M.S.

ROHR
CORPORATION

ENGINEERING

REPORT

FINAL REPORT

NASA COMPOSITE BULKHEAD DEVELOPMENT PROGRAM

NASA CONTRACT NO. 8-11874

W. Gore
Senior Design Engineer

Report: 24-6003
Project: 301-00-0
Issued: March 1966

The report was prepared by Rohr Corporation under Contract No. NAS 8-11874, Development of Composite Bulkheads, for the George C. Marshall Space Flight Center, National Aeronautics and Space Administration.

SUMMARY

The purpose of this program was to establish the feasibility of manufacturing an adhesive bonded honeycomb sandwich bulkhead utilizing a bond cycle which would not only cure the adhesive but would age the face sheet weldments and also size them to their exact contours. The 57-inch diameter bulkhead produced under this program definitely confirmed that this method of manufacture is not only feasible but would probably provide a simplified method of bonding this type of structure.

The program included detail design of the finished article, development of the cure cycle, tool design and fabrication, construction, testing of the assembly, and final evaluation and inspection. Testing included radiographic evaluation of weldments, adhesive bonding process control specimens, ultrasonic testing of the bond, and rigid dimensional recording at various stages of construction. Materials used in the design of the bulkhead were basically specified by NASA. The bond tool, consisting of an aluminum casting, was of Rohr design.

During the final bond and creep-sizing operation of the inner skin weldment, the skin failed in tension, and although this problem prevented completion of a representative finished article, the

cause of this difficulty has been determined to be not related to the basic manufacturing concept under investigation. Failure was due to a design deficiency in the peripheral "Z" section edge member, causing the weld joints in this member to be stressed beyond their ultimate strength in the creep-sizing process, and precipitating similar failures in the adjacent skins.

CONTENTS

CONTENTS

FIGURES

FIGURES

1 / INTRODUCTION

A basic problem in manufacturing an adhesive bonded compound contoured sandwich structure is that the manufacturing tolerances inherent in the formed face sheets cause the pressure application to the bond glue line to be non-uniform. This problem results because the shape of the skins in a compound contour assembly causes the skins to be relatively stiff, and therefore variations from theoretical contour make these skins "bridge" in some areas as uniform pressure is applied during the bond cycle. Since the bond integrity is largely dependent upon intimate contact between face sheets and core, it is necessary under present manufacturing methods to carefully sculpture the core to accept slight variations in contour on face sheet assemblies. These methods are very costly, and still provide only an approximate fit, with the result that bond strength and skin loads are not uniform and possibly lacking in reliability.

This program is aimed at simplifying the manufacture of compound contoured sandwich assemblies, such as eliptical bulkheads, by exactly matching the inner and outer face sheets through a series of creep-sizing operations. This technique, if successful, would provide an exact fit between outer skin, core, and inner skin assemblies, and would thereby provide uniform bond pressures, and uniform bond strengths, while at the same time eliminating pre-load conditions in the face sheets.

2 / PROCEDURE ANALYSIS

2.1 ESTABLISHMENT OF DESIGN CRITERIA

NASA's Request for Quotation, Contract NAS 8-11874, Article I, Scope of Work, specified the product engineering requirements and the tooling concept for use on the program. Engineering drawings and tooling sketches were prepared by Rohr for the Rohr Proposal Document, and approved by NASA after placement of the contract. The engineering drawings (Figures 24 and 25) required a minimum of clean-up for approval. The tooling was approved on the basis of the original sketches and verbal clarification. Final design of the tooling was accomplished by Rohr during the material procurement lead-time period, and the resulting tool configurations were varied a little, without change in the basic concept, from what was earlier indicated (Figures 26 through 30).

2.1.1 BULKHEAD CONFIGURATION - Using materials, skin and core thicknesses, and basic dimensions specified in the NASA "Contract Scope of Work", Rohr developed a producible sandwich bulkhead configuration (Figures 24 and 25). The bulkhead shape is an ellipsoid, with the dimensional relationship $X^2 + 2Y^2 = 28.5^2$.

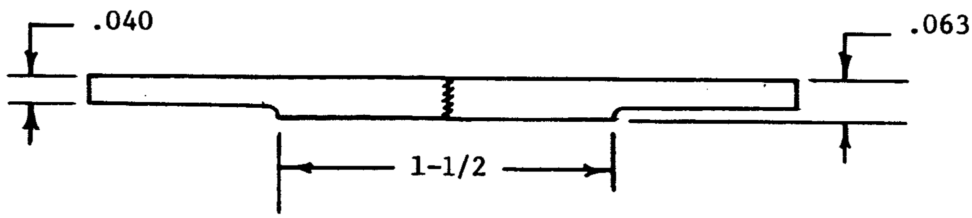
The skins were made of .063 thick 2219-T37 aluminum alloy, and were chem-milled in the field of each panel to a thickness of .040, while retaining .063 lands in areas to be welded. The sandwich core consisted of 1 inch thick heat resistant phenolic honeycomb with 3/16 inch cells. The inner and outer skin assemblies were each fabricated from 8 gores and a central circular panel, and welded together to form single piece shells. An .063 inch thick 2219-T37 aluminum alloy "zee" edge closure was welded to the inner skin assembly to simulate conditions which might occur in providing an attachment between the bulkhead and the tank side wall (see Detail "D" of Figure 24). The adhesive system selected by Rohr was American Cyanimide's HT424, and processing was in accordance with Rohr Process Specifications.

2.1.2 WELD JOINT DESIGN - Based on published data and established industry welding practices for thin sheet aluminum, a square butt joint weld design was established (Figure 1). Weld specimens were prepared and tested to confirm the adequacy of the weld joint, utilizing equipment, joint preparation, and settings which would be subsequently used on the full size bulkhead.

2.1.3 WELD JOINT EFFICIENCY - The configuration of the bulkhead skins included use of increased thickness weld seams to provide a strength of weld joint equivalent to the parent skin metal. NASA specified a maximum sheet thickness of .063 inch and instructed Rohr to develop a reduction of skin thickness that would satisfy the requirement of equivalent strength across welds.

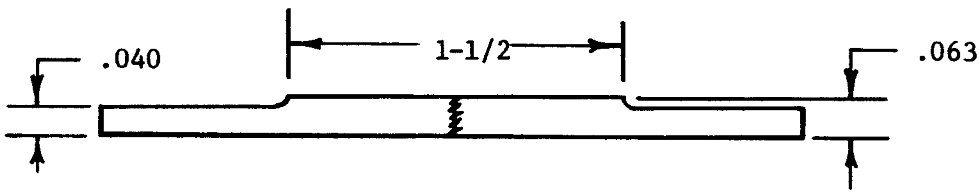
Results obtained from the weld joint tests noted in Section 2.1.2 were analyzed and the results used to determine the weld joint strength efficiency. This provided a ratio strength of weld joint to strength of parent metal that was used in determining a step from .063 inch to .040 inch required in the skin to maintain equal strength across welds (Figure 1). This step was obtained by chem-milling the central area of the skin gores to provide a 3/4 inch wide full thickness land on each side of the welded joints.

INNER FACING WELD JOINT

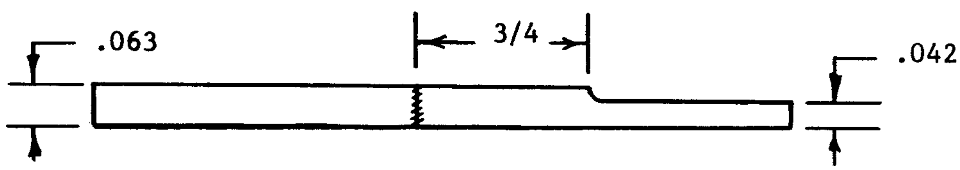


Skin to Skin and Cap to Skin Weld Joint

OUTER FACING WELD JOINT



Skin to Skin and Cap to Skin Weld Joint



Edge Facing to Skin Weld Joint

<u>Figure 1</u>

Square Butt Weld Joints
Used on Skin Assemblies

2.1.4 CREEP FORMING PARAMETERS - In order to successfully size the inner and outer skin assemblies during the bonding and aging cycle, the pre-forming contour was determined. The calculation was based on the criterion of limiting the maximum circumferential skin stress to a level greater than the yield stress, but sufficiently below the ultimate strength of the material during forming. It was, therefore, decided to strain the material approximately .8% (reference Figure 2) such that it would be in the low plastic range. As the strain rate for 2219-T37 material is 4-6% at ultimate stress, this margin of safety was deemed adequate for the bulkhead skins.

A one-inch strip of outer skin, with a diameter equal to the maximum diameter of the bulkhead, was considered as follows:

D_1 = Skin maximum diameter before creep forming

D_2 = Skin maximum diameter after creep forming = 57.00 inches

e = Strain = .008

ΔD = Elongation of diameter = $(D_2 - D_1)$

$$e = \frac{\Delta D}{D_1}$$

$$= \frac{(D_2 - D_1)}{D_1}$$

$$= \frac{D_2}{D_1} - 1$$

$$D_1 = \frac{D_2}{1 + e}$$

$$= \frac{57.00}{1.008}$$

$$D_1 = 56.597$$

A check was then made of the pressure required to stretch the skin to the contour of the die tool.

Assuming a minimum outer skin diameter of 56.50 (from the preceeding calculation), and to be conservative, a room temperature environment with the maximum outer skin thickness of .044 and maximum inner skin thickness of .068, a calculation was performed to establish the autoclave pressure required during a creep cycle, assuming both skins were sized at once.

F_Y = Tensile yield stress = 48,500 psi

P_Y = Yield pressure

D = Initial diameter of outer skin = 56.50

t = Skin thickness = .068 + .044 = 1.12

$$P = \frac{2\ t\ F}{D}$$

$$P = \frac{2 \times 1.12 \times 48{,}500}{56.50}$$

P = 192 psi

Therefore, any pressure greater than 192 psi would be adequate for creep forming the skins, and 200 psi was selected as the cure pressure.

STRESS-STRAIN CURVE FOR 2219-T37

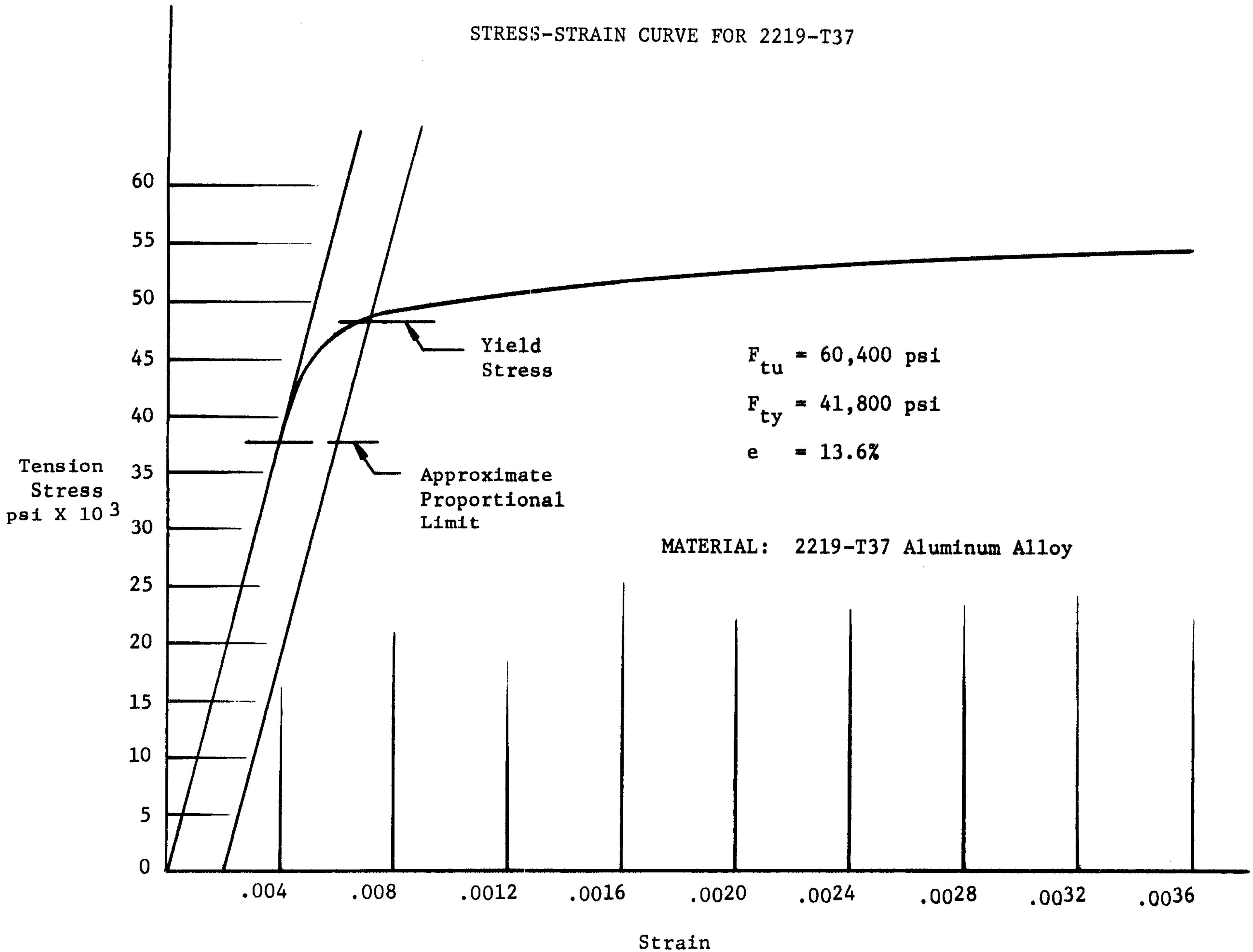


Figure 2

2.1.5 STRENGTH OF METAL BOND ASSEMBLY JIG - The 356-T6 cast aluminum bond jig was designed to include a wall thickness of two inches. This was considered practical for both production and handling, and would provide a stiffness that would preclude a dimensional change greater than .020 inches in the major diameter, assuming 200 psi autoclave pressure was required to form the skins.

NOTATION:

P	=	load	e	=	circumferential change
p	=	pressure	ΔD	=	diametral change
D	=	major diameter	E	=	Young's modulus
f	=	stress		=	10.3×10^6 for 356-T6 aluminum
ℓ	=	circumference			

Consider the conservative condition of 200 psi operating pressure acting in a room temperature environment on a 57-inch diameter ring of 1 inch width and 2 inch thickness:

$$P = \frac{pD}{2} = \frac{200 \times 57.00}{2}$$

$$= 5{,}700 \text{ Lbs.}$$

$$f = \frac{P}{A} = \frac{5{,}700}{1.00 \times 2.00}$$

$$= 2{,}850 \text{ psi}$$

$$e = -\frac{P\ell}{AE} = -\frac{5{,}700 \times 57.00}{1.00 \times 2.00 \times 10.3 \times 10^6}$$

$$= -.0495 \text{ inches}$$

$$\Delta D = -\frac{e}{\pi} = -\frac{.0495}{\pi}$$

$$= -.016 \text{ inches (contraction)}$$

2.2 EVALUATION OF MATERIALS AND PROCESSES

2.2.1 WELD PROCEDURES - In welding the bulkhead, selected processes and procedures were used as outlined below.

2.2.1.1 Type of Welding

a. Tungsten arc inert gas (TIG) welding - manual and automatic.

2.2.1.2 Cleaning

a. Prior to welding, all detail parts were chemically cleaned with double distilled acetone applied with a clean cheese cloth.

2.2.1.3 Weld Repair

a. Remove defects with rotary file
b. Radiographic inspect
c. Hand clean with double distilled acetone
d. Perform weld repair
e. Radiographic inspect

NOTE: NASA's repair procedure is the same as outlined except that the rotary file material is specified as carbide, and, in weld repairs, a buildup of 1/4 inch filler wire at the end of the weld is required. These items were incorporated into Rohr's weld repair procedure for this program.

2.2.1.4 Assembly (Typical both Skins)

a. Weld 8 gore skins to form 4 quarters.

b. Weld 4 quarters to form 2 halves.

c. Weld halves to form gore weldment assembly.

d. Weld center cap to gore weldment assembly.

e. Weld edge closure to inner skin gore weldment assembly.

2.2.1.5 Discussion

In welding the bulkhead assembly, both automatic and manual tungsten arc inert gas welding were used. Automatic welding was used in assembling the inner and outer gore skins; and manual welding was used for joining the cap, joining the edge closure to the inner skin weldment assembly, and for repairs. Weld settings shown in Table II of Section 2.2.2 were used in all automatic welding sequences. Pre-weld cleaning and weld repair were in accordance with Section 2.2.2.

To minimize porosity in the longitudinal welds of the gore skins, multiple pass type welding was used. In repairing for the remaining porosity, and also during the initial welding, distortion and warpage were constant problems. Manual re-forming of the parts after they were welded resulted in weld cracking, which led to another series of weld repairs. This cycle of weld, reform, and repair on thin gage material was a deterrant in obtaining a good quality product.

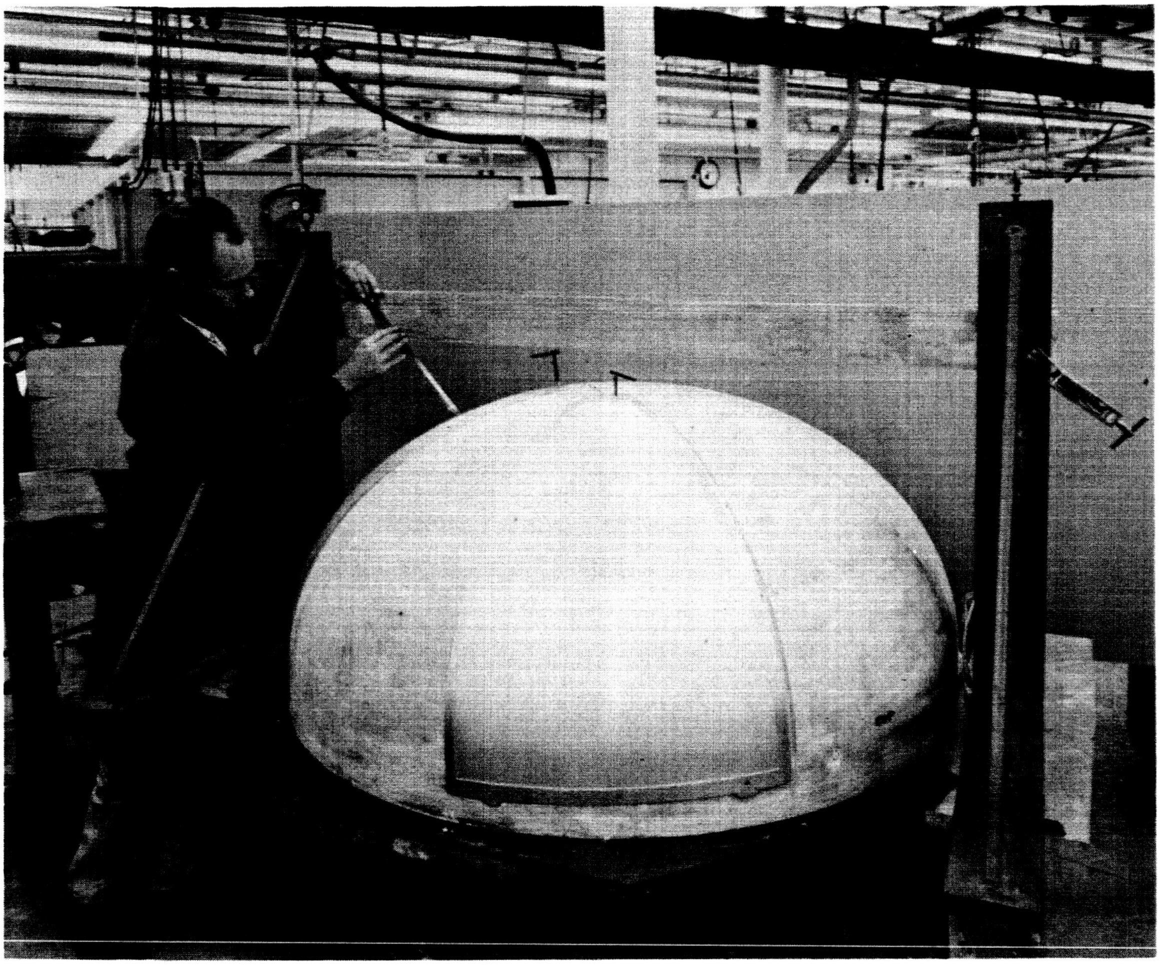
The skin gores used in the assembly were selected on the basis of their fit-up to contour and in some cases did not have good contour. The selected skins were placed on the weld fixture, as shown in Figure 3, and scribed for trimming of the excess material. After trimming, the gore skins were welded together on the plaster cast weld fixture. This fixture, shown in Figure 4, was mounted on a positioner and placed under the automatic welding head. The finished gore weldment assemblies are shown in Figure 5.

Welding of the outer gore skins produced a deviation in contour at the bulkhead center which required re-forming. This resulted in a repair that necessitated cutting back approximately 10-1/2 inches from the center opening on three longitudinal welds and re-welding.

The center panel was next added to the assembly after being trimmed, fitted, and tackwelded in position. However, the entire weldment did not adequately fit the fixture, causing a requirement for use of manual welding of the center panel. The shrinkage resulting from welding the center panel caused it to be out of contour. This was partially restored by the use of glass shot peening.

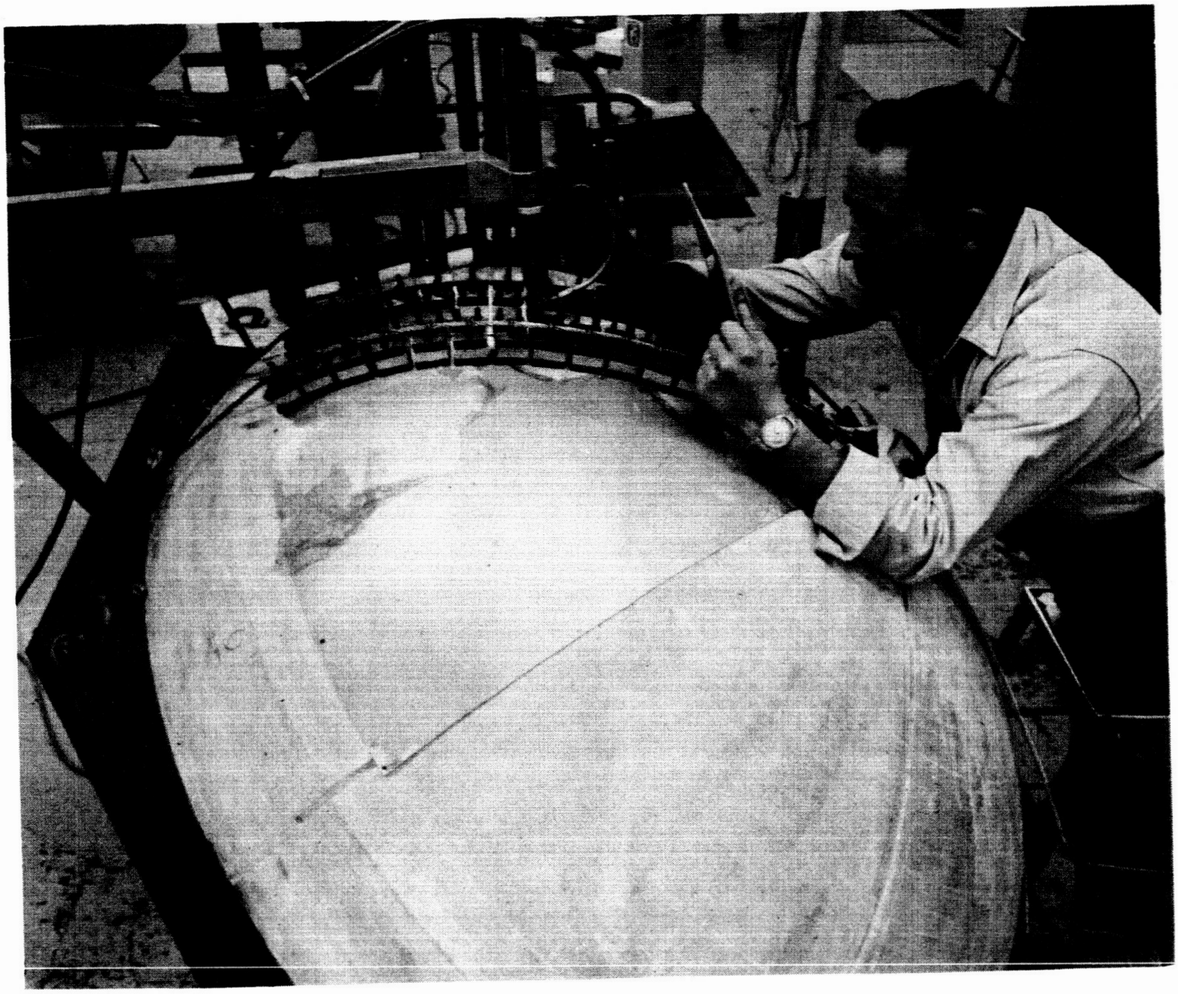
In assembling the inner skins, the same procedures were followed as in the outer skins. The same problems also became evident as the work progressed.

In making the closure between inner and outer skins, the edge member was tackwelded every six inches around the diameter using manual tungsten inert gas welding. This spacing was not sufficient to hold the parts to their mismatch tolerances and additional tackwelds were made every two inches. After completing three vertical welds on the edge member, closure of the gore assembly was obtained. This welding resulted in some distortion of faying surfaces at the point of closure which required the use of a hydraulic squeezer tool in straightening the assembly. While the finished bulkhead did contain weld porosity beyond the specification requirements, it was accepted by the Material Review Board.



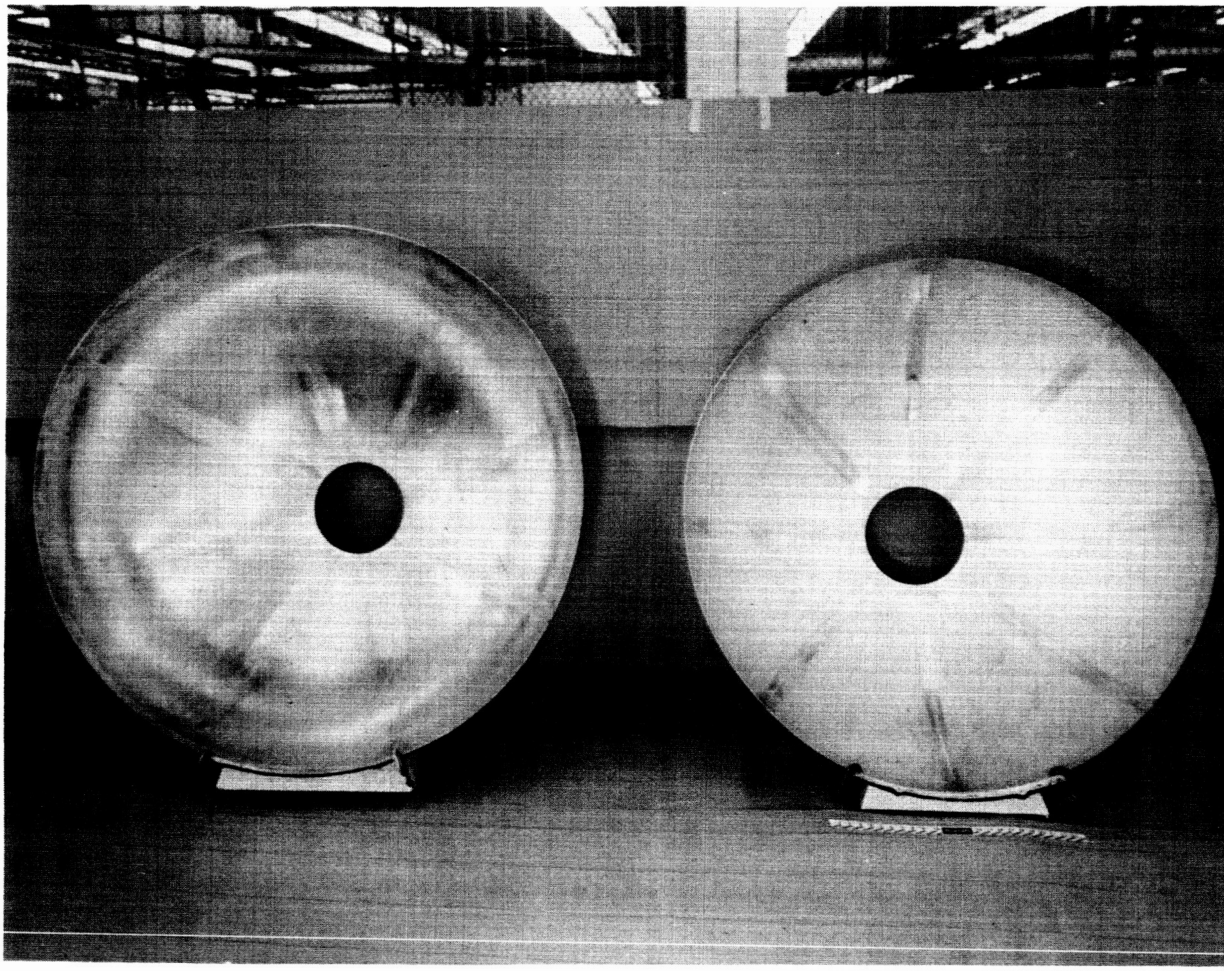
Scribing for Trim of Outer Skin Gore

Figure 3



Welding Skin Gores

Figure 4



Outer and Inner Skin Gore Weldment Assemblies

Figure 5

2.2.2 WELD TESTS - Tensile test specimens were made in both the welded and non-welded conditions. A square butt weld joint was used for the test specimens (Figure 1). This joint was selected based on Rohr's past experience with this material, and because of its applicability in this type of assembly.

The following tensile test specimens were made:

a. Parent metal in the as-received condition, 2219-T37.
b. Parent metal in the age-hardened condition, 2219-T87 per the specified fabrication thermal cycle.
c. As-welded condition, 2219-T37 per fabrication cycle.
d. As-welded and aged condition, 2219-T87 per fabrication cycle.

The results of these tests are shown in Table I. In preparing and welding these specimens, the equipment used was the same as used for the production bulkhead. The process used, such as weld settings and joint preparation, was the same as used in producing the finished assembly (See Table II).

TABLE I

	SPECIMEN/CONDITION	ULTIMATE STRENGTH psi	YIELD STRENGTH psi	ELONGATION IN 20" (%)	FAILURE AREA
a.	Parent Metal T-37 (.063 thick)	60,400	47,100	13.6	-
b.	Parent Metal T-87 (.063 thick)	67,800	54,000	8.8	-
c.	As-Welded T-37	58,300	55,000	11.0	Chem Milled Area (.040 thick)
d.	Welded & Aged T-87	67,800	56,500	8.7	Chem Milled Area (.040 thick)

TABLE II

Weld Process	Automatic TIG
Material Type	2219 Aluminum
Material Thickness	.062 inch
Position of Weld	Flat
Filler Material	2319 Aluminum -1/16 inch diameter
Electrode Type	2% Thoriated Tungsten
Shielding Gas	Argon
Backup Gas	None
Current Type	AC
Amperes	90
Arc Voltage	6
Weld Speed	14 ipm

2.2.3 FORMING PROCEDURES - The individual gore sections of the outer skin were separately stretch formed to obtain the required contour, as shown in Figure 6. This cold stretch forming of the 2219-T37 material proved to be difficult when using net contour tools.

To effectively accomplish this operation, the material had to be stretch formed very slowly in order to prevent tearing of the material. Approximately 7-10 minutes of actual stretching time was required for each gore to prevent tearing.

The stretching developed residual stresses in the parts to such a degree that after the excess material was trimmed off, the parts went out of contour approximately .050 inches. The subsequent chem-milling operation further relieved these residual stresses, causing the parts to become a total of .150-.200 inch out of contour. Extensive hand forming was required to make the contour of the gores match the weld jig.

To alleviate this problem, stretch dies should be developed that are approximately .250 inch undersize. An alternate solution is to fabricate stretch dies that include provisions for heating and will permit hot forming of the skins at the highest temperature level which would not adversely affect the properties of the material during the operation.

2.2.4 FORMING TESTS - Since the fabrication procedure for this bulkhead included a combination of sizing, bonding, and aging cycles, it was found desirable to determine the location, extent, and type of joint deformation that could be expected.

To determine this deformation, tensile weld specimens were prepared and scribed in one-half inch increments on either side of the weld. The specimens were loaded in tension to a nominal 0.8% strain, and the load was then removed. The percent elongation remaining in each one-half inch increment was measured and the results recorded as listed in Figure 7. From the data obtained, it was evident that deformation would not be completely uniform throughout the weld joint. It was also evident that the area of maximum deformation could not be predicted. The weld joint, however, did possess adequate overall ductility, and did indicate sufficient strength.

Efforts were also directed at simulating the creep action that would take place during the elevated temperature and bonding cycles. In order to simulate this creep action, tensile weld specimens were strained to a level representative of that to be used in the bonding cycle. The specimens were then heated to 350°F and held at this temperature for one hour.

Results of this constant creep test showed that approximately 0.5% permanent elongation could be achieved. The conclusions drawn from these forming tests are summarized as follows:

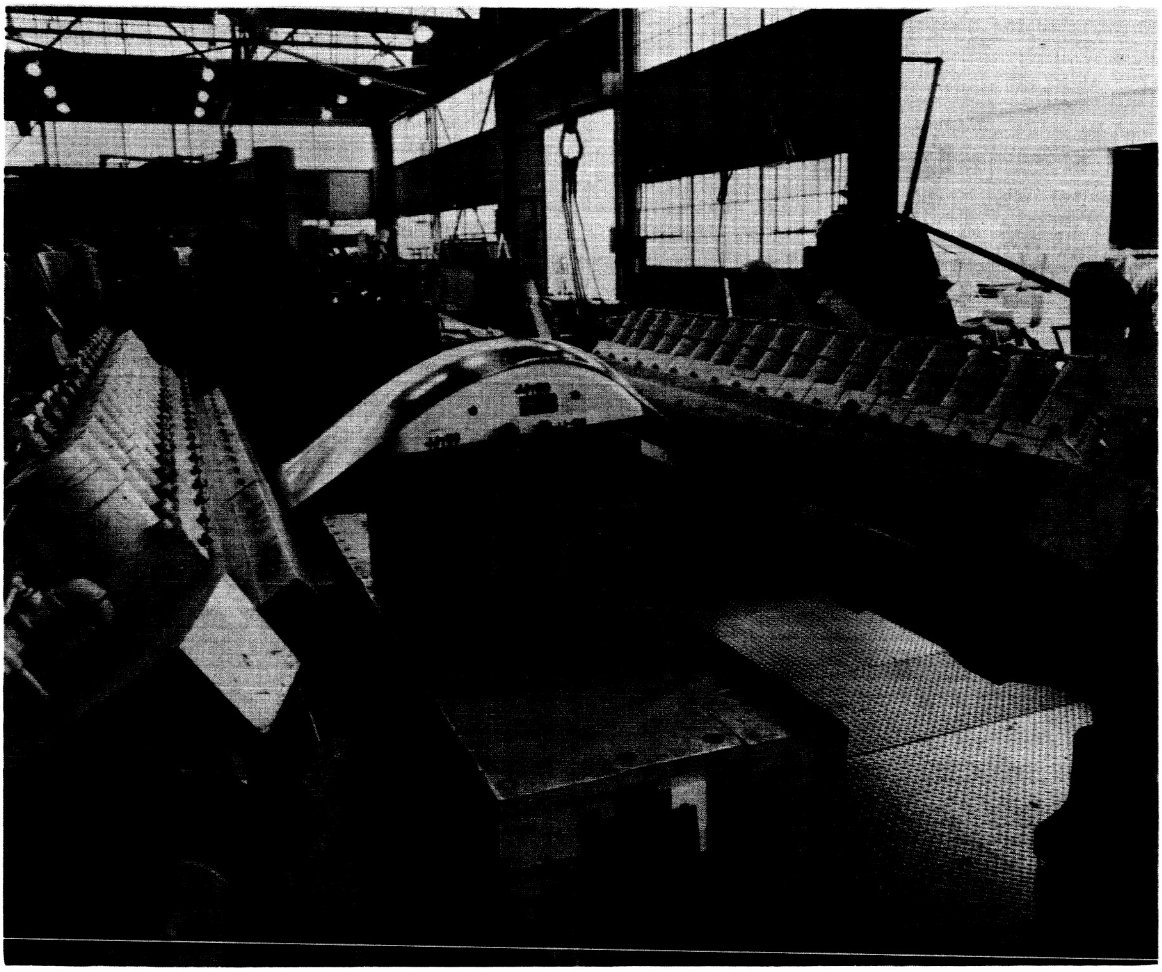
a. The weld joint will not develop uniform stretching, but the expected deformation will be satisfactory for the sizing operation.
b. The weld joint is strong enough to cause creep forming to occur in the parent material outside the weld zone.
c. The bonding and/or sizing operation at 350°F for one hour will produce creep forming in the order of approximately 0.5%.

The pre-fit of the HRP core gore sections into the outer skin for bonding proved difficult (Reference Figure 8). The core node bond failed in areas of greatest stress when the segments were forced into shape with the skin.

Interlocking core splicing was tried, but this was found to be impractical. Core gore sections were then butt-joined using Thermofoam 607, Type 2, forming type adhesive. The joints that showed excessive separation when the segments were pressed down to the skin were then spliced by placing strips of core over the joint and pressing them into the segments. The splice joints which did not fill during the cure cycle were then completed with potting compound. Potting compound was also used to stabilize the core in the closure transition areas.

The M-319-B potting compound was primarily formulated to stabilize the core transition area where it fays with the bulkhead closure member. Several possible formulations were evaluated for this use. Compressive strength, density, and handling properties were considered in the selection of this compound. The following are the average test values of the various compounds which were considered. The material selected was M-319-B.

Compound	Cure Cycle	Compressive Strength (PSI) Room Temp.	Compressive Strength (PSI) 350°F	Density
X-179	1 hr. @ 350°F	15,331	4,105	1.4
X-179	1 hr. @ 250°F	13,800	651	1.4
X-187	1 hr. @ 250°F	20,059	3,104	1.2
M-319-B	1/2 hr. @ 170°F plus 1 hr. @ 250°F	10,719	2,200	0.84



Stretch Forming a Skin Gore

Figure 6

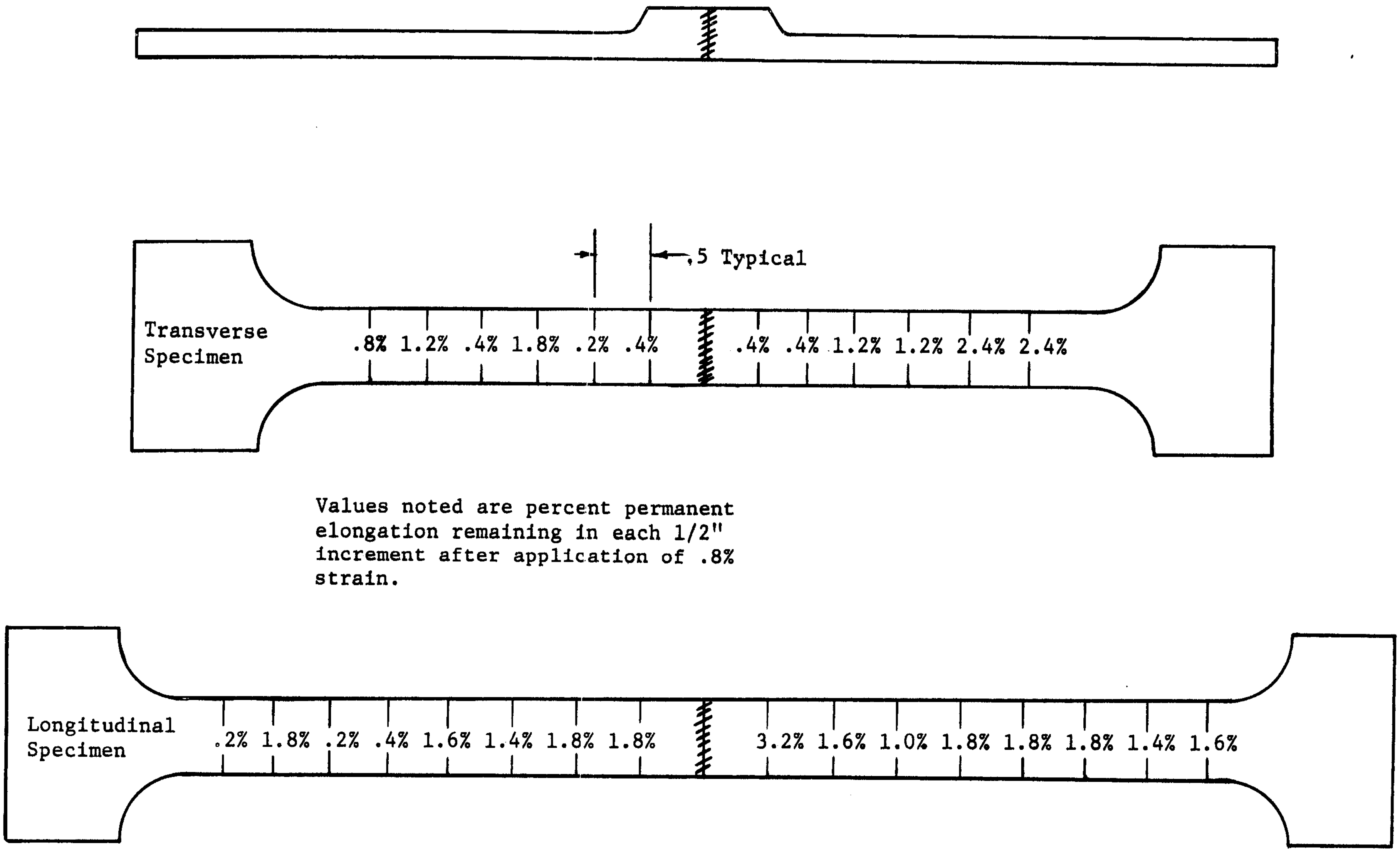
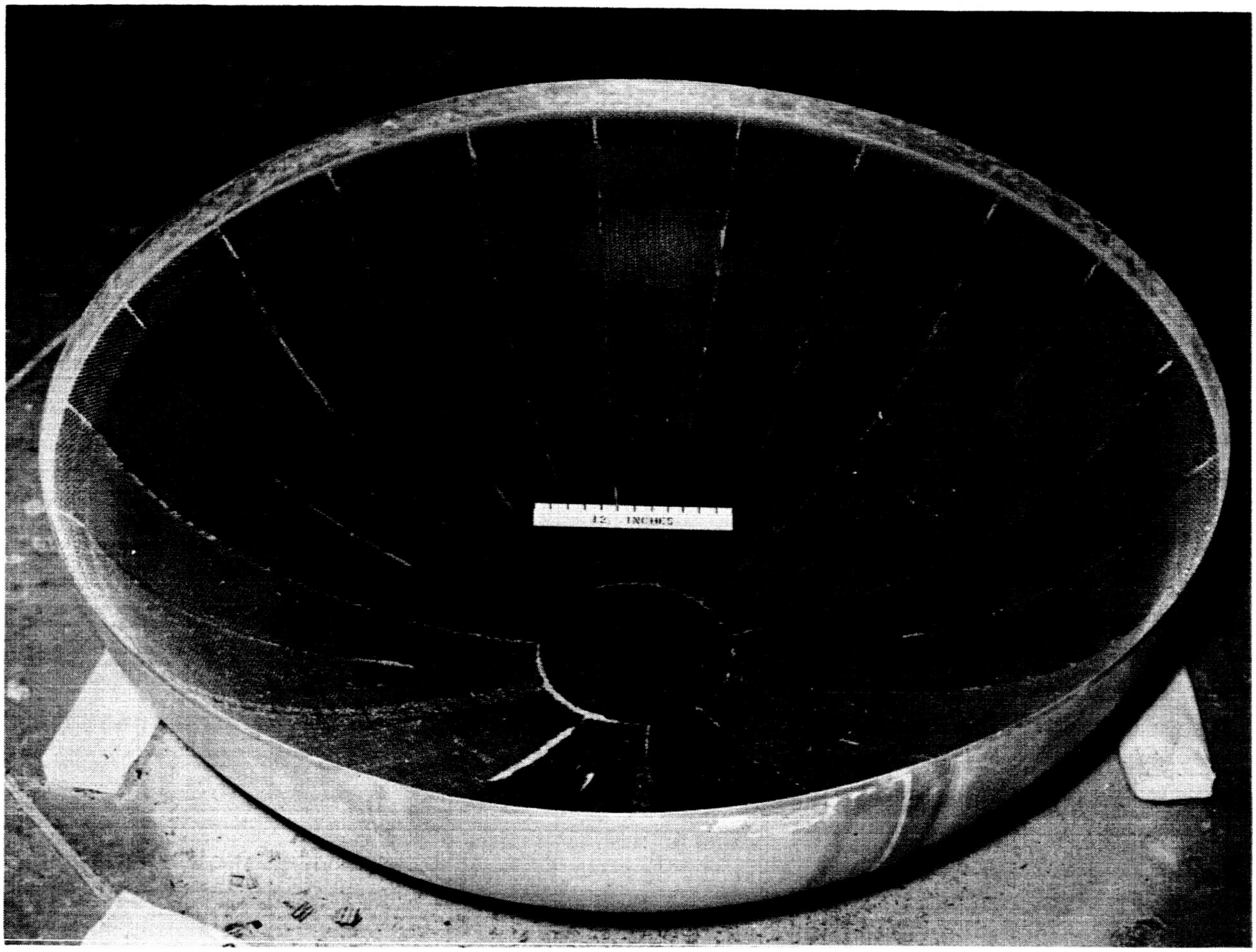


Figure 7

Percent Permanent Elongation of Welded 2219-T37 Aluminum



Multipanel Honeycomb Core Prebonded to Outer Skin

Figure 8

2.2.5 DETERMINATION OF ADHESIVE - The bonding system selected for the program had to possess curing and cured characteristics compatible with the time and temperature cycles presented in Section 2.2.9. Bloomingdale's HT-424 supported film and HT-424F primer was found to be most satisfactory, and was specified by Rohr to be used in the bonding of the bulkhead.

The HT-424 supported film weighed .135 PSF, and was manufactured in accordance with MIL-A-25463. Thermofoam 607, Type 2, foaming adhesive was also used in the peripheral transition area. This adhesive system is capable of supporting a 22-hour aging treatment at 335°F.

The HT-424 adhesive system, however, is volatile and could cause collapse of the core internal cell and/or bond delamination unless vent holes are provided for gas escape. While the particular core material used was perforated (Hexcel Products, HRP 3/16", GF perforated 1A-5.5 x 1.00" thick per MIL-C-8073), the perforations were not sufficient to allow for the necessary escape of gas. The core itself was slotted, however, to aid in the forming operation and these same slots served to provide an adequate means of escape for the gas generated during the curing cycle.

2.2.6 DEVELOPMENT OF CORE PRE-FIT - The core material prior to forming to contour was machined to net thicnkess in standard 18-inch widths. Contouring of the core was performed by heating the core segments in an oven and then forming them in a punch and die setup. The core was held to contour in the tool until it was cool and rigid. The core segments were then trimmed to a pie shape, slightly oversize to allow for proper fitting. It was also found that slotting sections of the core facilitated fitting the core material against the outer skin.

2.2.7 DETERMINATION OF CORE STRENGTH - In addition to the above tests, the bare compressive strength (F_c) of HRP was also determined on non-perforated, perforated, and non-perforated-slotted core. This testing was done in accordance with MIL-STO-401A, and the results were as follows:

Type of Core	Average F_c (PSI)
HRP non-perforated	766
HRP perforated	744
HRP non-perforated-slotted*	600

*NOTE: Cross-hatched slots 1/4 inch deep were cut across the face of the core in lieu of perforating as a vent.

It is recommended that further studies be performed on the advantages of perforations in HRP honeycomb core for adhesive bonding. Various types of perforations are conceivable, but the mechanical properties are altered accordingly, and must be correlated with the design parameters involved.

The pot life of X-187 at room temperature was found to be approximately twenty minutes as compared to 3-4 hours for M-319-B, and therefore possessed tendency toward slumping. The longer pot life, coupled with the low density of M-319-B, made it attractive for use.

Two tests performed on the slumping characteristics of M-319-B in 3/16-inch-cell HRP core are as follows: Two specimens of core were machined to represent the transition section in the bulkhead, and filled with the potting compound. The first test specimen core was positioned in a 170°F temperature air circulating oven in an attitude representative of the position it would be in the bulkhead. Curing was then performed for one hour at 170°F. The second test specimen was allowed to cure overnight at room temperature, then placed in an oven in the same manner as the first specimen, but cured for one hour at 250°F temperature. Both specimens exhibited some slumping, but were acceptable.

2.2.8 BONDING PREPARATION DEVELOPMENT - Standard chemical cleaning methods for 2219 aluminum include an alkaline cleaner, water immersion, and a sodium chromate etch followed by a water spray. These methods were not considered practical because of the size and shape of the bulkhead skins.

To provide an adequate cleaning method, an abrasion technique using fine grit aluminum oxide paper was tested and compared to the chemical etch method. Lap shear tests were run in accordance with MIL-S-5090E, Table I, Test No. 1, and the test values for both methods of cleaning were in excess of 5000 psi. The abraded specimens, however, showed slightly higher values.

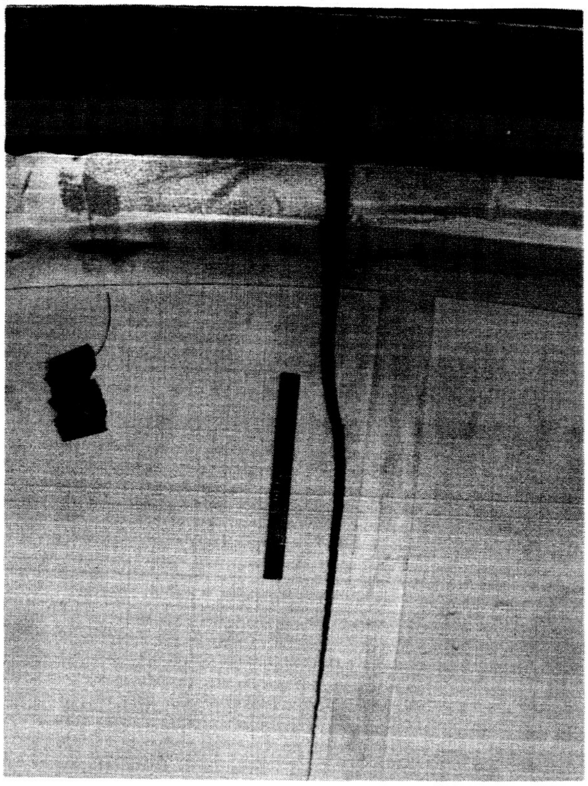
This abrasion cleaning technique consisted of scrubbing the surface of the skin with a 400 to 600 grit aluminum oxide abrasive paper until a bright, even appearance was attained. The residue was then washed free with clean shop wipers saturated with MEK, then wiped with dry shop wipers before the MEK had evaporated. Inspection for a water break free surface was done using distilled water. The subsequent bonding operation was conducted within 8 hours of this cleaning operation.

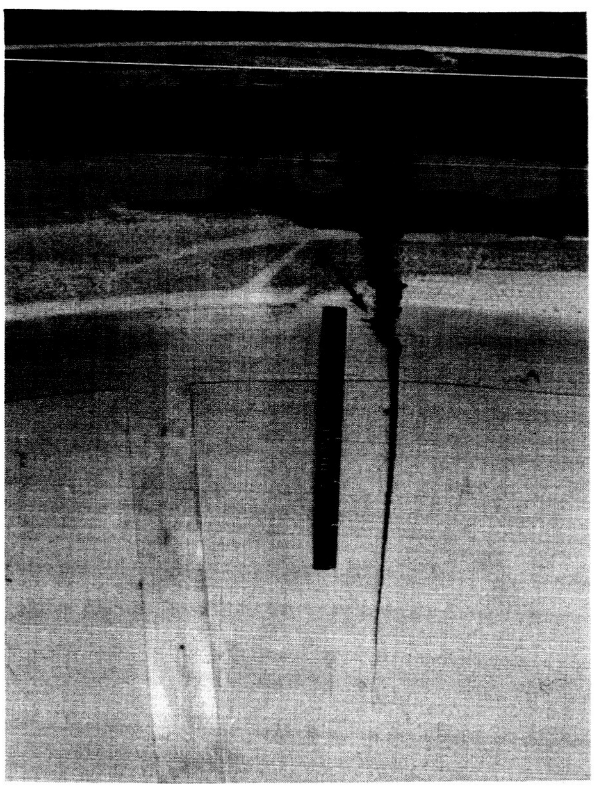
2.2.9 BOND CURE AND CREEP FORMING CYCLE DEVELOPMENT - It was the objective of this phase of the program to establish a curing cycle which would allow the part temperature and the autoclave temperature to be increased at the same time.

The following cure cycle was developed:

a. Increase the temperature of the part at a rate of 2 to 3°F per minute while simultaneously increasing pressure at a rate of 3-4 psi per minute until a pressure of 195 psi is attained. Apply both the heat and pressure such that the part temperature shall not exceed 225°F before the pressure has reached 195 psi.
b. Increase the temperature at a rate of 2 to 3°F per minute until the cure temperature of 350° $\pm$ 5°F is reached, then cure at this temperature for one hour $\pm$ 5 minutes.
c. Reduce the pressure at a rate of 4 to 5 psi per minute until atmosphere pressure is reached and reduce temperature to 150°F or less before removing the part from the autoclave.
d. After removal of the part from the autoclave, move the entire unit into a convection heated oven, and immediately apply a full vacuum of 28 inches Hg, and quickly raise the temperature to 325°F.
e. Hold at this vacuum and heat for 21 hours.
f. Cool to a temperature of 150°F, take the part out of the oven, and remove vacuum bag and bleeder cloth.

When the bulkhead was subjected to the above cure cycle, the weldments in the closure ring failed and cracks propagated into the skin in three places (See Figure 9 and Section 2.7 for discussion of this problem.). The cure cycle was completed, however, with the exception of the 21-hour aging at 325°F under vacuum.





Failure in Weld Joints of Peripheral Zee Edge Members (Arrow A) Showing Cracks Propagated into the Inner Skins (Arrow B)

Figure 9

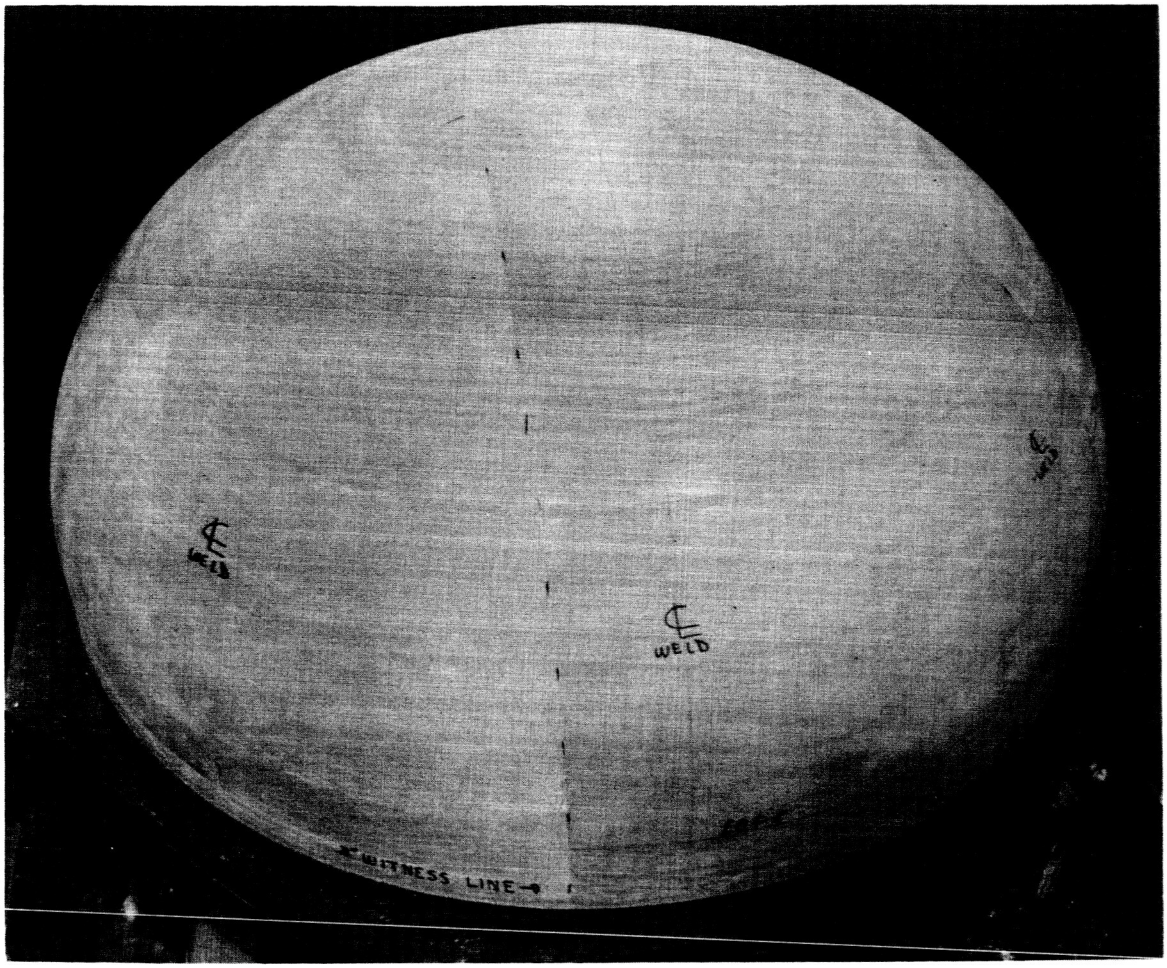
2.3 DESIGN AND FABRICATION OF TOOLS

2.3.1 TEMPLATES - The following contour templates for fabricating tools and checking the assembly were established and machined by numerical control methods using the formula furnished by NASA:

a. Outer and inner skin templates, developed undersize to allow for expansion during creep sizing, were used for fabricating the outer and inner skin master models.
b. A net male template with a setback allowance was used to check the outer and inner skins after expansion (Figure 11).
c. A net female template was used to check the completed assembly.

2.3.2 MASTER MODELS AND WELD JIGS - Full size plaster models were made to control contour of inner and outer skins (Figure 10). Both models were spun to contour using undersize templates described above. All skin net trim lines were layed out and scribed on each model, and stretch form and trim tool contours were taken from these models to produce the detail parts.

After all detail tools were coordinated to the models, the models were reworked into weld jigs (Figures 26 through 28). The plaster was relieved in the area of the weld joints to allow for gas backup. The model base plate was adapted for use on a standard weld positioner (Figure 4). Hold-down feet clamped the skins to the weld jig.



Plaster Form Tool

Figure 10

2.3.3 STRETCH DIES - Net skin stretch dies were made by taking plaster casts from the models, applying a plastic coating to the cast, and attaching a metal base plate for mounting the die on the stretch press (Figure 7). Due to problems encountered by the parts going out of contour after trimming and chem-milling, it is recommended that future dies of this sort either be developed undersize or made of a material such as Kirksite with heating rod inserts to allow hot forming of the parts.

2.3.4 STRETCH BLOCK - A stretch block was made to net contour for stretch forming of the zee closure member. A set of close tolerance rolls were made first in an attempt to roll-form the zee. Severe wrinkles developed in the inner flange due to the extreme compressing of material during roll-forming, with the result that the final contour was unsatisfactory. A stretch-form operation was substituted, and satisfactory parts produced.

It is recommended that the die be developed to accommodate material springback or be replaced with a die capable of hot forming.

2.3.5 DROP HAMMER DIES - Kirksite drop hammer dies with lead punches were used to form the circular center skin panels. A plaster die pattern made from the models was used as a pattern to cast the dies. The part was drop hammer-formed in the "O" condition, then solution heat treated and reformed in the "SW" condition to remove heat treat distortion.

2.3.6 DETAIL TRIM & CHEM MILL TOOLS - Plastic laminate tools coordinated to master models were used to scribe the trim and chem mill lines on the parts. The chem mill lines were developed to allow for "etch-back" of material during the chem milling in order to produce the land area required.

2.3.7 BOND JIG - A cast aluminum bond jig made per tool design (Figures 29 and 30) was used to support the assembly during creep forming of skins and bonding of the parts. The bond jig was machined to contour on a lathe using a tracer head attachment indicating from a net template.

The top of the bond jig was machined flat in relation to the contour so the contour check template could index to this surface and be rotated to any required position. In addition, this surface was used as a guide surface for scribing the trim of the welded skin assemblies (Figure 12). Filler plates of .020 inch thick, 2024-0 aluminum, formed to the configuration of the indented chem milled area of the outer skins, were made to support these indented areas when pressure was applied.

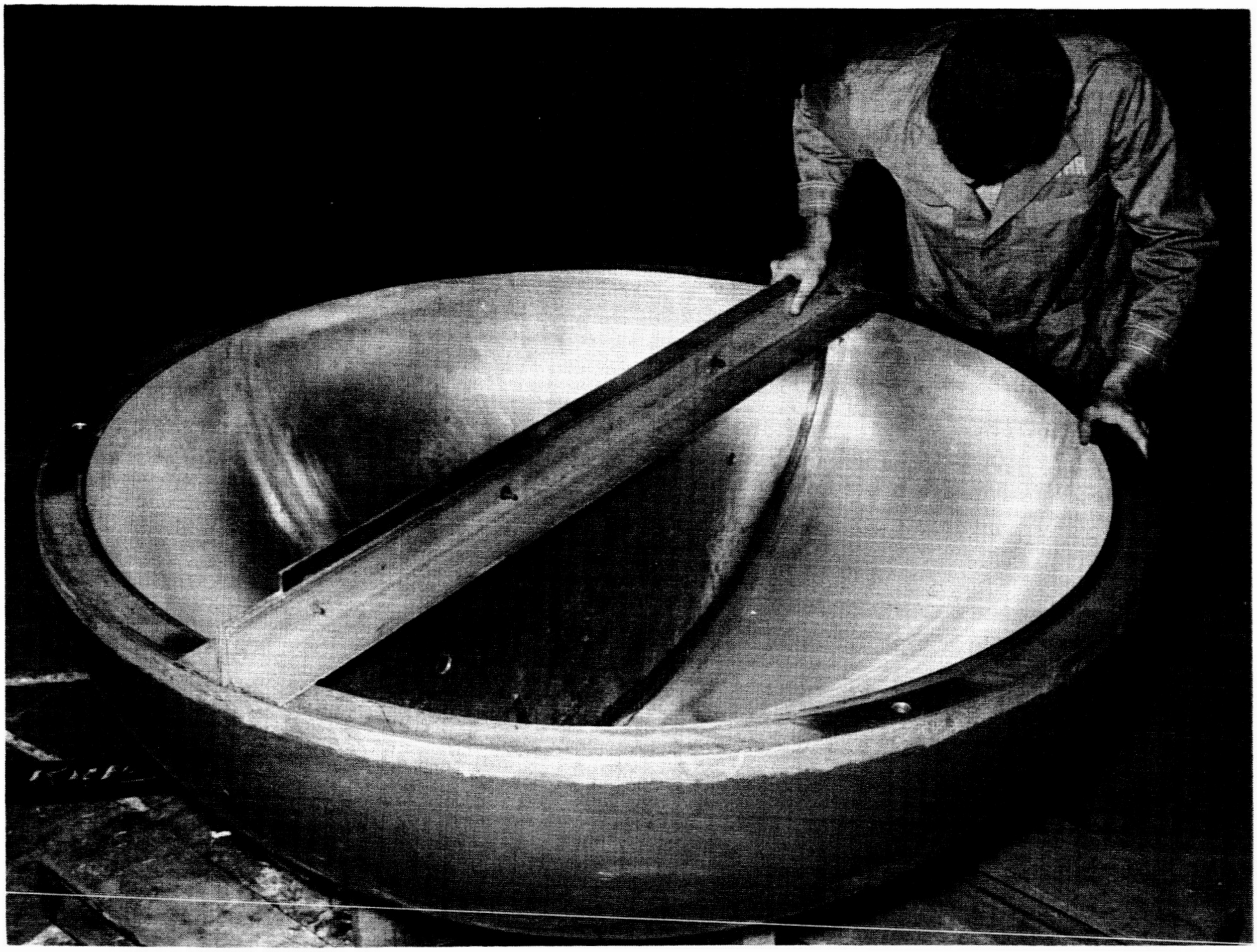
Cast aluminum is naturally porous, so, in order to enable the bond tool to retain the required pressure, the bond tool outer surface was sealed as follows:

a. The complete exterior surface of the tool was scrubbed with toluene, and air dried until there was an absence of solvent odor. Radiant heat was used to accelerate the drying.
b. Bleeder cloth and vacuum retention material was applied to the entire inner machined surface of the tool.
c. A full vacuum (28-inch Hg, minimum) was applied to the inside of the vacuum bag and inner tool surface through four vacuum outlets. A vacuum gauge was positioned at 180 degrees across the tool from one of the outlets.

d. One coat of DC 1200 primer was applied to the complete exterior surface of the tool approximately .001 thick. (NOTE: The color of the applied coat of primer must be bright pink in color. A colorless or weak pink coating indicates too thin an application.) The tool was air dried for one hour.
e. A 1/16 inch thick coat of DC 589 sealer was applied to the entire exterior of the tool. Leak paths were checked and additional sealer applied until leakage was stopped.
f. Full vacuum was maintained and the tool was then cured at ambient temperature for 24 hours.
g. Just prior to use in production, the tool was proof checked at working pressure for vacuum and pressure retention.

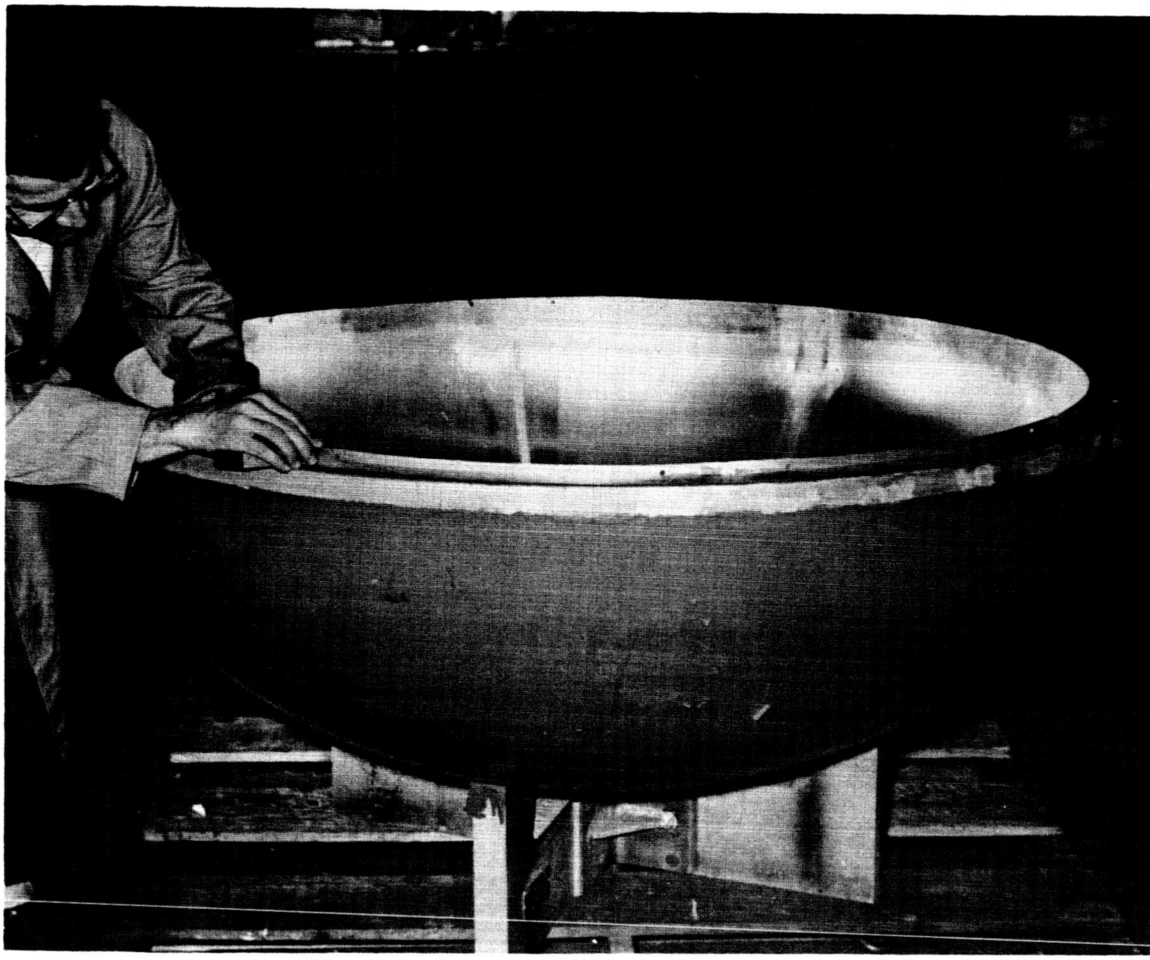
The bond tool fabricated for this project varied from the NASA concept of the bond tool in that cast aluminum was used instead of the aluminum-seed, resin-binder material which would have produced a much more porous tool. The intent of the NASA concept was to put vacuum outlets on the outside of the tool and pull a vacuum through the face of the tool. The NASA concept was not attempted because of the cure cycle requirement of 25 to 30 hours at 350°F temperature. Also, the specified 200 psi operating pressure is beyond the recommended use of the resin binder required to hold the glass beads to the contour required. (NOTE: According to Furane Plastic Company's Bulletin EP-59-69, Model 2, porous bonding fixtures using their prescribed materials have a maximum service temperature of 250°F.)

The bond tool maintained contour to design requirements during all heat and pressure ranges required by the manufacturing plan for this project.



Checking Outer Skin with Contour Template

Figure 11



Scribing for Edge Trim of Outer Skin

Figure 12

2.4 BULKHEAD FABRICATION PROCEDURE

2.4.1 MANUFACTURE AND STRETCH FORMING OF SKIN GORES - Both the outer and inner skin sections of the bulkhead were fabricated in basically the same manner. Both sections consist of 8 gore sections and a circular center panel all of which are subsequently joined by welding.

Prior to the welding operation, each individual gore section was stretch formed to the desired contour as previously described in Section 2.2.3. After the gore sections were properly stretch formed they were chem-milled over the central areas to a reduced thickness.

After chem milling was completed, each gore section was positioned on a plastic form where it was scribed for trimming the excess material. This scribing operation of the outer skins is shown in Figure 3.

2.4.2 WELDING OF SKINS - After the individual outer and inner gore sections were trimmed to final size they were repositioned back on the same plaster form previously used for the scribing operation.

The circular center panel was also positioned on the plaster form and welded to the gore sections, as previously described in Section 2.2.1. A completed skin weldment is shown in Figure 13.

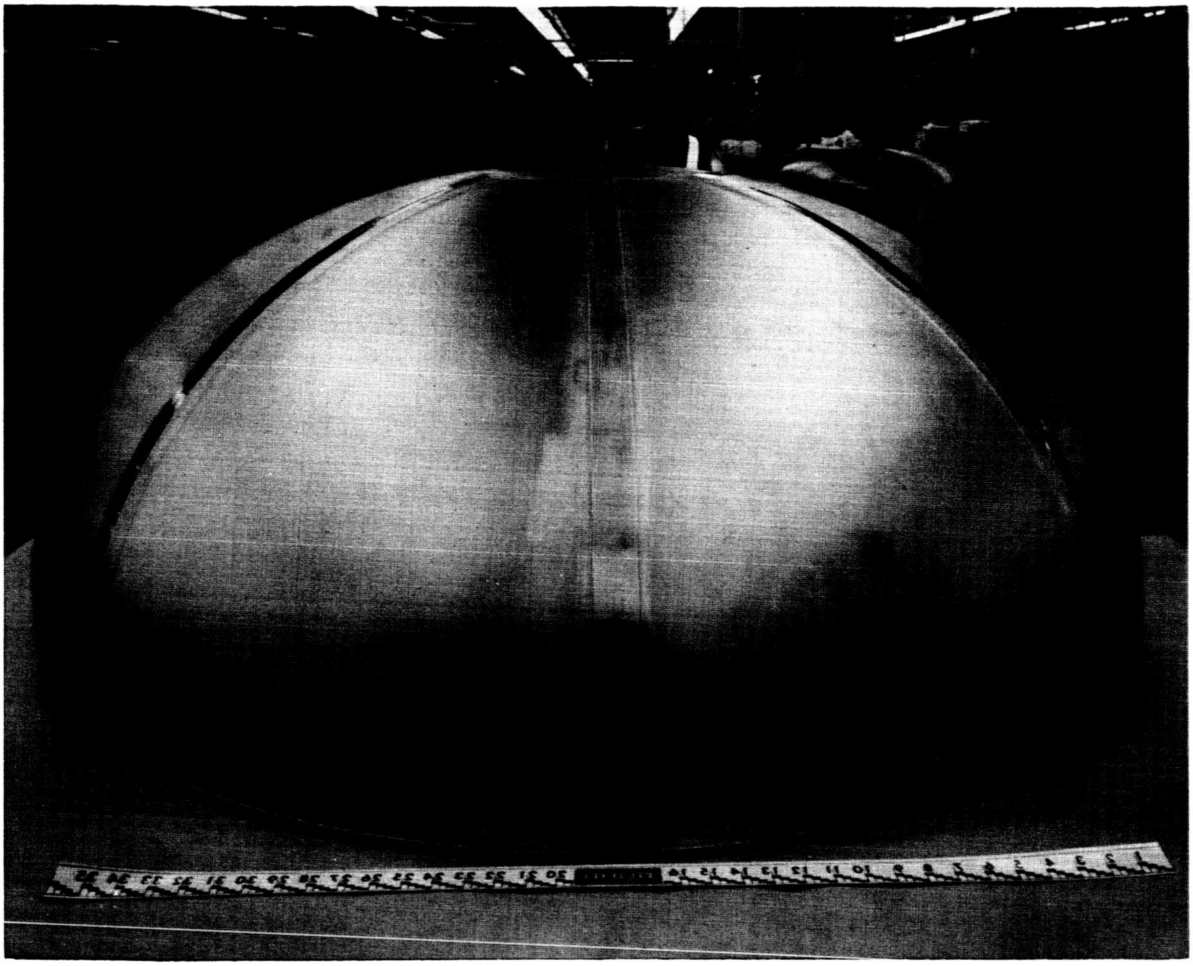
2.4.3 INITIAL SIZING OF OUTER SKIN - A basically proven state-of-the-art elevated temperature sizing technique was used for the initial sizing of the bulkhead outer skin.

This forming procedure consisted of first indexing the skin with the index points of an inspection and form tool (Figure 14) so that at least one skin weld joint aligned with an index point. The inner contour of the outer skin was then checked with a set back template as shown in Figure 11. This assembly of skin and tool was then installed in a metal bond assembly jig. Bleeder cloth and vacuum retention material was then applied to the full circle of the upper 6 inches of the skin and extended 6 inches onto the tool. The cloth and retention material was sealed in place with double rows of No. 1912A sealing tape.

Thermocouples were attached equally spaced at three different areas on the exterior of the tool. The air space between the tool and the skin was evacuated to 28 inches Hg, minimum, and the unit was then loaded into a convection heated autoclave (Figure 15). A vacuum of 28 inches Hg was reapplied and the thermocouples hooked up.

Autoclave pressure and heat were applied until an effective differential pressure of 209 psig and a temperature of 350°F $\pm$ 5 degrees was attained. These heat and pressure levels were retained for one hour before the autoclave pressure was bled off. The autoclave door was then opened and the skin allowed to cool down to 150°F.

After being unloaded from the autoclave, and vacuum bag and bleeder cloth removed, the inner contour of the skin was rechecked with the set back template.

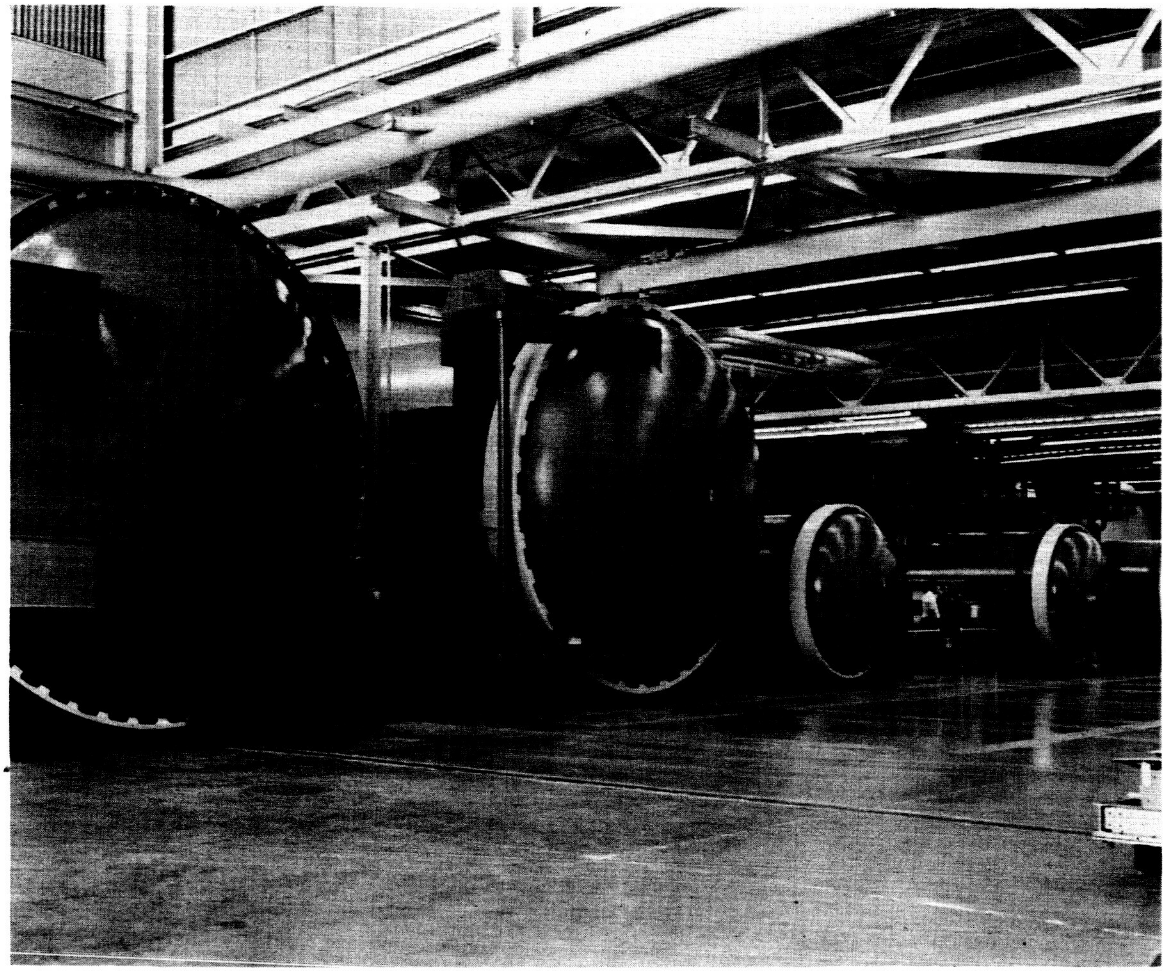


Outer Skin Weldment Assembly Prior to Stretch Forming

Figure 13

Positioning Outer Skin in Form Tool

Figure 14



The Rohr Autoclave, Second from Left, was used to Perform all Bonding and Curing Operations

Figure 15

2.4.4 BONDING OF CORE DETAILS AND BULKHEAD ASSEMBLY - All layup and bonding operations were conducted in a controlled atmosphere clean room. All personnel involved with these operations wore white cotton gloves.

The first operation in the lay-up and bonding operation was to spray the inner surface of the outer skin on the area to be bonded with one box coat of HT 424F primer with a dry thickness of .001 to .0015 inch. This was accomplished by diluting the primer to 30% solids with a primer-thinner for spray application.

The outer skin, with the filler plates attached, were next installed into the Metal Bond Assembly Jig while making sure that the centers of the skin and the jig were concentric within ± 1/8 inch and indexed to the tool.

At this point, gore sections of HT 424 film adhesive were installed onto the primed surfaces of the skin. Each gore section was butted closely with each respective adjacent section. The quantity of gore sections used was predicated on the minimum required for full coverage without wrinkling or folding.

Once the core segments were fitted against the outer skin, Thermofoam 607, Type 2, tape adhesive was fitted between the core segments in order to provide a continuous, void-free splice bond between the core segments. An alternate method of splicing that could be used would be to center a one-inch-wide ribbon of HRP core over the joint and press it into the core segments to make a smooth splice.

A Mylar parting film was then positioned over the areas where the tape adhesive had been used. The Mylar film was held in place with a Mylar pressure sensitive tape. Armelon may also be used in place of the Mylar film.

After securing the Mylar parting film in place, the entire exposed area was blanketed with sections of 121 glass cloth in two layers. The sections of the second layer were positioned 90° to the first layer. Both layers of cloth were extended over the top of the core frame and onto the surface of the tool. These sections of glass cloth were held in place with strips of pressure sensitive tape.

The entire glass bleeder area was next blanketed with one layer of HS 8171 nylon film. This film was sealed to the tool approximately one inch above the bleeder cloth for the full circle with double rows of No. 1912A sealing tape.

After sealing was completed, the pressure envelope was evacuated to 28 inches Hg. The vacuum source was then blocked off and the vacuum gauge reading recorded. After 15 minutes, the gauge was rechecked. Since there was no loss of vacuum discernible on the gauge, the vacuum was considered acceptable.

Once the acceptability of the vacuum was ascertained, the unit was loaded into a convection heated autoclave, and a vacuum source, gauge lines, and thermocouples attached. A vacuum of 28 inch Hg was then reapplied.

The autoclave pressure and heat were applied until an effective differential pressure of 59 psig and 350°F was reached. After curing the unit for one hour at these conditions, the autoclave pressure was bled off, the door opened, and the unit cooled down to 150°F. After removing the unit from the autoclave, the vacuum bag and bleeder cloth were removed, and the bonded sub-assembly extracted from the Metal Bond Assembly Jig.

Upon removal from the jig, the outer skin was ultrasonic and tap tested for bond integrity. The exposed surface of the core was also checked with the set-back template and the coordinates recorded.

The next operation required that the transition area of the core be cut to the drawing requirements and stabilized. After the core was cut, the honeycomb cells in the transition area, and those up to one inch beyond the transition area, were filled with M-319-B potting compound. The potting compound was cured at 170°F for 1/2 hour, and then the temperature was increased to 250°F and the compound cured for an additional one hour.

After the curing operation was completed, the unit was turned upside down and blown clean of all residue with filtered air. The edges of the core were swabbed lightly with MEK and air dried until odor of solvent was no longer present. The outer skin with bonded core is shown in Figure 8.

The next phase of the bonding operation required that the inner skin be prepared for the bonding cycle. This inner skin was initially prepared and cleaned in accordance with the cleaning procedure previously set forth in Section 2.2.8. After being cleaned, the inner skin was handled during the curing cycle in the same manner as the outer skin.

The final curing cycle was at 350°F cure temperature for one hour as depicted in Section 2.2.9. Unfortunately, during this final cure cycle the weldments in the closure ring failed. Cracks were propagated into the skin in three places and, because of this condition, the 21-hour aging cycle at 325°F temperature under vacuum was not performed.

2.5 QUALITY CONTROL PROCEDURES

2.5.1 MEASUREMENT AND TEST EQUIPMENT - All measurement and test equipment was subjected to visual, dimensional, and operational inspection, as applicable, when initially received and at periodic intervals thereafter. Accuracy of equipment used as masters for calibration of measuring and test equipment is traceable to the National Bureau of Standards. The calibration of measuring and test equipment is in conformance with MIL-C-45662A. Records are maintained on recalibration cycles for each piece of equipment. Written procedures concerning calibration and periodic recalibration are outlined in IM 25-9.

2.5.2 TOOLING - All tooling required tool inspection acceptance prior to release to Production. Tool inspection procedures are outlined in IM 24-5. All tooling used for acceptance media is periodically reinspected. Records of all periodic reinspections are maintained. Tool periodic reinspection procedures are outlined in DI 10-6.

Maintenance, storage, and care of all tooling are under Quality Control surveillance, and written procedures are outlined in DI 10-8 and IN 21-1. Master gages are preserved, stored, sealed, and handled as outlined in IM 23-12.

2.5.3 RECORDS - Adequate records of inspections and tests have been prepared to enable assessment and review for assurance of quality.

Records will be retained for a period of time conforming to contractual requirements as specified in IM 20-3.

2.5.4 INSPECTION STAMPS - The use of inspection stamps as a means of indicating inspection action covering materials, parts, assemblies, processes, and operations, provided positive identification of the inspection status of the product.

2.5.5 PROCUREMENT CONTROL - Outside procurement was limited to vendors who have been approved by a Quality Control Survey. A qualified vendors list is maintained by the Quality Control Department. Continued conformance to specifications is assured by periodic survey of vendors' facilities. Procedures governing Quality Control Surveys of vendors' facilities are outlined in IM 24-7.

2.5.6 RECEIVING INSPECTION - All vendor parts were subjected to 100% inspection or inspected per a sampling plan in accordance with MIL-STD-105. All inspection and testing was in accordance with Rohr and/or Government specifications, and the Receiving Inspection procedure is outlined in DI 6-1.

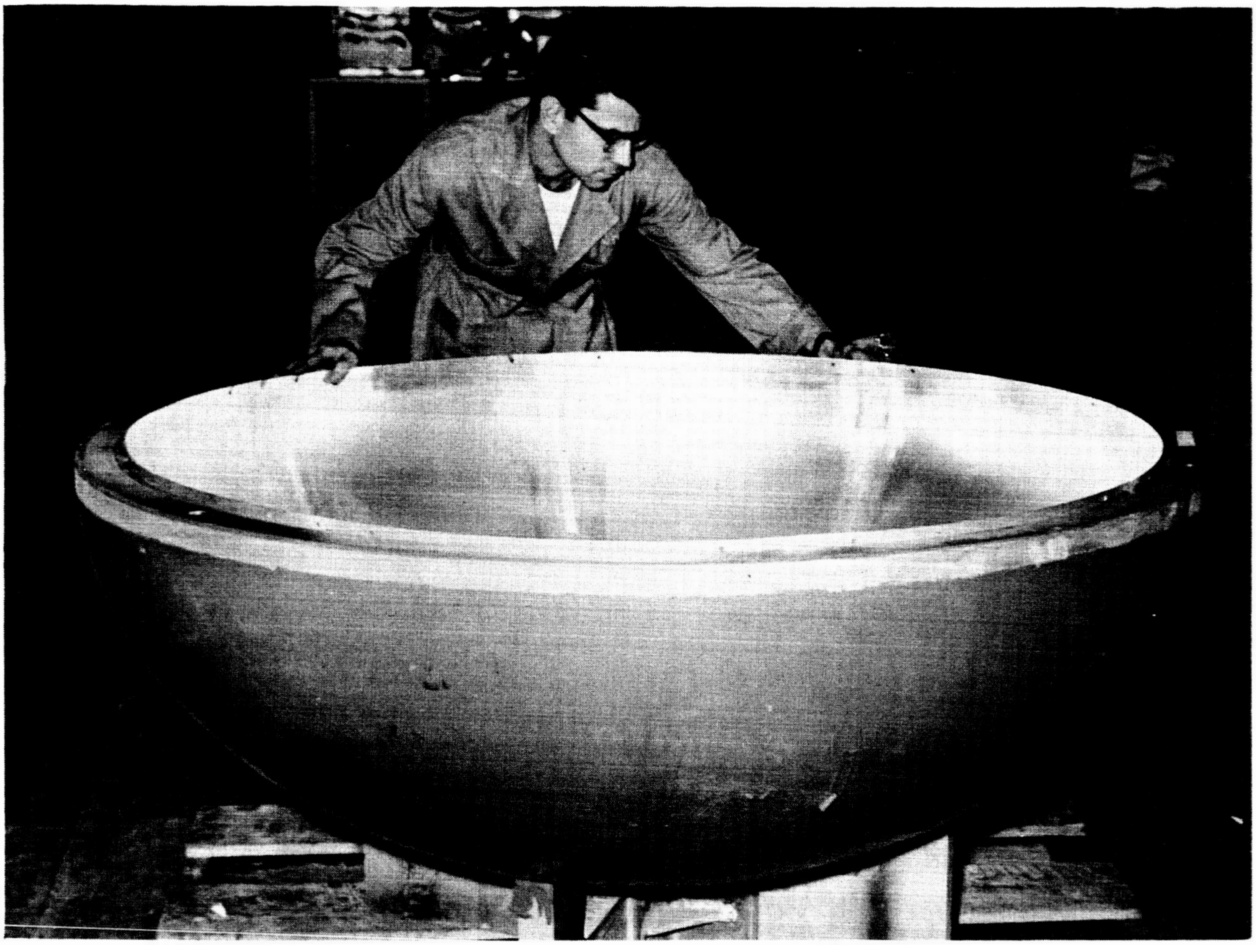
Certification of conformance to specification and/or report of chemical and physical properties were required on all raw materials. Certifications and test reports were checked against Rohr Process Specifications and/or Government requirements, and are presently recorded in the Receiving Inspection Department.

2.5.7 DRAWING AND SPECIFICATION CONTROL - Quality Control personnel used only controlled, valid drawings and specifications for acceptance criteria. The procedures for use of these documents are outlined in IM 20-4.

2.5.8 MANUFACTURING CONTROL - Quality Control maintained controls to assure compliance with engineering drawings, manufacturing process specifications, and quality standards throughout all phases of fabrication, from receipt of material through final shipment. In-process inspection operations were included where necessary to insure quality standards, and where economically beneficial for the detection of defects at early stages in the manufacturing process. In-process controls did not eliminate requirements for final inspection of the product. The sequence of manufacturing operations and required inspection functions were established in, and controlled by, Parts and Operation Log (POL) for assemblies, and Detail Operational Traveler (DOT) for detail parts. Each operation was stamped by Production personnel to signify completion. Pertinent test report numbers and materials review identification numbers were recorded adjacent to applicable operations. Written procedures for use of POL and DOT are outlined in IM 25-4. The POL and DOT are retained as specified in the contract, using record retention procedures outlined in IM 20-3. The parts and/or assemblies are identified with part number and date of manufacture.

2.6 MEASUREMENT AND RECORDING OF BULKHEAD DIMENSIONS - Using direct measurement type equipment such as contour templates, gages, and scales, recording of the bulkhead dimensions was performed both prior and subsequent to creep forming of the outer skin weldment and the total bulkhead assembly (Figure 16).

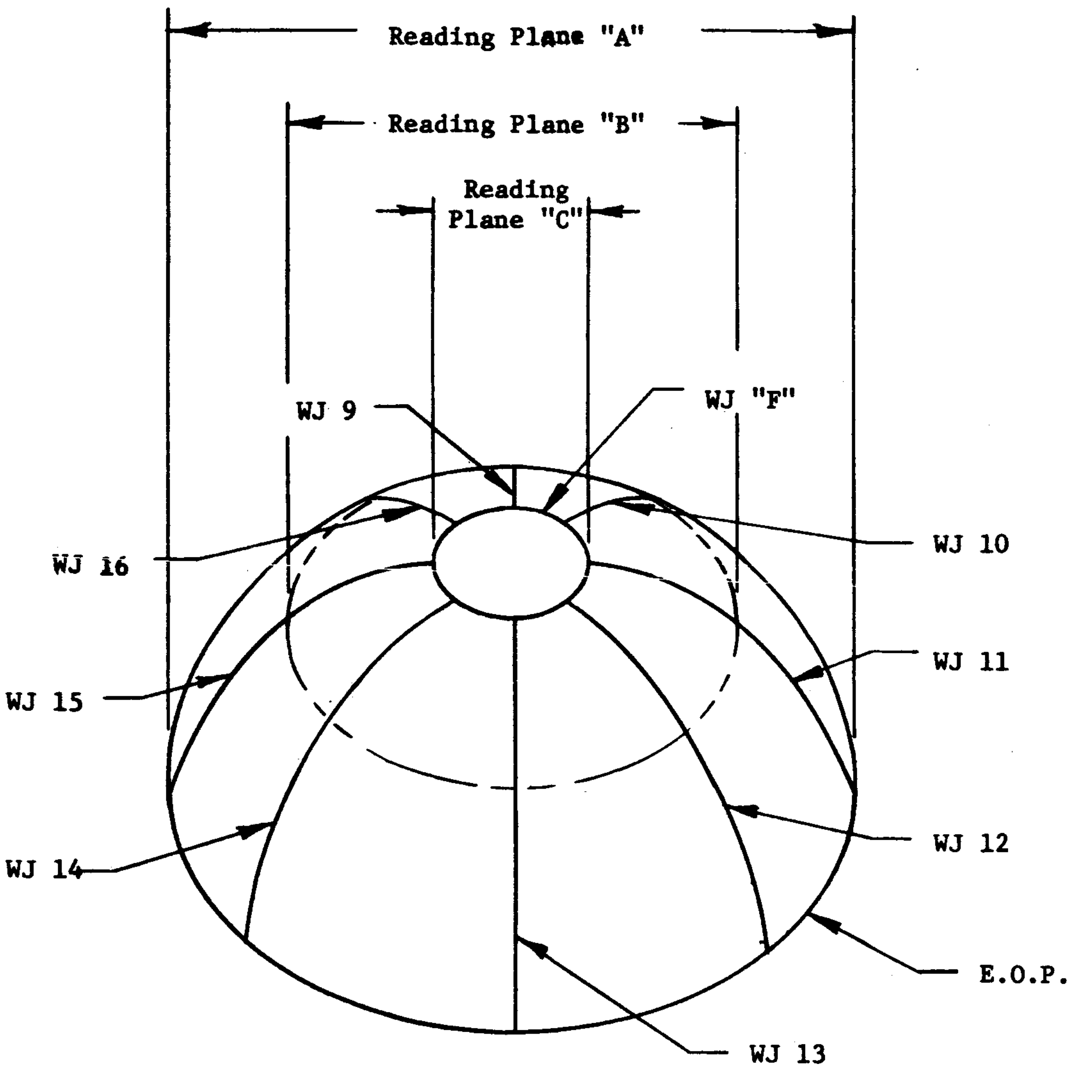
2.6.1 DIMENSIONAL CHECK OF WELD AREA - With the formed and trimmed skin panel gores assembled for welding, a dimensional check of the weld gap was performed on both skins (Figures 17 and 18). After welding and weld clean-up, weld land thicknesses were checked and recorded as shown in Table III for the outer skin and Tables IV through VII for the inner skin.



Inspecting and Recording Outer Skin Setback Prior to Creep Forming

Figure 16

GAP AT WELD JOINTS													
WJ 9	A	008	B	000	C	006	WJ 13	A	000	B	005	C	007
WJ 10	A	012	B	000	C	001	WJ 14	A	003	B	000	C	006
WJ 11	A	006	B	001	C	003	WJ 15	A	004	B	002	C	005
WJ 12	A	008	B	003	C	010	WJ 16	A	004	B	008	C	012



Dimensional Check Chart
Weld Joint Gap in Outer Skin

Figure 17

TABLE III

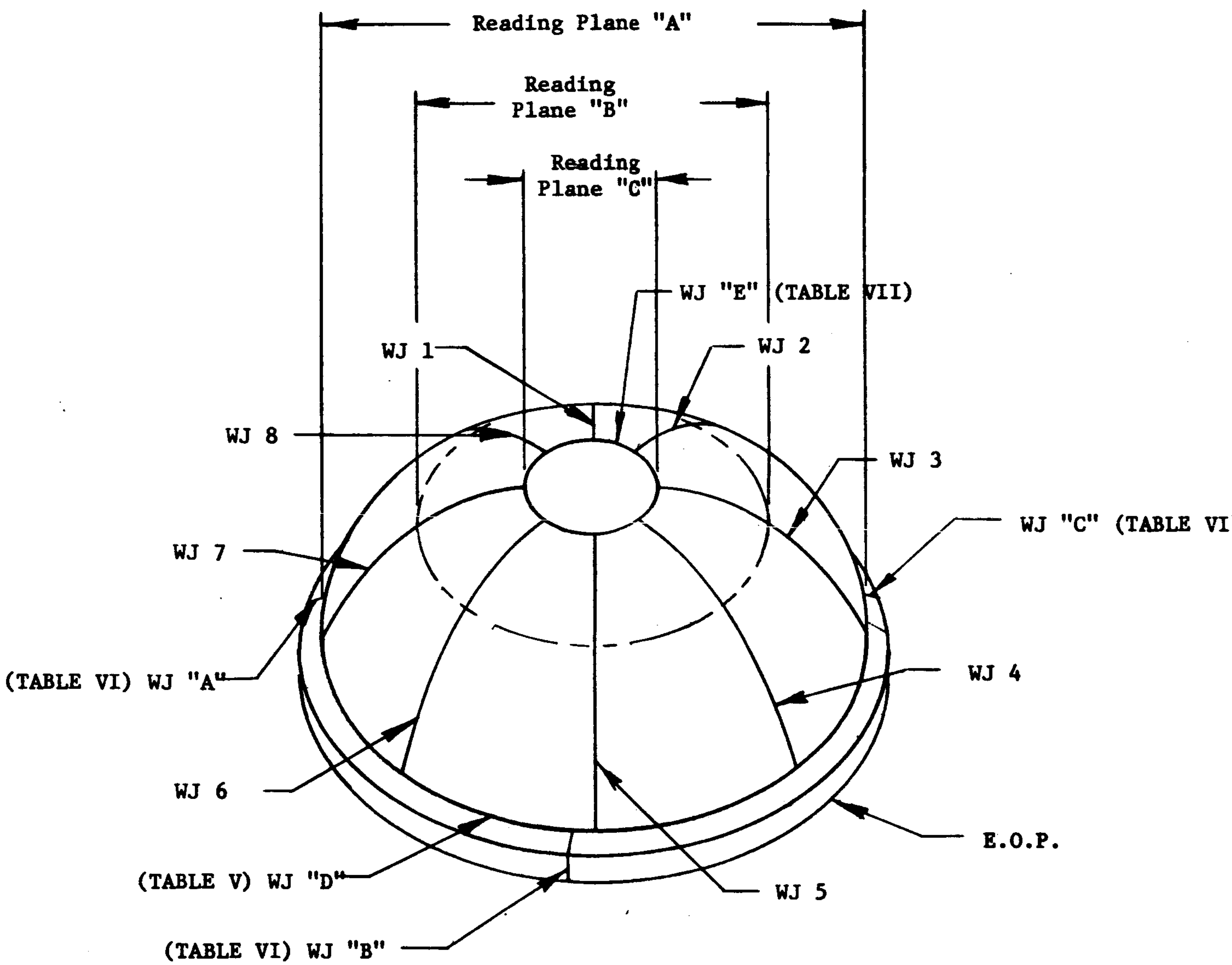
(See Figure 17 for reference)

Thickness Dimensions in Weld Joint Area (After Weld)
Dimensions Taken Every 2 Inches from E.O.P.

	WJ 9	WJ 10	WJ 11	WJ 12	WJ 13	WJ 14	WJ 15	WJ 16	*WJ "F"
1.	.059	.054	.054	.057	.060	.053	.055	.057	.061
2.	.059	.055	.054	.058	.060	.058	.060	.059	.062
3.	.059	.055	.058	.058	.059	.059	.056	.059	.062
4.	.057	.057	.060	.057	.061	.058	.056	.059	.059
5.	.056	.057	.059	.057	.060	.058	.057	.057	.063
6.	.058	.056	.060	.057	.059	.058	.054	.057	.063
7.	.058	.057	.061	.060	.059	.058	.058	.058	.060
8.	.055	.058	.059	.061	.059	.058	.059	.058	.062
9.	.058	.058	.058	.063	.059	.057	.058	.057	.063
10.	.055	.058	.059	.056	.058	.058	.057	.058	.064
11.	.056	.056	.059	.058	.058	.058	.057	.058	.059
12.	.054	.051	.055	.056	.058	.058	.057	.058	.062
13.	.054	.053	.054	.059	.058	.058	.057	.057	.061
14.	.054	.053	.052	.056	.057	.058	.054	.052	.062
15.	.056	.056	.053	.057	.055	.057	.055	.055	.062
16.	.053	.055	.059	.055	.058	.058	.058	.058	.062
17.									.062

* Starting from WJ 9 clockwise, every 2 inches.

GAP AT WELD JOINTS														
WJ 1	A	004	B	000	C	003		WJ 5	A	000	B	003	C	000
WJ 2	A	006	B	002	C	000		WJ 6	A	004	B	000	C	003
WJ 3	A	005	B	003	C	000		WJ 7	A	000	B	001	C	003
WJ 4	A	009	B	003	C	000		WJ 8	A	002	B	000	C	004



Dimensional Check Chart

Weld Joint Gap in Inner Skin Prior to Weld

Figure 18

TABLE IV

(See Figure 18 for reference)

Thickness Dimensions in Weld Joint Area (After Weld)
Dimensions Taken Every 2 Inches from E.O.P.

	WJ 1	WJ 2	WJ 3	WJ 4	WJ 5	WJ 6	WJ 7	WJ 8
1.	.060	.059	.058	.061	.058	.055	.057	.059
2.	.030	.059	.062	.060	.056	.051	.056	.061
3.	.060	.058	.062	.059	.056	.056	.055	.060
4.	.061	.059	.061	.060	.050	.057	.057	.062
5.	.060	.060	.060	.061	.051	.054	.058	.060
6.	.060	.060	.059	.060	.055	.054	.058	.060
7.	.060	.056	.058	.059	.056	.054	.057	.060
8.	.059	.058	.060	.059	.054	.057	.056	.061
9.	.059	.058	.060	.059	.052	.058	.056	.060
10.	.059	.058	.059	.058	.050	.057	.057	.061
11.	.058	.057	.060	.058	.052	.055	.056	.061
12.	.060	.060	.059	.058	.054	.057	.057	.060

TABLE V

(See Figure 18 for reference)

WJ "D"							
*1	.058	16	.057	31	.059	46	.059
2	.058	17	.059	32	.052	47	.060
3	.058	18	.058	33	.056	48	.058
4	.056	19	.057	34	.055	49	.058
5	.056	20	.057	35	.055	50	.059
6	.055	21	.053	36	.058	51	.057
7	.057	22	.054	37	.059	52	.051
8	.059	23	.056	38	.052	53	.056
9	.057	24	.055	39	.062	54	.056
10	.055	25	.058	40	.059	55	.058
11	.056	26	.057	41	.061	56	.056
12	.057	27	.059	42	.059	57	.055
13	.058	28	.058	43	.058	58	.057
14	.056	29	.055	44	.058	59	.061
15	.050	30	.051	45	.059	60	.061

TABLE VI

(See Figure 18 for reference)

	WJ "A"	WJ "B"	WJ "C"
1	.062	.059	.060
2	.057	.059	.061
3	.059	.059	.061

* Dimensions taken every 2 inches from weld joint #1 clockwise on WJ "D" and WJ "E".

TABLE VII

(See Figure 18 for reference)

WJ "E"			
*1	.061	7	.061
2	.062	8	.058
3	.061	9	.060
4	.061	10	.060
5	.060	11	.059
6	.061	12	.061

2.6.2 DIMENSIONAL CHECK OF OUTER SKIN DURING CREEP FORMING - Following the sequence provided in Figure 19, a dimensional check of the inside contour of the outer skin was performed both prior and subsequent to the creep forming operation. The readings were recorded as shown in Figures 20 and 21 for the prior and subsequent conditions, respectively.

2.6.3 DIMENSIONAL CHECK OF BULKHEAD ASSEMBLY PRIOR TO CREEP FORMING - Following the sequence provided in Figure 22, a dimensional check of the interior surface of the inner skin was performed and the readings recorded as shown in Figure 23.

2.6.4 DIMENSIONAL CHECK OF BULKHEAD ASSEMBLY SUBSEQUENT TO CREEP FORMING - Because of the failure of the welds in the peripheral zee-section edge member, and the resulting precipitation of failures in the adjacent skins, this dimensional check was deemed of little value and hence was not performed.

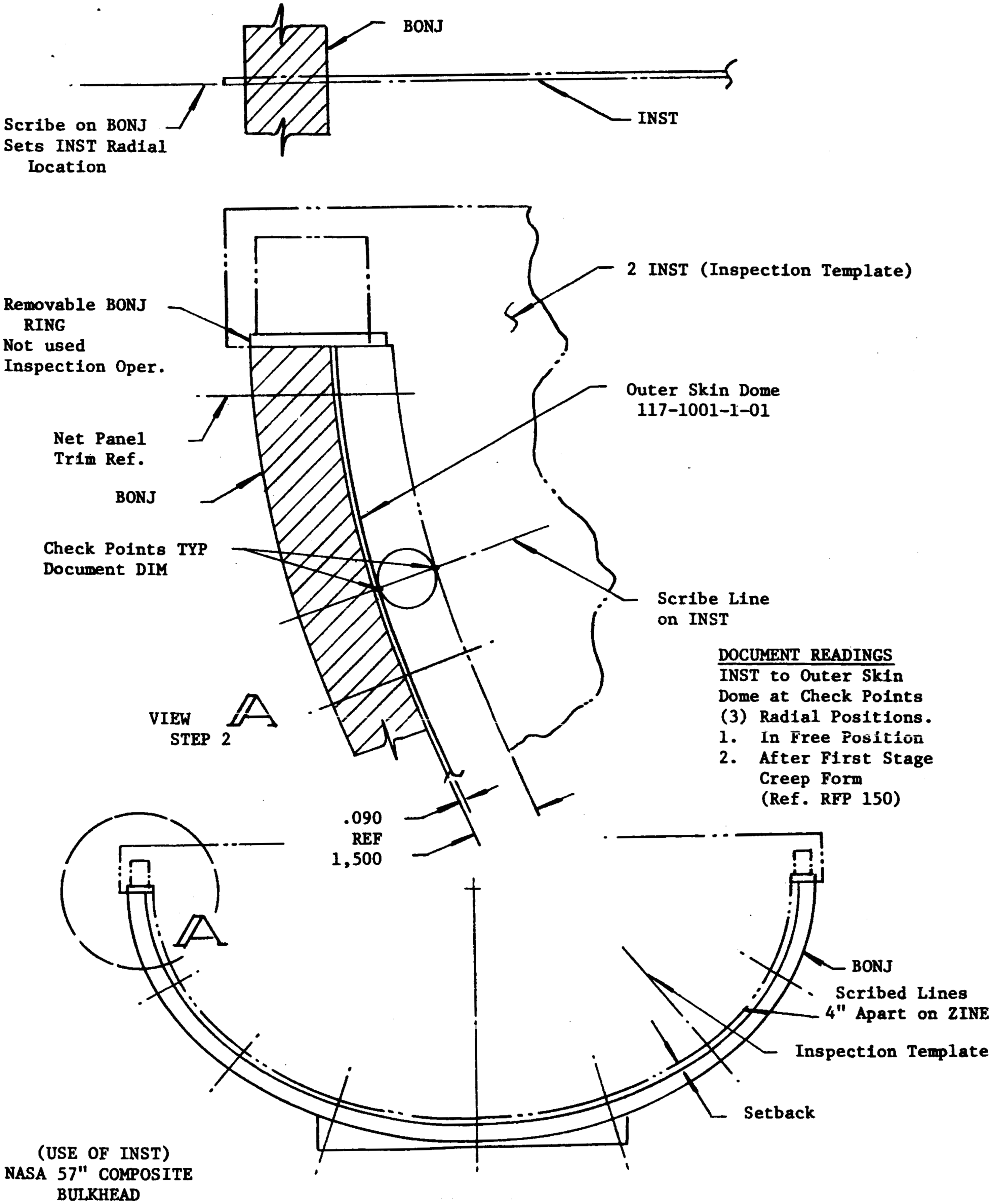
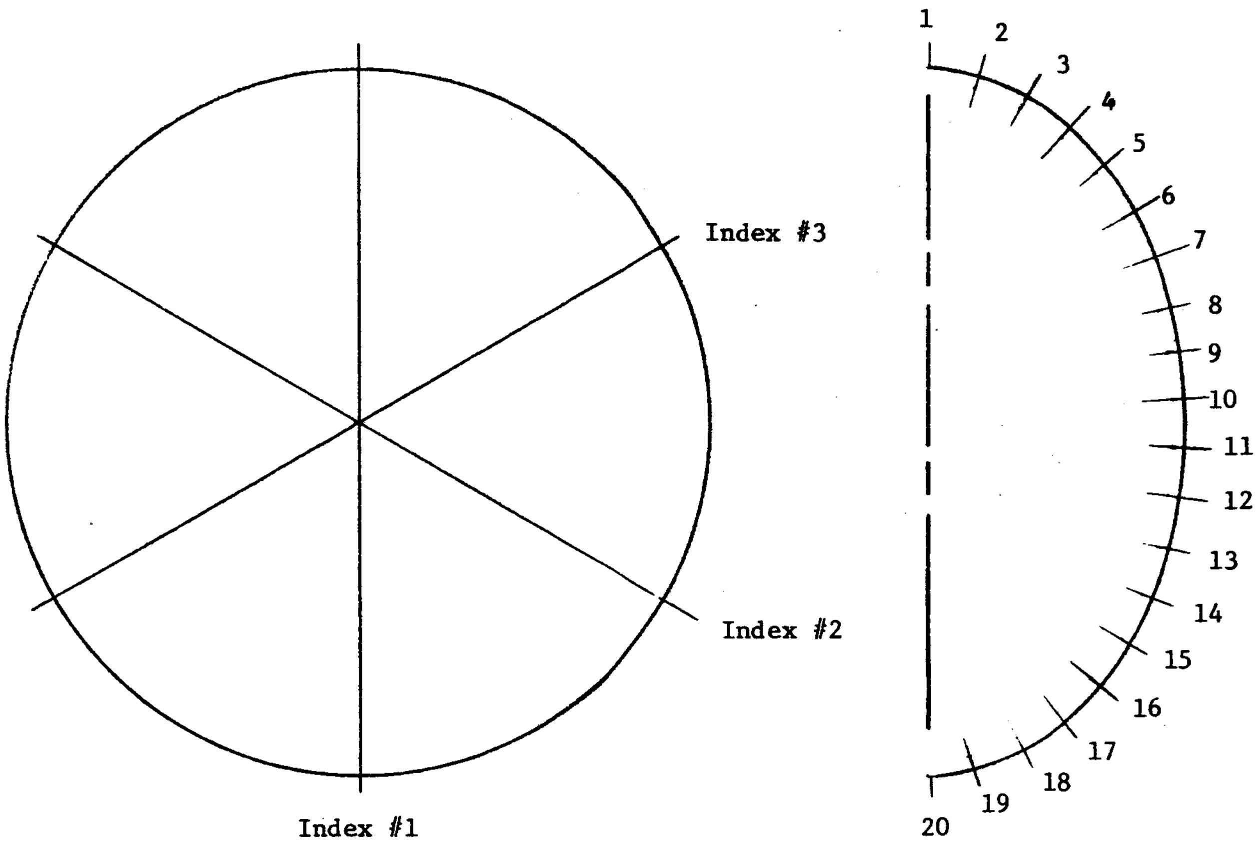


Figure 19

Inspection Sequence - Outer Skin

NASA 57" BULKHEAD

This chart reflects readings taken from edge of the inspection template to the inner surface of the outer skin while installed in the metal bond assembly jig prior to creep forming. The inspection template has a 1.500 in. setback.



Index #1			
1	1.350	11	.900
2	1.400	12	.975
3	1.325	13	1.200
4	1.330	14	1.320
5	1.310	15	1.325
6	1.325	16	1.360
7	1.300	17	1.325
8	1.300	18	1.340
9	1.275	19	1.320
10	1.00	20	1.310

Index #2			
1	1.300	11	.900
2	1.280	12	1.050
3	1.300	13	1.210
4	1.325	14	1.370
5	1.370	15	1.350
6	1.420	16	1.325
7	1.410	17	1.300
8	1.430	18	1.250
9	1.250	19	1.200
10	1.00	20	1.180

Index #3			
1	1.260	11	1.100
2	1.260	12	1.250
3	1.275	13	1.325
4	1.340	14	1.350
5	1.400	15	1.275
6	1.380	16	1.250
7	1.310	17	1.225
8	1.125	18	1.240
9	.900	19	1.250
10	.900	20	1.200

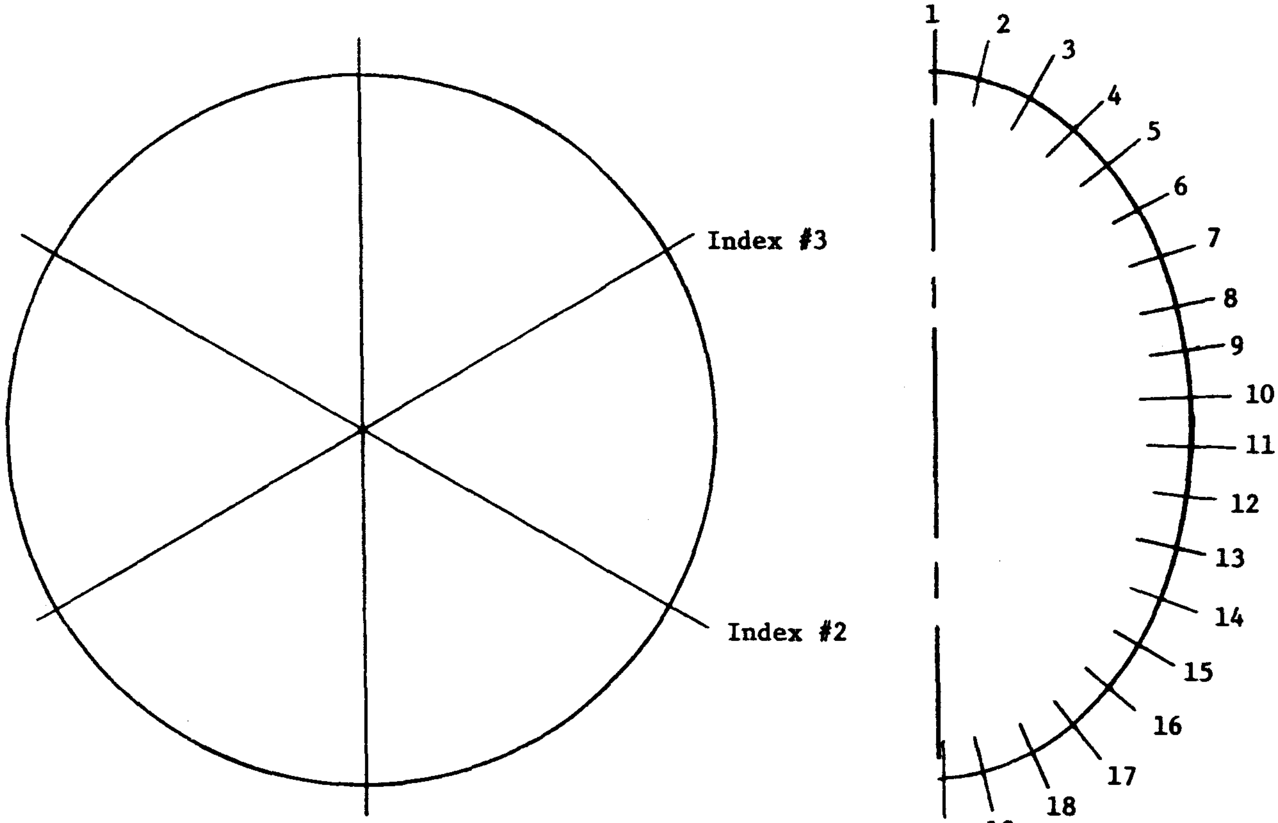
Dimensional Check Chart

Contour of Outer Skin Prior to Creep Forming

Figure 20

NASA 57" BULKHEAD

This chart reflects readings taken from edge of the inspection template to the inner surface of outer skin after creep forming and repair of cracked area. The inspection template has a 1.500 inch setback.



Index #1			
1	1.350	11	1.125
2	1.375	12	1.175
3	1.360	13	1.325
4	1.360	14	1.350
5	1.350	15	1.350
6	1.350	16	1.410
7	1.325	17	1.400
8	1.340	18	1.425
9	1.325	19	1.410
10	1.200	20	1.400

Index #2			
1	1.400	11	1.150
2	1.400	12	1.175
3	1.410	13	1.300
4	1.425	14	1.400
5	1.450	15	1.375
6	1.450	16	1.400
7	1.430	17	1.350
8	1.410	18	1.330
9	1.350	19	1.280
10	1.200	20	1.225

Index #3			
1	1.360	11	1.150
2	1.375	12	1.175
3	1.390	13	1.275
4	1.380	14	1.330
5	1.425	15	1.340
6	1.425	16	1.310
7	1.400	17	1.300
8	1.400	18	1.250
9	1.330	19	1.240
10	1.175	20	1.230

Dimensional Check Chart

Contour of Outer Skin After Creep Forming

Figure 21

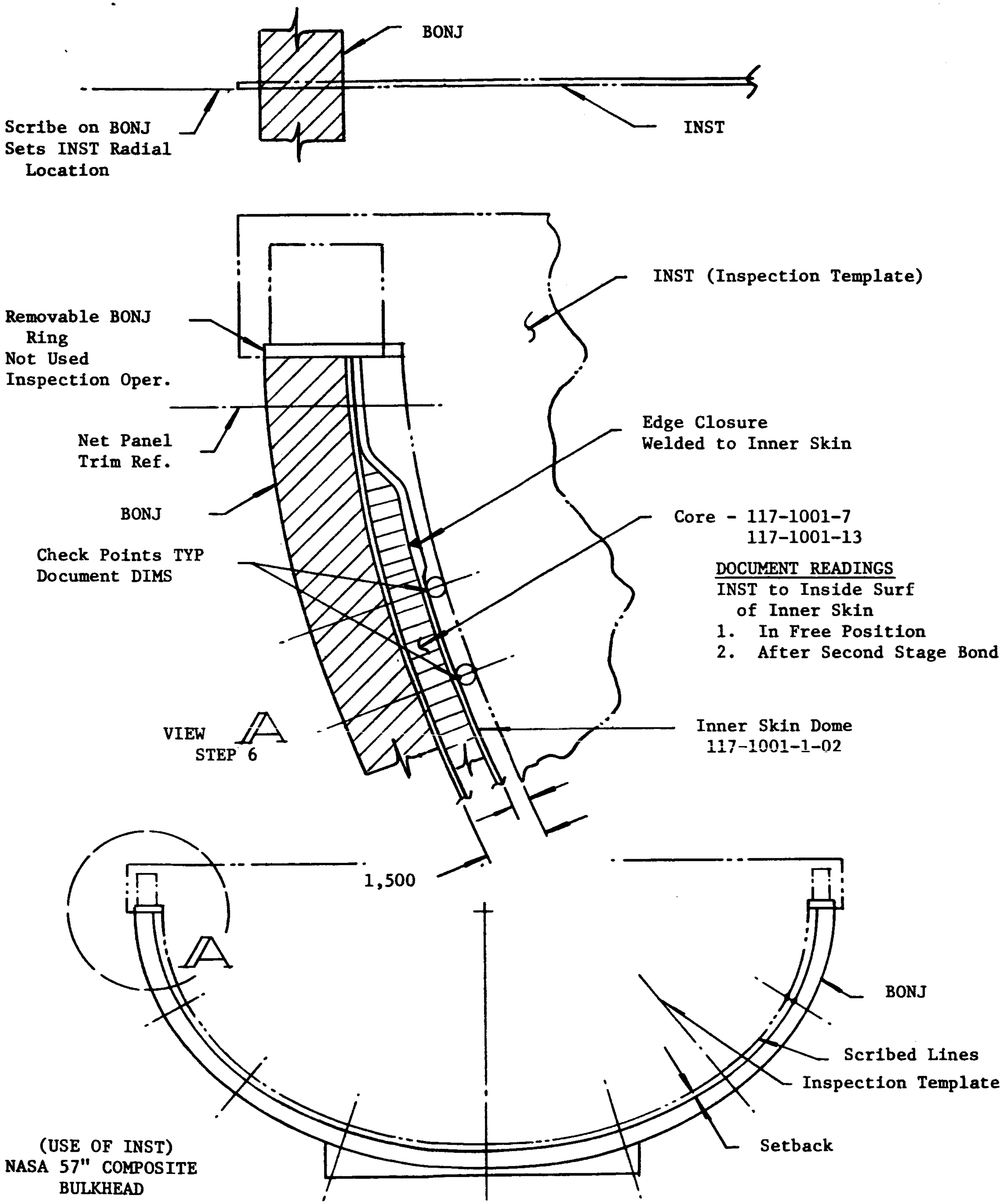
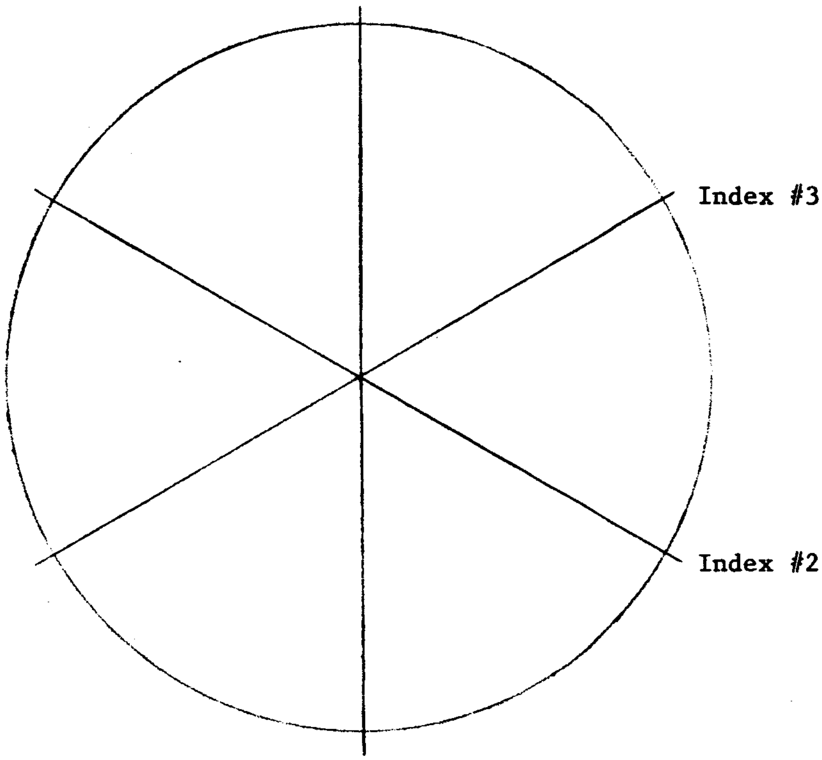


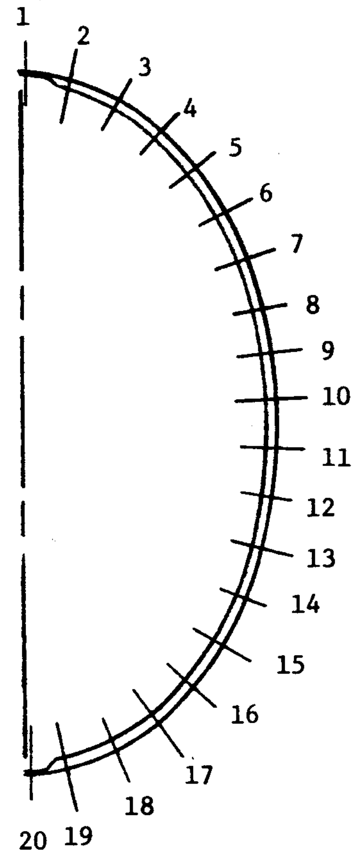
Figure 22

Inspection Sequence - Bulkhead Assembly

NASA 57" BULKHEAD

This chart reflects readings taken from edge of the inspection template to inner surface of the inner skin. The inspection template has a 1.500 inch setback.





Index #1			
1	1.37	11	.260
2	.410	12	.290
3	.410	13	.350
4	.425	14	.360
5	.410	15	.410
6	.410	16	.420
7	.400	17	.410
8	.380	18	.420
9	.380	19	.430
10	.310	20	1.127

Index #2			
1	1.149	11	.320
2	.380	12	.380
3	.380	13	.380
4	.400	14	.400
5	.410	15	.400
6	.410	16	.400
7	.410	17	.380
8	.400	18	.370
9	.360	19	.360
10	.300	20	1.133

Index #3			
1	1.31	11	.320
2	.400	12	.380
3	.400	13	.410
4	.410	14	.410
5	.420	15	.420
6	.420	16	.400
7	.420	17	.430
8	.410	18	.410
9	.370	19	.380
10	.300	20	1.127

Dimensional Check Chart

Contour of Inner Skin

Prior to Creep Forming of Bulkhead Assembly

Figure 23

3 / RESULTS AND CONCLUSIONS

The feasibility of utilizing creep forming techniques in the manufacture of contoured bonded honeycomb structures has been confirmed by the Composite Bulkhead Fabrication Development Program. Though failure in radial weld joints was experienced in the creep forming cycles of both the outer skin and the inner skin, sufficient progress was made to definitely establish the practicality of the concept of combining a curing cycle for adhesive bonding with a creep forming and aging cycle for skin weldments.

Failure in the initial creep forming of the outer skin weldment assembly and in the subsequent creep forming cycle of the completed bulkhead were in each case due to a similar type of deficiency in the design of the peripheral edges. The outer skin had been manufactured with a full thickness land around the edge due to a lack of clarity of the engineering drawing. That a doubler area around the edge appeared to be a natural requirement contributed to the error. This edge doubler provided a ring of constant thickness material through the welded areas and defeated the purpose of maintaining equal strength across the weld joints. Failure occurred when the lessor strength weld was loaded beyond its ultimate tensile strength.

The same basic type of design deficiency that caused failure in the outer skin was inherent in the design of the "zee" section edge closure member at the periphery of the inner skin. A ring of constant thickness material that was weakened by the use of welded joints caused failure under tension during the combined creep forming and bond cure cycle.

Inclusion of chem-milled steps at the skin panel edges, to conform with what is a basic feature in the center areas of the panels, will, combined with greater care in the welding of the edges, solve the problem. Further study of the integrity of weld joint edge is advised, because development testing in this area was handicapped by a shortage of material early in the program when development studies would have been most beneficial.

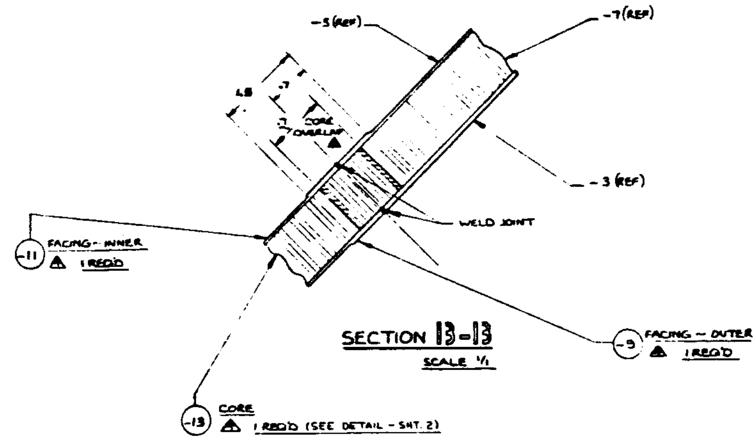
The basic tooling philosophy of stretching 2219-T37 skin gores to panel contour proved satisfactory, except that subsequent chem-milling relieved the residual stresses induced during forming. Further development of the die tools will alleviate this problem. The bond tooling performed satisfactorily and maintained shape throughout the elevated temperature and pressure cycles.

Difficulties experienced in the splicing and forming of the core were solved by developing a butt joint using a specially formulated potting compound, and reinforcing the most critical areas with strips of core pressed into place across the joints.

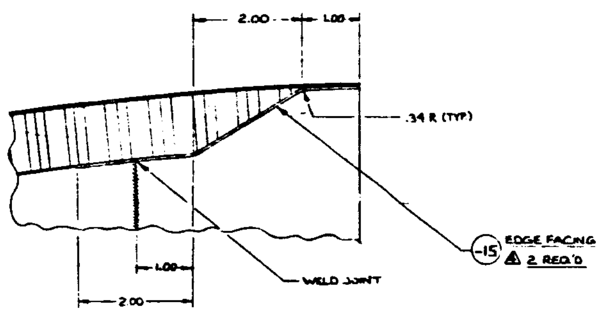
The adhesive bonding cure cycle was adjusted to include a capability for elevated temperature creep forming of the skins, and, though the aging phase was terminated before completion because of primary failure in the skins, the feasibility of the process was adequately demonstrated.

The outer skin assembly exhibited some spring-back when creep formed, but the contour improvement and overall sizing was substantial. The inner skin likewise took a substantial permenent set during creep forming. In general, the amount of permanent deformation which occurred in the bulkhead skins (as determined by measurement) agreed with the .5% which was predicted by the laboratory specimens. Obviously, a longer creep cycle would provide a permanent set more nearly approaching the .008 strain. In addition, we recommend that the inner skin be sized before the adhesive is cured, and the adhesive cured in a subsequent cycle.

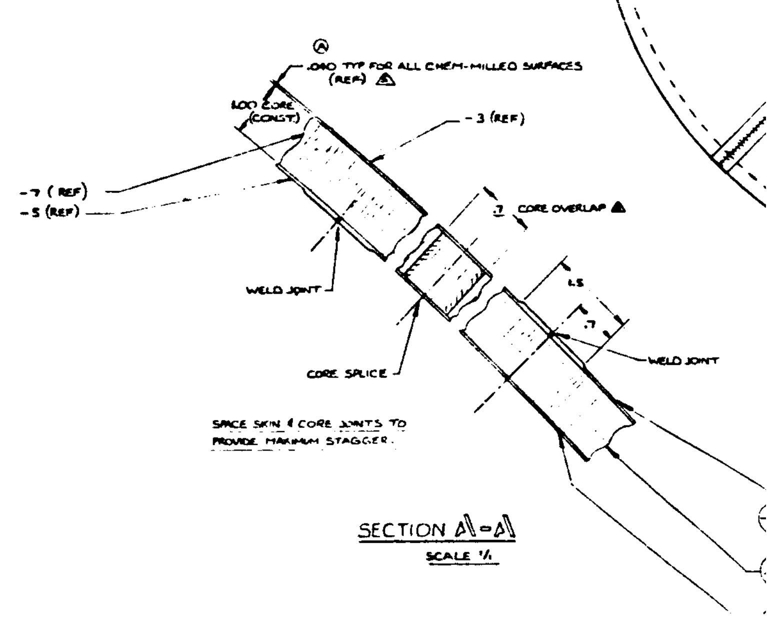
Continuance of the program is recommended, either as a separate follow-on development program or as a modification to the existing program, by reducing the core thickness from the present 1 inch to 3/8 inch in order to provide a finished article suitable for analysis and structural testing by NASA.



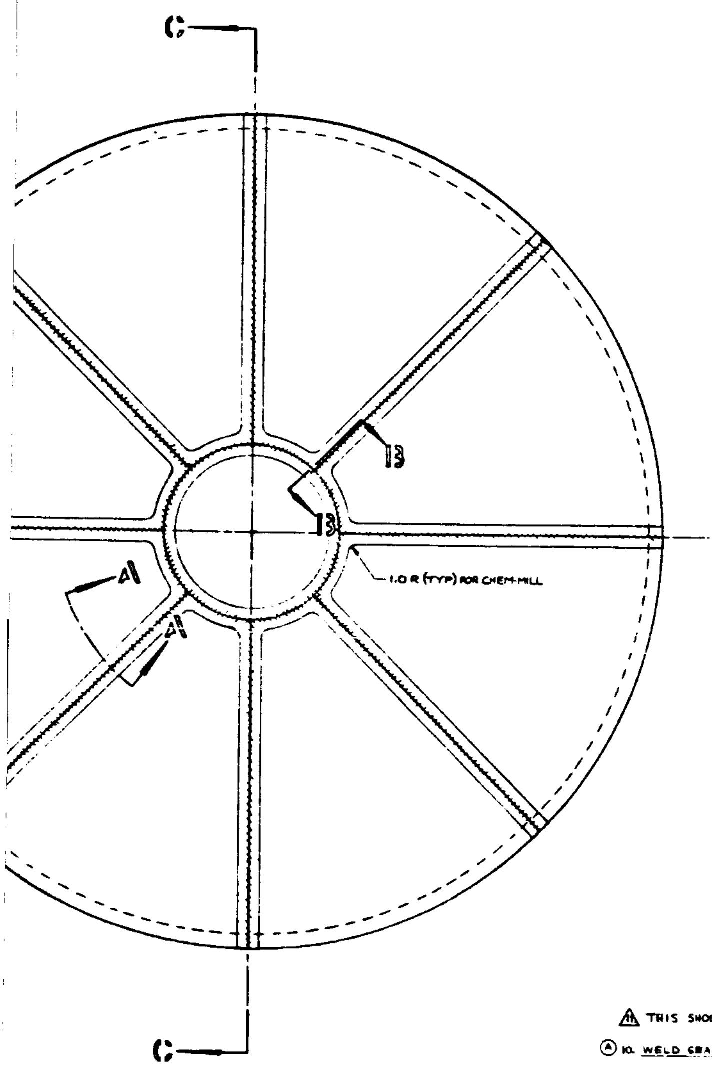
SECTION B-B
SCALE 1/1

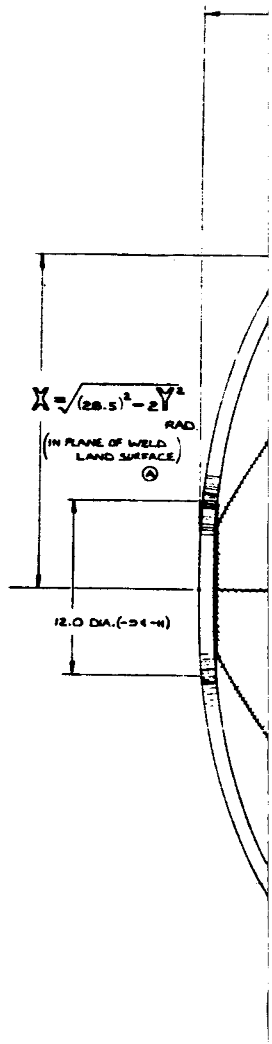


DETAIL B
SCALE 1/1



SECTION A-A
SCALE 1/1





FACING — OUTER
8 PLACES

CORE
11 PLACES (SEE DETAIL - SHT. 2)

FACING — INNER
8 PLACES

2

THIS SHOULDER TO BE LOCATED PRIOR TO AGE FORMING TO PROVIDE CREEP ALLOWANCE IN

(A) 10. WELD SEAM SHOWN THUS:

9. INSPECT WELDS PER MIL-STD-453, ACCEPTANCE CRITERIA PER ROHR PROCESS SPEC 18.02

CORE LAP JOINTS TO BE IN ACCORDANCE WITH ROHR PROCESS SPEC 17.33, PARAGRAPH 4.7, EXCEPT THAT CORE SEGMENTS SHALL BE INTERLOCKED USING 4 CELLS EACH SEGMENT SLOTT

DIMS GIVEN ARE NET. THE PRE-STRETCH DIA TO PROVIDE FOR AGE-CONTOURING OF THE OUTER SKIN SHOULD BE $\frac{56.75}{56.50}$ OVERALL. THE INNER SKIN DIA. SHOULD BE REDUCED PROPORTIO

6. FLUSH GRIND WELD BEADS ON SURFACES ADJACENT TO CORE

(A) FACINGS CHEM-MILLED TO .040 THKNESS BETWEEN WELD LANDS ON SURFACE AWAY FROM CORE

(A) MATERIAL:- FACINGS: .063 THK 2219-T37 ALUM ALLOY PER MIL-A-8920. HEAT TREAT TO T-87
CORE: HRP 3/16 - GF12-3.5 REINF. PLASTIC HONEYCOMB PER MIL-C-8073A.

3. PREPARE FACINGS FOR BOND IN ACCORDANCE WITH ROHR PROCESS SPEC. 17.23, REVISION

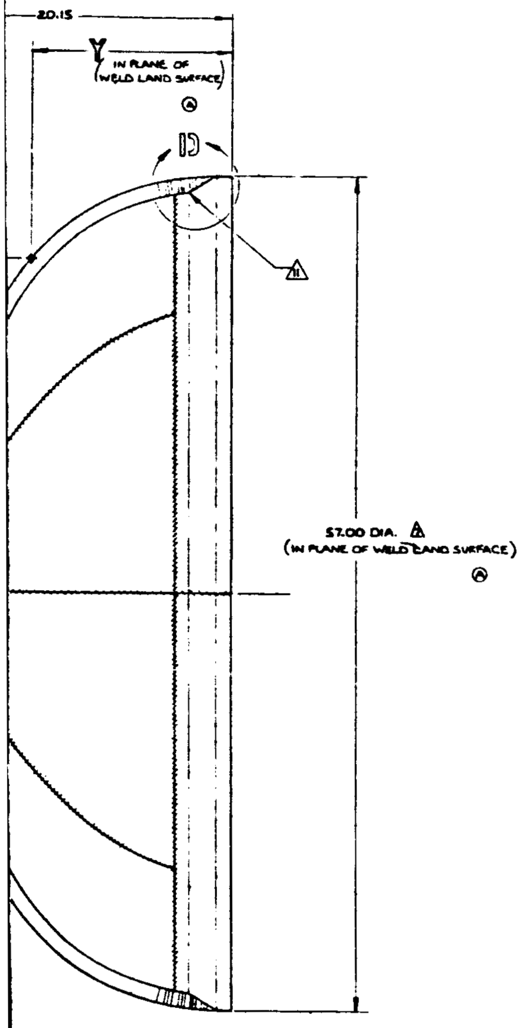
2. BOND IN ACCORDANCE WITH ROHR PROCESS SPEC 17.20 USING HT-424 ADHESIVE PER

1. WELD PER T.I.G. PROCESS IN ACCORDANCE WITH ROHR PROCESS SPEC. 11.35.

NOTES:

REVISIONS

		DESCRIPTION	DATE	APPROVAL
		NEW DWG		
	A	-15 ADDED. DETAIL D ADDED. G/N 10 & 11 ADDED. SECTION A-A: DIM ".080 TYP FOR ALL CHEM MILL SURFACES" WAS ".080 TYP FOR ALL CHEM MILL SURFACES." SECTION C-C: NOTE (3 PLACES) "IN PLANE OF WELD LAND SURFACE" WAS "IN PLANE OF CHEM MILL SURFACE". G/N 5: "FACINGS CHEM MILLED TO .040 THKNESS..." WAS "FACINGS CHEM MILLED TO .080 THKNESS..." G/N 4: "MATERIAL FACINGS .063..." WAS "MATERIAL FACINGS .090..."		



OTH PLANES. 7 SECTION C-C

CLASS II.

D TO CORE HALF DEPTH.

MATELY.

PER ROHR PROCESS SPEC 14.06.

ER MIL-A-6088 EXCEPT THAT AGING TIME BE 22 HOURS.

:

HR PROCESS SPEC 17.31 TYPE I.

3

Figure 24

DO NOT SCALE

SATURN S-IC MISSILE SCALE MODEL NASA, M.S.F.C. HUNTSVILLE, ALA.		SULKHEAD - 57" DIA HONEYCOMB	ROHR CORPORATION
			117-1001 A
	LAYOUT NO.	SCALE 1/4	11501 SHT 1 OF 2

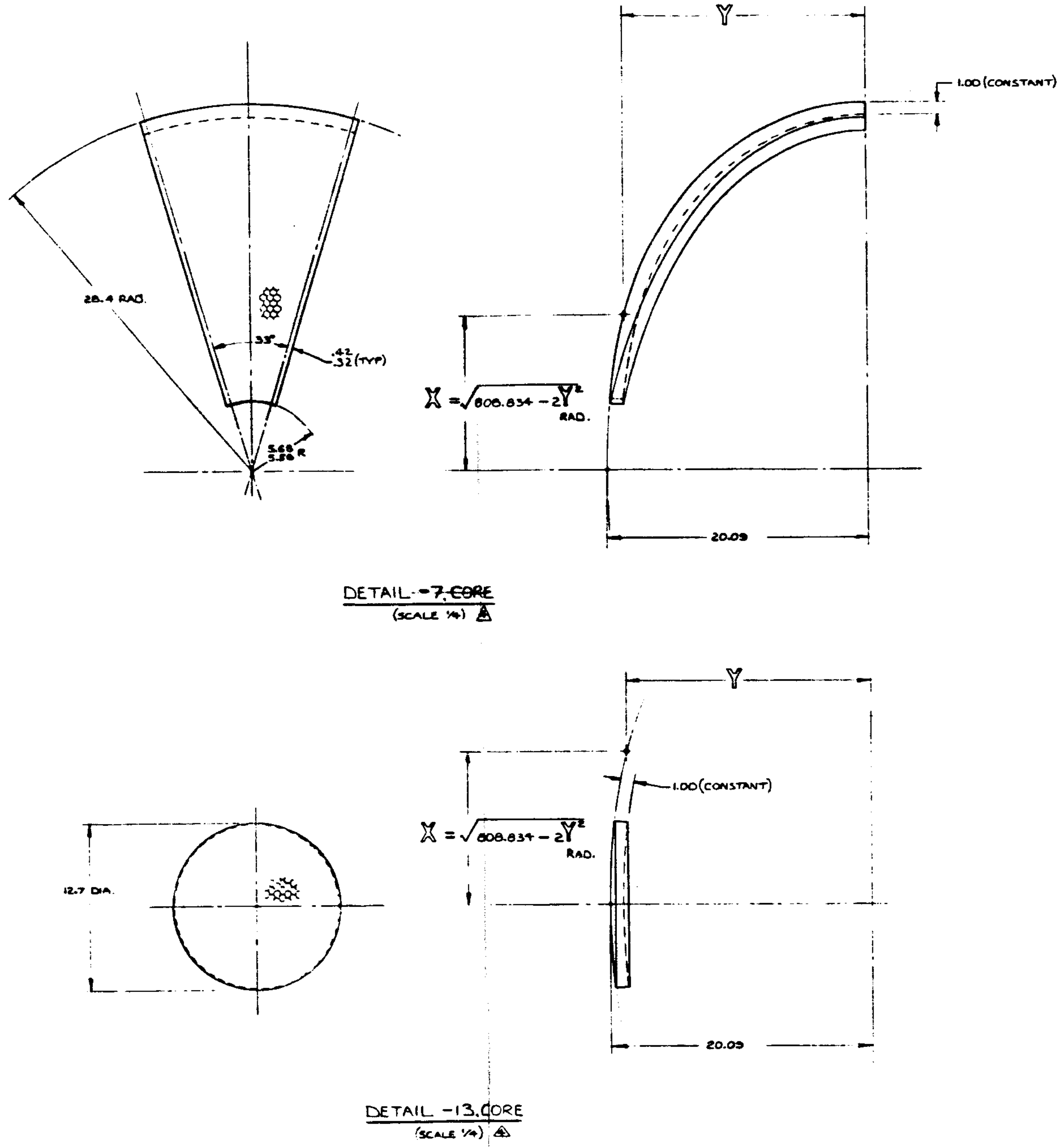
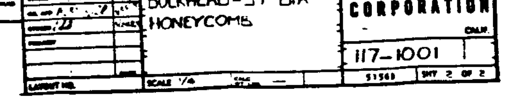
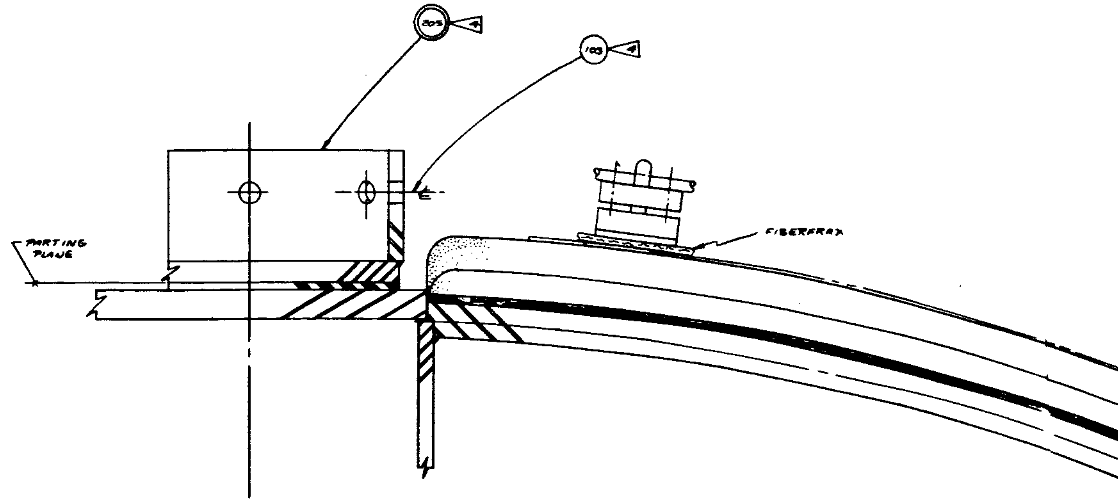
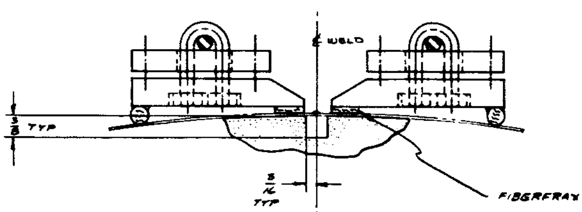


Figure 25

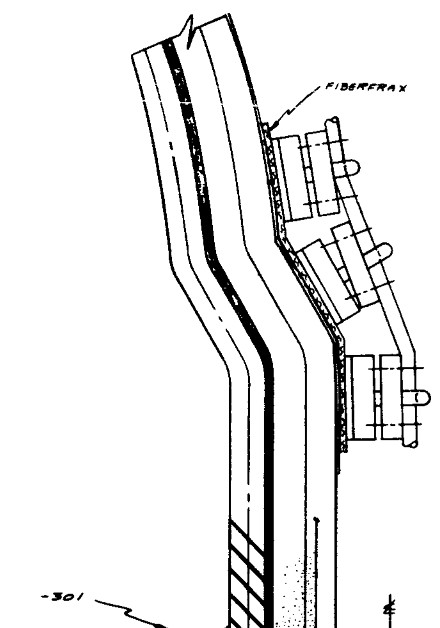
DO NOT SCALE



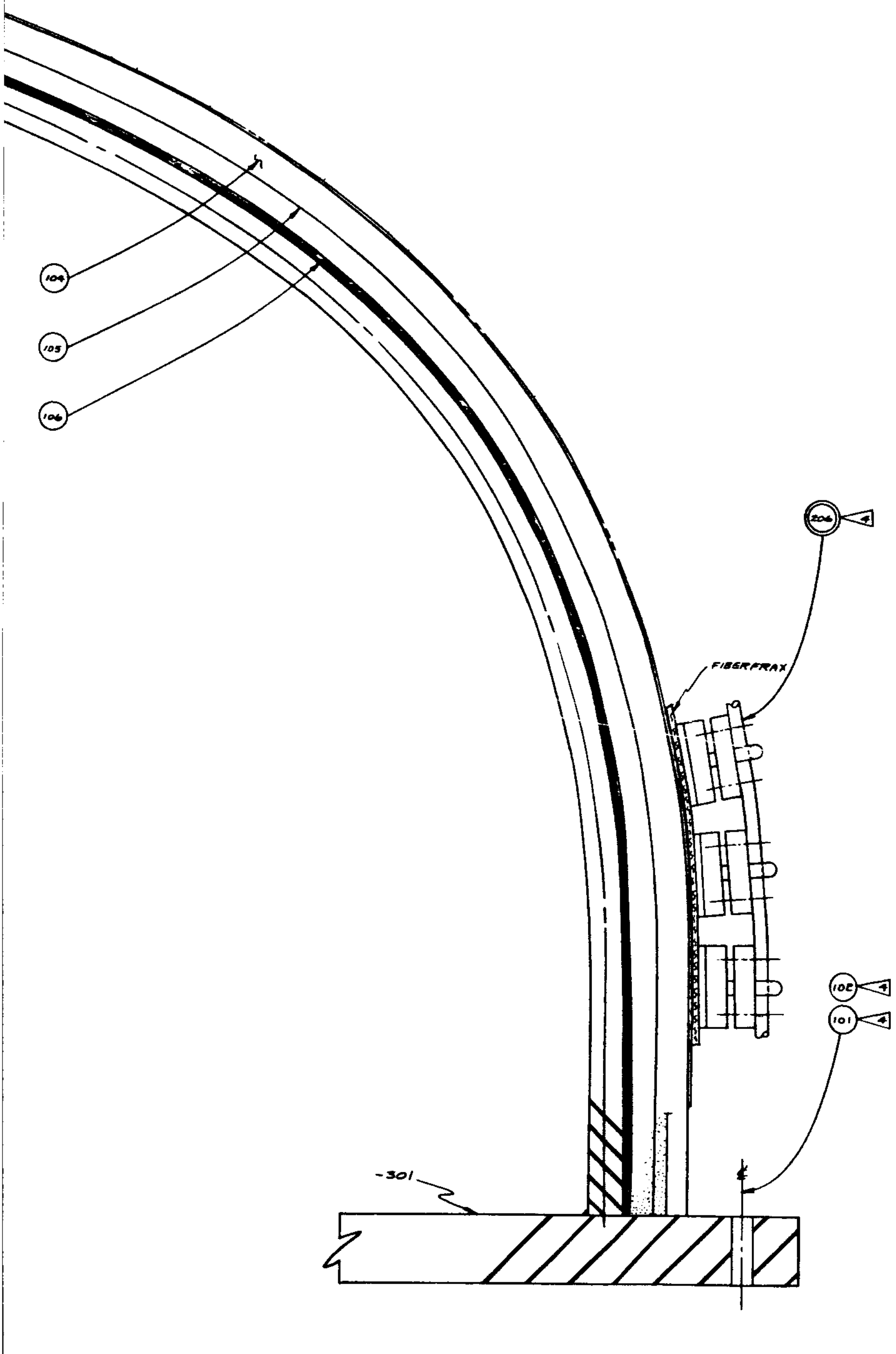




SECT B-B
FULL SCALE

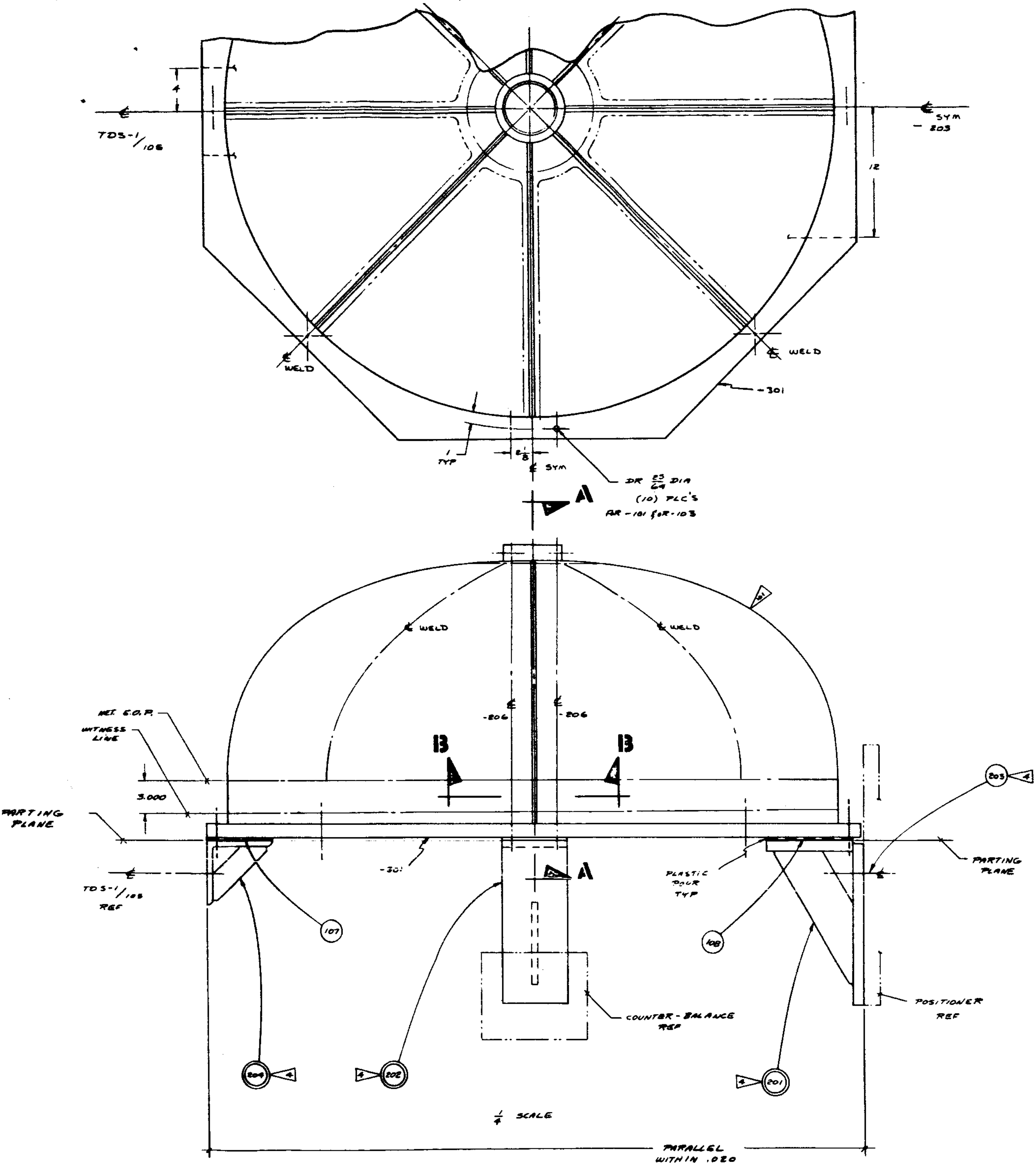


AUX SECT A-A
FOR 117-1001-1 ℄ WLDJ
FULL SCALE



SECT **A-A**
FOR 117-1001-1 1WLDJ
FULL SCALE

2


TDS-1/106
SYM
-203
WELD
WELD
-301
1 TYP
SYM
DR 23/64 DIA
(10) PLC'S
FR -101 & R-103
A
WELD
WELD
-206
-206
B
B
MKT. E.O.P.
WITNESS LINE
3.000
PARTING PLANE
-301
A
TDS-1/105 REF
107
PLASTIC POUR TYP
108
203
PARTING PLANE
COUNTER-BALANCE REF
POSITIONER REF
204
202
201
1/4 SCALE
PARALLEL WITHIN .020

3

TOOL FUNCTION

AUTO-WELD SKINS COMPLETE

GENERAL NOTES

1. BOLT, DOWEL AND/OR WIRE SEAL PER STD. SHOP PRACTICE.
2. CLEAR AS REQUIRED AT TOOL TRIAL.
3. STAMP DASH NUMBER ON DETAILS.
4. PAINT TOOL AND BOX PER CUSTOMER SPECIFICATIONS.
5. MATING AND LOCATING SURFACES NOT TO BE PAINTED.
6. PROVIDE STORAGE BOX FOR REMOVABLE DETAILS. HIGH WIDE LONG: USE
7. LAST VIEW AND/OR SECTION USED:
8. PAINT ALL LIFT POINTS AND MASTERED DETAILS PER CUSTOMER SPEC.
9. STAMP TOTAL NUMBER OF REMOVABLE DETAILS ON TOOL.
10. LOCATE HARDWARE FOR REMOVABLE DETAILS AT MAXIMUM AVAILABLE SPACING. ALTER HARDWARE AS REQUIRED FOR CLEARANCE.
11. SUBSTITUTION OF PARTS AND MATERIAL TO BE FUNCTIONALLY AND PHYSICALLY EQUIVALENT.
12. BREAK SHARP EDGES AND CORNERS EXCEPT AS NOTED.
13. GUSSET GLASS LAMINATES AS REQUIRED.
14. TOOL TO TOOL SURFACES 250 RMS FINISH.
15. TOOL TO PART SURFACES 125 RMS FINISH.
16.

FLAG NOTES

1. SCRIBE AND/OR IDENTIFY INFORMATION AS SHOWN.
2. PURCHASE PER. T.F.M.R. NUMBER.
3. DESIGN A/U 117-1001-1 2 WLDJ
4. THIS DET IS A/U ON 117-1001-1 2 WLDJ

101. SCRIBE ALL ℄ OF WELDS ℄ NET E.O.P.'S PER LATEST ENG. ℄ 117-1001-1 2 TOLT ℄ OR 117-1001-1 3 TOLT

LET.	CHANGE	DATE	APPR.
	PRE-RELEASE #1 SHT 3 ONLY 6-8-65		
	FINAL RELEASE ALL SHTS 6-18-65		

DRAWING NO.	TOOL CODE
117-1001-1	3 TOLT
117-1001-1	2 TOLT

REFERENCE TOOLS THAT ARE USED IN THE FABRICATION OF THIS TOOL

Figure 26

DRAWING NO.	SHT.	CHANGE
117-1001	2	N/C
117-1001	1	A

ENGINEERING AUTHORITY CONTROLLING THE DESIGN OF THIS TOOL

DET. NO.	REQ.	DESCRIPTION	STOCK SIZE	MATERIAL	STD. OR CUST. NUMBER
301	1	WELD ASSY			
206	2	MECH ASSY			
205	1	WELD ASSY			
204	1	WELD ASSY			
203	1				
202	1	WELD ASSY			
201	1	WELD ASSY			
108	1	PAD	½ x 8 x 24	COLD R.S.	
107	1	PAD	½ x 6 x 8	COLD R.S.	
106	1		AS REQD	BURLAP	
105	1		AS REQD	WIRE SCREEN	
104	1		AS REQD	HYDROCAL	
103	2	EYE BOLT	1 BOL 21-003	STK	
102	4	HEX NUT	½-16	STD	
101	2	EYE BOLT	1 BOL 80-020	STK	CL-37-EB

STAMP: (1) TOOL No. ON ALL TOOLS. (2) TYPE STEEL ON ALL HARDENED DETS.

TOLERANCE: ANG. ± 30' FRAC. ± 1/32 DEC. ± .010 UNLESS SPECIFIED

ROHR CORPORATION

PLANT: CHULA VISTA

SCALE: NOTED | MODEL: SATURN S-IC | PART NAME: BULKHEAD - 57" DIA HONEYCOMB

SHEET NO. 1 OF 3 | T.O. NO. 301 GD | TOOL NAME: WELD JIG

ORIG. LET: NEW | DATE: 12th 2

REQ. APP. 6-25-65
PROD. APP. E.K. HUDSON
CHECK 6-11-65
DESIGN ROYAL 6-9-65

CUSTOMER CODE: —

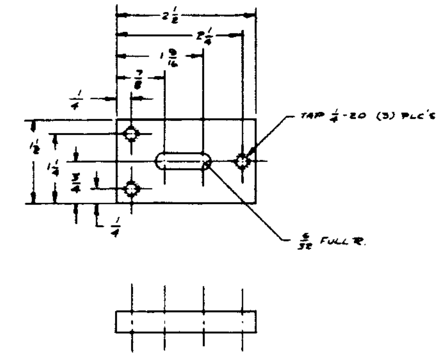
ALSO USED: 3

TOOL NO. 117-1001-1 1 WLDJ

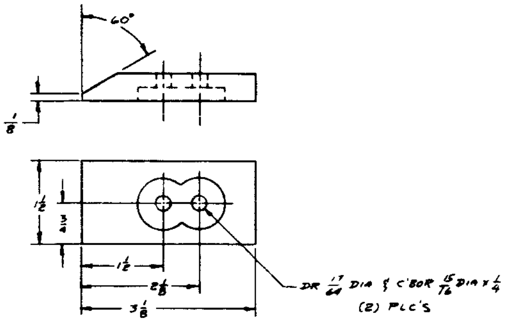
SER. NO. M3304

TOOL CODE

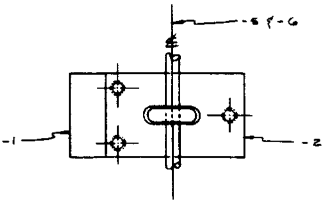
4

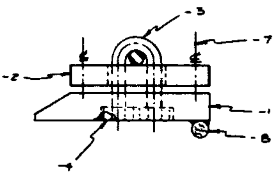


−2



−1



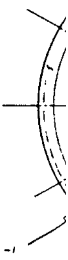


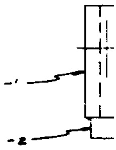
1 BOND WITH RUBBER TO METAL CEMENT

8	16	REQD	5/16 DIA x 1/2	RUBBER 50-55 SHORE
7	48	REQD	1/4-20 OVAL POINT	STD
6	2	REQD	3CLA 90-015C	STK
5	1	REQD	3CAB 76-015C x 48	STK
4	32	REQD	1/4-20 JAM NUT	STD
3	16	REQD	3CLI 90-015	STK
2	16	REQD	3/8 x 1 1/2 x 2 1/2	COLD R.S.
1	16	REQD	1/2 x 1 1/2 x 3 1/8	AL. T. PLT.

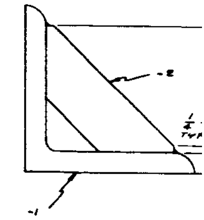
(206) 2 REQD MECH ASSY

FULL SCALE

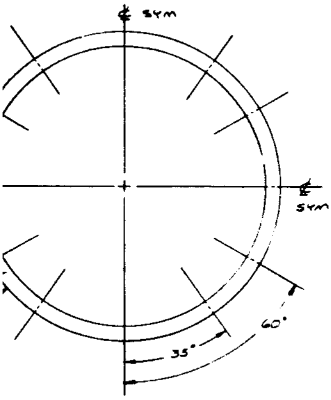


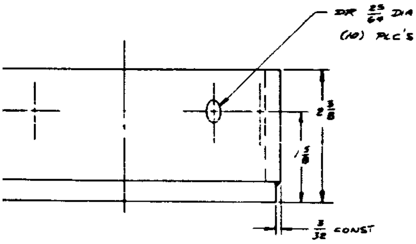


2 / REQD 3/8 x 5
1 / REQD 5 NOM
(205) / REQD WELD



2 / REQD 1/2 x 2 x
1 / REQD 6 x 6 x 3/4
(204) / REQD WELD

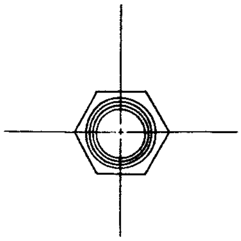


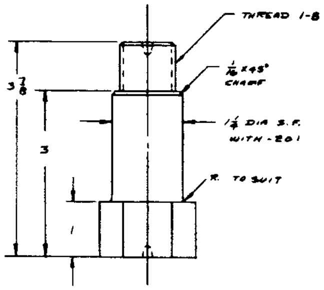


1. WELD 1 SKIP 2

$\frac{?}{?} \times 5\frac{7}{8}$ HOT R.S.
STD × 2 B. PIPE
ASSY

FULL SCALE

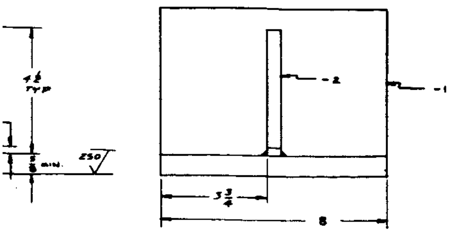




1. DIA TO BE CONCENTRIC WITHIN .010

(203) 1 REQD $1\frac{1}{2}$ HEX × 4 COLD R.S.

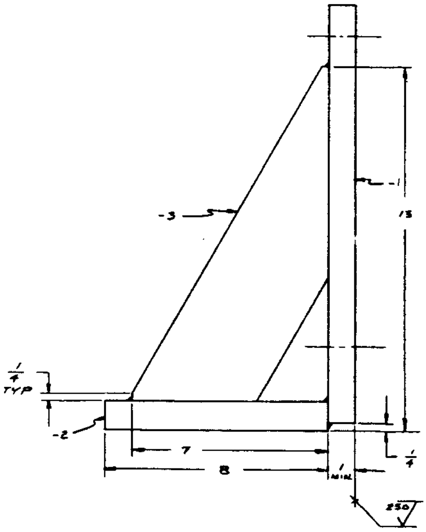
FULL SCALE



1. STRESS RELIEVE $\frac{3}{4}$ MACH.

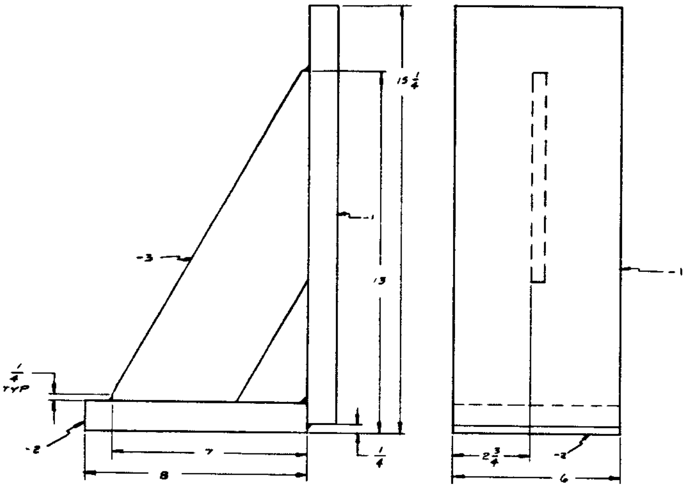
$\times \frac{3}{4}$ HOT R.S.
× 8 STL ANGLE
ASSY

$\frac{1}{2}$ SCALE



3 2 REQD $\frac{1}{2} \times 4 \times 14\frac{1}{2}$ HOT R.S.
2 1 REQD 1 × 8 × 24 HOT R.S.
1 1 REQD $1\frac{1}{4} \times 16 \times 24$ B PLATE
(201) 1 REQD WELD ASSY

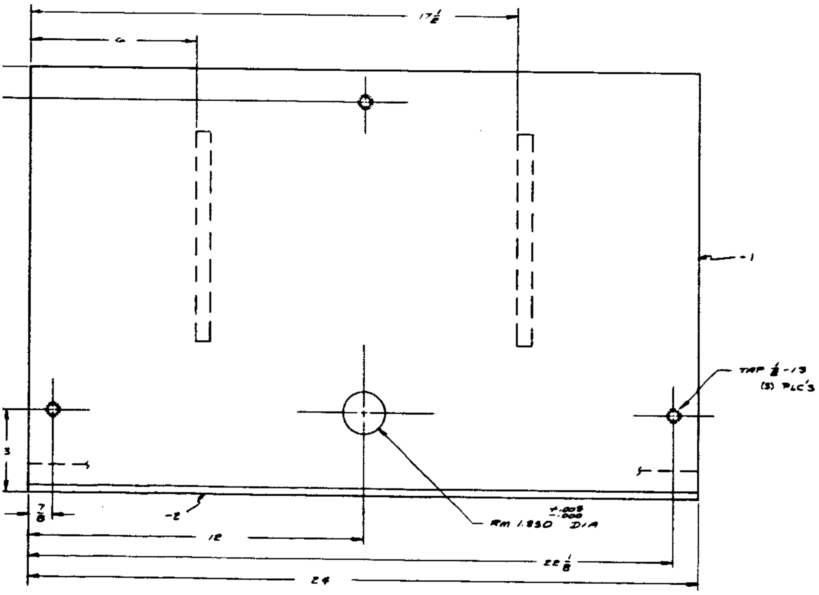
2



1. WELD 1 SKIP 2

3 1 REQD 1/2 x 4 x 14 1/2 HOT R.S.
2 1 REQD 1 x 6 x 8 HOT R.S.
1 1 REQD 1 x 6 x 15 HOT R.S.
202 1 REQD WELD ASSY

1/2 SCALE



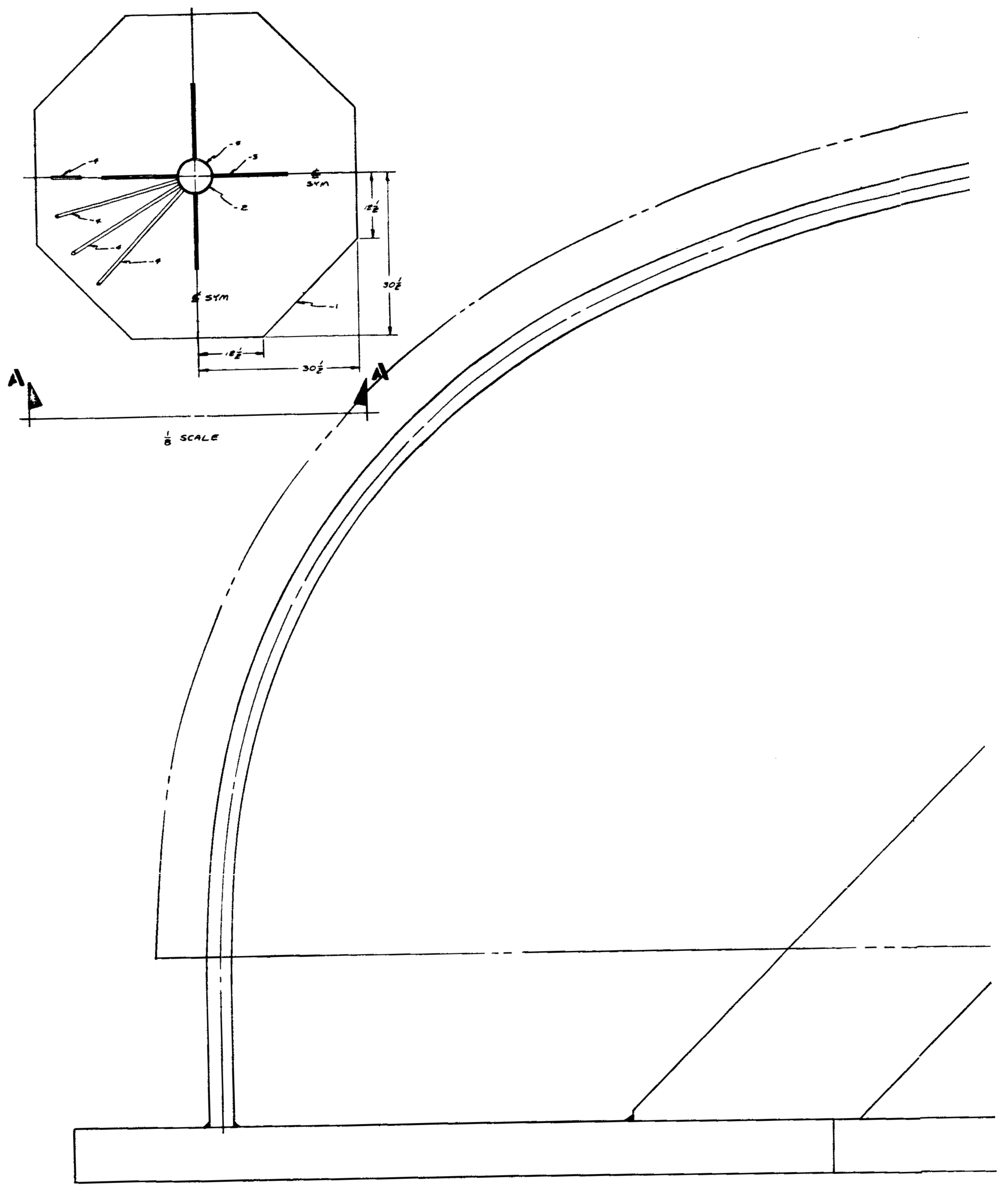
1. WELD 1 SKIP 2
2. STRESS RELIEVE 3/4 MACH

3

1/2 SCALE

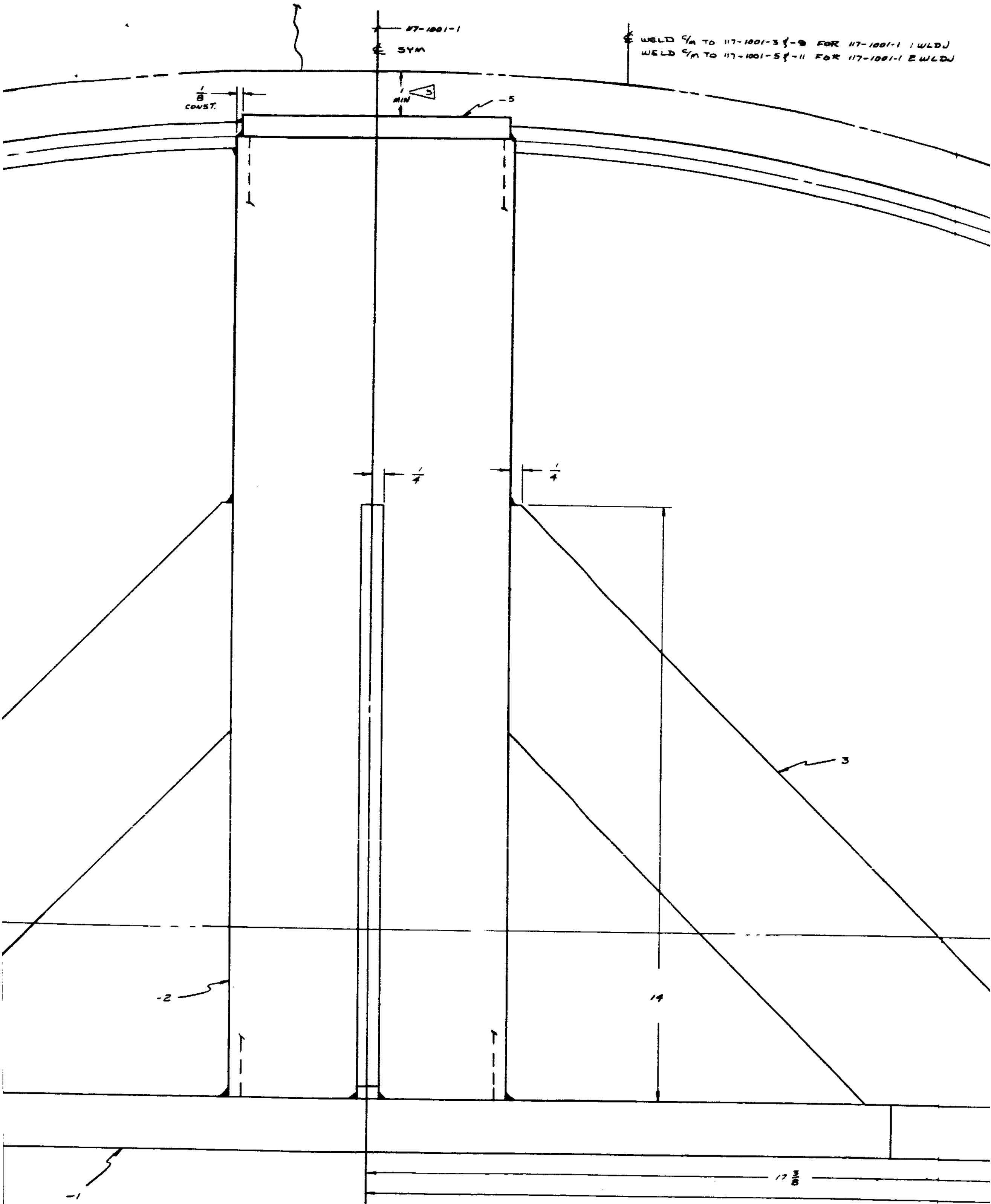
Figure 27

STAMP
(1) TOOL No. ON ALL TOOLS
(2) TYPE STEEL ON ALL HONED DETS
TOLERANCE
UNLESS SPECIFIED
ROHR CORPORATION
PLANT: CHULA VISTA
6-23-65
6-11-65
ROYAL 6-9-65
PART NAME: BULKHEAD - 57" DIA HONEYCOMB
S-IC
SHEET NO. 2
301-00
TOOL NAME: WELD JIG
TOOL NO. 117-1001-1
NEW TD#2
CUSTOMER CODE
SECTION
TOOL CODE: 1 WLDJ



5	1	REQD	½ X 6½ X 6½	HOT R.S.
4	22	REQD	½ DIA X 39	REINFORCING ROD
3	4	REQD	½ X 4 X 20¼	HOT R.S.
2	1	REQD	6 X STA X 22½	BLACK PIPE
1	1	REQD	1¼ X 61 X 61	B PLATE
301	1	REQD	WELD ASSY	

1

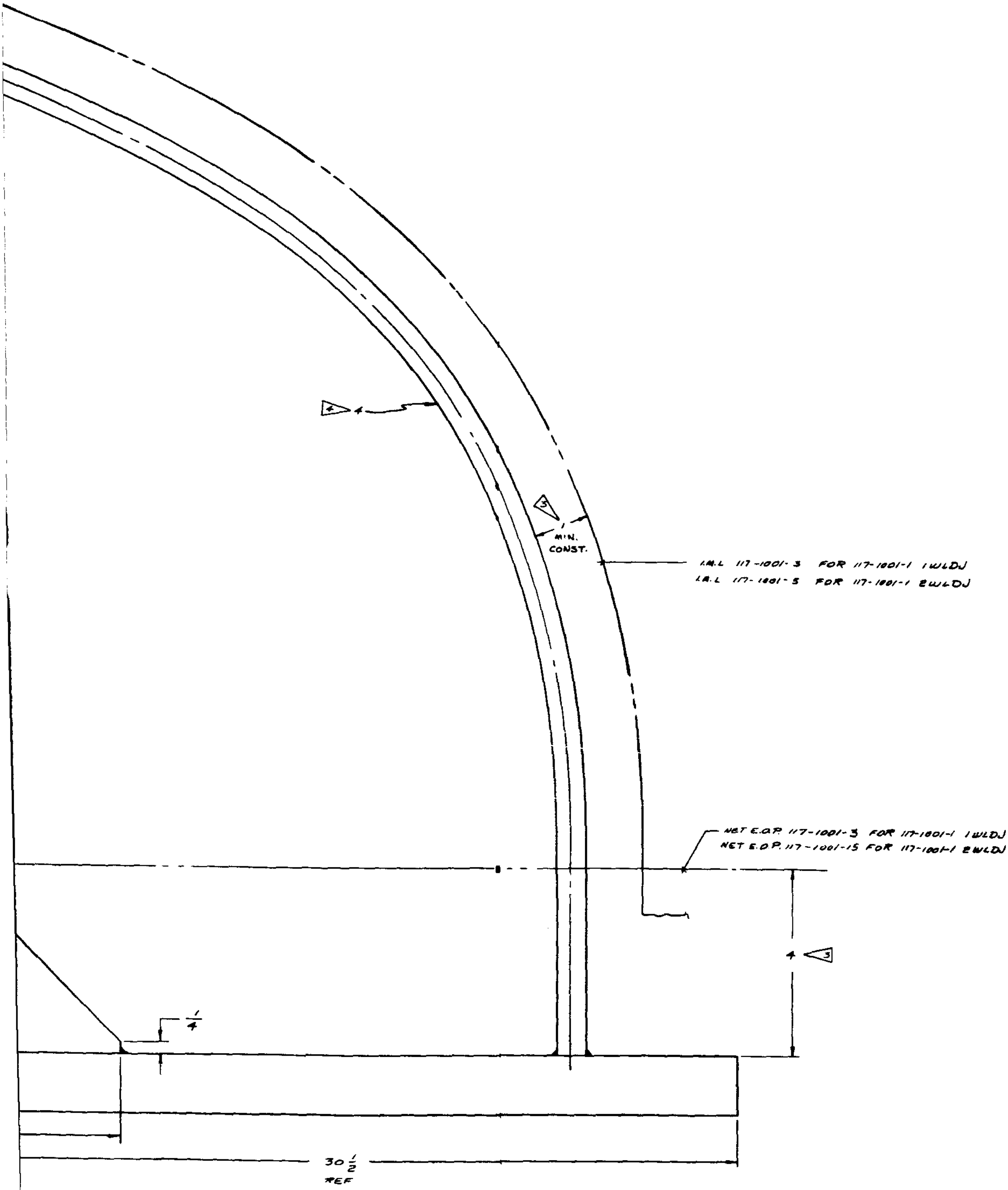


VIEW A-A
FULL SCALE

2

PRE-RELEASE #1
FOR WELDING & STRESS RELIEVING ONLY
JB Royal 6-5-65 RE

FINAL RELEASE
JB Royal 6-10-65



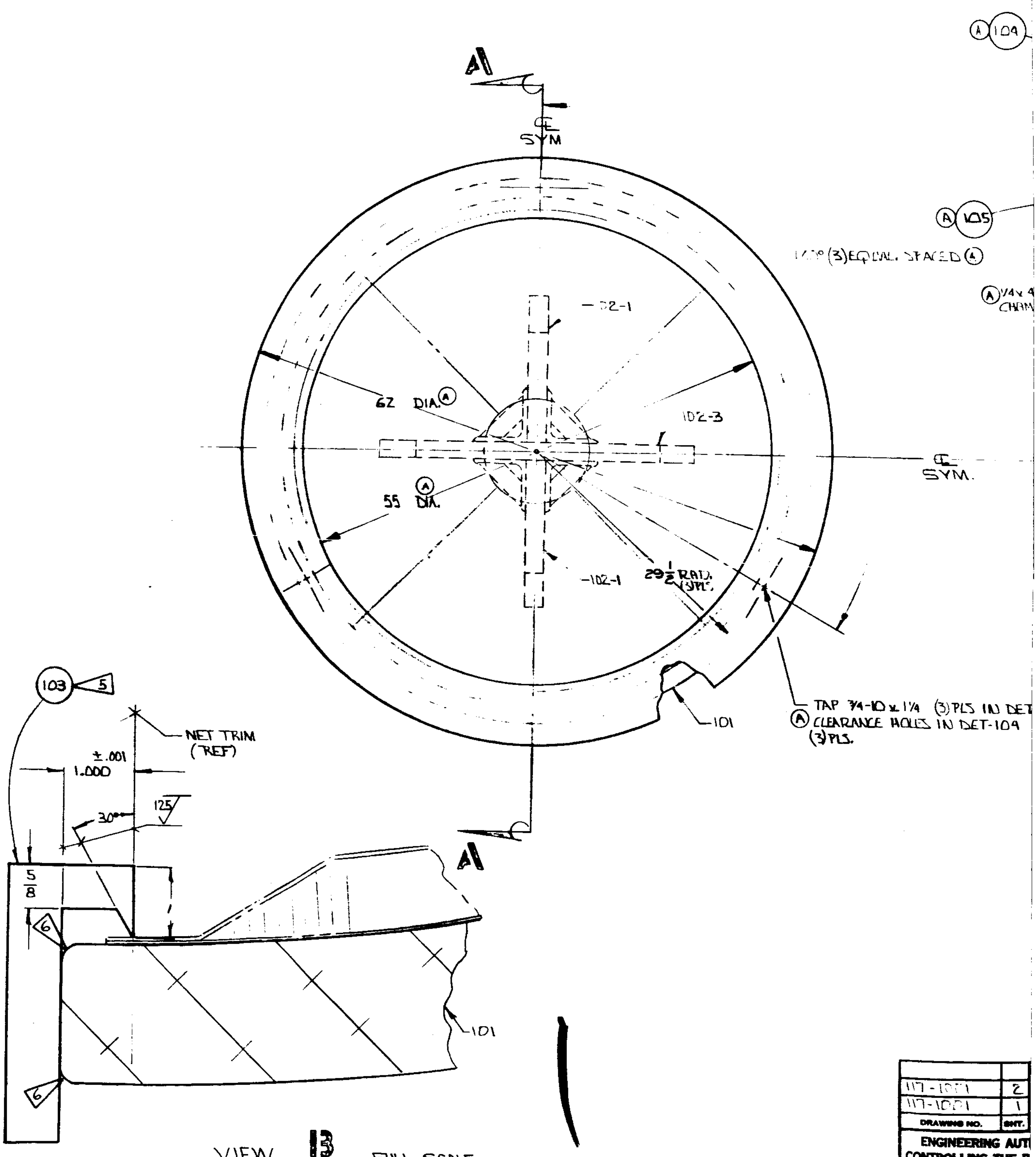
LD 1 SKIP 2 TYP
RESS RELIVE
ETERMINE FROM 117-1001-1 2 TOLT FOR 117-1001-1 1WLDJ
117-1001-1 3 TOLT FOR 117-1001-1 2WLDJ
EQUALLY SPACED

SCALE NOTED

3

Figure 28

ROHR CORPORATION
PLANT: CHULA VISTA
PART NAME: BULKHEAD - 57" DIA S-IC HONEYCOMB
3 WELD JIG
TOOL NO. 117-1001-1
TOOL CODE 1WLDJ
Royal 6-7-65



VIEW B FULL SCALE

117-1001	2
117-1001	1
DRAWING NO.	SHT.

ENGINEERING AUT
CONTROLLING THE D
THIS TOOL.

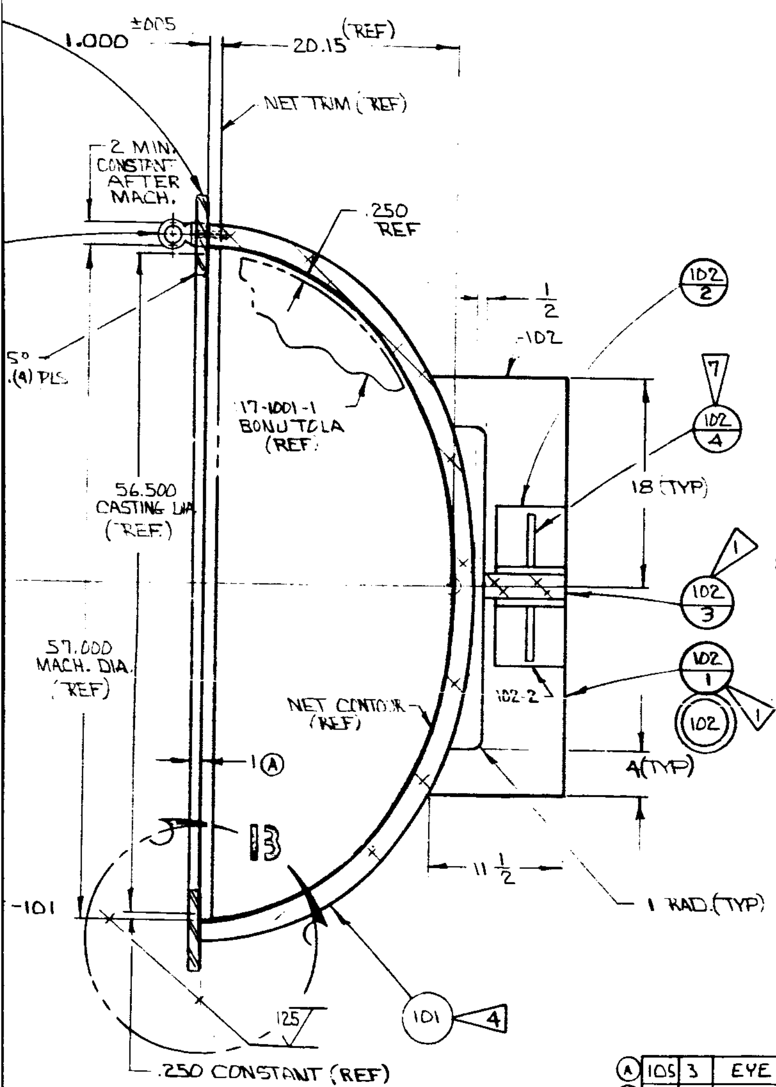
LET.	CHANGE	DATE	APPRD
A	ACTIVE CHANGE ADDED DET-104, -105 & NOTES Nº 8 PER T.O. Nº 2 DTD 9-3-65 SEQ Nº 02 ECA 99-0004 SHT 1 AFF	[illegible]	[illegible]
B	ACTIVE CHG NOTE #8 WAS DC 1200 PRIMER & DC 589 SEALER PER TO #3, DTD 10-6-65, SEQ 03, SHT 1 AFF	[illegible]	[illegible]

TOOL FUNCTION

TO HOLD 57" DIA HONEYCOMB BULK HEAD WHILE BONDING IN AUTO CLAVE. SCRIBE NET TRIM

NOTES

1. CONTOUR PER 117-1001-1 BONJ TOLA (SEE SHT2)
2. BOLT & DOWEL PER STD SHOP PRACTICE.
3. JIG TO JIG SURFACE 250, JIG TO PART 125
4. CONTOUR TO BE ESTABLISHED PER NUMERICAL CONTROL &/ OR 117-1001-1 BONJ TOLA
5. HEAT TREAT RC 58-60.
6. 1/4 RADIUS TYP FOR PERIPHERY OF INNER & OUTER EDGE
7. WELD -102-4 TO 102-2
8. (B) SEAL EXTERIOR OF BONJ USING (1) COAT OF PR 1903 (B) (A) PRIMER & (1) COAT OF PRC1933 SEALER & CURE 24 HRS. PER REP. 150 (B)



SECTION A-A

Figure 29

DET. No.	REQ.	DESCRIPTION	STOCK SIZE	MATERIAL	MFG. OR SUPT. NUMBER
(A) 105	3	EYE BOLTS	1BOL-Z1-01C	STK.	
(A) 104	1		1x6Zx6Z	HOT R. S.	
103	1	SCRIBE	3/4 X 2 X 4	CLASS O-1 T.S.	
4	4		3/8 X 2 X 6	6061-T6	
3	1		2 X 12 X 36	AL TOOL PLT	
2	4		6X6X 1/2 X6	AL ANG	
1	2		2X12 X 17	AL TOOL PLT	
102	1	MECH ASSY	(BASE)		
101	1	SHELL	LAYOUT	356-T6 CAST AL.	

STAMP: (1) TOOL No. ON ALL TOOLS. (2) TYPE STEEL ON ALL HONED DETS.	TOLERANCE ANG. ±30 FRAC. ±1/32 DEC. ±.010 UNLESS SPECIFIED	ROHR CORPORATION PLANT CHULA VISTA	MFG. APR. / PROD. APR. / TOOL ENG. / CHECK / DESIGN	Chadwick 6-1-65 H. Hendricks 5-27-65 H. [illegible] 5-27-65 R.E. O'BRIEN 5-28-65 FROEDE 5-26-65
SCALE NO SCALE UNLESS NOTED	MODEL SATURN S-IC	PART NAME BULK HEAD -57" DIA HONEY COMB	CUSTOMER CODE	ALSO USED
SHEET NO. 1 OF 2	W.O. NO. 301-00	TOOL NAME BOND JIG	TOOL NO. 117-1001-1 BONJ	TOOL CODE
CHG. LET. B	AUTH. T.O. #1		S.Nº 906980	

2

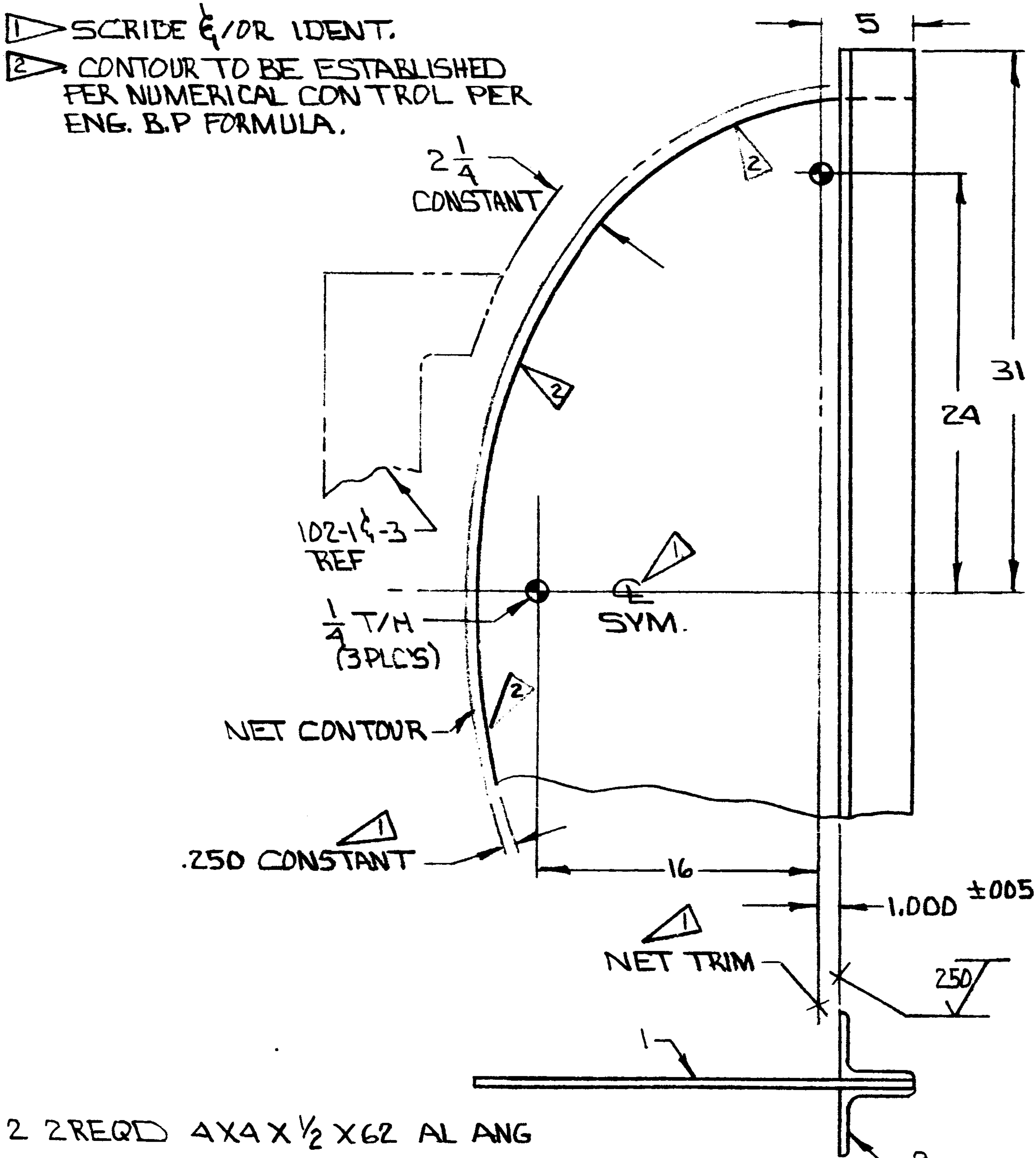
117-1001-1 BONJ	TOLA
DRAWING NO.	REF. TOOL CODE

TSWD D-16210

REFERENCE TOOLS THAT ARE USED IN THE FABRICATION OF THIS TOOL

N C
A
CHANGE

...HORITY
...ESIGN OF



-2 2REQD 4X4 X 1/2 X62 AL ANG

-1 1REQD 1/4 X25 1/2 X58 6061-T6AL

117 -1001-1 BONJ TOLA 1

Figure 30

SCALE	MODEL	PART NAME		DRAFT
NONE	SATURN S-1C	BULK HEAD 57"DIA HONEYCOMB	ROHR CORPORATION	FROEDE 5-27-65
SHEET NO. 2	W.O. NO. 301-00	TOOL NAME BOND JIG	TOOL NO. 117-1001-1 BONJ	CHECK O'Brien 5-28-65
CHG. LET. NEW	AUTH. TO 1	CUSTOMER CODE	TOOL CODE	DES. APR. Chedurich

40A-7 REV 4/62