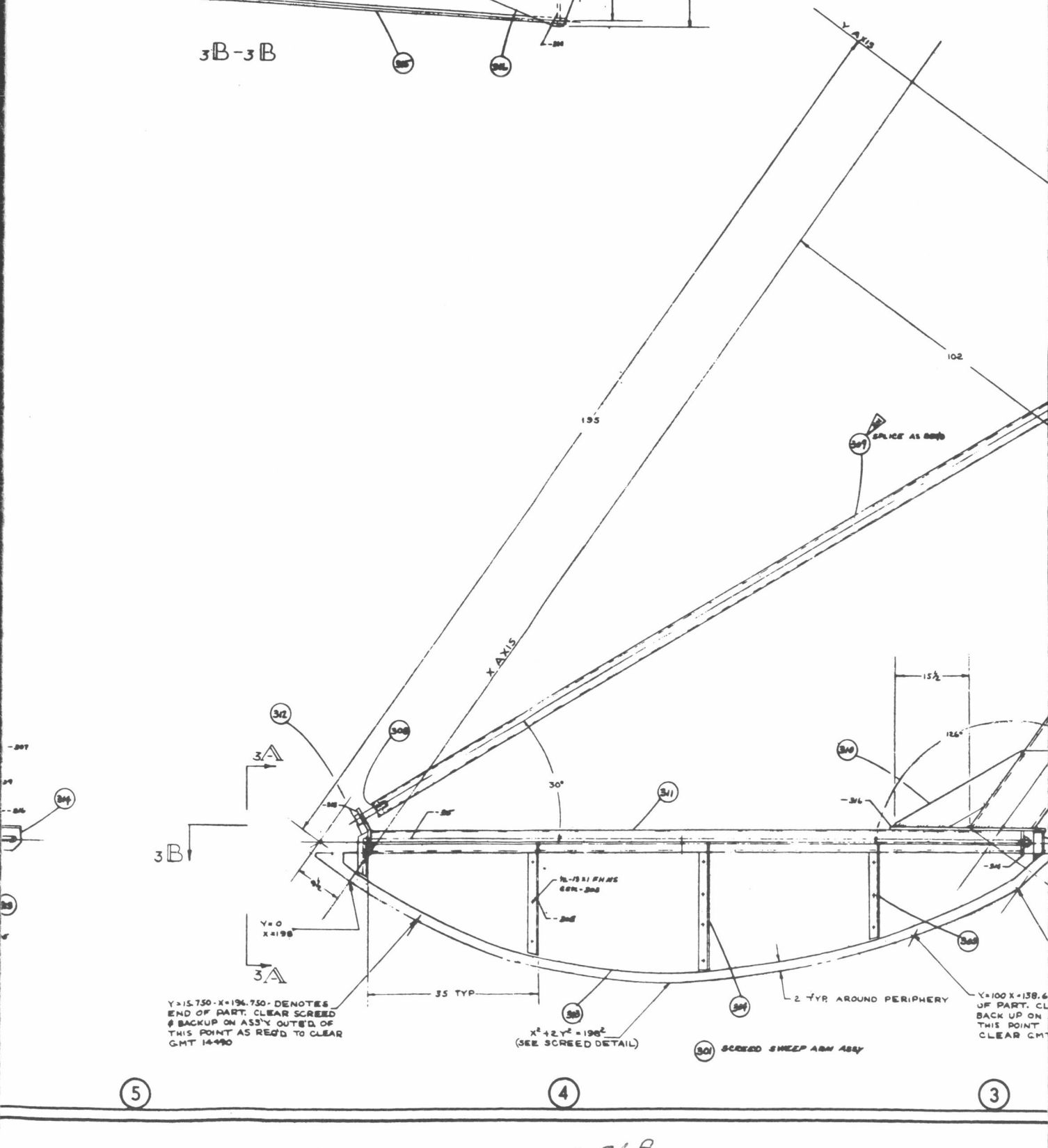

3C – 3C ROTATED 36°
½ SIZE





3A – 3A
½ SIZE

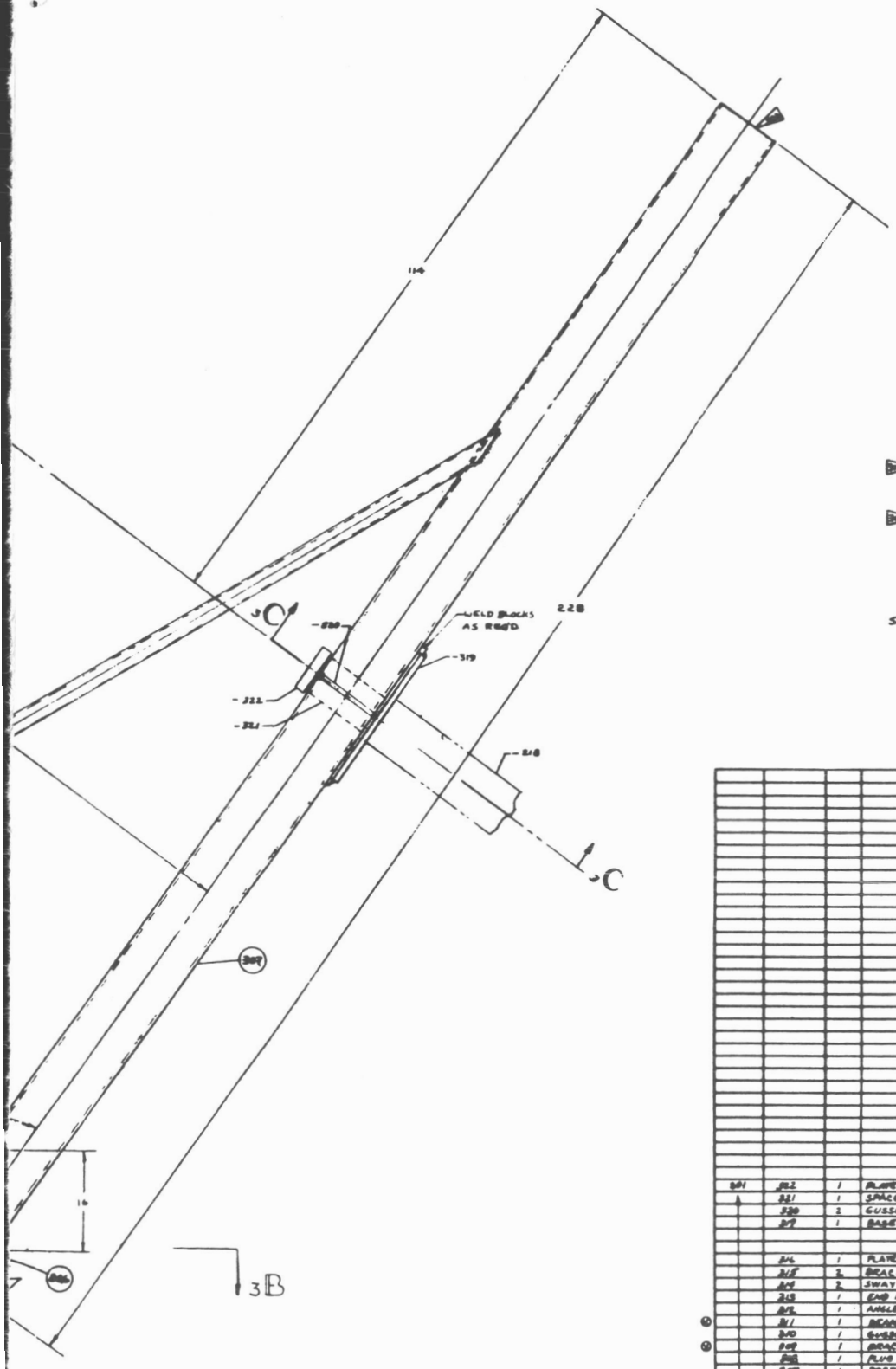

139
32
3B-3B


Y AXIS
102
135
X AXIS
SPLICE AS REQ'D
3A
3B
30°
15½
12.6"
35 TYP
2 TYP AROUND PERIPHERY
Y=15.750 - X=196.750 - DENOTES END OF PART. CLEAR SCREED & BACKUP ON ASS'Y OUTB'D OF THIS POINT AS REQ'D TO CLEAR GMT 14490
Y=0 X=198
X²+2.Y²=198²
(SEE SCREED DETAIL)
SCREED SWEEP ASM ASSY
Y=100 X=138.6
OF PART. CL
BACK UP ON
THIS POINT
CLEAR GMT

5 4 3

1-76B

SHT. 3 SHOWS SWEEP ARM & SCREED HOLDER ONLY




CounterBalance As Req'd

Fill with plastic foam per Bac 5934 Class X in Lieu of Subbase Fabrication Type X except Drip Boarding

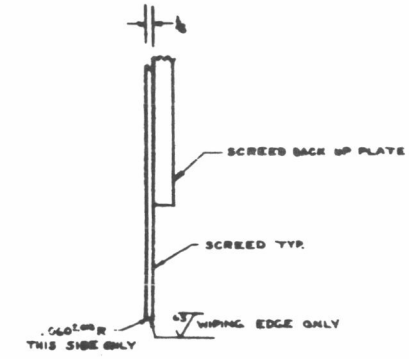
See Sht 1 for General Notes

| | | | | |
|---|---|---|---|---|
| 321 | 322 | 1 | PLATE | MS 1/2 x 8 x 8 |
| | 321 | 1 | SPACER | BLK PIPE 6" SCH 80 x 11" |
| | 320 | 2 | GUSSET | MS 3/8 x 8 x 12 1/2 |
| | 317 | 1 | BASE | MS 1/2 x 8 x 8 x 8 |
| | 314 | 1 | PLATE | MS 1/2 x 24 x 32 |
| | 315 | 2 | BRACE | MS 1/4 x 12 |
| | 314 | 2 | SWAY BRACE | MS 3/8 x 5 x 11 |
| | 313 | 1 | END PLATE | MS 1/4 x 8 x 10 |
| | 312 | 1 | ANGLE | MS 2 x 2 x 1/8 x 10 |
| | 311 | 1 | BEAM | STR TUBING 6 x 6 x 080 x W 12# |
| | 310 | 1 | GUSSET | MS PLT 1/2 x 6 x 20 |
| | 309 | 1 | BRACE | STR TUBING 3 OD x .065 WALL x 26 |
| | 308 | 1 | PLUG | MS 1A 3 3/8 |
| | 307 | 1 | POST | BLK PIPE 10" SCH 40 x 22 5 |
| | 306 | 1 | ANGLE | MS 2 1/2 x 1/8 x 3 |
| | 305 | 2 | ANGLE | MS 2 1/2 x 1/8 x 20 |
| | 304 | 1 | ANGLE | MS 2 1/2 x 1/8 x 2 5 |
| 301 | 303 | 1 | SCREED BACKUP | AL 6061-T651 7 1/2 x 2 1/2 x 144 |
| | 301 | | SCREED SWEEP ARM ASSY | |

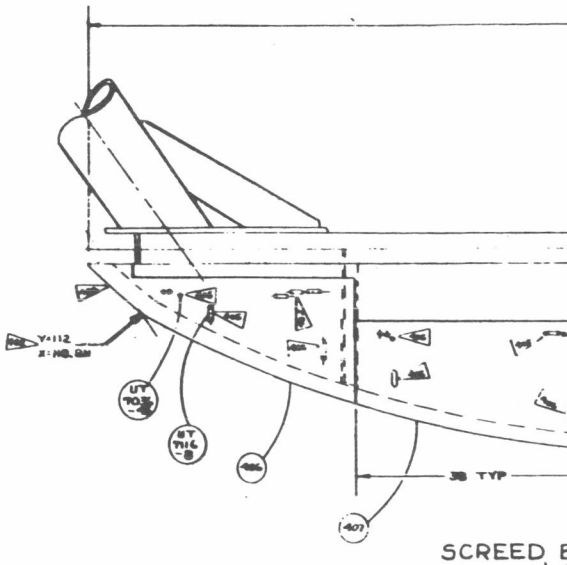
EMIT 12 R 17260

| | | | |
|---|---|---|---|
| SIZE B | | | 21 |
| | | TOOL DRAWING | |
| | | THE BOEING COMPANY | |
| | | AERO-SPACE DIVISION | |
| | | SCREED TITANIUM GORE | |
| | | EMIT 12 R 17260 | 3 |

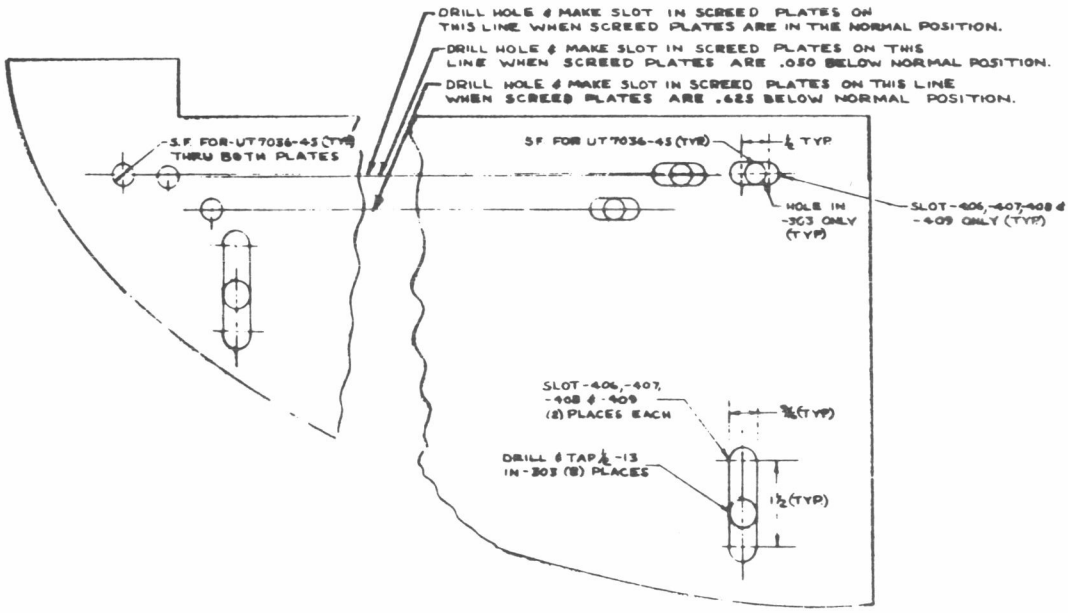
(2)




-B-B
FULL SIZE
SHOWS TYP. SCREED EDGE ONLY.

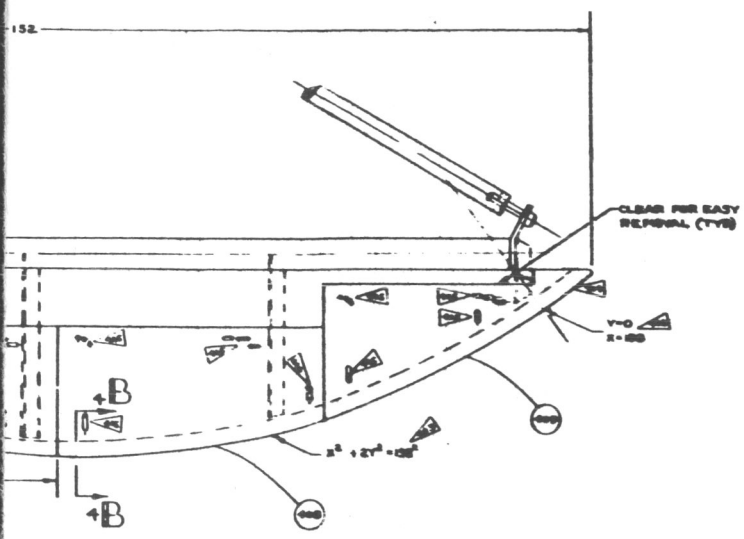



SCREED E

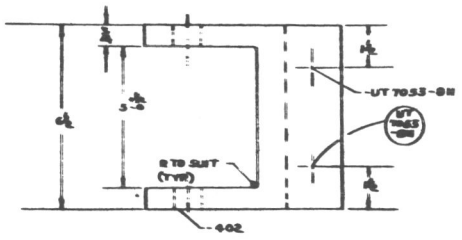


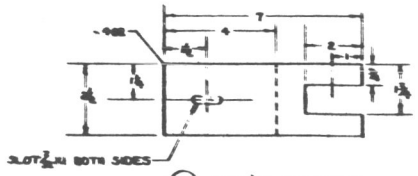

SCREED BLADE HOLE LOCATIONS
FULL SIZE
TYP ALL SCREED BLADES

Y=112
X=11



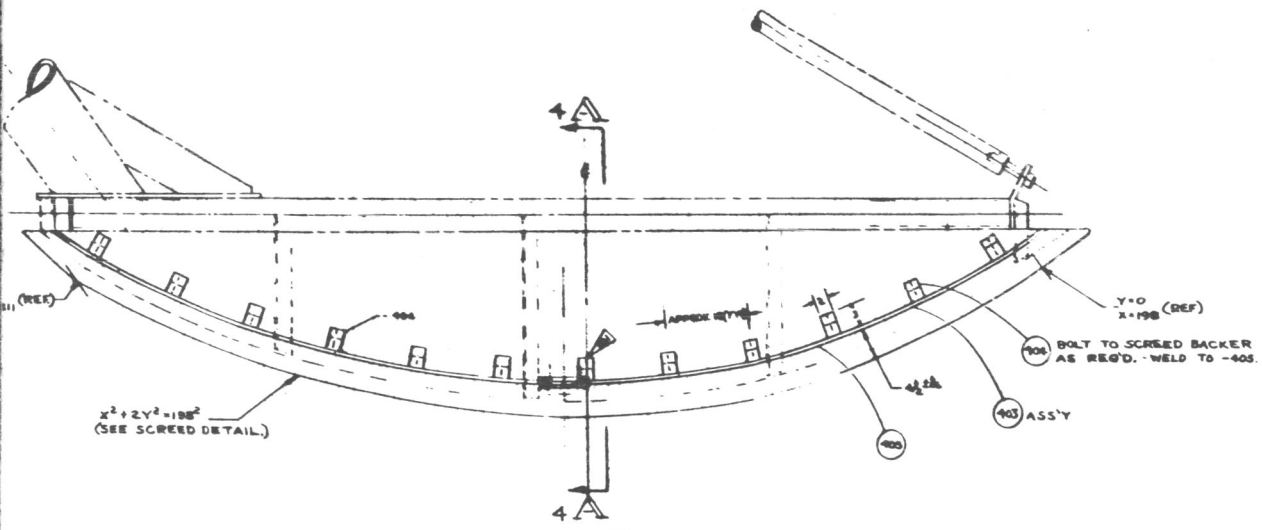

BLADE DETAILS
SIZE




(901) ASS'Y DETAIL
SIZE

ROUTER SFC 19215 (REF.)
FURNISHED BY SHOP 2-383




SIDE VIEW
SIZE



178B

SHT. 4 SHOWS ROUTER ATTACHMENT

(1) SET ROUTER 30 BIT IS 1 INCH BELOW FINAL FACE CONFIGURATION. ROUTE GLASS BLOCKS TO 1 INCH ± 1/64 BELOW FINAL FACE CONFIGURATION. REMOVE ROUTER # -401 # -403 ASS'Y FROM TOOL.

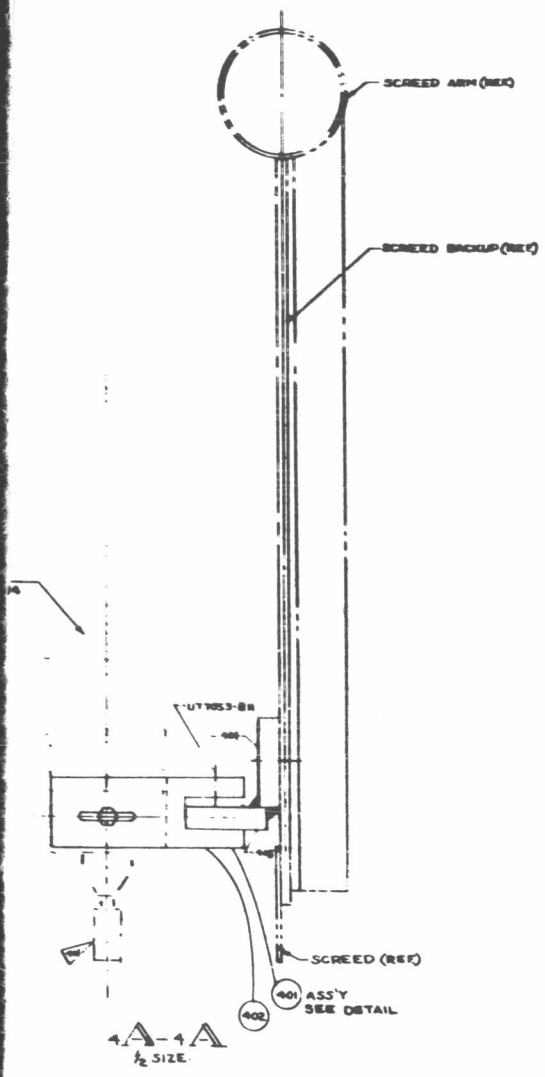
(2) THESE ARE NOMINAL DIMS. & SCREED BLADES MUST BE SET PER THESE DIMS.

(3) THIS IS THE NOMINAL CONTOUR # IS TO BE MACHINED USING NUMERICAL CONTROL # ON THE SAME SET UP. OPTIONAL TO MACHINE IN ONE PIECE # SAW INTO SECTIONS.

(4) FAIR THESE SURFACES TO SUIT.

(5) THESE HOLES # SLOTS TO BE LOCATED APPROX. AS SHOWN. LOCATION IN THE DETAIL IS NOT CRITICAL BUT LOCATION IN RELATION TO EACH OTHER IS CRITICAL. SEE DETAIL IN ZONE 7 FOR RELATIVE LOCATIONS.

SCALE DWG. FOR NON CRIT DIMS. NOT GIVEN.




| | | | | | |
|---|---|---|---|---|---|
| 401 | UT7053 | 8 | KEENSERT INSERT | 3 | -8 H |
| | UT7036 | 8 | LOCATING PIN | 6 | -45 |
| | UT7116 | 8 | THUMB SCREW | 6 | -8 |
| | 409 | 1 | SCREED BLADE | 5 | SS .06 X .81 X 38 |
| | 408 | 1 | SCREED BLADE | 5 | SS .08 X .81 X 38 |
| | 407 | 1 | SCREED BLADE | 6 | SS .08 X 1.81 X 38 |
| | 406 | 1 | SCREED BLADE | 6 | SS .08 X 2.0 X 38 |
| 403 | 405 | 1 | RAIL | 4 | AL6061-T651 ¼ X 3 X 144 |
| 403 | 404 | 12 | ATTACH BARS | 4 | AL6061-T651 ¼ X .81 X 3 |
| | 403 | 1 | RAIL ASS'Y | 4 | |
| 401 | 402 | 1 | CLAMP BAR | 2 | AL6061-T651 2½ X 6½ X 9 |
| | 401 | 1 | ROUTER CLAMP ASS'Y | 2 | |

NOTED

NONE

MAT'L 7A7T

SHT 21

AERO ARMS

SCREED
TITANIUM GORE

EMIT12R17260 — 4

S-72963-401
17260D

EMIT12R17260 — 4

(2)