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# FABRICATION OF A BERYLLIUM TEST PANEL


By G. H. Jones and C. M. Wood


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# FABRICATION OF A BERYLLIUM TEST PANEL

## ABSTRACT

This report describes the fabrication of a Beryllium Test Panel made in support of projected programs which will use beryllium for major structural applications. Manufacturing techniques involved were machining, forming, etching, and assembly. By using proper tooling and by exercising close controls over each operation, the panel was fabricated to the required configuration and tolerances.

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# FABRICATION OF A BERYLLIUM TEST PANEL

## SUMMARY

An in-house effort was established to fabricate a Beryllium Test Panel in support of projected programs which will use beryllium in major structural applications. Design of the panel reflected manufacturing complexities commensurable with the requirements of future programs.

Precision forming of beryllium to 6T bend radii was accomplished with precision tools at 1350°F with negligible spring-back. Uniform and close temperature controls were required and the formed parts were slowly cooled in the dies to room temperature.

Rigid support of the workpieces during machining with good back-up was required for all machining operations. Textolite which is very rigid and produces dust rather than chips when machined proved to be an excellent back-up material.

Precision formed parts of 0.025 and 0.050-inch thick beryllium were assembled with mechanical fasteners into a structural panel.

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# FABRICATION OF A BERYLLIUM TEST PANEL

## SECTION I. INTRODUCTION

A joint effort was established between the Manufacturing Engineering and Propulsion and Vehicle Engineering Laboratories to develop a beryllium hardware test specimen in support of projected programs which will use beryllium in major structural applications. A test panel was designed by R-P&VE-SAF to reflect a degree of manufacturing complexity commensurate with future aerospace requirements. The Manufacturing Engineering Laboratory fabricated the Test Panel which required beryllium operations in the following areas:

a. Hot Forming

b. Machining

c. Etching

d. Assembly

Cross-rolled 0.025 and 0.050-inch thick beryllium sheet with 70,000 psi minimum tensile strength and 50,000 psi minimum yield strength, purchased in December, 1964, was used for the program. Hot forming was accomplished in a large brake press with special inserts in the box beam titanium hot forming dies which were heated to 1350°F. Flattening of the beryllium face sheets was achieved between heavy 303 stainless steel plates in conventional electric furnaces at 1350°F.

Beryllium machining capability is not currently available in the Manufacturing Engineering Laboratory so this phase of the work was performed in the R-ASTR-PS facility. All final assembly work was completed in the Manufacturing Engineering Laboratory.

## SECTION II. OPERATIONS

### A. TOOLING

1. General. Precision tooling is essential to the fabrication of beryllium sheet structures. Hot forming of this material requires that the precision tooling be capable of maintaining a uniform temperature at the die face and be resistant to oxidation. Integrally heated ceramic dies which have practically no thermal expansion, distortion, or oxidation have been used for similar forming applications on the Beryllium Box Beam (Reference 1).

Steel dies were selected for the box beam application because the titanium hot forming dies, AT-17-A-X-101, with heating platens and electrical controls were available. Type 303 stainless steel inserts for use with these tools were fabricated to produce the required configurations.

Forming was accomplished with the dies installed in a 12-foot brake press (Figures 1 and 2). Many problems were encountered:

a. Forming temperature of 1350°F was the maximum available temperature of the heating platens and could be obtained only after 5 to 7 hours of continuous heating (Figure 3).

b. Temperature variation in the flattening dies was 150°F and approximately 40°F in the "hat" section dies.

c. Excessive warpage of the platens and dies was evident.

d. Electrical failures were caused by arcing between the wires leading to the heating elements.

e. Insulated heat shields had to be fabricated for the sides and ends of the dies in order to reach the 1350°F forming temperature.

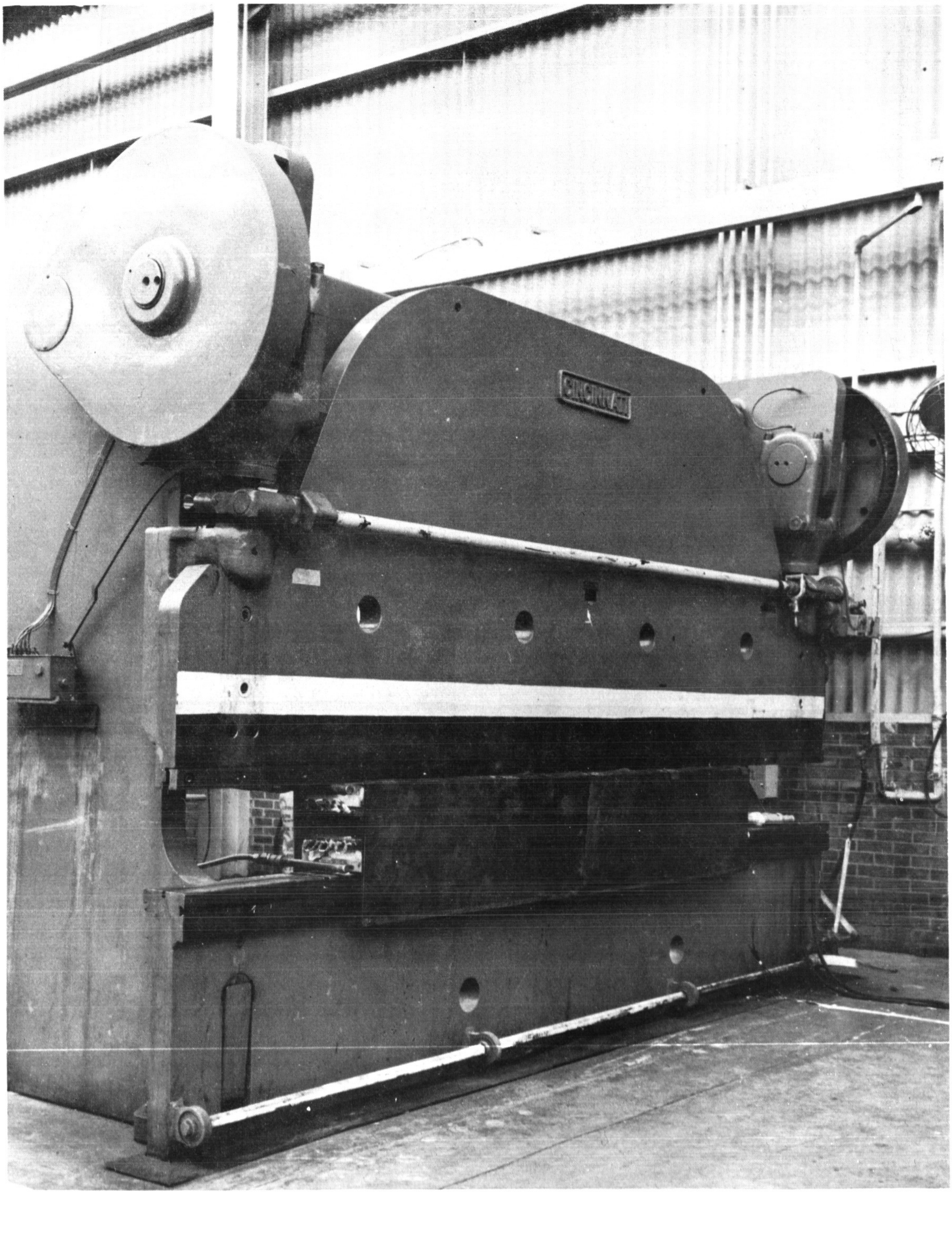


FIGURE 1. 12-FOOT BRAKE PRESS WITH HEATING PLATENS

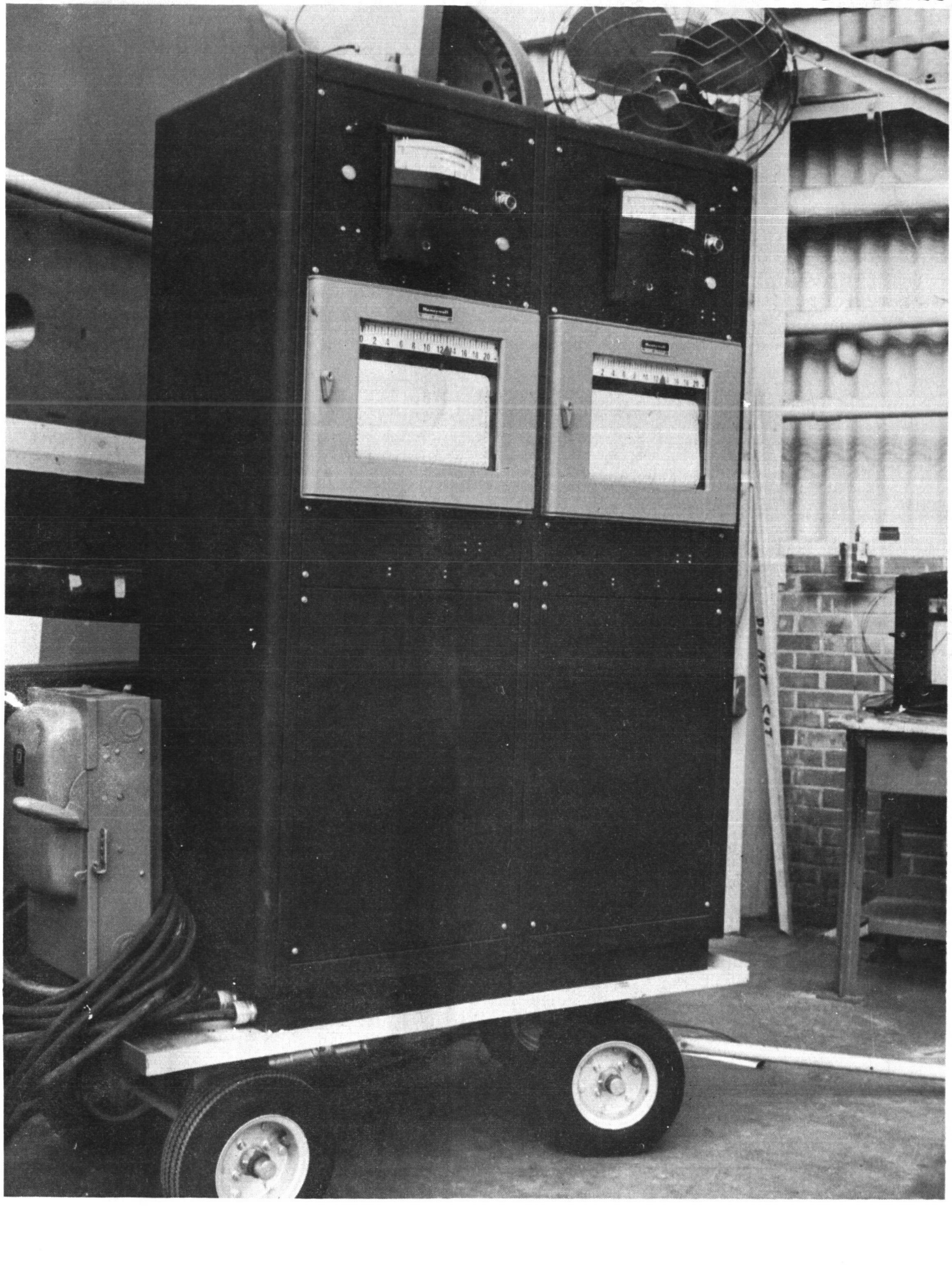

FIGURE 2. ELECTRICAL CONTROLS FOR HEATING ELEMENTS IN 12-FOOT BRAKE PRESS

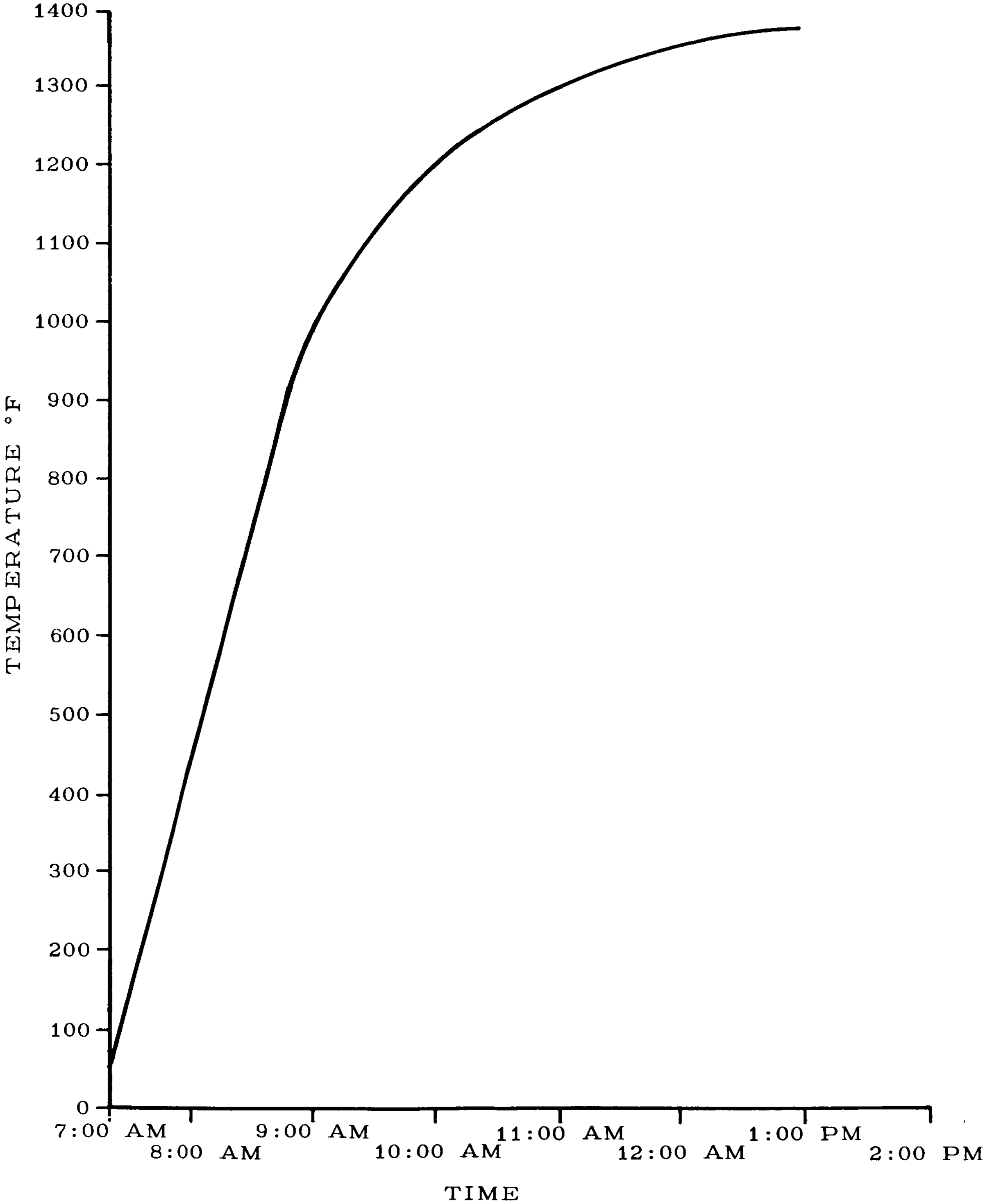


FIGURE 3. HEATING CURVE OF HOT FORMING "HAT" SECTION DIE

2. "Hat" Section. The hot forming "hat" section die as originally designed had approximately 0.0505-inch clearance between the male and female parts. This clearance was considered insufficient for forming 0.050-inch material, so the female die was opened 0.005-inch on both sides. Since parallel sides were required on the finished part, it was decided the die clearance should be held to a minimum. Utilizing 0.050-inch stainless steel blanks, a determination was made that there was adequate clearance for forming. Figures 4 and 5 show forming of the "hat" section and Figures 6 and 7 show the "hat" section after forming.

Boron nitride paste was used as a lubricant (Figure 8). A smooth thin coating was applied on the beryllium blank prior to heating and was removed after forming with emery paper while the part was submerged in water. The lubricant was carefully applied since uneven coating results in impressions in the formed parts.

The following procedure was established for forming the beryllium blanks:

a. Heat the forming dies to 1350°F and allow sufficient soaking time for the temperature to equalize.

b. Lubricate the beryllium blank with a smooth thin coating of boron nitride paste and place against the hot die to heat.

c. Place the beryllium blank on the locating pins after it has expanded sufficiently (10 to 15 minutes) for the slotted holes in the blank to slide over the pins.

d. Soak the blank 15 to 20 minutes.

e. Form the blank in approximately one minute using the adjustment feature of the brake press.

f. Soak 15 minutes after forming.

g. Cool the formed part to room temperature in the die to prevent warpage.

A total of eight blanks were formed. Four were satisfactory in all respects; two had cracks around the locating hole

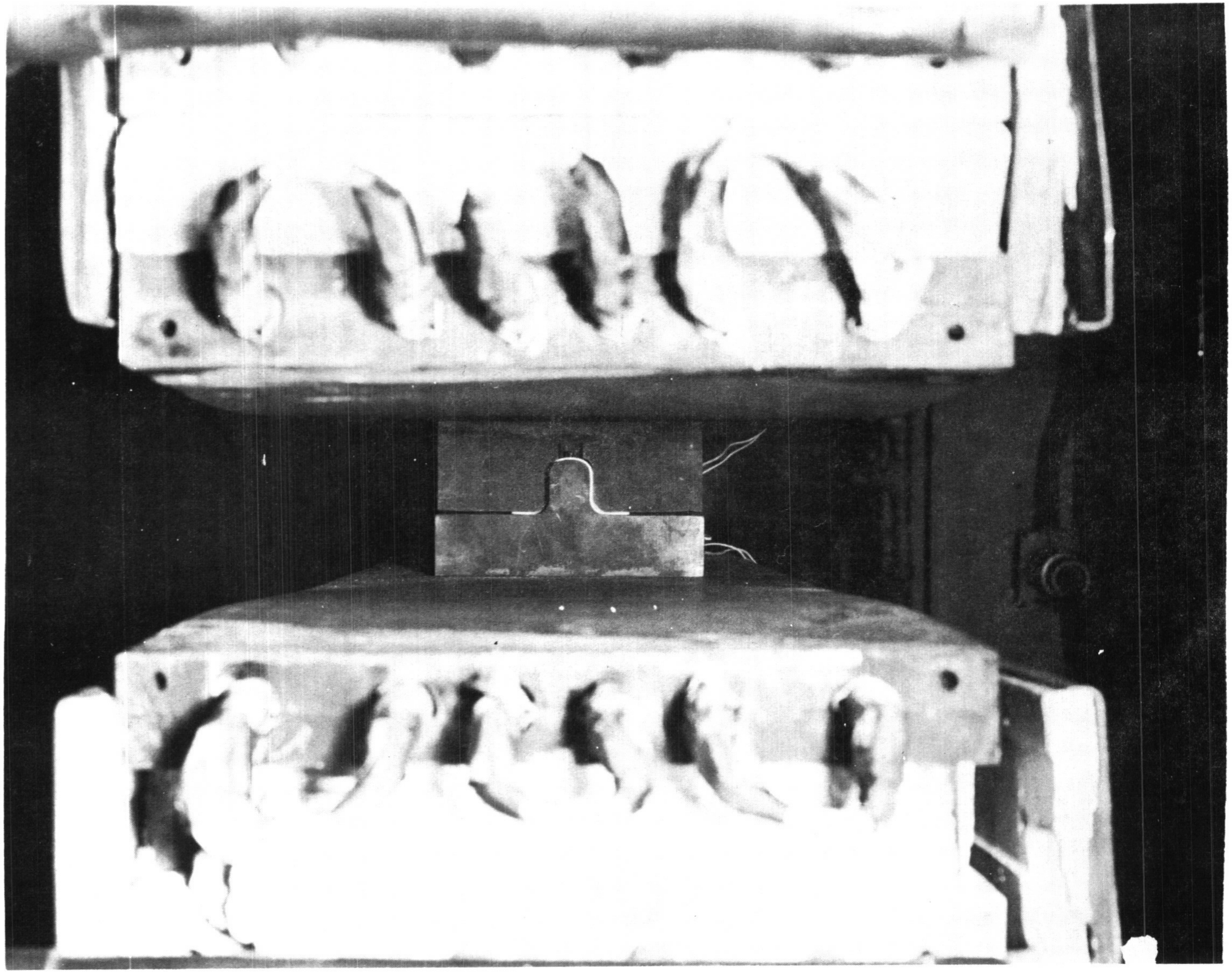

FIGURE 4. FORMING OF THE "HAT" SECTION - END VIEW

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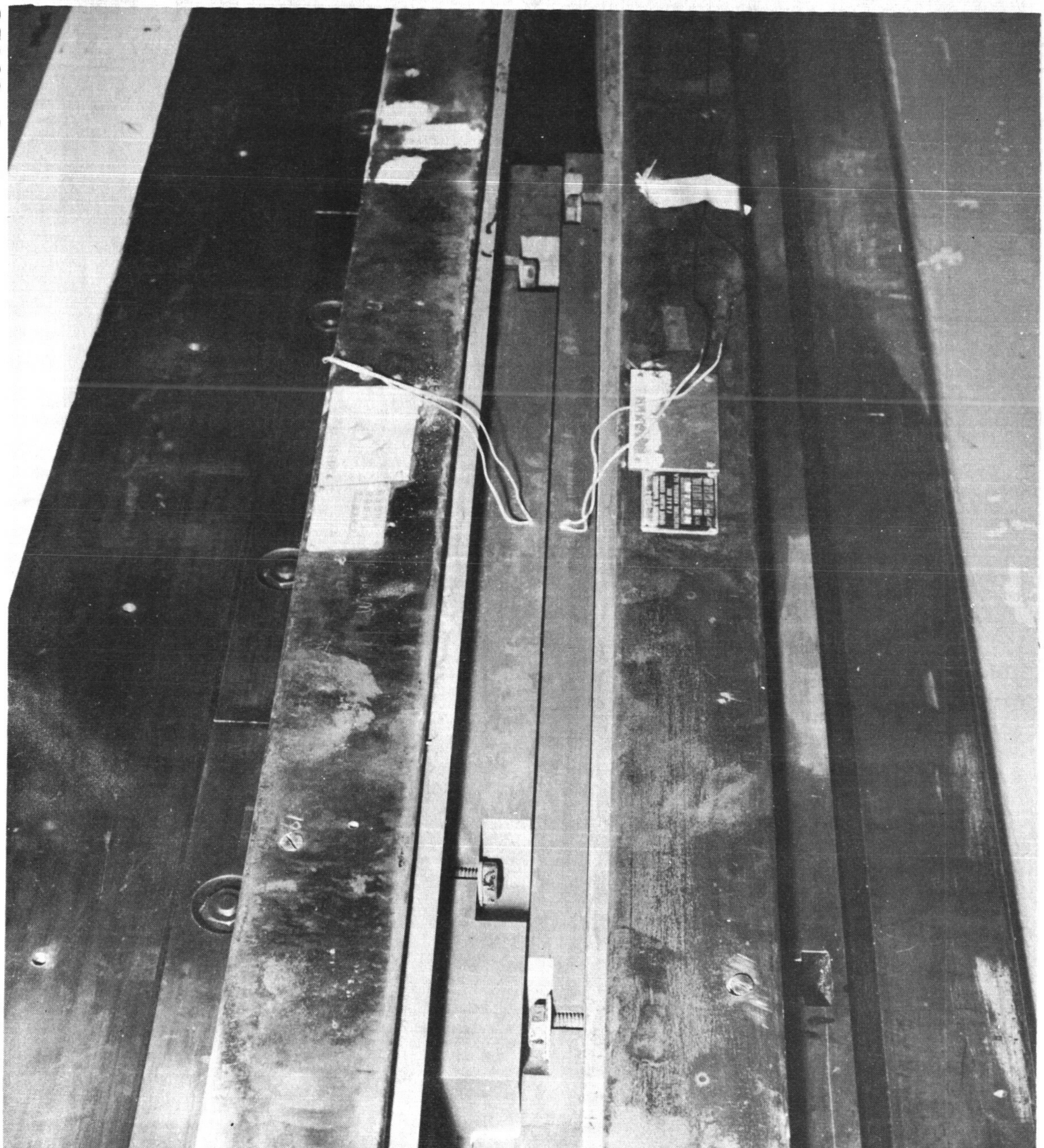

FIGURE 5. FORMING OF THE "HAT" SECTION - SIDE VIEW

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FIGURE 6. FORMED "HAT" SECTION - END VIEW

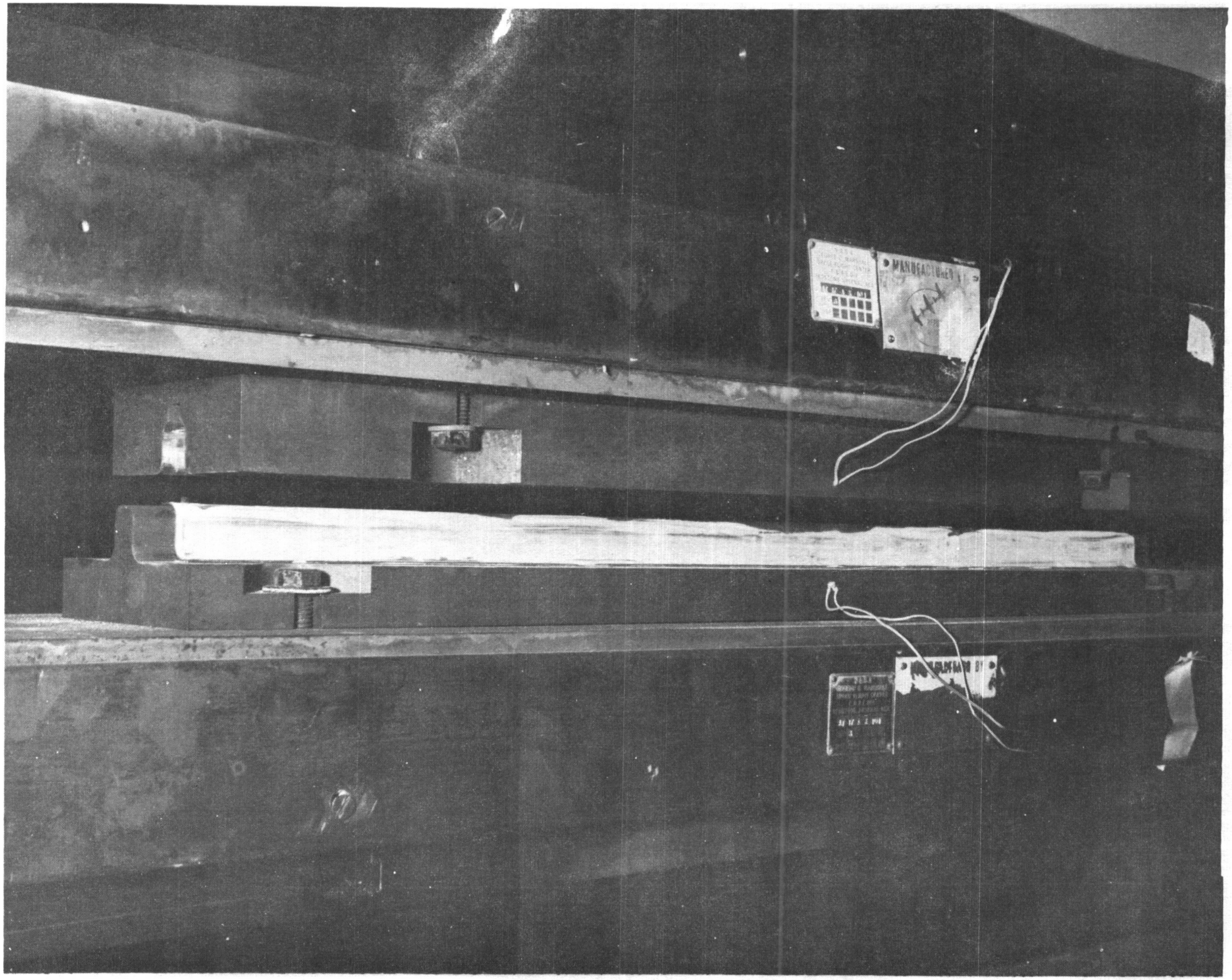

FIGURE 7. FORMED "HAT" SECTION - SIDE VIEW

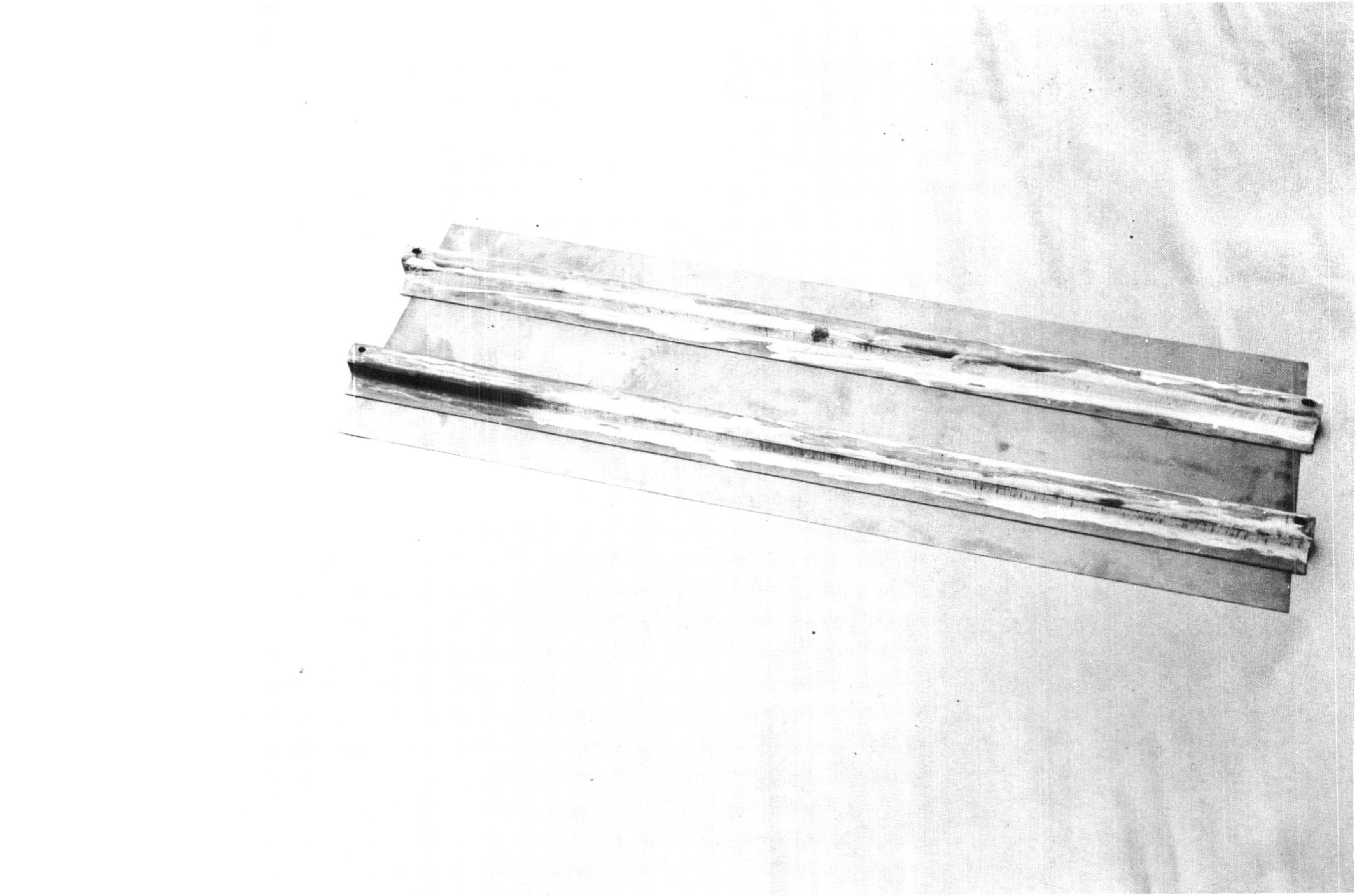

FIGURE 8. FORMED "HAT" SECTION WITH BORON NITRIDE LUBRICANT

at one end; and two had large scattered cracks. No difficulty was experienced in meeting the 6T bend radii. The results of the forming are summarized in Table I.

| TABLE I. FORMING RESULTS | | | |
|---|---|---|---|
| Blank No. | Lubricant | Clearance Between Dies in Inches | Results |
| 1 | Boron Nitride Paste | 0.056 | Satisfactory<br>Light Scratching |
| 2 | Boron Nitride Paste | 0.056 | Cracks at one end around locating hole |
| 3 | Boron Nitride Paste | 0.056 | Large Cracks |
| 4 | Molybdenum Disulfide with 0.0015-inch scuff sheets | 0.061 | Large Cracks Caused by Scuff Sheet Tearing |
| 5 | Boron Nitride Paste | 0.061 | Very Light Scratching |
| 6 | Boron Nitride Paste | 0.061 | Satisfactory<br>Very Light Scratching |
| 7 | Boron Nitride Paste | 0.061 | Satisfactory<br>Very Light Scratching |
| 8 | Boron Nitride Paste | 0.061 | Cracks at one end around locating hole<br>Very Light Scratching |

3. Flattening. Beryllium sheet received from the manufacturer was not flat enough for the close tolerance requirements of the panel. A flattening operation was required and dies were made for the heated platens on the brake press. Three attempts were made to flatten the 0.025-inch face sheets but all were unsuccessful because of the wide variation in temperature (150°F) within the dies. The 1 3/4-inch by 13-inch by 60-inch 303 stainless steel plate dies were removed and used successfully to flatten the beryllium sheets in an electric furnace.

The following procedure for flattening was established:

a. Heat the dies to 1350°F in the furnace.

b. Insert the beryllium sheet between the hot dies.

c. Soak 10 minutes, then lower the top die.

d. Soak 30 minutes at 1350°F.

e. Furnace cool to room temperature between the two dies.

The resulting blanks, 0.025-inch by 12-inch by 37.180-inch, were flat to a surface plate within 0.005 inch at all edges.

## B. MACHINING

All machining was performed in the R-ASTR-PS facility using their equipment and personnel. Dust, chips, etc., were exhausted through a 1 1/2-inch flexible hose with an air velocity of 5000 - 8000 feet per minute. A conventional type Bridgeport vertical milling machine with solid carbide 3/8-inch diameter, 8 flute, spiral beryllium type end mill cutters and solid carbide burr type beryllium drills was used for all machining. Both type cutting tools were obtained from Metal Removal Corporation, Chicago, Illinois.

Data on cutting and drilling was as follows:

Cutting

RPM - 660

Manual Feed - 3/4 to 1 foot per minute

Rough Cut - 0.125 to 0.175 inch removed per cut

Finish Cut - 0.030 to 0.080 inch removed per cut

Drilling

RPM - 660

Feed - 0.0015 inch per revolution

In drilling and machining beryllium sheet the parts must be rigid and should be backed up with a material that produces dust rather than chips during machining. Textolite obtained from General Electric was found to be an ideal back-up material.

Drilling the holes in the final Assembly Drill Jig, ADJ 14512, was satisfactory for the "hat" sections but unsatisfactory for the face sheet because of insufficient back-up. Assembly of parts in the drill jig is shown in Figures 9, 10, 11, and 12. Two face sheets were broken using the drill jig as designed. Successful drilling was accomplished by backing up the entire blank with a textolite sheet ( 1/2 inch by 13 1/2 inches by 36 inches) which was fastened to the drill plate with eight bolts and four dowel pins (Figure 13 and 14).

Two breaks in a "hat" section were caused by aluminum chips lodged between the aluminum channel and the beryllium. It was determined that this could be eliminated by withdrawing the drill and removing all aluminum chips as soon as the drill came in contact with the beryllium.

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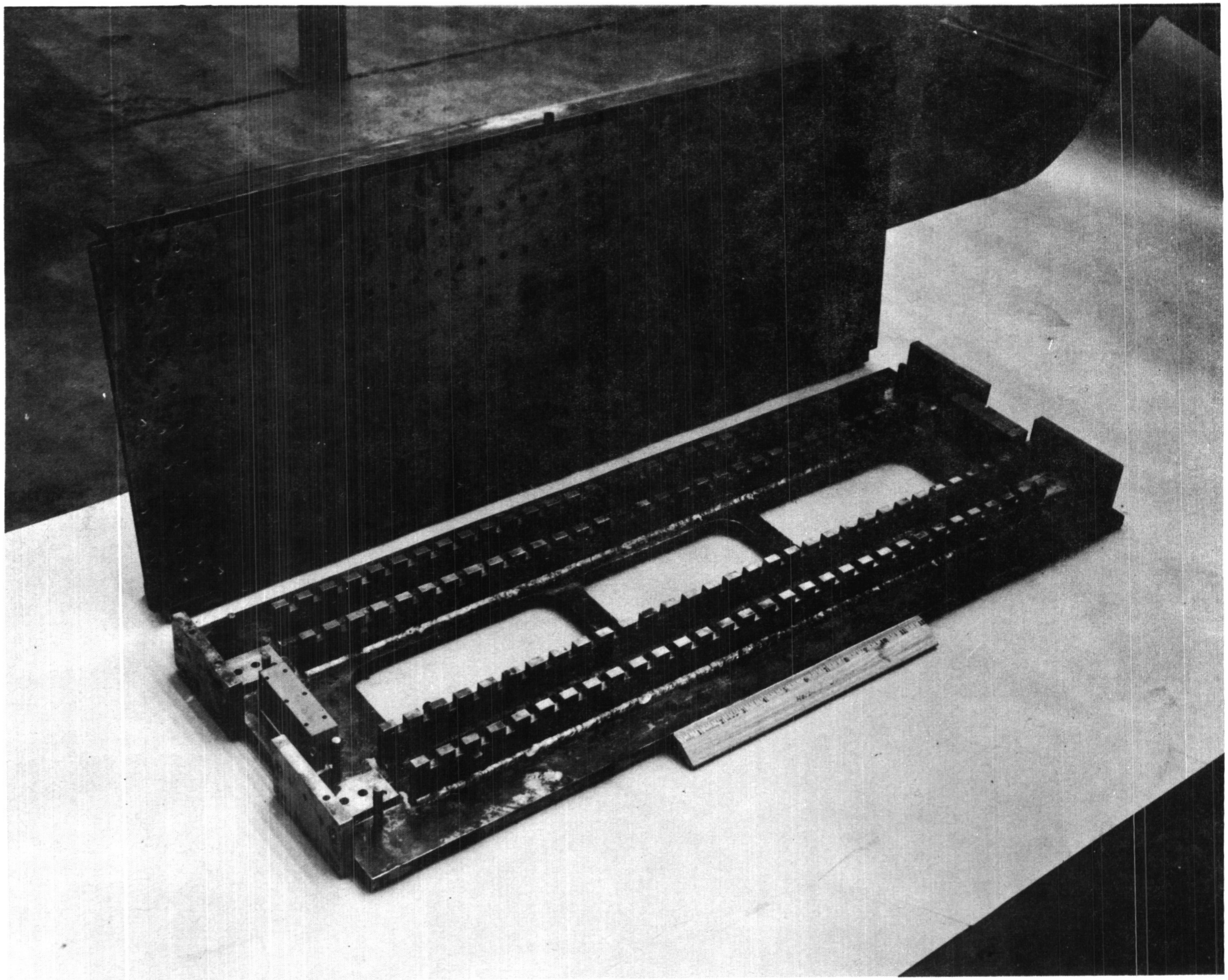

FIGURE 9. OPEN DRILL JIG

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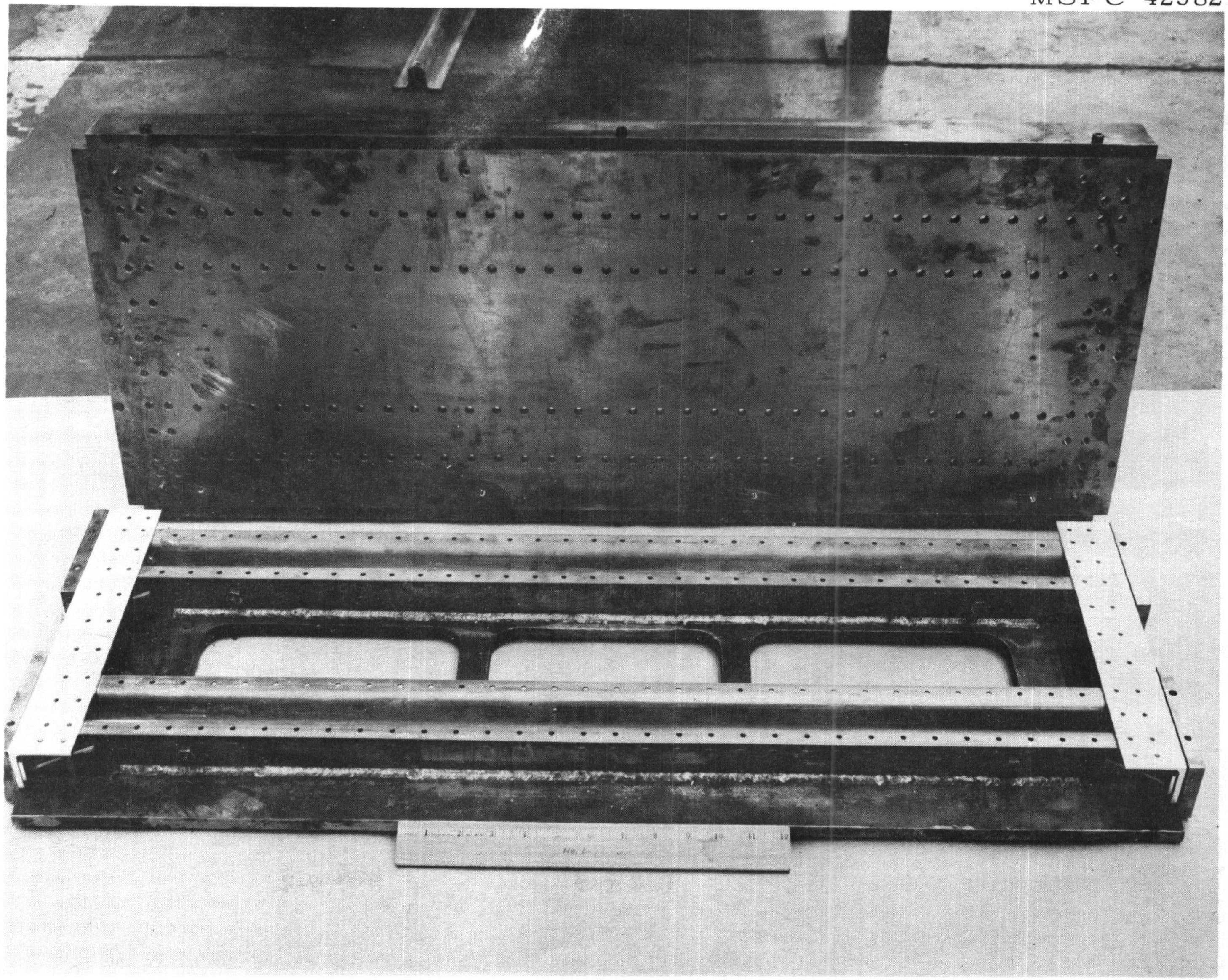

FIGURE 10. DRILL JIG WITH INSTALLED "HAT" SECTIONS AND CHANNELS

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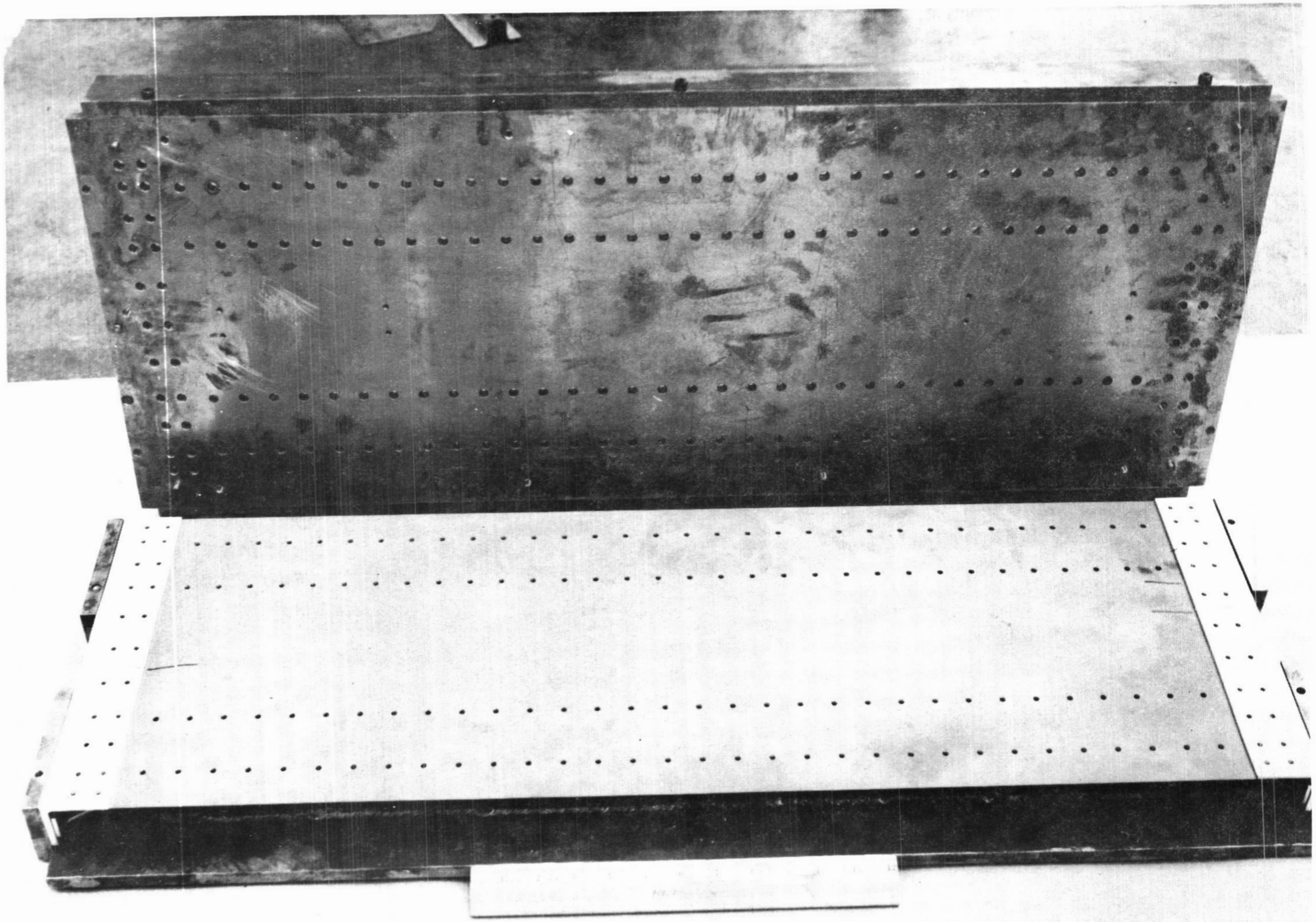

FIGURE 11. DRILL JIG WITH INSTALLED "HAT" SECTIONS, CHANNELS AND FACE PLATE

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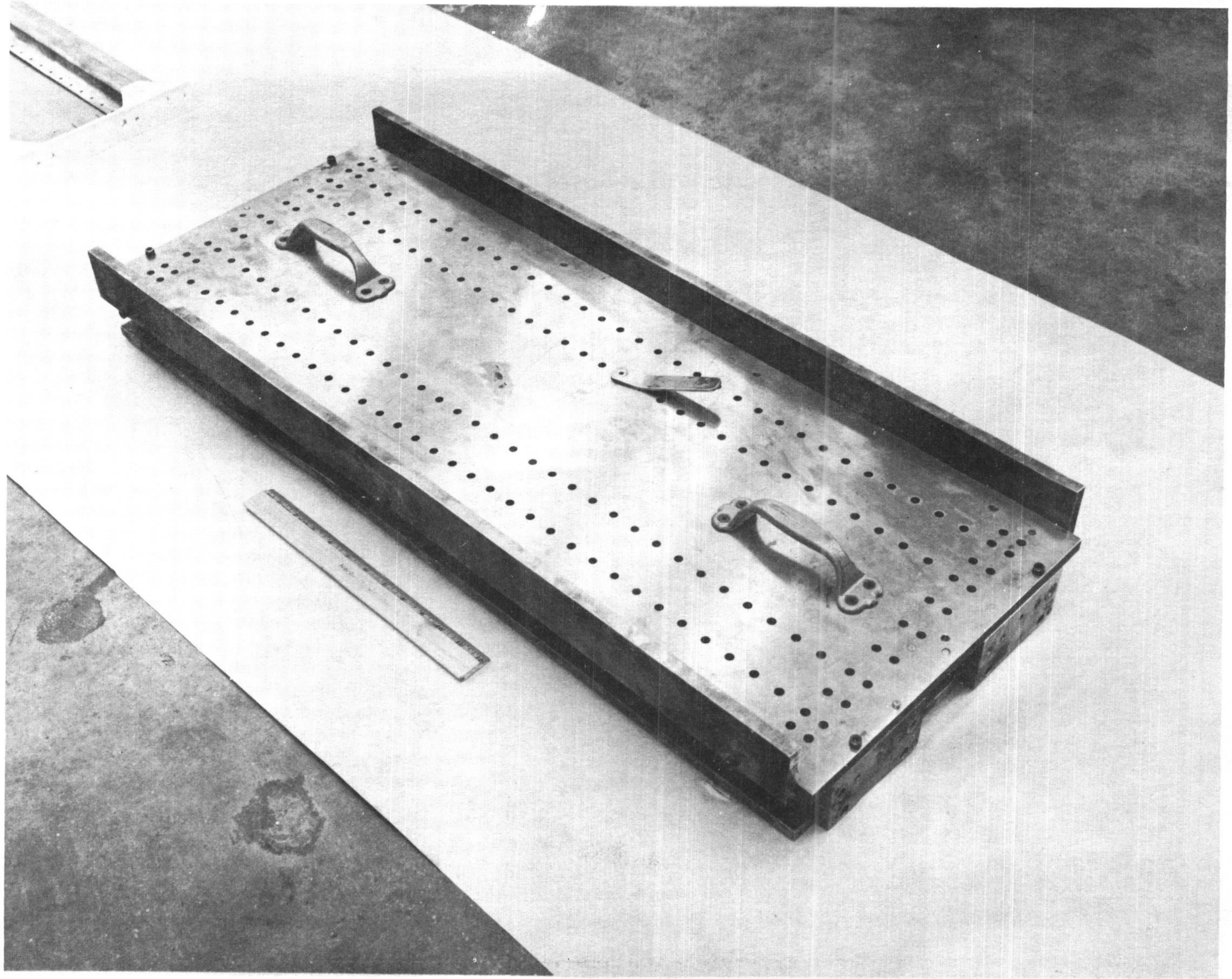

FIGURE 12. DRILL JIG ASSEMBLED FOR DRILLING

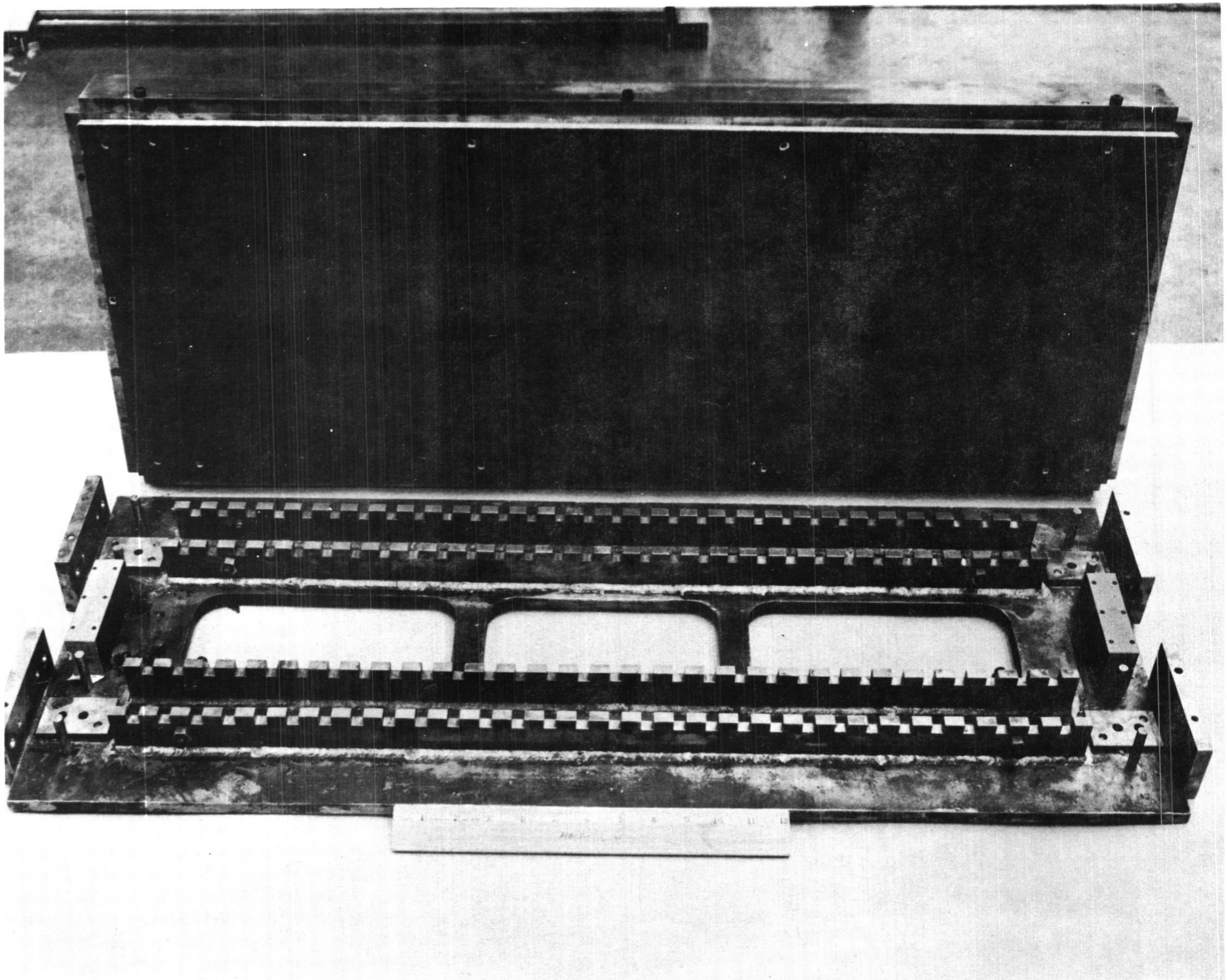


FIGURE 13. DRILL JIG WITH INSTALLED TEXTOLITE BACK-UP SHEET - BEFORE DRILLING

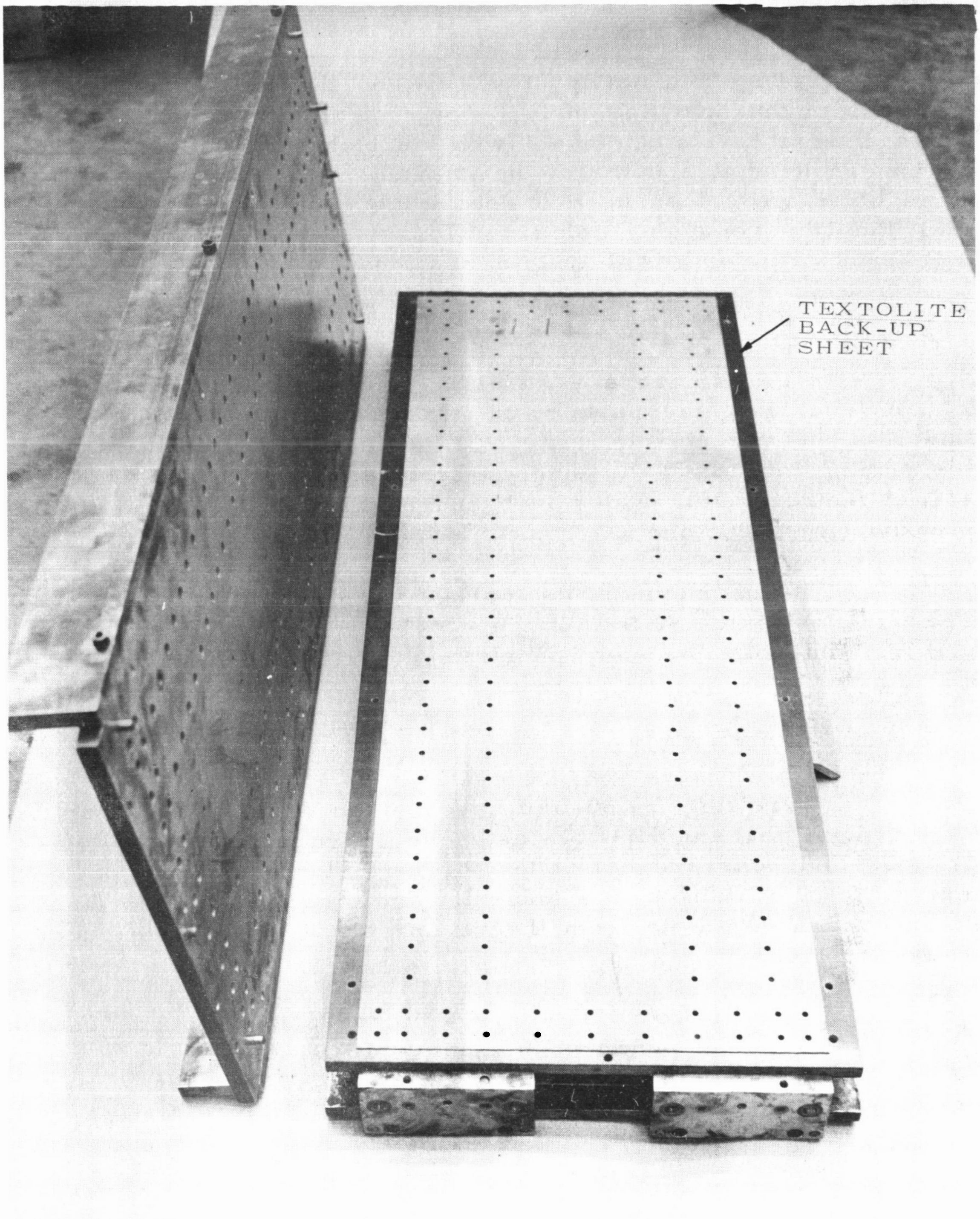


FIGURE 14. DRILL JIG AFTER DRILLING WITH TEXTOLITE BACK-UP SHEET

To eliminate spacers between the channel and beryllium parts in the final assembly, a pair of channels was fabricated to give a metal-to-metal contact with the etched beryllium. Three holes were located in each of the channels with a transfer punch. These holes were then used to locate the channel in the drill jig for drilling the remaining holes.

## C. ETCHING

To remove any material damaged by machining, drilling, or deburring, the parts were etched in a 10 percent (by weight) solution of sulfuric acid to remove 0.002 inch from all surfaces. This etching increased the size of the holes in the 0.025-inch material approximately 0.006 inch and in the 0.050-inch material, approximately 0.005 inch.

On removal of the parts from the etching tank, cracks were quite evident. A few of the cracks, extending to 1 1/2 inches in length, did not completely penetrate the 0.025-inch material.

## D. HARDWARE

Drawing SK30-566 specified blind bolts, flat head bolts with locking nuts, and Hi-Lok fasteners (Figure 15). The Hi-Lok and blind bolts are controlled torque fasteners whose parts shear when a certain torque and minimum tensile stress in the bolt are reached. Data from the vendor show the following loads can be expected:

1. Hi-Lok Fasteners - 15 to 25 inch-pounds required to torque off. Minimum tensile in bolts - 1220 pounds.

2. Blind bolts - minimum tensile load of fastener - 992 pounds.

The Hi-Lok bolts had a 0.015-inch radius between the head and the shank which could cause cracks in the beryllium sheet unless clearance was provided. Washers (AN960-PD8) with a 90 degree countersink for clearing this radius, were used in 128 locations on the beryllium face sheet.

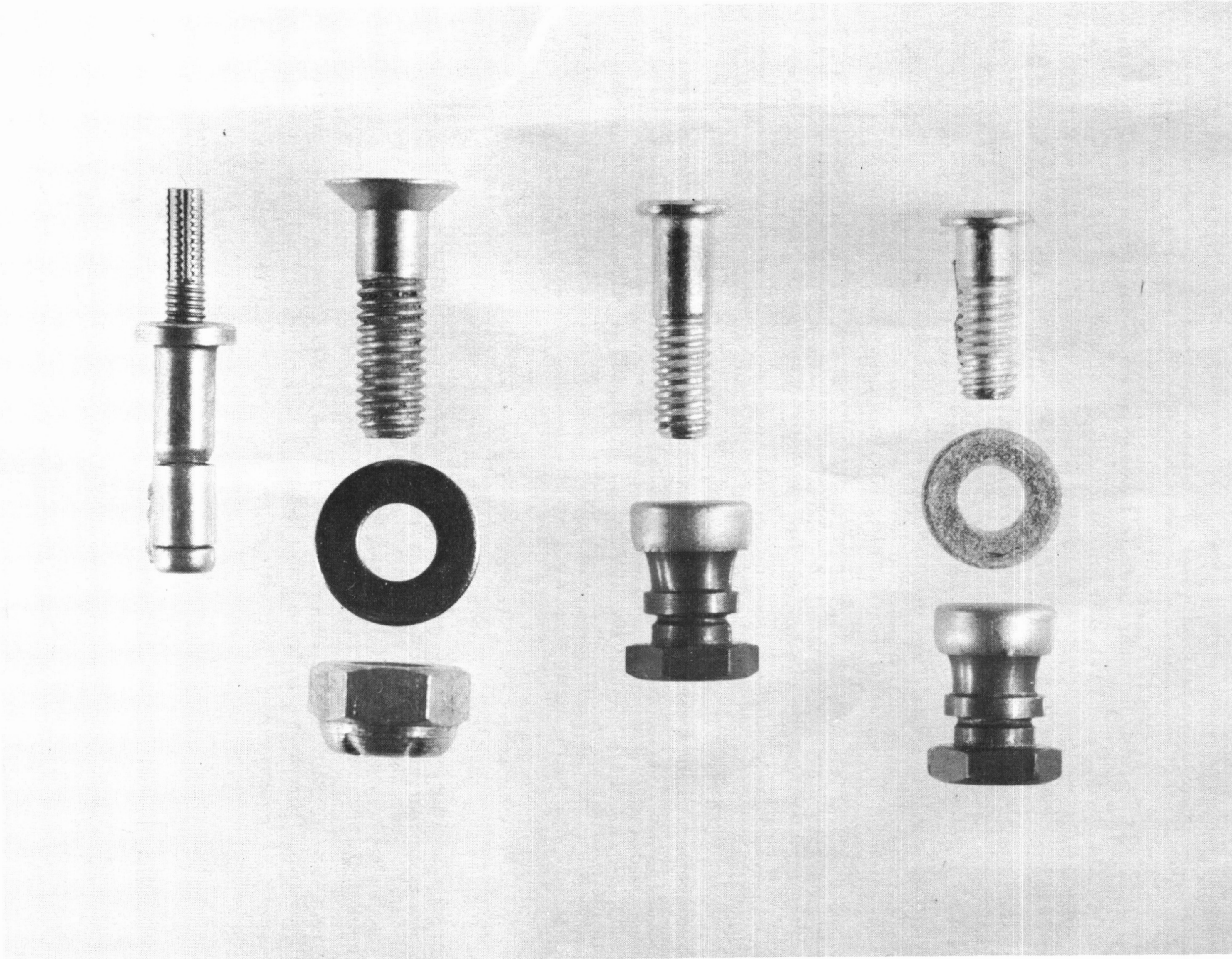

FIGURE 15. BLIND BOLT, FLAT HEAD BOLT WITH LOCKING NUT AND HI-LOK FASTENERS

E. ASSEMBLY

The following method was established for installing the components into the final assembly:

1. Fasten the clip angles to the "hat" sections (Hi-Lok fasteners were substituted for blind fasteners).

2. Assemble all parts and insert all fasteners without tightening (by varying the sequence of assembly, all fasteners were inserted in the holes).

3. Tighten every other fastener without torquing off the nut, beginning at the center of the panel and working in both directions.

4. Tighten all fasteners and torque off nuts, beginning at the center and working in both directions.

Washers which were chamfered sufficiently to clear the fastener stem to head radius were used where the heads were next to the beryllium face sheet.

Sixteen Hi-Lok fasteners were substituted for blind bolts for fastening the clip angles to the "hat" section. This was necessary because some of the fasteners were back-ordered and never received. Two views of the assembled Beryllium Test Panel are shown in Figures 16 and 17, respectively.

Component parts of the Beryllium Test Panel were weighed and the results are tabulated in Table II. Total weight was 1913.5 grams (4.25 pounds) which was distributed as follows:

| | Percent of Total Weight |
|---|---|
| Beryllium Face Sheet | 15 |
| Beryllium "Hat" Sections | 23 |
| Fasteners | 22 |
| Aluminum Clip Angles | 6 |
| Aluminum Channels | 34 |

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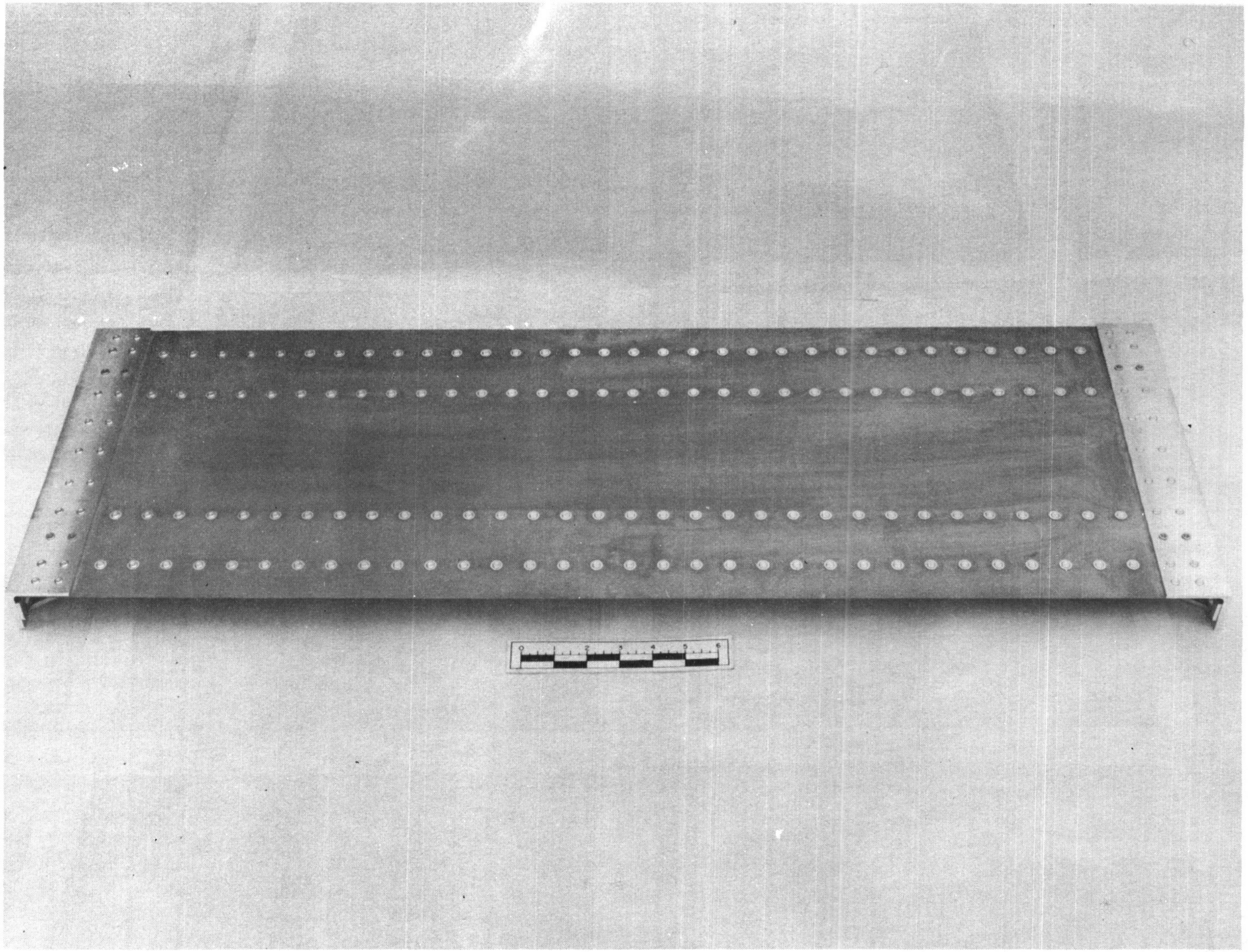

FIGURE 16. ASSEMBLED BERYLLIUM TEST PANEL - VIEW 1

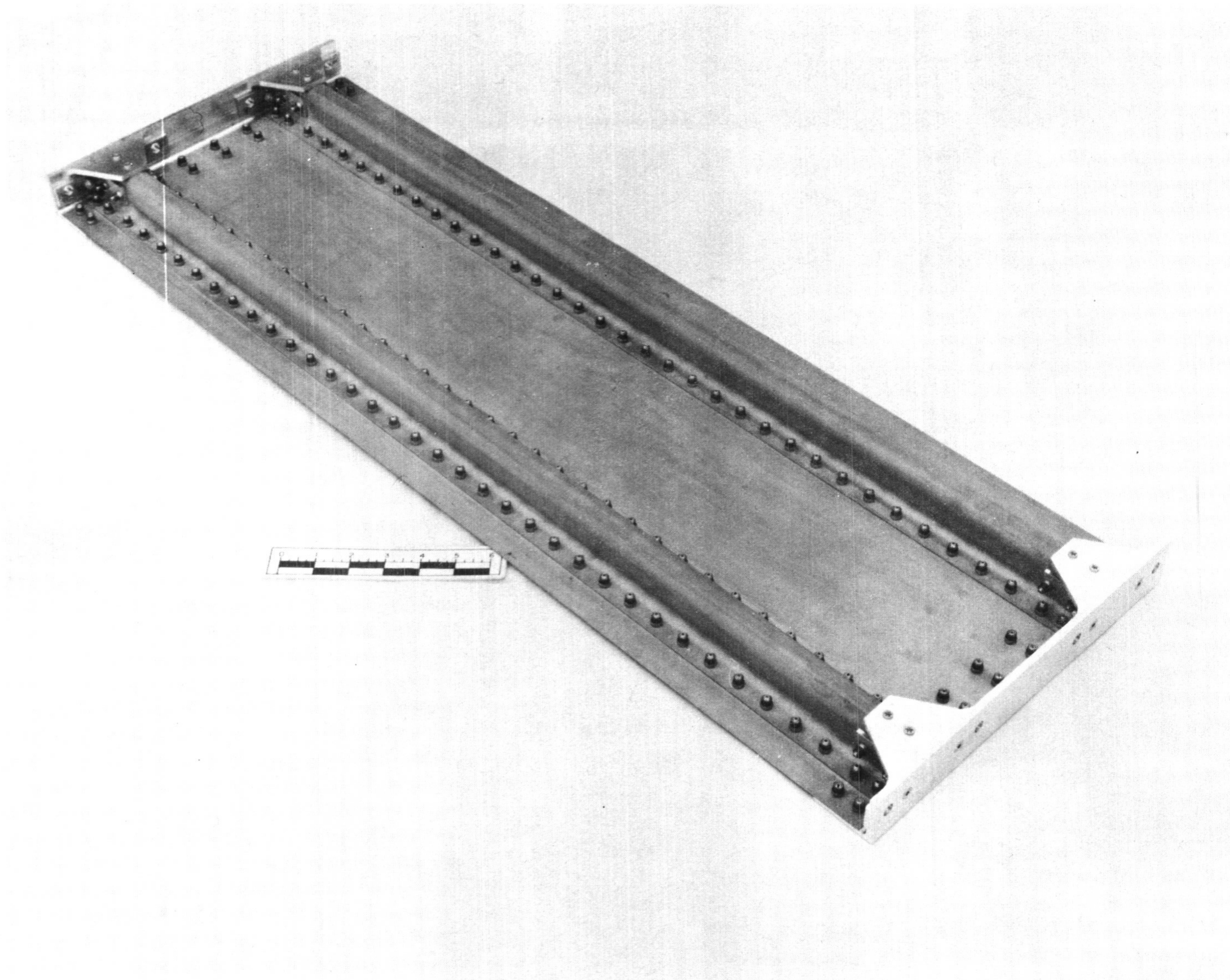

FIGURE 17. ASSEMBLED BERYLLIUM TEST PANEL - VIEW 2

TABLE II. WEIGHT OF BERYLLIUM TEST PANEL

| Hardware | Wt. of Assembly | Discard Wt. | Net Wt. | No. Used | Total Wt. in Grams |
|---|---|---|---|---|---|
| BB602-5-2 | 1.9474 | 0.3906 | 1.5568 | 32 | 49.9 |
| A1 Clip Angle | 14.5490 | None | 14.5490 | 8 | 116.4 |
| HL 1870-5-4 | 2.3245 | 0.2776 | 2.0469 | 32 | 65.6 |
| No. 8 Washers | 0.1189 | None | 0.1189 | 128 | 15.1 |
| HL 1870-5-2 | 1.9699 | 0.2776 | 1.6923 | 148 | 250.1 |
| MS20365-1032<br>AN960C10<br>NAS333CA6 | 5.1510 | None | 5.1510 | 8 | 41.2 |
| AL Channels | 328.3 | None | 328.3 | 2 | 656.6 |
| Be Face Sheet | 280.0 | None | 280.0 | 1 | 280.0 |
| Be "Hat" Section | 219.3 | None | 219.3 | 2 | 438.6 |
| Total | | | | | 1913.5 grams<br>or 4.25 pounds |

## SECTION III. CONCLUSIONS AND RECOMMENDATIONS

Beryllium sheet of 0.025 and 0.050-inch thicknesses can be fabricated into mechanically fastened assemblies if proper controls are maintained. Every effort must be made to eliminate operator error and to ensure optimum conditions in every phase of cutting, drilling, forming, handling, and assembly.

Close tolerances can be met in the hot forming operations through proper tooling and close control of time and temperature. There was negligible springback in beryllium when parts were formed at 1350°F and then slowly cooled to room temperature in the forming dies to prevent warpage.

Rigid support of the workpiece during all machining operations is necessary. Textolite produced by General Electric was an excellent backup material.

No failures in bends were experienced during the forming of 0.050-inch beryllium sheet to 0.300-inch radii (6T bends) when accomplished at 1350°F.

Boron nitride paste was a satisfactory lubricant for hot forming the beryllium "hat" section. A very thin even coat was required since uneven coating results in impressions in the formed beryllium parts. Removal of the lubricant was accomplished with emery paper while the part was submerged in water.

A minimum clearance of 0.060 inch between the male and female die is recommended for "hot" forming 0.050-inch beryllium sheet to 6T bend radii. Less clearance can be used but will result in more scratches.

Drilling through aluminum into beryllium is not recommended but can be accomplished with proper precautions. If the drill is withdrawn and all aluminum chips removed as soon as the drill contacts the beryllium, no chips can become lodged between the two alloys to cause breakage.

## REFERENCES

1. "Final Report - Beryllium Box Beam Development Program," Contract No. NAS8-11784 by Fairchild Hiller, Farmingdale, Long Island, New York.

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# FABRICATION OF A BERYLLIUM TEST PANEL

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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