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HOT VACUUM CREEP FORMING OF SCALE SHUTTLE EXTERNAL TANK DOME CAPS

by

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FINAL TECHNICAL REPORT

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FOREWORD

This report was prepared by the AVCO Corporation Aerostructures Division, Nashville, Tennessee under Marshall Space Flight Center contract number NAS8-30664.

Mr. Carl Wood was the technical representative for MSFC.

Mr. A. O. Thomas was the principal investigator for AVCO.

This final technical report has been reviewed and is approved.

G. Martin, Director
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ABSTRACT

This program covered selected tasks incidental to conducting a feasibility study for forming the shuttle external tank dome caps by hot vacuum creep forming. It was necessary to conduct this study on a sub-scale configuration due to a limited material availability; this limitation concerned both sheet size and quantity.

The study was limited to forming 2219-T37 aluminum at an elevated temperature equivalent to the artificial aging time and temperature used to produce the T87 condition while achieving MIL-HBK-5 properties of 2219-T87 aluminum alloy material.

The feasibility study was conducted in two phases; the design and build of a sub-scale hot vacuum creep forming (HVCF) die and the forming evaluation of various cap configurations. The contour was constant in all evaluations.

Conclusion summary is that this particular configuration is too severe for the limited forming force available by HVCF.

TABLE OF CONTENTS

FINAL REPORT

SHUTTLE TANK CAP HVCF FEASIBILITY STUDY

1. INTRODUCTION

The current design trends for aerospace structures are favoring large contoured components of high strength aluminum. Emphasis is also on sculpturing to produce one-piece panels and eliminate separate stiffener details. Standard forming methods present problems for the new designs due to high tooling cost and the lack of sufficiently large facilities (stretch presses, etc.).

The present design concepts for the space shuttle fuel tanks incorporate large sculptured panels of 2219-T87 aluminum. This particular program is concerned with the end bulkheads. The size and contour of these bulkheads are shown in Figure 1. It is understood that the base line method to produce these panels is bulge forming.

A major problem in forming results from presculpturing which presents non-uniform cross sections in the strain areas. The feasibility of minimizing this problem by hot vacuum creep forming was sufficiently real as to warrent an investigation. This program concerned the design, development, fabrication and test evaluation of a hot vacuum creep forming die.

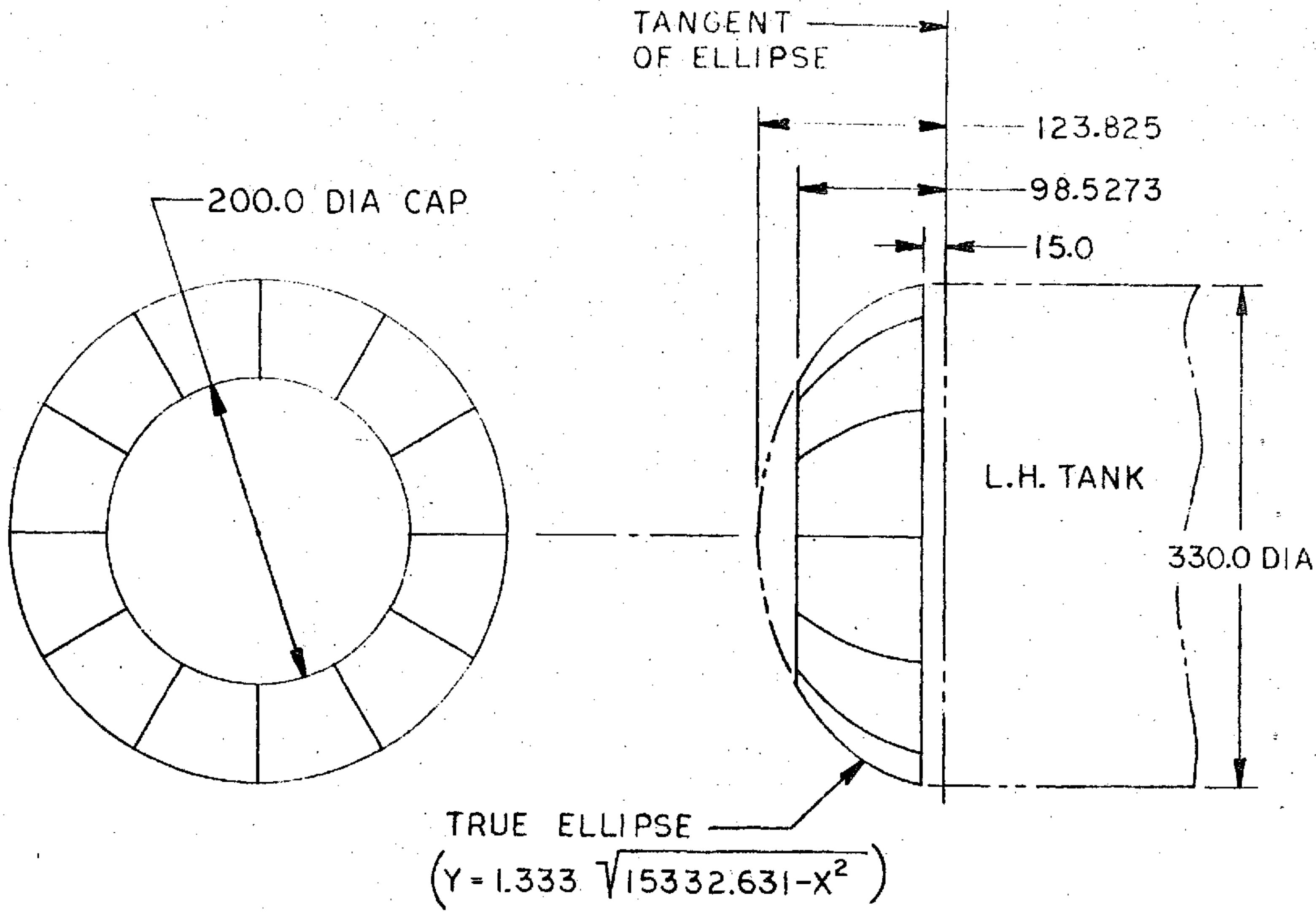


FIGURE 1 LIQUID HYDROGEN TANK HEAD
12 GORE CONFIGURATION

II. OBJECTIVES

The objectives of this program are to 1) determine through a series of tasks which are described in Section VI of this report whether certain configurations of the external tank dome caps can be formed by the HVCF method and reach MIL-HDBK-5 properties for 2219 T87, and 2) conduct a study for the purpose of providing cost data such that full scale tooling and external tank dome caps at specific production rates could be developed.

III. MATERIAL INVESTIGATION

A review of the room temperature tensile properties of 2219 aluminum showed the T87 design values to be 52 KSI yield and no design values available on T37 temper. Data on T37 acquired in-house with .125 material gave values ranging from 46.2 KSI yield to 48.2 KSI yield. Tensile specimens, .169 inch material machined from .500 inch T37 plate, produced values of 44.9 KSI yield.

Starting a HVCF cycle with the lower strength T37 material increases the odds of achieving a fully formed panel. Considering this, a series of T37 tensile specimens were artificially aged to determine the aging time and temperature that would be compatible with the forming operation. Figure 2 plots a series of aging times for yield strength versus temperature. A sixteen hour forming cycle at 360°F will bring T37 material to T87 temper per MIL-HDBK-5 and should be sufficient time to allow substantial material creep.

ALCOA data indicates that 2219-T37 aluminum has a 9 percent decrease in ultimate strength at 212°F within 45 minutes and is below the T37 values for a total of approximately 20 hours. The conditions under which the data was given were not clear and verification was required. Tensile specimen, .125 inch-T37, were pulled at temperature with the following results:

Temperature (°F)	Time (Hrs.)	F_{tu} (KSI)
212	0.5	50.64
350	0.5	42.86
350	4.0	45.88
350	8.0	44.13
350	16.0	44.21

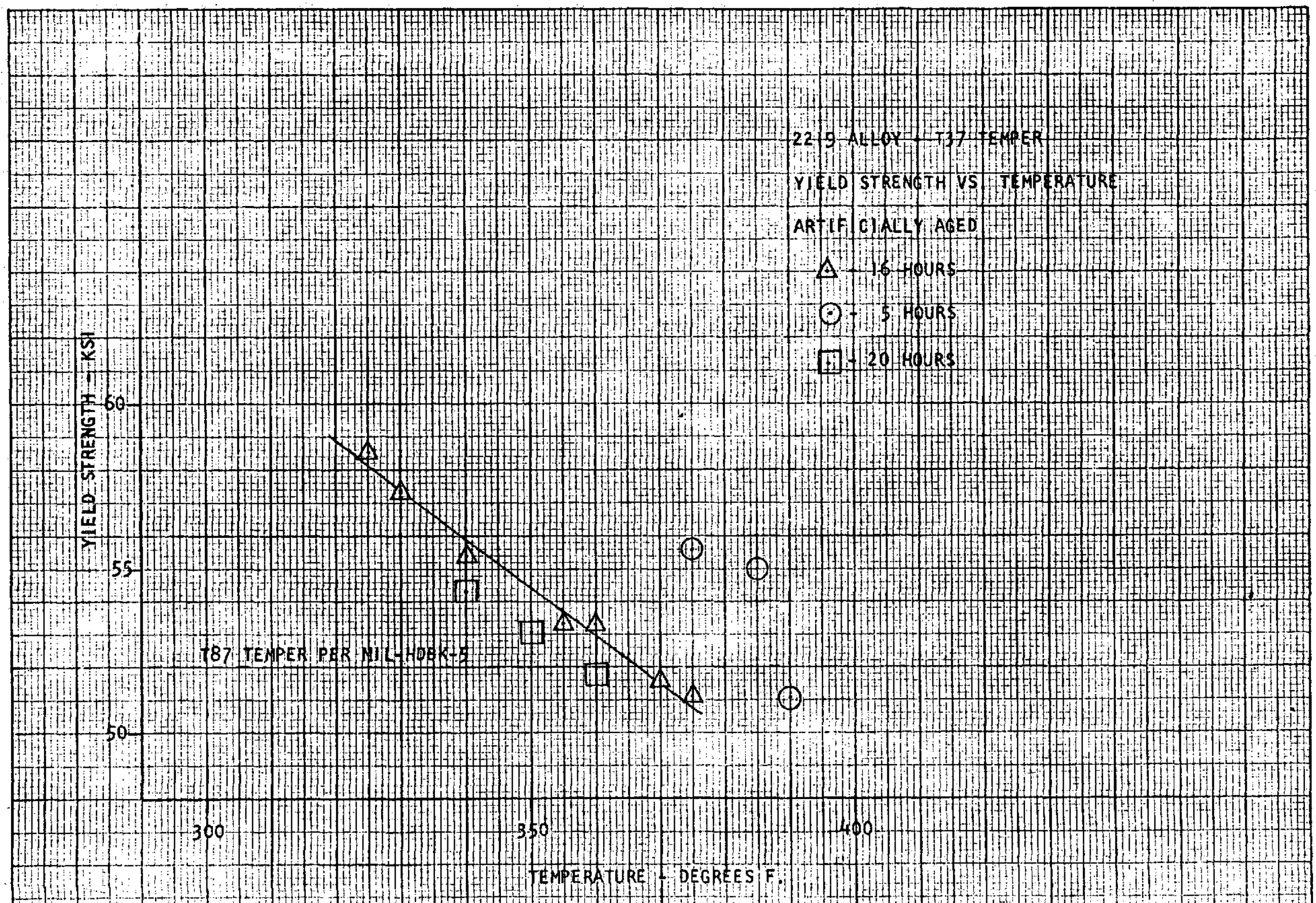

2219 ALLOY - T37 TEMPER
YIELD STRENGTH VS. TEMPERATURE
ARTIFICIALLY AGED
△ - 16 HOURS
⊙ - 5 HOURS
□ - 20 HOURS
YIELD STRENGTH - KSI
60
55
50
T87 TEMPER PER MIL-HDBK-5
300
350
400
TEMPERATURE - DEGREES F.

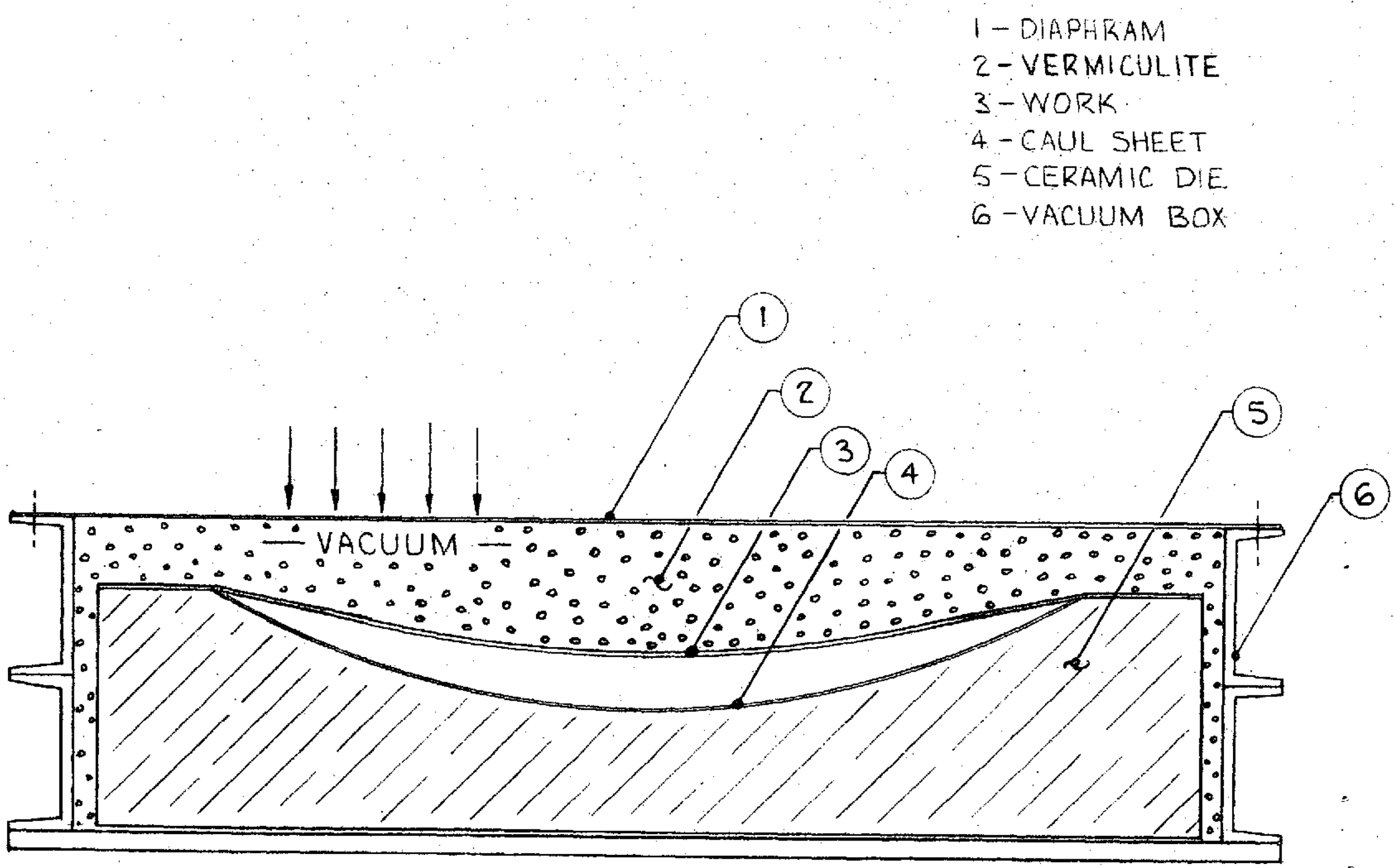
FIGURE 2

The preceding data indicates that the major portion of any forming occurs early in the HVCF cycle when using an accepted artificial aging temperature.

IV. DESCRIPTION OF HVCF METHOD

The forming method known as hot vacuum creep forming consists of a integrally heated ceramic forming die (AVCORAMIC TOOLING) enclosed in a structural steel container with an open top. The material to be formed is first placed in the die. Then the remainder of the container is filled with a granular insulating material known as vermiculite. The top is sealed with a plastic sheet diaphragm identified as VAC PACK. A vacuum system is used to evacuate the sealed enclosure. When evacuated, the plastic diaphragm transmits the load resulting from the pressure differential to the work surface via the vermiculite medium. A combination of heat and controlled pressure provides conditions for creep stretching the work into the ceramic die.

Figure 3 illustrates the fundamental arrangement of a HVCF die with work in place.



HOT VACUUM CREEP FORMING

FIGURE 3.

V. DESIGN AND CONSTRUCTION OF HVCF TOOLING

Evaluation of the forming ability of HVCF to produce the dome cap portion of the end bulkhead focused on the design and fabrication of a reduced scale forming tool. The spherical cap size selected was a 56 inch chord and 57.75 inch radius which requires a 4.45% forming elongation, and duplicates the forming conditions of the full scale dome cap. To maintain a minimum Δ temperature across the tool and part, a convolute integral heating wire pattern was adopted. The convolute was divided into four independent heating zones to maintain uniform temperature.

The construction procedures used to fabricate the AVCORAMIC forming die are shown in the following figures.

Figure 4. Casting box with plaster splash and casting core to produce the convolute heating wire groove on the die surface.

Figure 5. Placement of styrofoam casting cores to produce cooling cavities and reduce overall tooling weight.

Figure 6. Completed casting box.

Figure 7. Ceramic casting operation.

Figure 8. Cast forming die with Nichrome heating wire being cemented in the convolute groove.

Figure 9. Completed forming die placed in the vacuum enclosure.

A 1/8 inch 3003 aluminum "caul sheet" was HVCF in the forming die and became a permanent part of the tooling. Its function was to protect

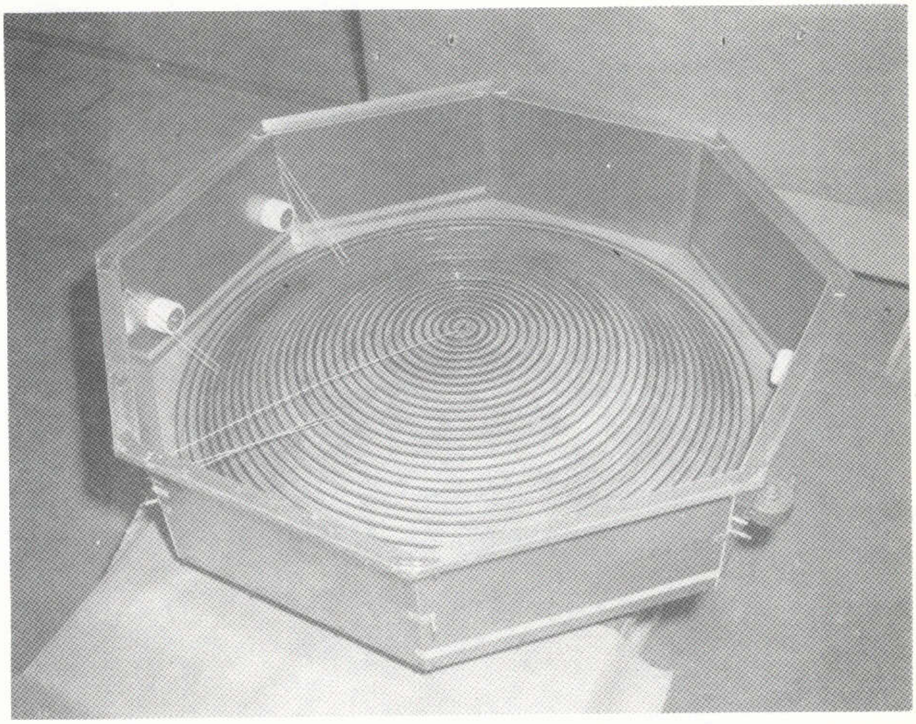


FIGURE 4

FIGURE 5

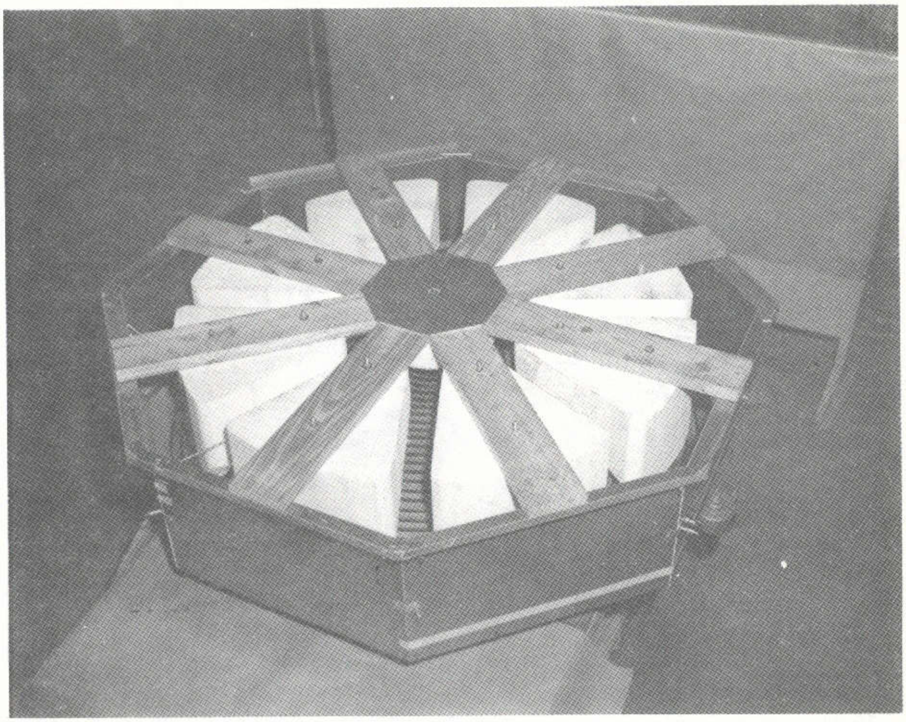


FIGURE 6

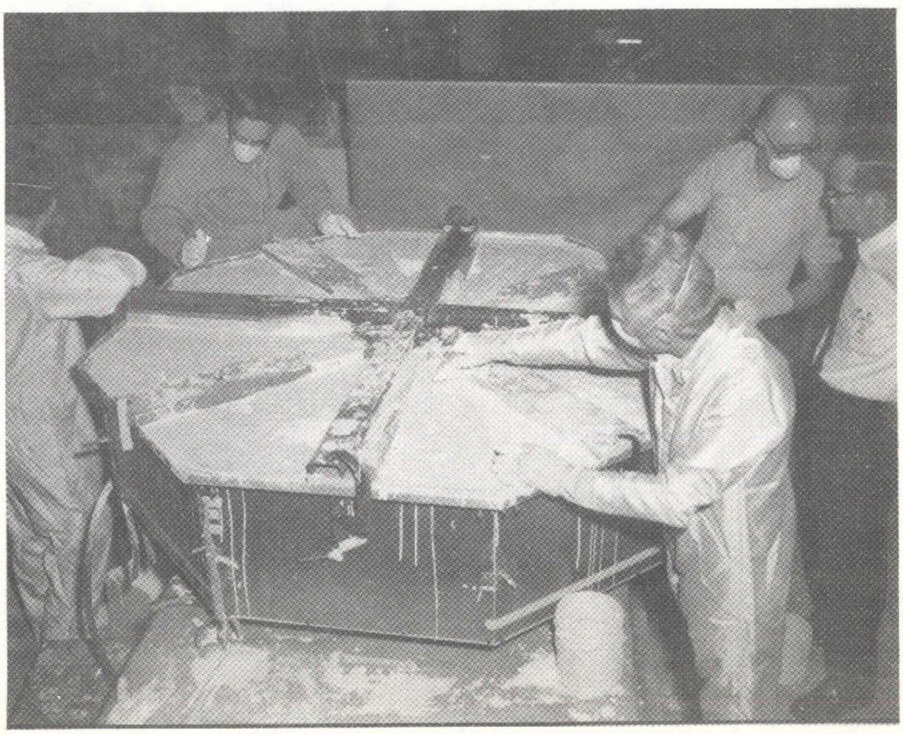


FIGURE 7

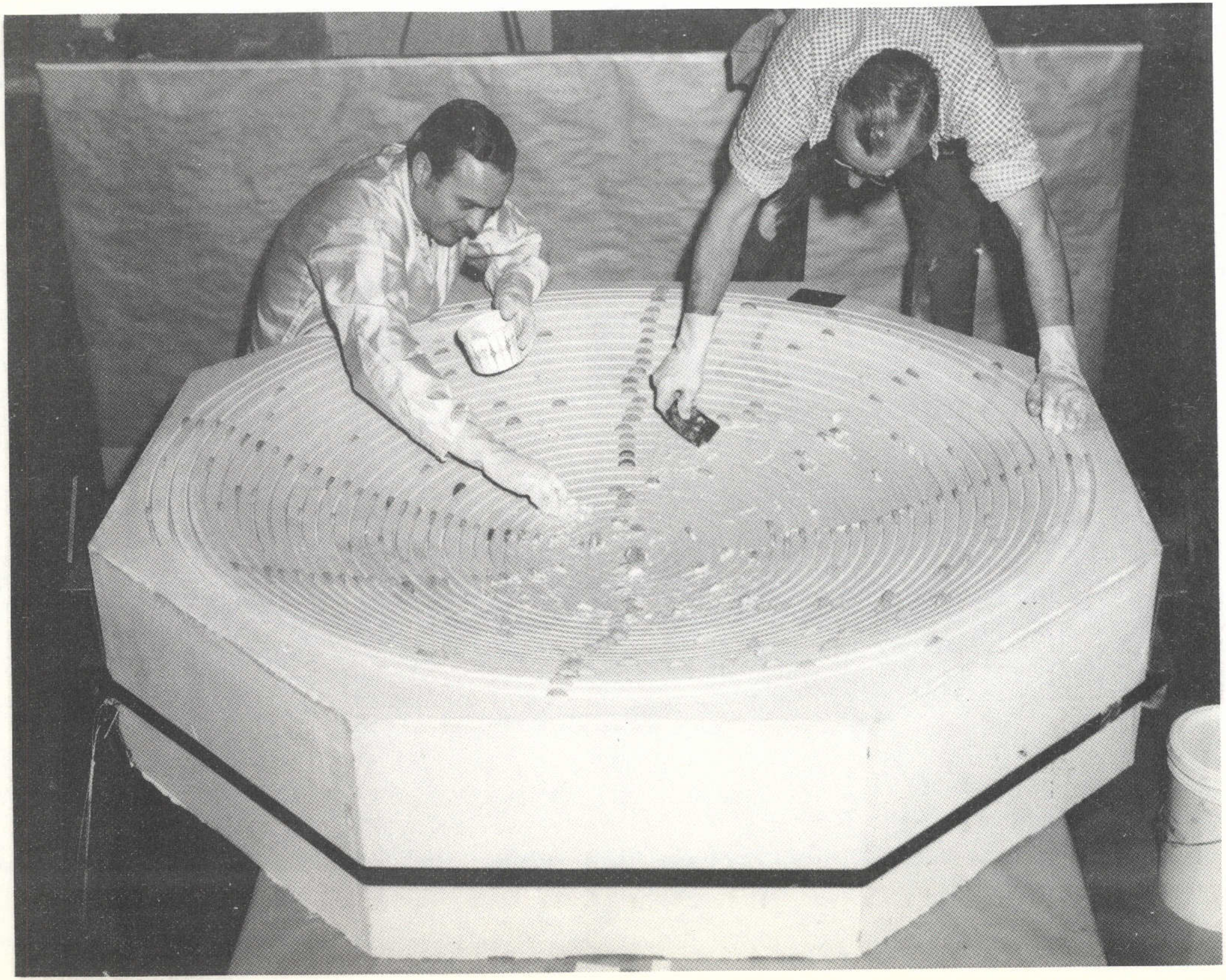


FIGURE 8

FIGURE 9

both die and part from surface galling and to further reduce the Δ temperature. Figure 10 shows the flat blank "caul sheet" in place to be formed. Note the flange around the perimeter which provides positive drawing of the material into the contour. The sealed enclosure is shown in Figure 11 prior to applying vacuum. Figure 12 shows the formed "caul sheet" after the forming cycle. The forming cycle was accomplished at 900°F for two hours and a forming pressure up to 8.3 inches Hg.

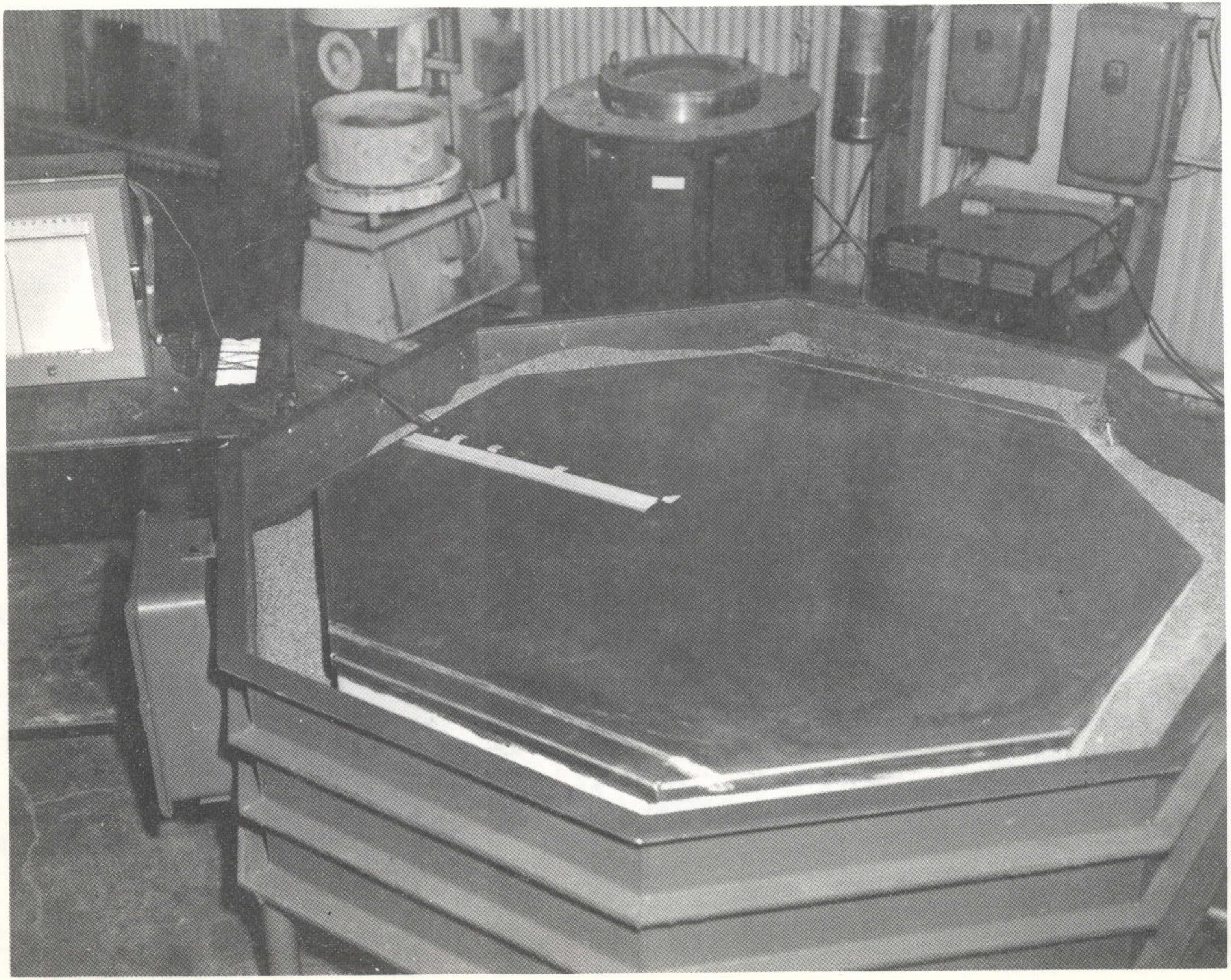


FIGURE 10

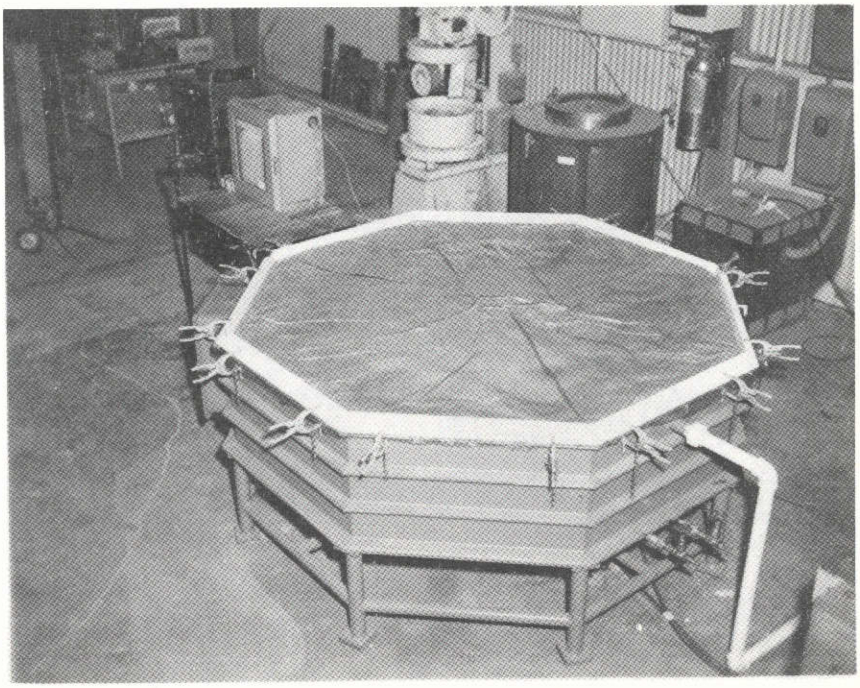


FIGURE 11

FIGURE 12

VI. HVCF EVALUATION

A series of test blanks were established to evaluate the HVCF technique. Additional test blanks were also studied and are shown in double letters. The task and description are as follows:

TASK	DESCRIPTION
A	48 inch diameter, 1/8 inch thickness, no welds or sculpturing.
AA	48 inch diameter, .060 thickness with full thickness land (.125) around the periphery & no welds.
B	63 inch diameter, 1/8 inch thickness with a single weld through the center. MSFC Dwg. MIT 15876-1.
C	58.5 inch diameter, 1/8 inch thickness with single weld off center. MSFC Dwg. MIT 15876-2.
D	58.5 inch diameter, 1/8 inch thickness with two welds. MSFC Dwg. MIT 15876-3.
DD	(Same as D)
E	58.5 inch diameter, stepped cross section, no weld. (AVCO supplied material.)

The 48 inch diameter (Task A) blank was center punched with 2 inch gauge points in the pattern illustrated in Figure 13. This gauging pattern was the standard used on all tasks to determine material elongation. Figure 14 shows Task A during HVCF cycle. The forming conditions for Task A are plotted in Figure 15, and are typical for all tasks except maximum temperature. At the completion of the forming cycle, a springback occurred when the vacuum was released. This resulted in a chord height (h) loss of 1.625 inches. Actual formed chord height of Blank A was 1.650 inches and is shown being inspected in Figure 16. Changes in gauge lengths were not significant and a trend was not noted. The measurements are recorded in Figure 17 which also gives mechanical properties before and after forming. The 57.5 KSI tensile yield strength achieved during the forming cycle is well within the MIL-HDBK-5 requirements.

The Task AA blank was reduced to .060 inch thickness with a one inch full land remaining around the periphery, in order to achieve increased unit loading values lost with the 48 inch diameter area. At 10 inches HG in the forming cycle, the blank instantaneously buckled, resulting in a ruptured diaphragm. The results are shown in Figure 18.

A 63 inch diameter blank, Task B, placed the material perimeter out of the contoured area and on the tool flat. The application of vacuum, equivalent to 2 PSI forming pressure began drawing the material into the contour with a buckling condition developing. The blank was removed from the tool to incorporate a hold-down ring consisting of eight flat segments with sixteen evenly spaced clamping points on the flat area of the tool perimeter. The use of the hold-down ring permitted up to 27 inch Hz to be applied during the forming cycle. Three hours into the forming operation a buckling failure occurred. Visual inspection indicated a failure

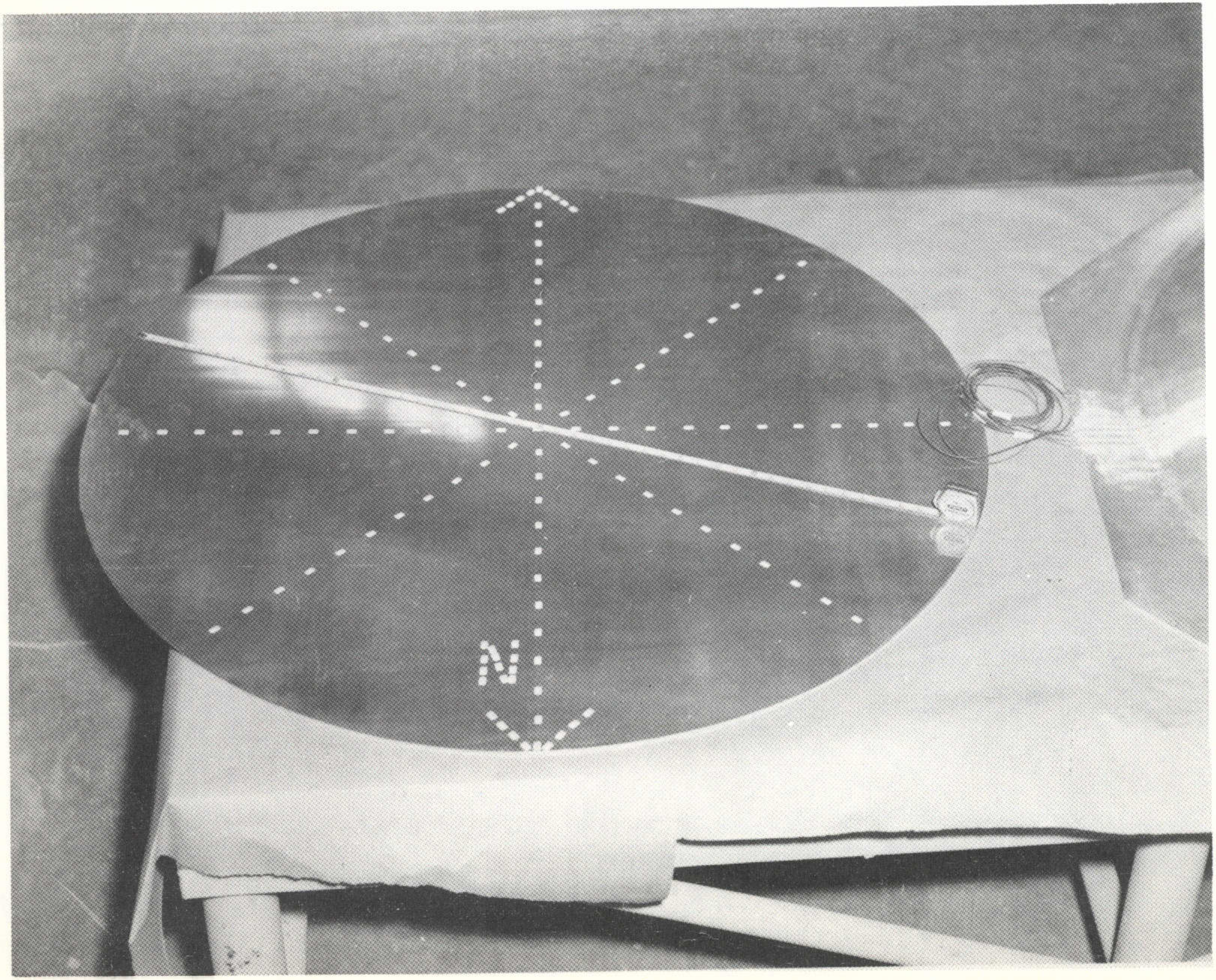


FIGURE 13

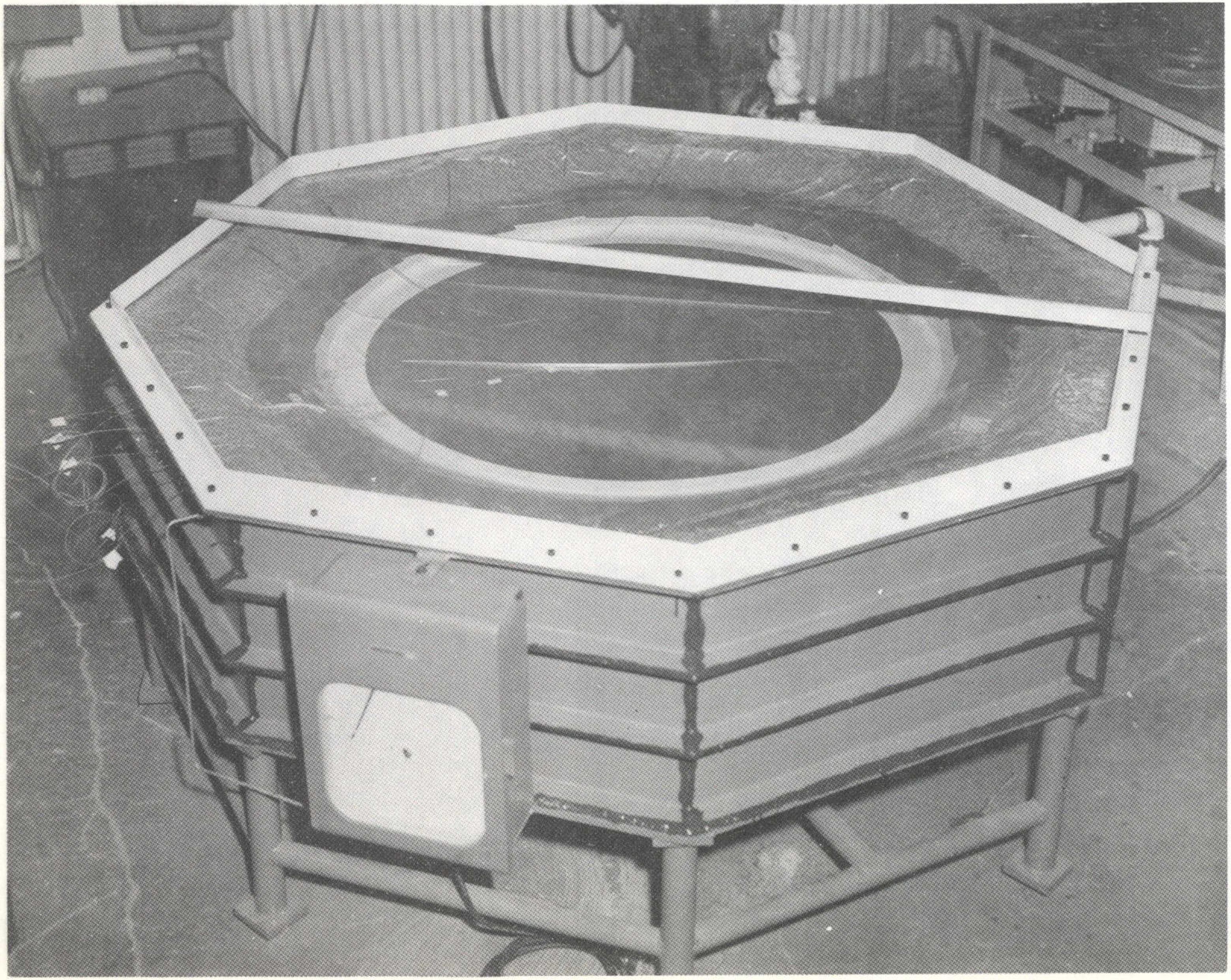


FIGURE 14

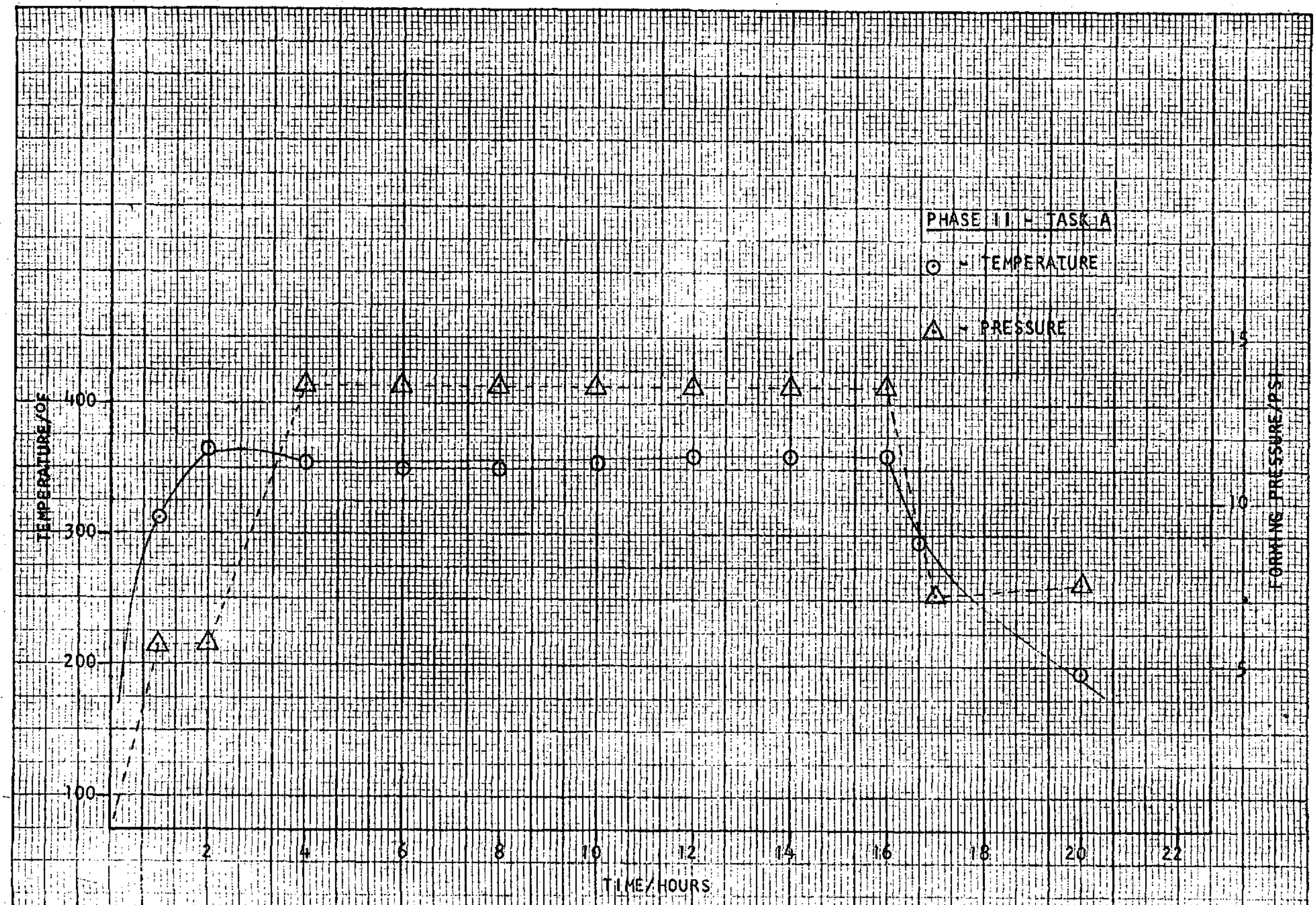

PHASE II - TASK A
⊙ - TEMPERATURE
△ - PRESSURE
TEMPERATURE/°F
FORMING PRESSURE/PSI
100
200
300
400
5
10
15
2
4
6
8
10
12
14
16
18
20
22
TIME/HOURS

FIGURE 15

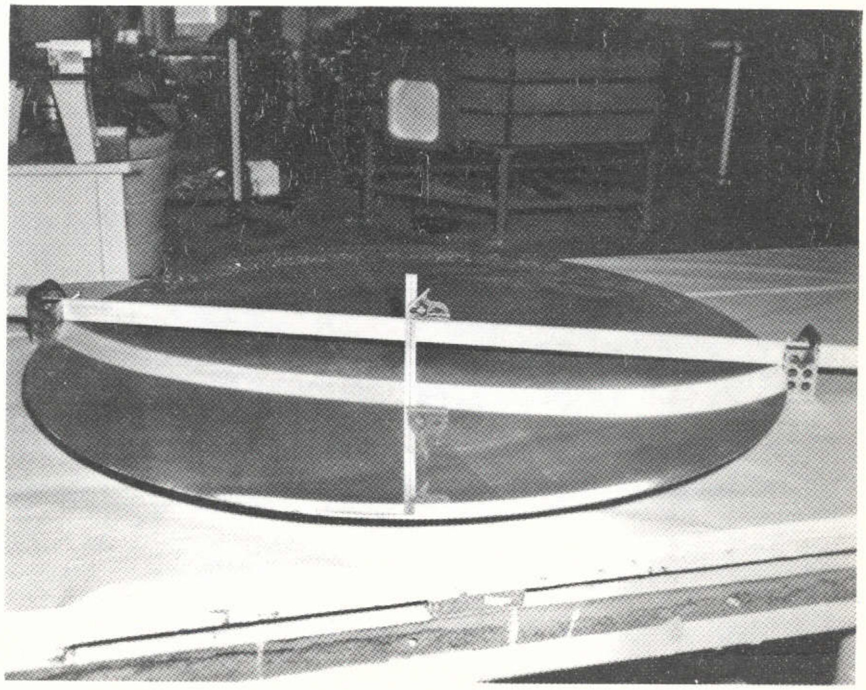
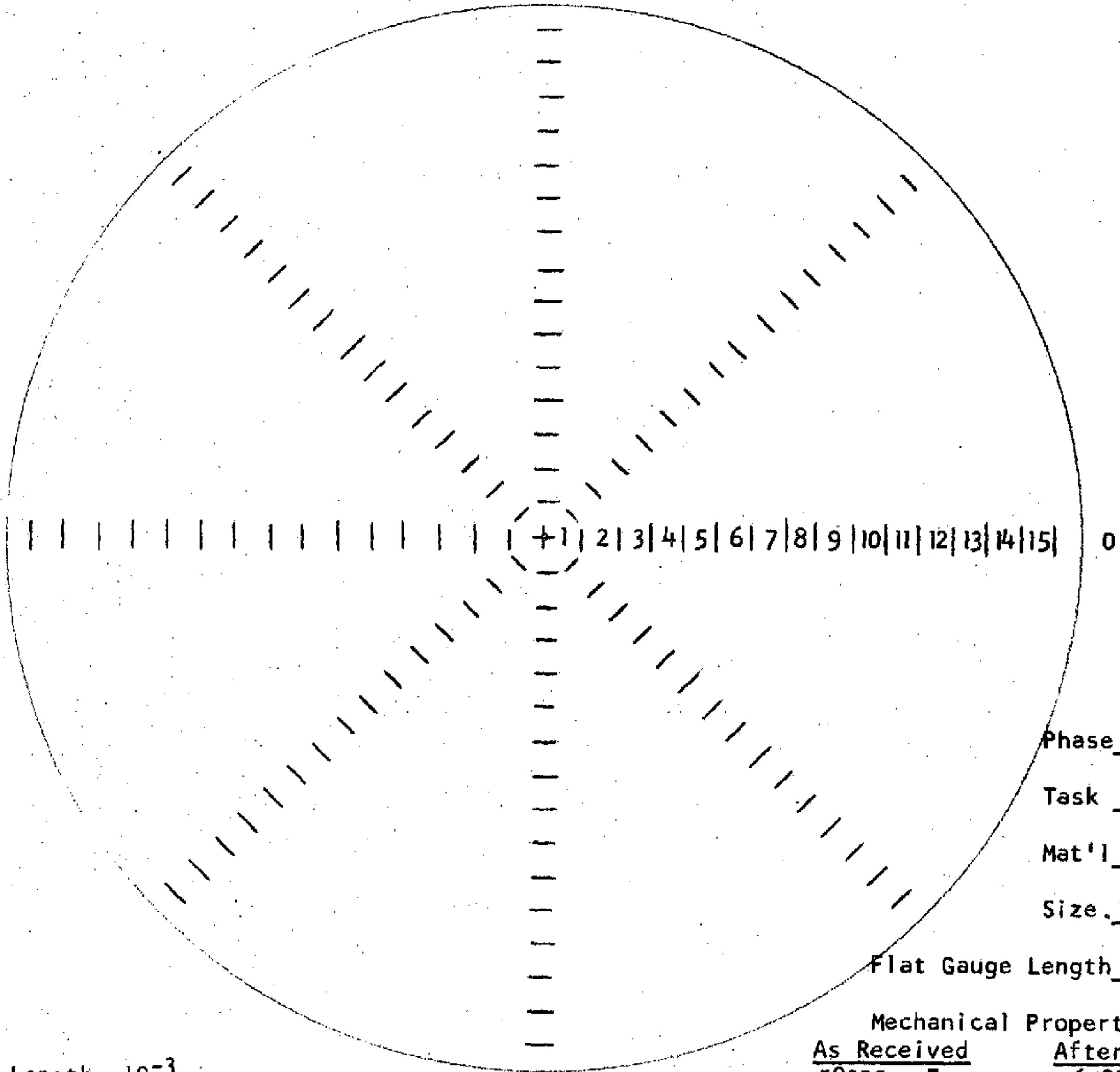


FIGURE 16



Phase II

Task A

Mat'l 2219

Size .125 x 48

Flat Gauge Length 2.000

Mechanical Properties:

As Received		After Forming	
58030	Ftu	67884	Ftu
48240	Fty	57549	Fty

Change in Length, 10^{-3}

Formed Contour Gauge Length (Starting at 0 Clockwise):

Area 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-.005	0	-.005	+.005	-.005	+.008	+.006	+.015	-.005	0	-.005				
-.005	+.005	+.005	+.005	-.005	+.005	+.020	-.005	+.015	-.005	+.005				
0	+.005	+.005	0	+.005	+.005	+.010	+.005	+.005	+.005	+.005				

FIGURE 17

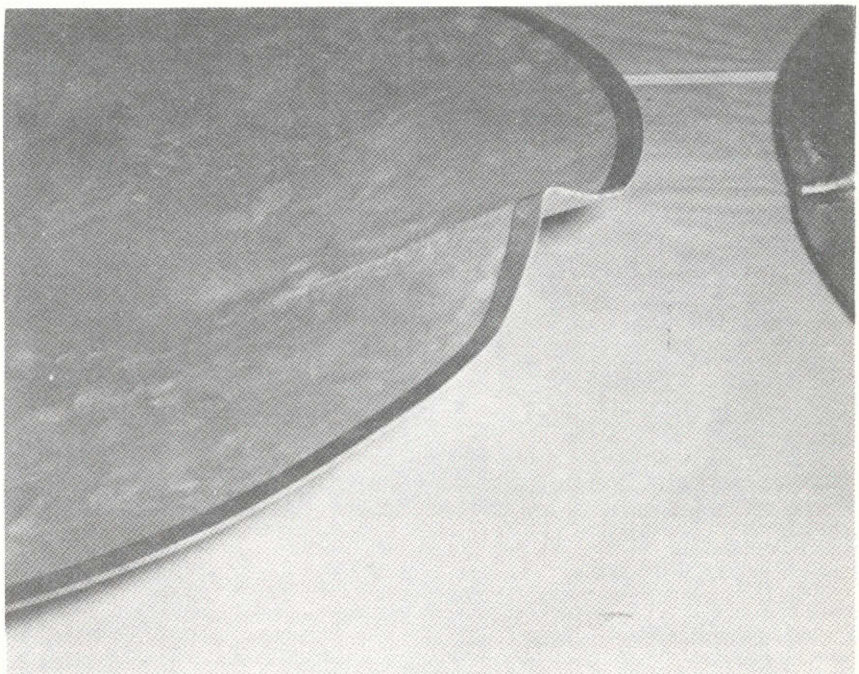


FIGURE 18

with the blank buckling in the butt weld area. Figure 19 shows the hold-down ring and the damaged area.

The hold-down ring was redesigned using one inch diameter cold rolled steel formed to a 56 inch diameter and utilizing the existing clamping joints. This permitted the clamping force to be applied inside the tool contour perimeter which results in the blank being partially drawn into the tool. With a blank and ring clamped in place, a 3/4 inch concave condition can be achieved when 20 ft./lb. torque is applied to the clamping bolts.

The forming cycle for Task C incorporated the 56 inch diameter hold-down ring. Fifteen hours into the forming cycle a blank failure occurred in the weld area adjacent to the hold-down ring which was also damaged, see Figure 20.

Visual inspection of the hold-down ring indicates a loss of clamping pressure as the forming progresses. The clamping points were redesigned to permit the clamping force to be adjusted outside the vacuum enclosure during the forming cycle. With the use of a torque wrench, the clamping force can then be held constant throughout the cycle. An additional one inch web hoop was welded to the hold-down ring to increase overall ring stiffness.

The modified ring, shown in Figure 21 prior to Task D forming cycle, was clamped in place with 20 ft./lbs. torque at each of the sixteen hold-down points. The torque was readjusted and maintained throughout the forming cycle. Figure 22 shows Task D after forming. A maximum chord height of 3-7/16 inches was achieved without buckling. The change in gauge lengths and mechanical properties are recorded in Figure 23.

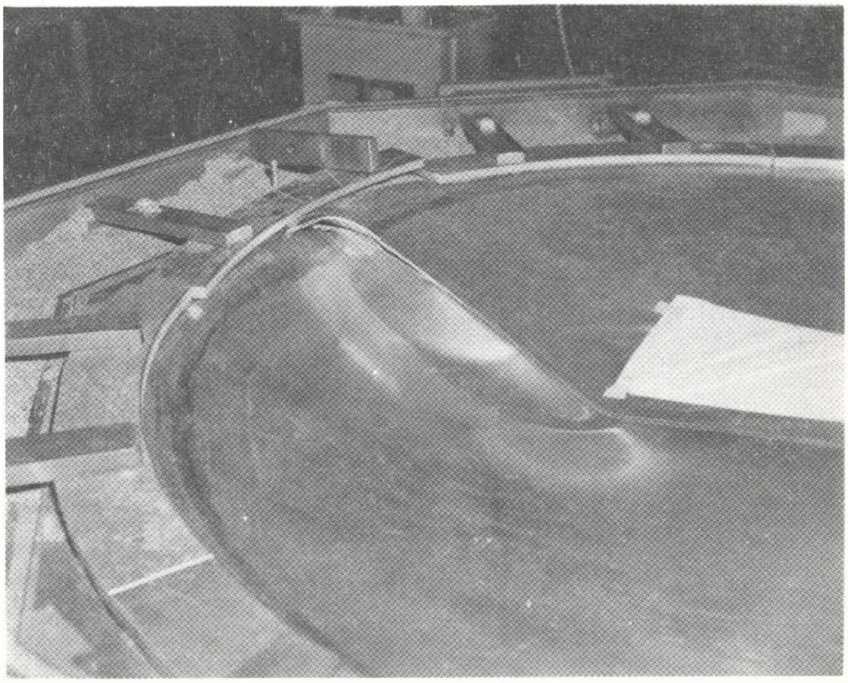


FIGURE 19

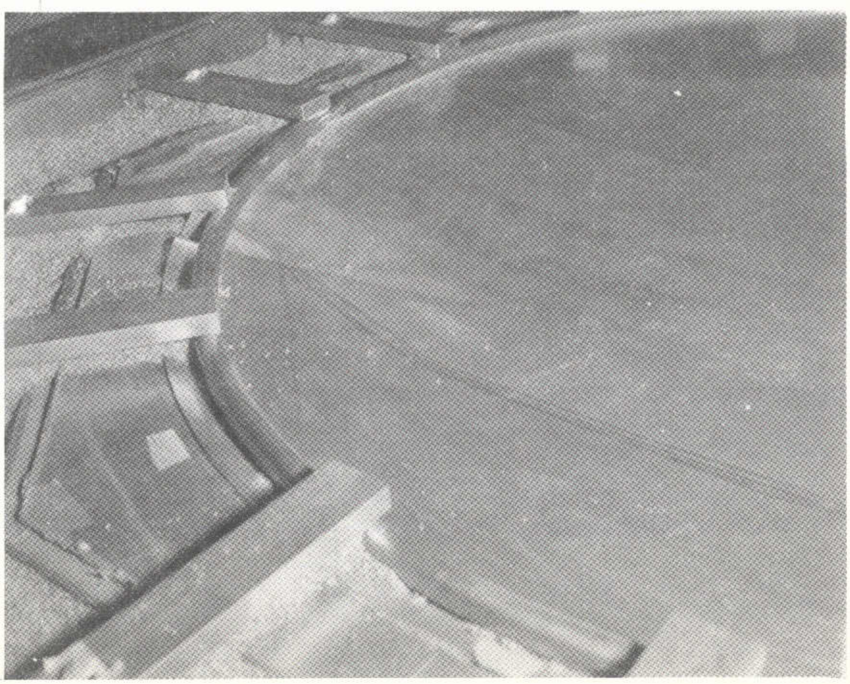


FIGURE 20

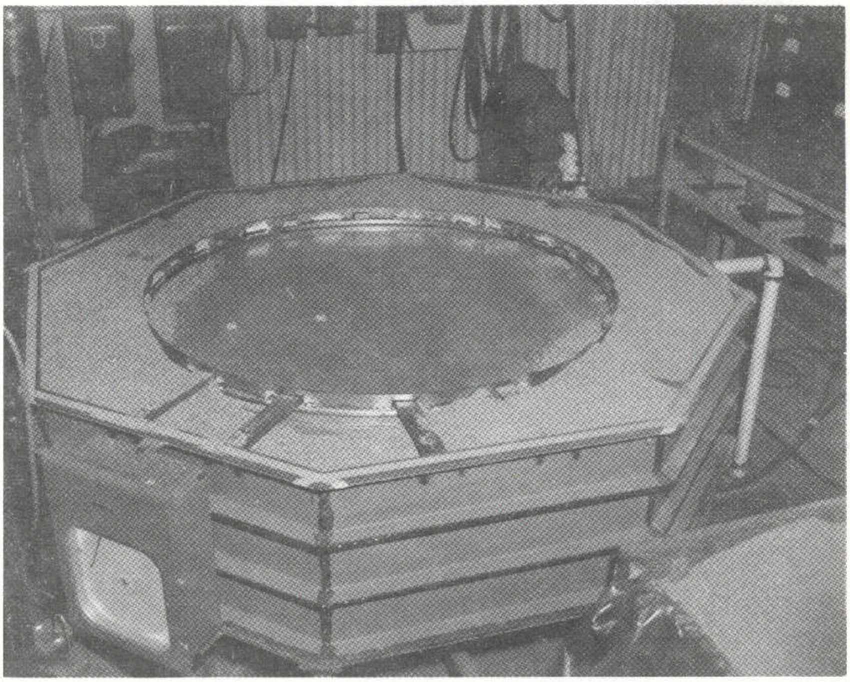


FIGURE 21

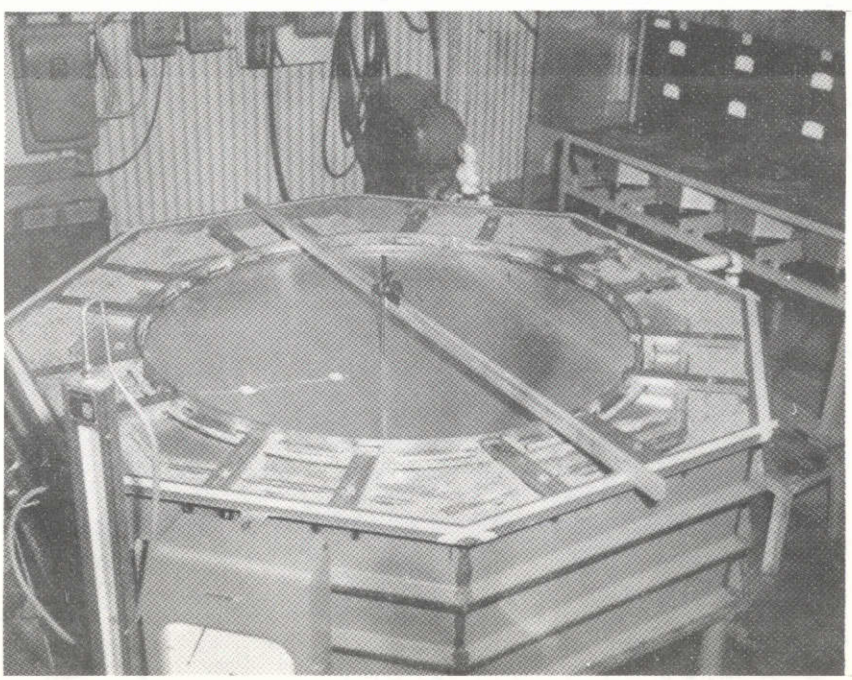
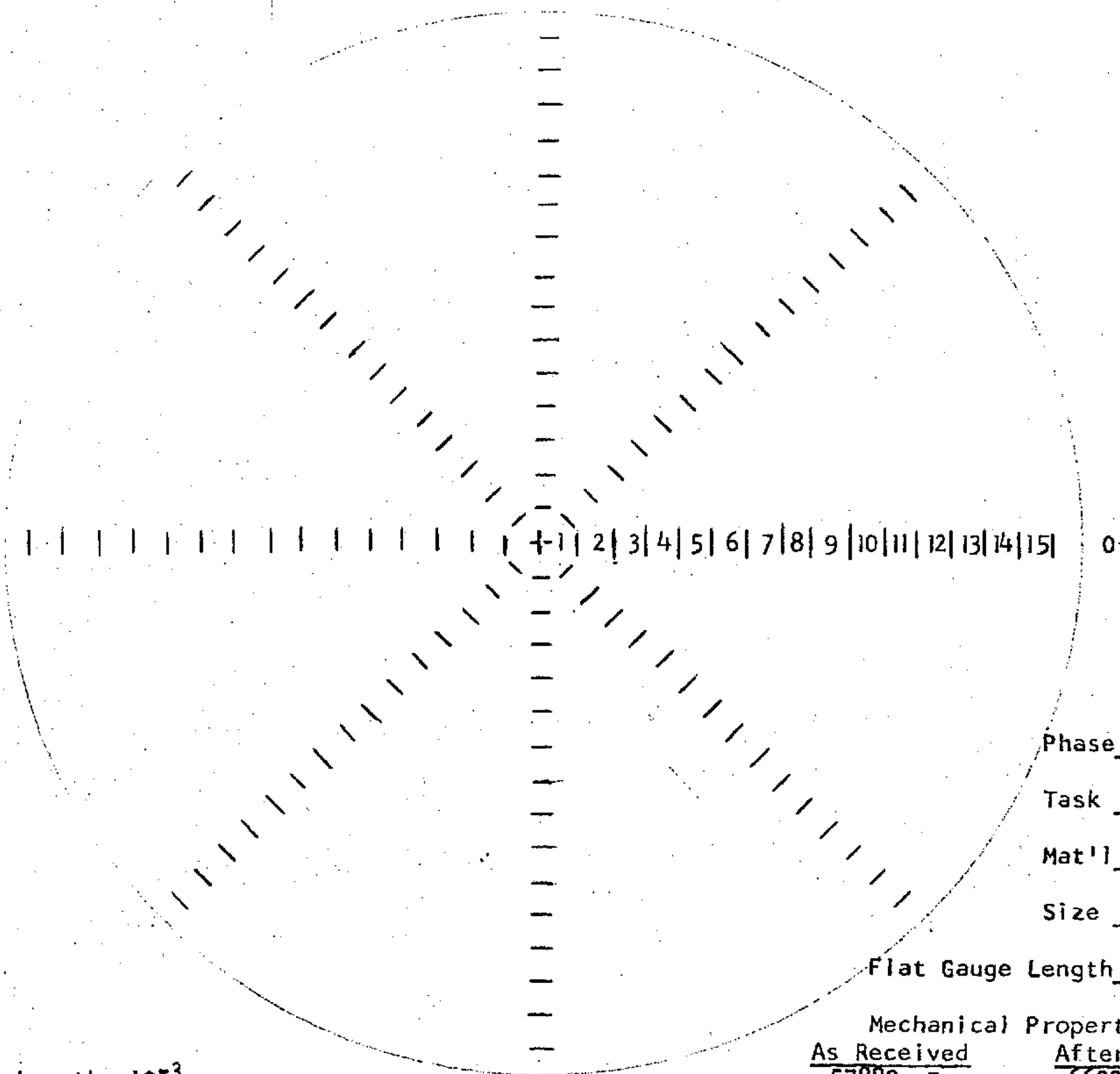


FIGURE 22



Phase II

Task D

Mat'l 2219

Size 58½ Dia.

Flat Gauge Length 2.00

Mechanical Properties:

As Received		After Forming	
57889	Ftu	66027	Ftu
47335	Fty	51790	Fty

Change in Length, 10^{-3}

Formed Contour Gauge Length (Starting at 0 Clockwise):

Area 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
5	15	5	10	5	10	5	5	10	30	20	10	20	10	
0	5	10	5	5	15	10	15	0	30	15	25	0	25	
-5	15	10	10	10	15	10	10	10	20	20	10	15	15	
-5	15	5	10	5	15	5	10	0	25	15	15	15	15	
5	5	20	10	5	25	5	10	10	15	15	25	5	25	
15	10	10	5	5	10	10	5	-5	25	5	25	-10	25	
10	15	5	5	-5	15	10	5	-5	25	15	15	15	15	
5	15	5	10	5	15	10	5	0	25	15	15	15	10	

FIGURE 23.

Task DD forming cycle ran with reduced clamping torque (18 ft./lbs.) to allow a limited amount of material movement into the contour. Figure 24 shows Task DD after forming. Buckling occurred at the ring in the weld area.

An additional blank was machined with a stepped cross section; the material was AVCO supplied. The stepped blank, Task E, had a cross section thickness of .125, .104, .083, and .062. The forming cycle used a clamping torque of 20 ft./lbs. Figure 25 shows the buckling which occurred in the stepped area during the forming cycle.

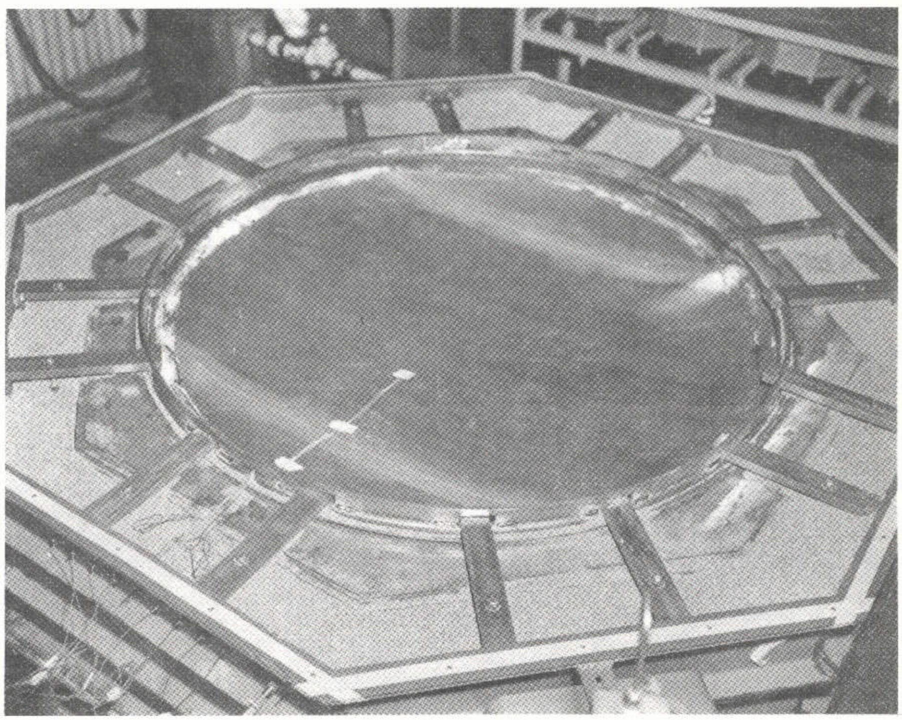


FIGURE 24.

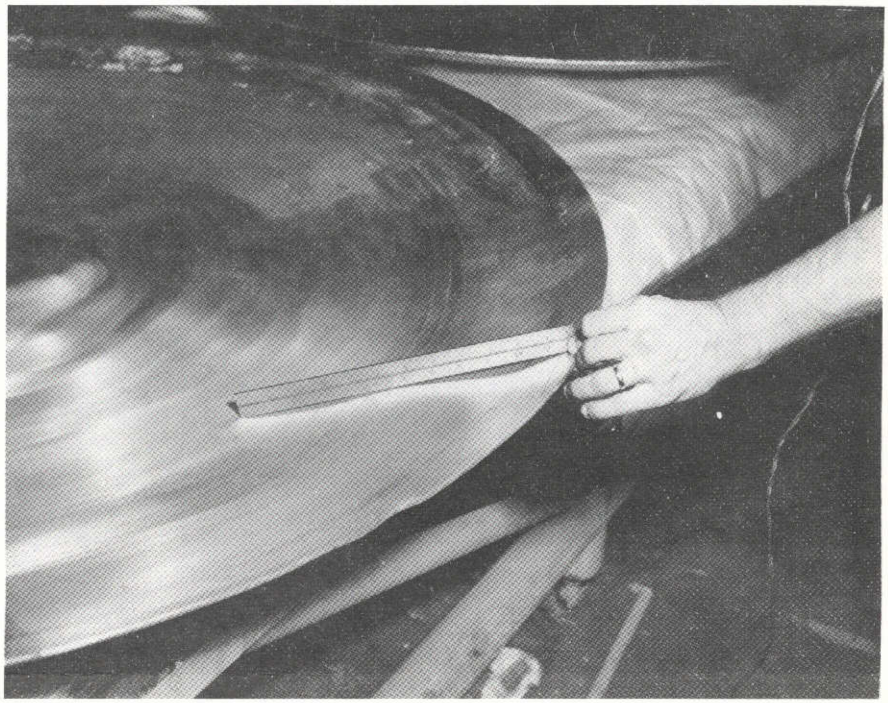


FIGURE 25

VII. CONCLUSIONS

Hot vacuum creep forming (HVCF) does not provide sufficient force to cause plastic strain to the degree required for the subject dome cap configuration. A compound plastic strain of 4.45 percent is required.

Allowing an excess of elastic flow into the die cavity results in severe wrinkling. This problem could only be resolved by providing a precise elastic flow control such as by a vice action at the blank edge. A hold-down ring was added to the HVCF die but could not be controlled to the degree required since the original tool concept did not consider this necessary.

The 2219 alloy, when starting in the T37 condition and artificially aging during forming, is believed limited to some two percent plastic strain by the HVCF method and the cross section contour should be eliptic not spherical. For reasons not yet fully understood, the center area of the work does not strain, hence it produces a flattening effect such as that with an ellipse. This effect is also true for the dome gores as observed during a similar program.