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FABRICATION OF PLENUM TANKS BY EXPLOSIVE FORMING AND ELECTRON BEAM WELDING

by L. O. Hamilton, E. R. Coleman, and K. K. Hanchey

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George C. Marshall Space Flight Center, Huntsville, Alabama

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MANUFACTURING RESEARCH AND TECHNOLOGY DIVISION
MANUFACTURING ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

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ABSTRACT

This report presents the results of a program initiated to study the use of explosive forming and electron beam fusion welding techniques in the fabrication of pressurized cryogenic materials containers.

Using these techniques, vessels were successfully formed from 304 stainless steel and X7106 aluminum alloy in the T63 condition.

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PREFACE

A study to investigate the feasibility of fabricating pressure vessels by the explosive forming technique and electron beam welding process was conducted by Hayes International Corporation and the Welding Development Branch, Manufacturing Research and Technology Division, Manufacturing Engineering Laboratory.

Hayes International Corporation, under Manufacturing Engineering Laboratory single support contract NAS8-20083 at Marshall Space Flight Center, conducted the explosive forming study. Principal Hayes International Engineers were L. O. Hamilton and E. R. Coleman, Methods Development Group, Manufacturing Engineering Laboratory Operations.

The welding was accomplished in the Welding Development Branch, Manufacturing Engineering Laboratory, by K. K. Hanchey.

This program was conducted under the technical direction of Mr. P. H. Schuerer, Section Chief, and Mr. C. N. Irvine, Project Engineer, Metals Processing Section, Manufacturing Research and Technology Division, Manufacturing Engineering Laboratory.

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FABRICATION OF PLENUM TANKS BY EXPLOSIVE FORMING AND ELECTRON BEAM WELDING

SUMMARY

The study of the fabrication of one or more plenum tanks for cryogenic materials by a combination of explosive forming and subsequent electron beam fusion welding is presented in this report. Two materials, 304 stainless steel and X7106 aluminum, were selected for the forming and welding study because of their characteristics at cryogenic temperatures and their weldability.

The 304 stainless steel was successfully formed from 3/8-inch thick material using the metal gathering technique. Work hardening of this material is a unique characteristic and can be used advantageously.

The X7106 aluminum bulkheads were successfully formed from 1-inch thick material, using the metal gathering technique, then heat treated and aged to the T63 condition. This material was desirable because of its strength-weight relationship.

Satisfactory welds resulted using electron beam welding for both the X7106-T63 aluminum and the 304 stainless steel explosively formed bulkheads. Although the 304 stainless steel bulkheads were readily adaptable to electron beam welding, metallurgical analysis indicated the presence of sulfides, considered detrimental to the end use of the cylinder as a pressure tank.

The X7106-T63 aluminum cylinders presented some problems attributed to the out-gassing of the zinc in the alloy and resulting in the emission of a metal vapor, subsequently causing an arc-out. This problem of arc-outs was solved by the fabrication of a shield of the same electrical potential as the workpiece, which was attached to the electron gun. This process is considered to be a major advance in the technique of electron beam welding of aluminum alloys.

INTRODUCTION

Engineering Project Number 5080 was issued on July 6, 1965, to fabricate one or more tanks, intended for use at liquid hydrogen temperature (-423° F), by a combination of explosive forming and electron beam fusion welding processes. The hemispherical bulkheads of the tanks were to be formed by the explosive forming technique and welded together by the electron beam welding process. The tanks were required to withstand an operating pressure of 3000 psi at room temperature in a vessel 20 inches in diameter, as shown in Figure 1.

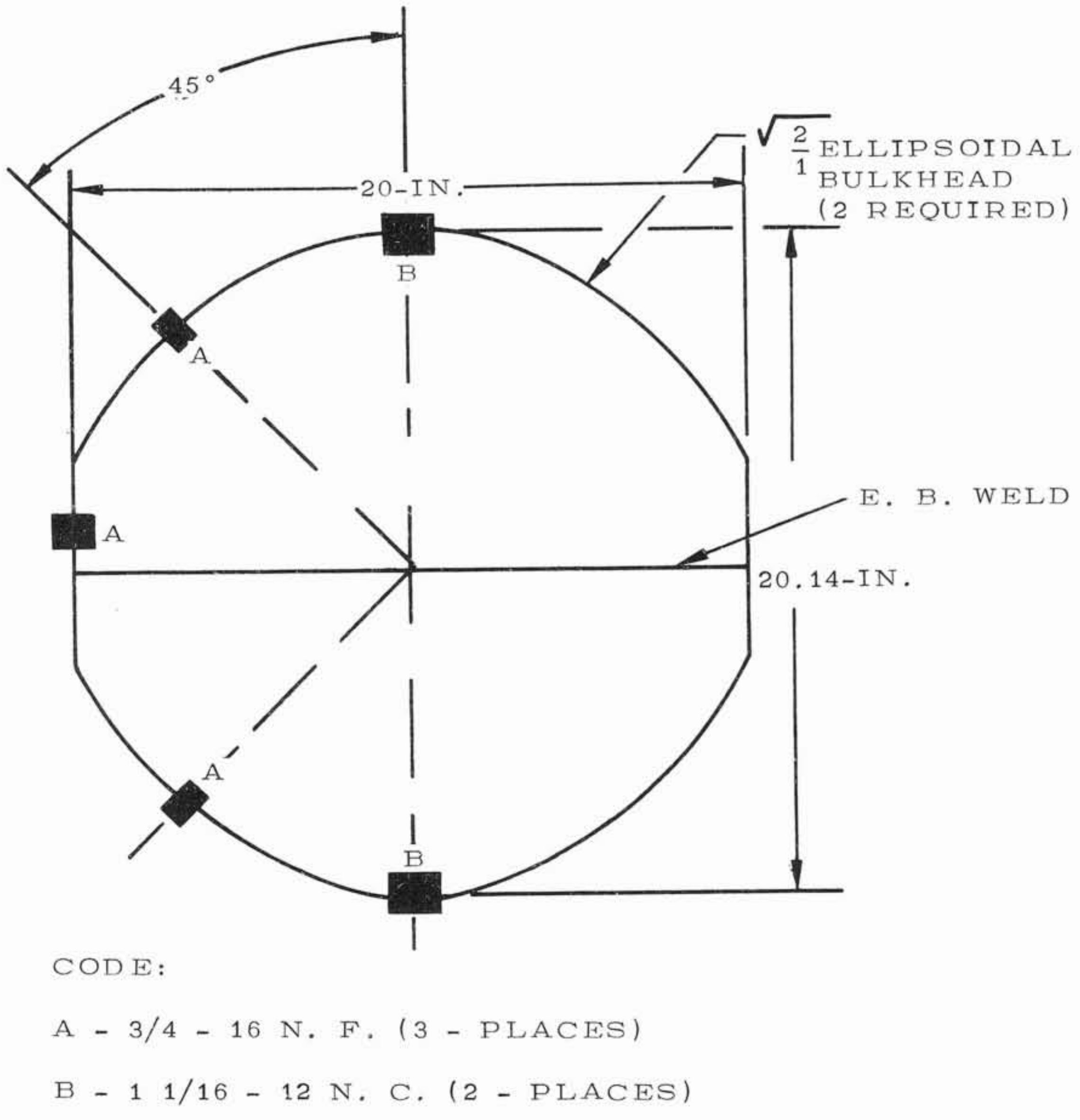


FIGURE 1. PLENUM TANK CONFIGURATION

This report deals with the materials selected, tooling, forming techniques and results, and welding techniques and results.

EXPLOSIVE FORMING OF HEMISPHERICAL BULKHEADS

Forming Materials

Two materials were selected for the explosive forming studies: 304 stainless steel and X7106 aluminum. Each of the materials chosen has some desirable characteristics, as evidenced by the following descriptions. The mechanical characteristics of these materials are presented in Table I.

TABLE I. MECHANICAL PROPERTIES OF FORMING ALLOYS

Before Forming				After Forming			
Material	U.T.S. (psi)	Y.S. (psi)	% Elongation (in 2 inches)	Location	U.T.S. (psi)	Y.S. (psi)	% Elongation (in 2 inches)
304 Stainless Steel	avg - 80,918 max - 82,949 min - 79,915	avg - 34,517 max - 36,866 min - 33,566	avg - 66.3 max - 66.5 min - 66.1	Skirt	avg - 95,958 max - 98,043 min - 93,873	avg - 69,622 max - 71,317 min - 67,927	avg - 38.4 max - 44.2 min - 32.6
				Dome	avg - 109,103 max - 110,760 min - 107,445	avg 87,713 max - 90,038 min - 85,388	avg - 23.9 max - 25.8 min - 22.0
				Apex	avg - 111,805 max - 112,037 min - 111,572	avg - 92,097 max - 92,982 min - 91,211	avg - 29.35 max - 29.7 min - 29.0
*X 7106-T63 Aluminum	* 61,000	* 55,000	* 13	** Trans-verse	avg - 62,550 max - 64,128 min - 60,679	avg - 56,350 max - 57,769 min - 54,391	avg - 15.4 max - 16.4 min - 14.2
				** Longi-tudinal	avg - 64,250 max - 65,538 min - 62,749	avg - 57,650 max - 58,964 min - 55,976	avg - 14.95 max - 17.4 min - 13.8

* - Values supplied by manufacturer

** - Material heat treated and aged to a T-63 condition after forming.

1. 304 Stainless Steel. A decreasing toughness and a corresponding tendency to brittleness at low temperatures are characteristic of most carbon and alloy steels. Only the 9 percent nickel alloy steel and the chromium-nickel stainless steel fail to exhibit this ductile-brittle transition at very low

temperatures. Therefore, the austenitic (18 percent chromium - 8 percent nickel) stainless steels are inherently well suited for cryogenic service at temperatures from 300° F to -452° F.

Type 304 stainless steel was selected for this operation because it is easy to fabricate and weld, does not require heat treatment after fabrication, and is shock resistant at very low temperatures [1].

2. X7106 Aluminum Alloy. Aluminum alloy is desirable to use in the plenum tank investigation because of its unit weight compared to that of steel. X7106 aluminum, an improved heat treatable Al-Zn-Mg alloy containing zirconium, was chosen. This alloy has the highest level of notch toughness and tear resistance of all the aluminum alloys. Also, it is one of the best aluminum alloys to weld since cracking seldom appears when the proper filler is used. The yield properties of X7106 aluminum alloy are increased when naturally aged, and this alloy exhibits increased stress corrosion resistance compared with other aluminum alloys.

3. Theoretical Thickness Calculations. The following calculations were used in determining the thickness requirements of the materials selected to withstand a test pressure of 3000 psig in a 20-inch diameter vessel.

Formula:

$$G = \frac{Pr}{2T}$$

G = Thickness required

P = Test pressure (psi)

r = Radius, inside tank

T = Yield Strength (psi)

Examples: (No safety factor included)

304 Stainless Steel

$$G = \frac{3000 \times 10}{2 \times 118,000} = \frac{30,000}{162,000} = 0.185\text{-inch thick}$$

X7106 Aluminum

$$G = \frac{3000 \times 10}{2 \times 55,000} = \frac{30,000}{162,000} = 0.27\text{-inch thick.}$$

Metals normally increase in strength as they cool from 70° F to -423° F, so the calculated thickness required at 70° F may be considered adequate at -423° F.

Tooling

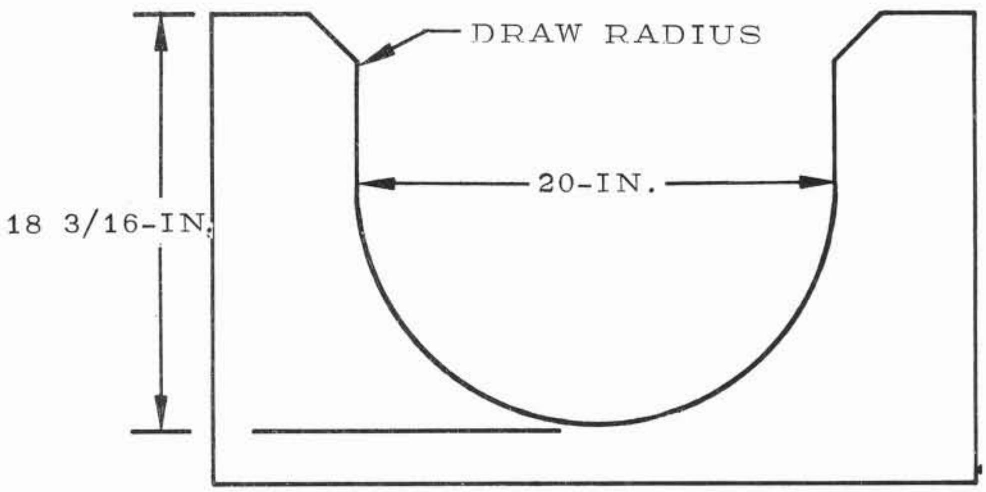
An elliptical die of a 20-inch diameter and an x-y axis relationship of $\frac{x^2}{2} + \frac{y^2}{1} = 1$ was used throughout the forming. A 45-degree draw ring having a 3-inch radius was used on all successful forming tests.

Explosive forming with a draw ring having a 45-degree lead-in angle, without any clamping of the blank, is defined as the "metal gathering" technique. The basic principle of the metal gathering technique is to gather or "bunch" the metal, thereby thickening the metal at the edges and allowing it to flow instead of stretching, thus decreasing the thinout at the apex of the formed part. Figure 2, "Die Draw Ring Configuration," is included in this report for a better understanding of this definition.

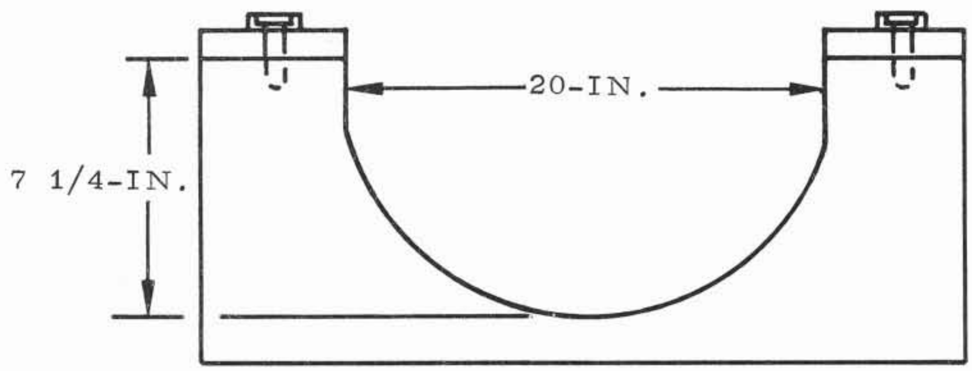
Forming

All forming tests were conducted by Hayes International Corporation under Manufacturing Engineering Laboratory single support contract NAS8-20083. The tests were conducted in the MSFC facilities. Appendix A contains the "Explosive Forming Charts" of the successfully formed parts, presenting the test conducted and the techniques used.

1. 304 Stainless Steel. The 304 stainless steel was found to be very receptive to the metal gathering technique of forming. Four bulkheads were formed of this material; one is depicted in Figure 3. Mechanical properties were taken of one bulkhead before and after forming, indicating yield strength



$\left(\frac{x^2}{2} + \frac{y^2}{1} = 1\right)$ ELLIPSOIDAL DIE WITH 45° DRAW RING



$\left(\frac{x^2}{2} + \frac{y^2}{1} = 1\right)$ ELLIPSOIDAL DIE WITH FLAT DRAW RING

FIGURE 2. DIE DRAW RING CONFIGURATION

increases of approximately 46,000 psi. Tables II and III present tensile test data of 304 stainless steel before and after forming.

TABLE II. TENSILE TEST DATA OF PARENT 304 STAINLESS STEEL

Sample Number	Width	Thick-ness	Area	Ultimate Load	Ultimate psi	Yield Load	Yield psi	Percent Elong.	Hardness
L1	0.5012	0.3983	0.1996	17,135	85,847	6,640	33,267	68.5	Rb 77-79
L2	0.5010	0.3984	0.1996	17,175	86,047	6,696	33,547	69.2	
L3	0.4939	0.3984	0.1968	16,945	86,103	6,552	33,292	66.7	
			Average		86,000		33,400	68.1	
T1	0.4998	0.3984	0.1991	17,185	86,313	6,480	32,546	67.0	
T2	0.4987	0.3987	0.1988	16,675	83,878	6,600	33,199	66.0	
T3	0.4976	0.3987	0.1984	17,025	85,812	6,440	32,460	66.1	
				Average	85,300		32,700	66.4	

TABLE III. TENSILE TEST DATA OF EXPLOSIVELY FORMED 304 STAINLESS STEEL

Sample Number	Width	Thick-ness	Area	Ultimate Load	Ultimate psi	Yield Load	Yield psi	Percent Elong.	Location of Tensile
1	0.5025	0.3370	0.1693	20,000	118,133			34.8	Yield unattainable -Apex
2	0.5025	0.3430	0.1724	20,025	116,154	11,700	67,865	35.3	Apex
3	0.5025	0.3590	0.1804	19,425	107,677	12,180	67,515	40.8	Midway on Dome
4	0.5025	0.3580	0.1800	19,150	106,389	11,920	66,222	38.9	Midway on Dome
5	0.5005	0.4180	0.2092	19,320	92,352	12,640	60,421	52.0	Flange
6	0.5010	0.4030	0.2019	21,950	108,717	14,440	71,521	43.6	Flange
7	0.5025	0.4250	0.2136	26,750	125,234	17,300	80,993	24.8	Flange
8	0.5035	0.4390	0.2210	29,050	131,448	14,720	66,606	21.0	Flange (end)
				Average	113,263		68,734	36.4	

The characteristic of 304 stainless steel to work harden while explosive forming indicated it would be a very good material for pressure tanks since thickness and thus weight could be reduced. A metallurgical examination of 304 stainless steel is contained in Appendix B.

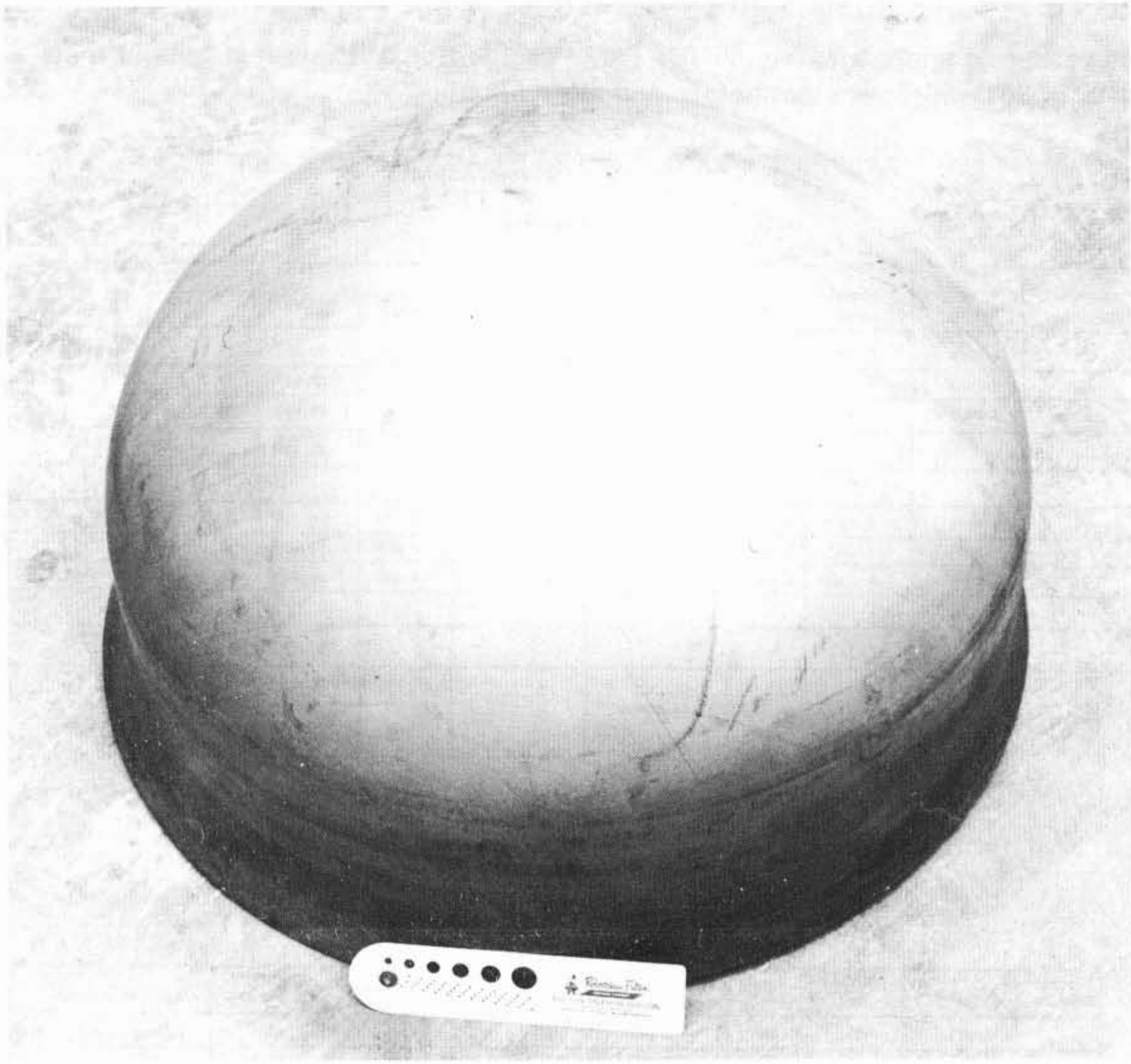


FIGURE 3. 304 STAINLESS STEEL (BEFORE TRIMMING)

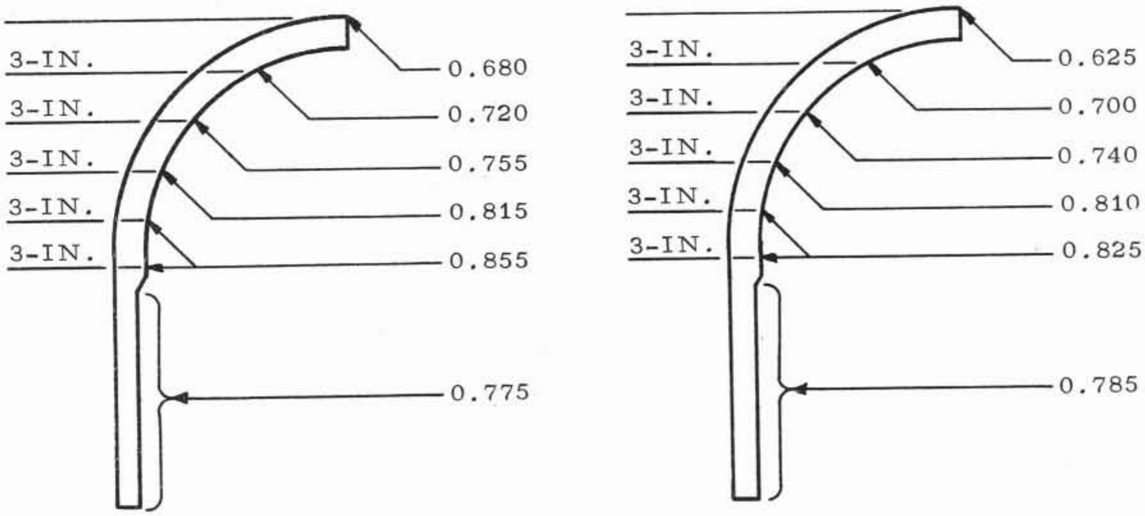
2. X7106-Aluminum Alloy. An X7106 aluminum blank 1-inch thick was necessary to fulfill the pressure test requirements. This presented a challenge because of the draw-diameter ratio (approximately 1:2) of the bulkhead. The metal gathering technique coupled with a ring configuration of sheet explosive and primacord were used to overcome this problem. This technique caused the material to flow toward the apex of the part by exerting the greatest force on the periphery and not on the center. Thus, splitting at the thin section (apex) of the bulkhead was reduced.

A number of bulkheads were formed using the 45-degree draw ring with a 3-inch draw radius as shown in Figure 4, and the draw exceeded the stretch

FIGURE 4. X7106 ALUMINUM (3-INCH RADIUS)

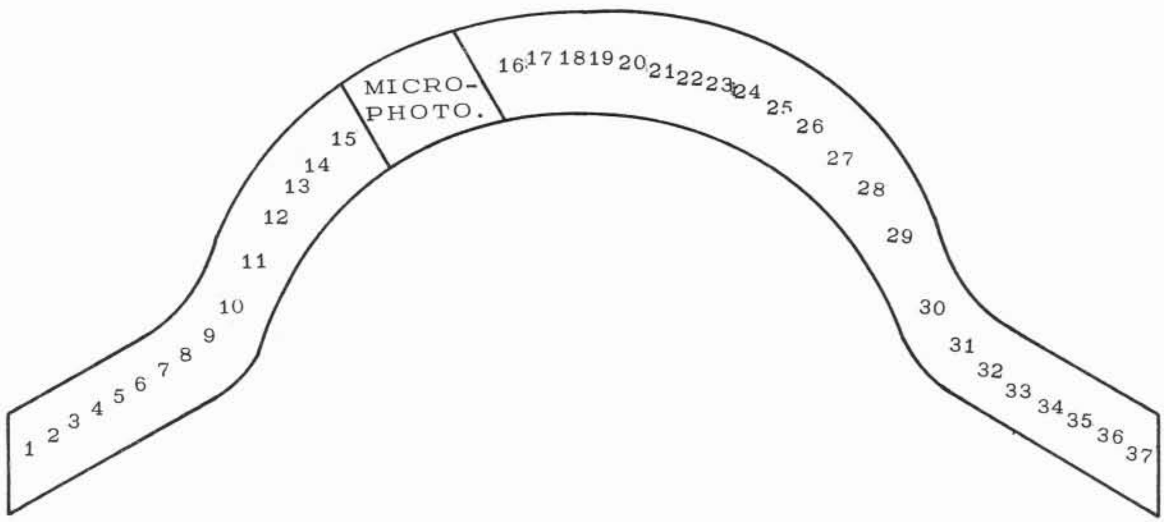
by a factor of approximately 3 to 2. Photomicrographs of an explosively formed dome of X7106 aluminum are contained in Appendix C. Vidigage measurements of the two bulkheads used in fabricating the pressure vessel are presented in Figure 5 and indicate a thinout at the apex of approximately 44 percent.

Product evaluation by Quality Assurance indicated the X7106 aluminum bulkheads were acceptable for pressure tank fabrication. The quality assurance results are presented in Figure 6, and Tables IV and V.



VIDIGAGE MEASUREMENTS

FIGURE 5. QUALITY ASSURANCE MEASUREMENTS AFTER TRIM



APPROXIMATE LOCATION OF TEST POINTS

FIGURE 6. PRODUCT EVALUATION OF FORMED X7106 ALUMINUM (HARDNESS - THICKNESS)

TABLE IV. PRODUCT EVALUATION OF EXPLOSIVELY FORMED AND TRIMMED X7106 ALUMINUM

Measurement	Required	Actual	
		2AL	4AL
Outside diameter	21 ± 1.0 Inch	19.94/20.01	19.96/19.94
Length (Sum of two)	24 ± 2 Inches		22.64 Inches
Thickness: Apex - Min. 0.500 inch	0.625 Inch	0.570 Inch	
Cylinder Section - Min	0.770 Inch	0.770 Inch	
Threads: Each End	AN 1 1/16 - 12-2 B	OK	OK
Quarter, half and three quarter points	AN 3/4-16-2B	OK	OK

TABLE V. PRODUCT EVALUATION (HARDNESS - THICKNESS) FORMED X7106 ALUMINUM

Location	Thickness Inches	Hardness	
		Rockwell - B O. D.	Rockwell - B I. D.
1	1.232	62.8	67.2
2	1.151	73.6	54.8
3	1.116	75.6	74.3
4	1.040	74.9	69.5
5	0.942	72.0	71.0
6	0.840	70.2	82.8
7	0.835	70.0	62.8
8	0.906	75.1	77.8
9	0.895	73.4	70.1
10	0.850	73.5	73.7
11	0.815	76.6	75.9
12	0.804	76.8	78.0

TABLE V. (Concluded)

Location	Thickness Inches	Hardness	
		Rockwell - B O. D.	Rockwell - B I. D.
13	0.786	75.5	77.9
14	0.771	74.8	76.8
15	0.741	77.1	79.1
16	0.625	75.4	74.1
17	0.526	65.3	72.5
18	0.544	69.8	72.1
19	0.589	73.8	74.0
20	0.640	74.9	72.0
21	0.679	74.0	78.1
22	0.711	77.2	78.4
23	0.742	76.2	79.9
24	0.770	75.5	79.7
25	0.797	77.0	77.9
26	0.808	76.5	73.3
27	0.842	74.5	76.4
28	0.872	75.0	76.9
29	0.884	77.4	61.3
30	0.843	77.1	80.0
31	0.805	76.2	82.0
32	0.882	66.3	75.3
33	0.977	80.0	68.0
34	1.050	78.6	77.0
35	1.092	74.5	72.2
36	1.155	73.2	70.8
37	1.180	73.6	73.0

ELECTRON BEAM WELDING

Welding X7106-T63 Aluminum Alloy

1. Problems and Solutions. The metallurgical composition of X7106-T63 aluminum presented problems in making electron beam weldments. The

relatively high percentage of volatile zinc in this alloy produces a very detrimental metal vapor which may cause a direct contact or short between the cathode and anode, thus resulting in an arc-out.

One of the most successful techniques for reducing this arcing condition has been the placing of a vapor shield between the electrode gun and the workpiece, thus trapping or collecting the metal vapors. This technique, employing a shield of the same electrical potential as the workpiece, was used successfully to weld 1-inch thick flat plates of X7106-T63 aluminum but was not deemed feasible for welding cylinders because of the contour of the part. Therefore, MSFC personnel developed an adaptor or supressor attached to the electron gun between the focus coil and the workpiece (Fig. 7) to weld aluminum cylinders successfully.

FIGURE 7. SECONDARY EMISSION SUPPRESSOR

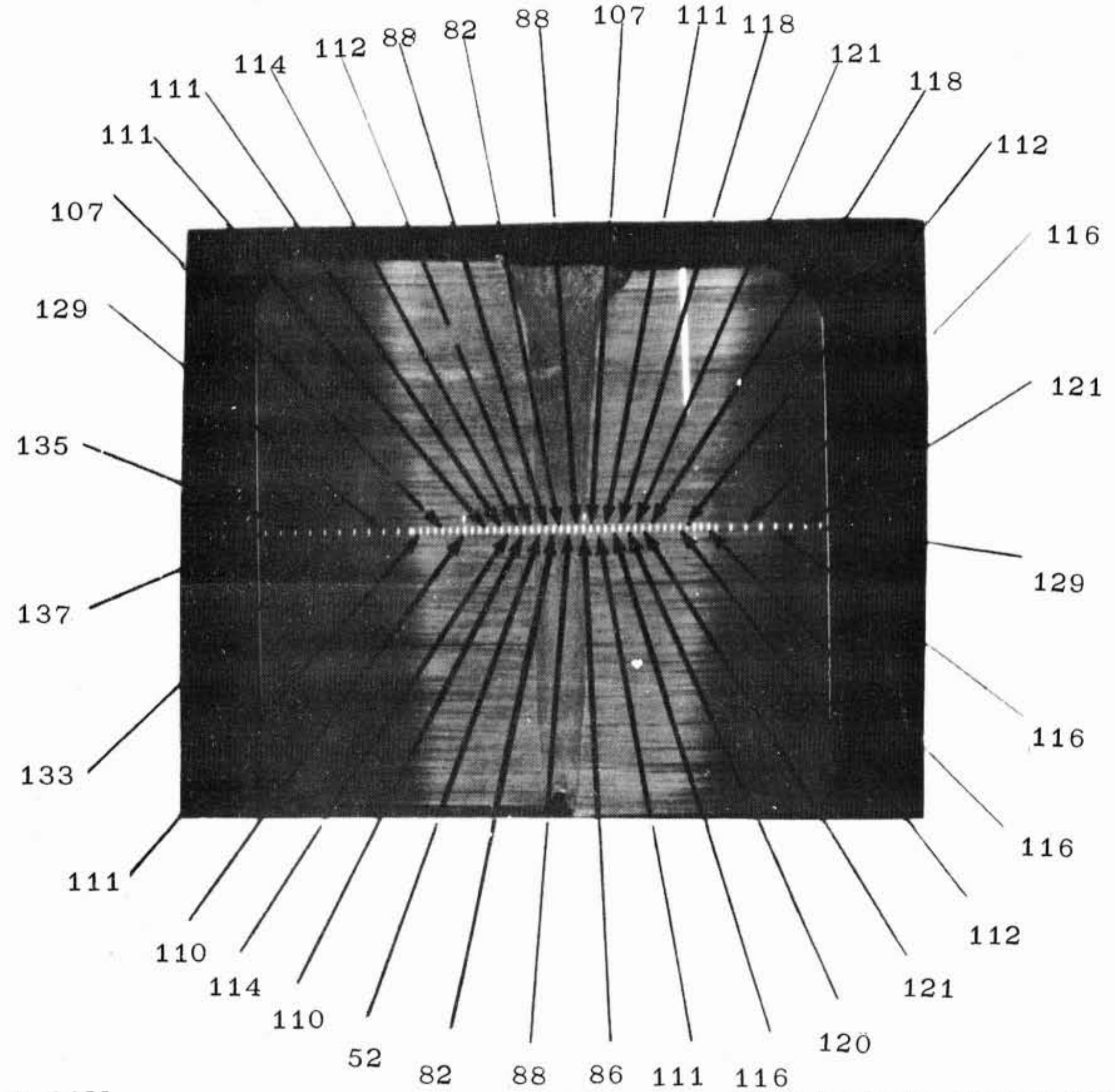
2. Establishing Weld Parameters. Aluminum Alloy X7106-T63 plates of 3/4-inch thickness were electron beam welded to establish operational parameters prior to welding the pressure vessel of the same material and thickness. The depth-to-width ratio was approximately 11 to 1.

Weld parameters for single pass, fully penetrated weld in the aluminum alloy plate were as follows:

High Voltage	29 kilovolts
Beam Current	250 Milliamperes
Focus Current	6.31 amperes
Filament Current	57 amperes
Travel Speed	40 inches per minute
Gun to Work Distance	2 inches

One weld was butt joined with an intentional mismatch. Other aluminum welds were of the bead-on-plate type. The above weld parameters were used in both cases.

Sample specimens for metallographic examination were obtained from the welds made with the derived parameters; micrographs of the weld cross-sections with associated microhardness values are shown in Figure 8. The Knoop hardness values are converted to Rockwell B values in Table VI.



3.66X

KELLER'S REGENT

NOTE: KNOOP HARDNESS VALUES ARE GIVEN FOR POSITIONS INDICATED

FIGURE 8. ELECTRON BEAM WELD IN 3/4-INCH THICK X7106-T63 ALUMINUM PLATE

TABLE VI. WELD PROPERTIES OF X7106-T63 ALUMINUM

Sample Number	Width	Thick-ness	Area	Ultimate		Yield		Percent Elong.	Remarks
				Load	psi	Load	psi		
90-1-1	0.997	1.009	1.0059	60,800	60,443	47,100	46,824	- 11.5	Pulled to 60,000 psi then set 24 hours and pulled to destruction.
-2	0.980	1.008	0.9878	60,100	60,842	46,400	46,973	10.8	
-3	0.990	1.005	1.003	60,790	60,608	46,960	46,820	10.0	
					60,600		46,872	10.8	
90-2-1	0.997	1.009	1.0059	61,000	60,642	47,520	47,241	9.8	
-2	0.980	1.010	0.9898	58,800	59,406	46,400	46,878	6.9	
-3	0.998	1.010	1.0079	61,200	60,720	47,360	46,989	11.8	
					60,300		47,000	9.5	
90-3-1	0.983	1.007	0.9898	57,120	57,709	46,400	46,878	6.3	
-2	0.980	1.009	0.9888	59,220	59,891	45,200	45,712	9.8	
-3	0.999	1.009	1.0079	60,000	59,530	46,400	46,036	8.4	
				Average	59,043		46,000	8.2	

TABLE VI. WELD PROPERTIES OF X7106-T63 ALUMINUM (Concluded)

Sample Number	Width	Thick-ness	Area	Ultimate Load	Ultimate psi	Yield Load	Yield psi	Percent Elong.	Remarks
90-4-1	0.996	1.009	1.0049	50,920	50,672	47,040	46,811	5.3	Lack of fusion at root of weld.
-2	0.980	1.010	0.9898	59,650	60,263	45,760	46,232	10.1	
-3	0.997	1.008	1.0049	61,125	60,827	47,720	46,492	11.9	
					57,300		46,500	9.1	
90-5-1	0.982	1.010	0.9918	60,650	61,151	46,240	46,622	11.0	
-2	0.980	1.011	0.9908	59,720	60,275	46,400	46,831	8.8	
-3	0.996	1.011	1.0069	61,050	60,632	46,480	46,161	11.8	
					60,700		46,500	10.5	
90-6-1	0.981	1.009	0.9898	60,080	60,699	46,480	46,959	11.4	
-2	0.980	1.010	0.9898	60,500	61,123	46,480	46,959	11.4	
-3	0.996	1.009	1.0049	60,980	60,683	46,560	46,333	10.3	
				Average	60,800		46,800	11.0	

3. Welding a 20-Inch Diameter Pressure Vessel. The same control parameters were used to obtain a radiographically acceptable welded cylinder, as were used to weld the flat aluminum plates. Figures 9, 10, and 11 show a bulkhead trimmed for welding, two bulkheads before welding, and the plenum

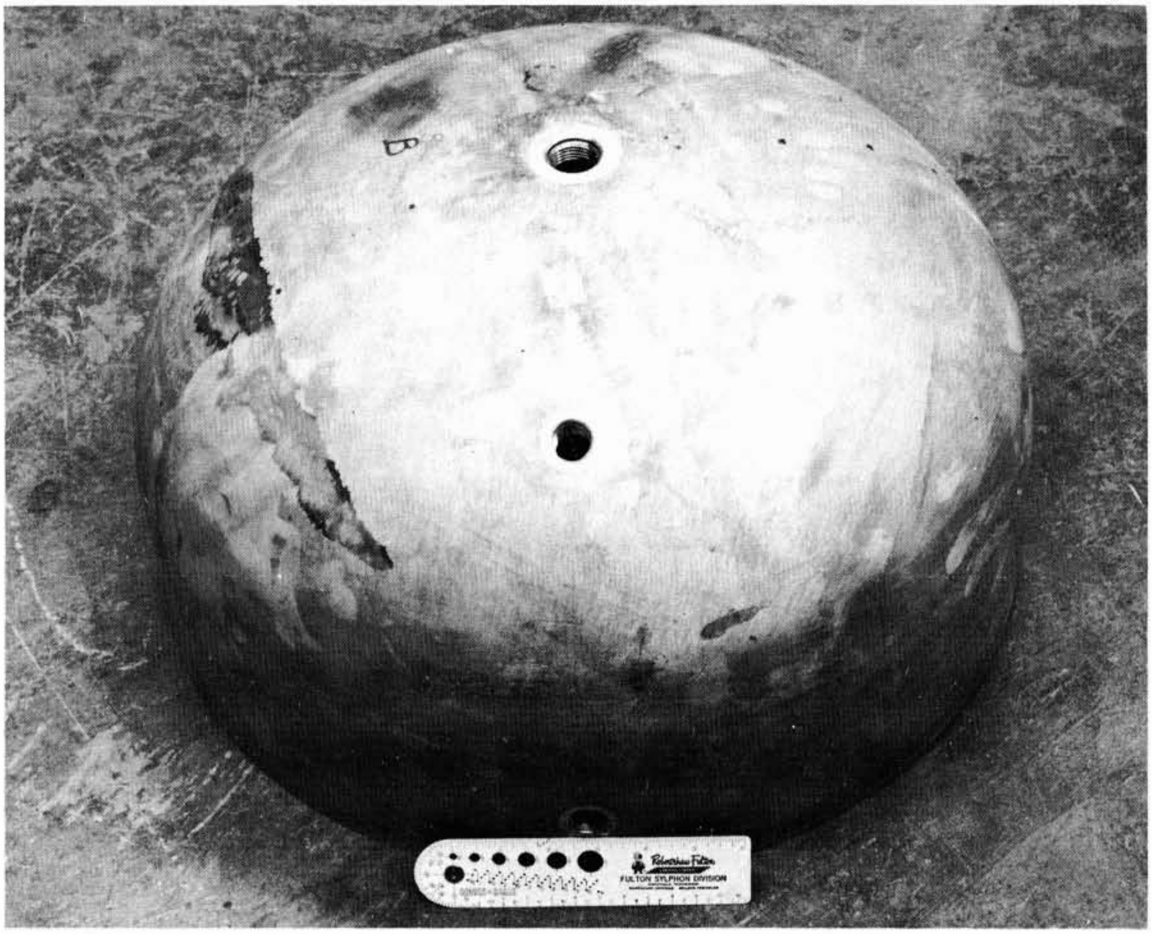


FIGURE 9. X7106-T63 ALUMINUM BULKHEAD TRIMMED FOR WELDING

tank welding fixture, respectively. Figures 12, 13, and 14 show the bulkheads in the fixture ready for E. B. spot welds, the welding of the cylinder, and the welded cylinder, respectively.

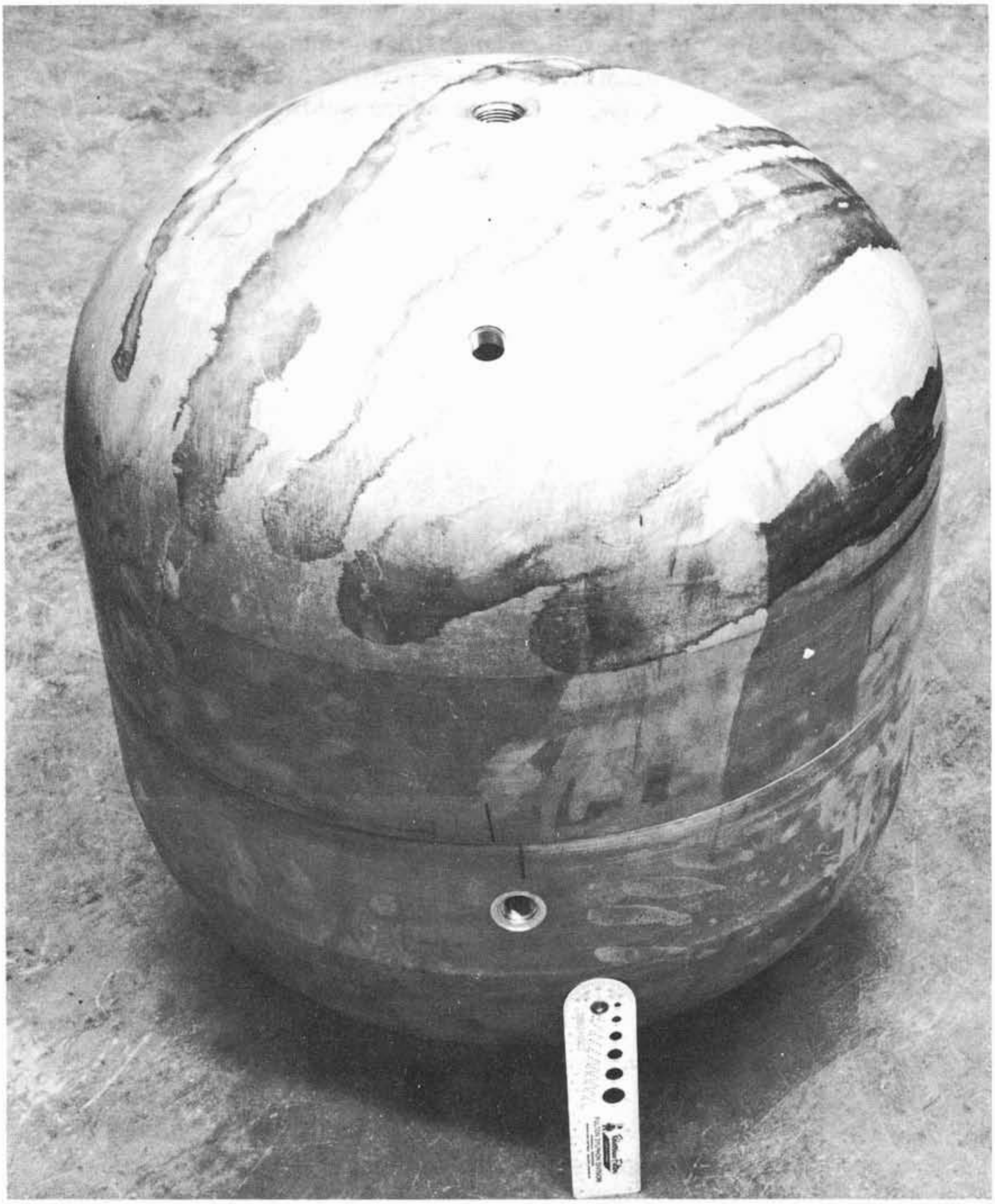


FIGURE 10. X7106-T63 ALUMINUM BULKHEAD BEFORE WELDING

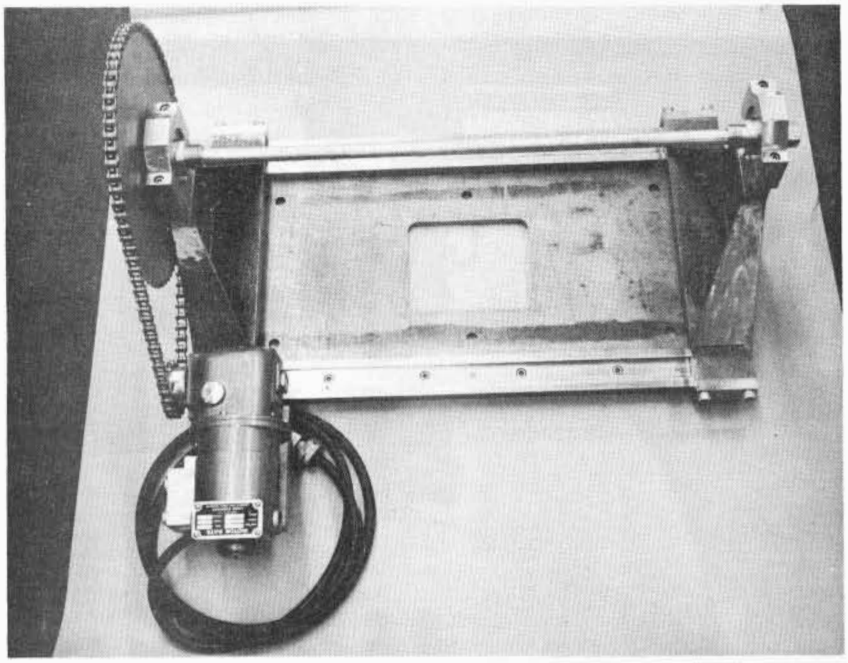


FIGURE 11. PLENUM TANK WELDING FIXTURE

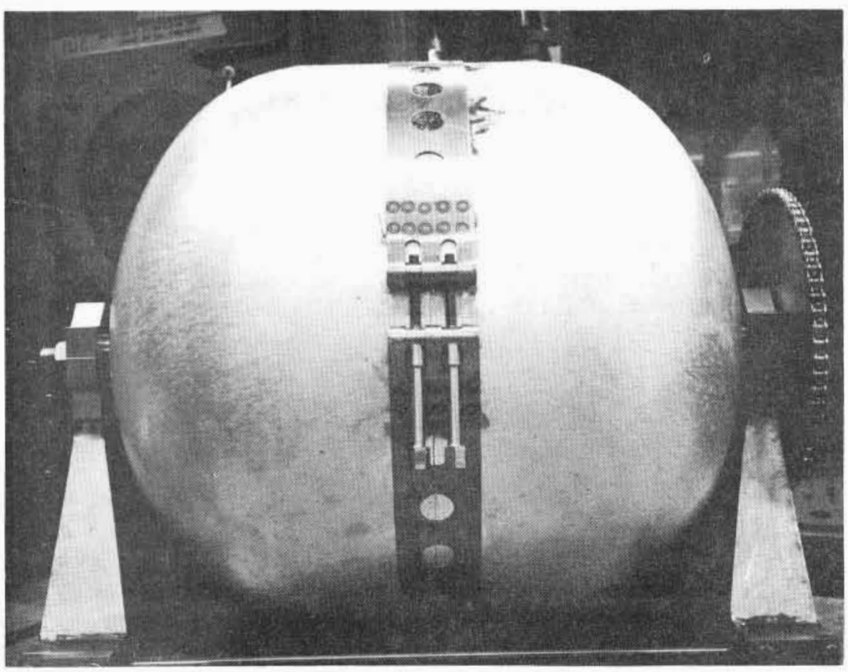


FIGURE 12. PLENUM TANK IN FIXTURE READY FOR E. B. SPOT WELDS

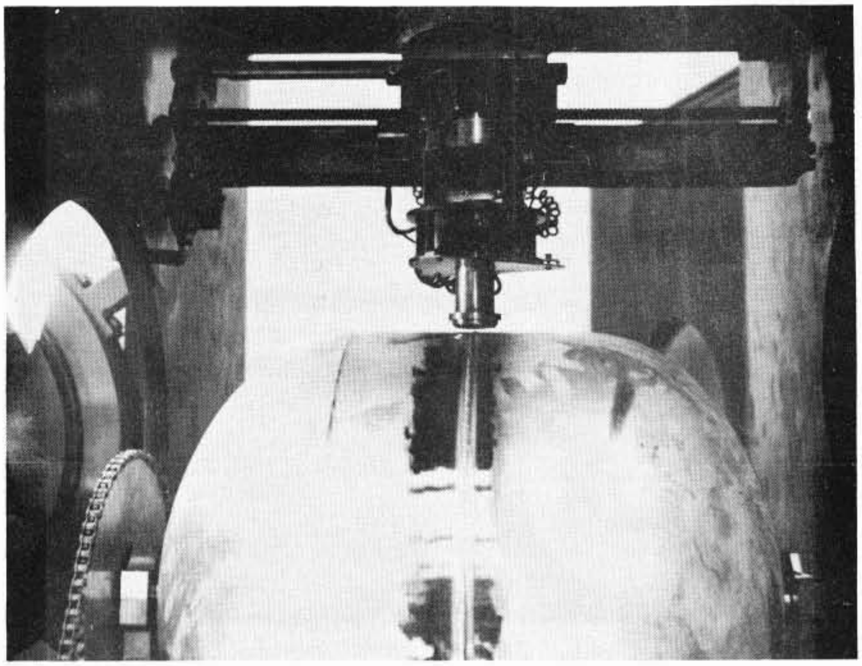


FIGURE 13. WELDING OF PLENUM TANK

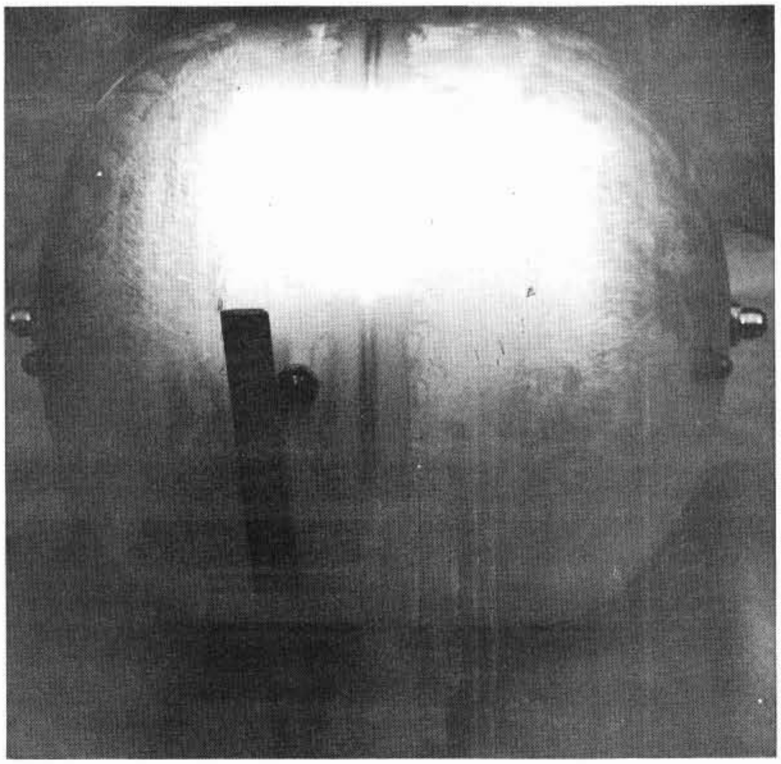


FIGURE 14. X7106-T63 ALUMINUM WELDED PLENUM TANK

Welding 304 Stainless Steel

1. Establishing Weld Parameters. Weld parameters for single pass, fully penetrated, bead-on-plate weld in 3/8-inch thick 304 stainless steel were as follows:

High Voltage	30 amperes
Beam Current	230 milliamperes
Focus Current	6 amperes
Filament Current	57 amperes
Travel Speed	40 inches per minute
Gun to Work Distance	2 inches.

Gradual decrease in penetration at the terminal end of the weld (tailout) was accomplished by slowly decreasing the gun filament current from the required for full penetration to zero penetration. A cross-section of the tailout in the stainless steel plates is shown in Figure 15. A photomacrograph of the weld cross-section containing the tailout with associated microhardness values is shown in Figure 16. Sample specimens for metallographic examination were obtained from welds made with the derived parameters.

2. Welding a 20-Inch Diameter Pressure Vessel. The same control parameters were used to obtain a radiographically-acceptable welded cylinder as were used to weld the flat stainless steel plates. Figures 17 and 18 show the welded 304 stainless steel cylinder.

PLENUM TANK PRESSURE TEST DATA

The two plenum tanks, X7106-T63 aluminum and 304 stainless steel, were pressure tested by the test section of P&VE.

The tanks were filled with water and pressurized by a hand pump to a pressure of 2500 psi and held for 30 minutes (monitored by a pressure gage). It was determined that the original test pressure of 3000 psi was excessive; therefore, the cylinders were tested at 2500 psi. No leak developed and there was no visual damage to the tanks.

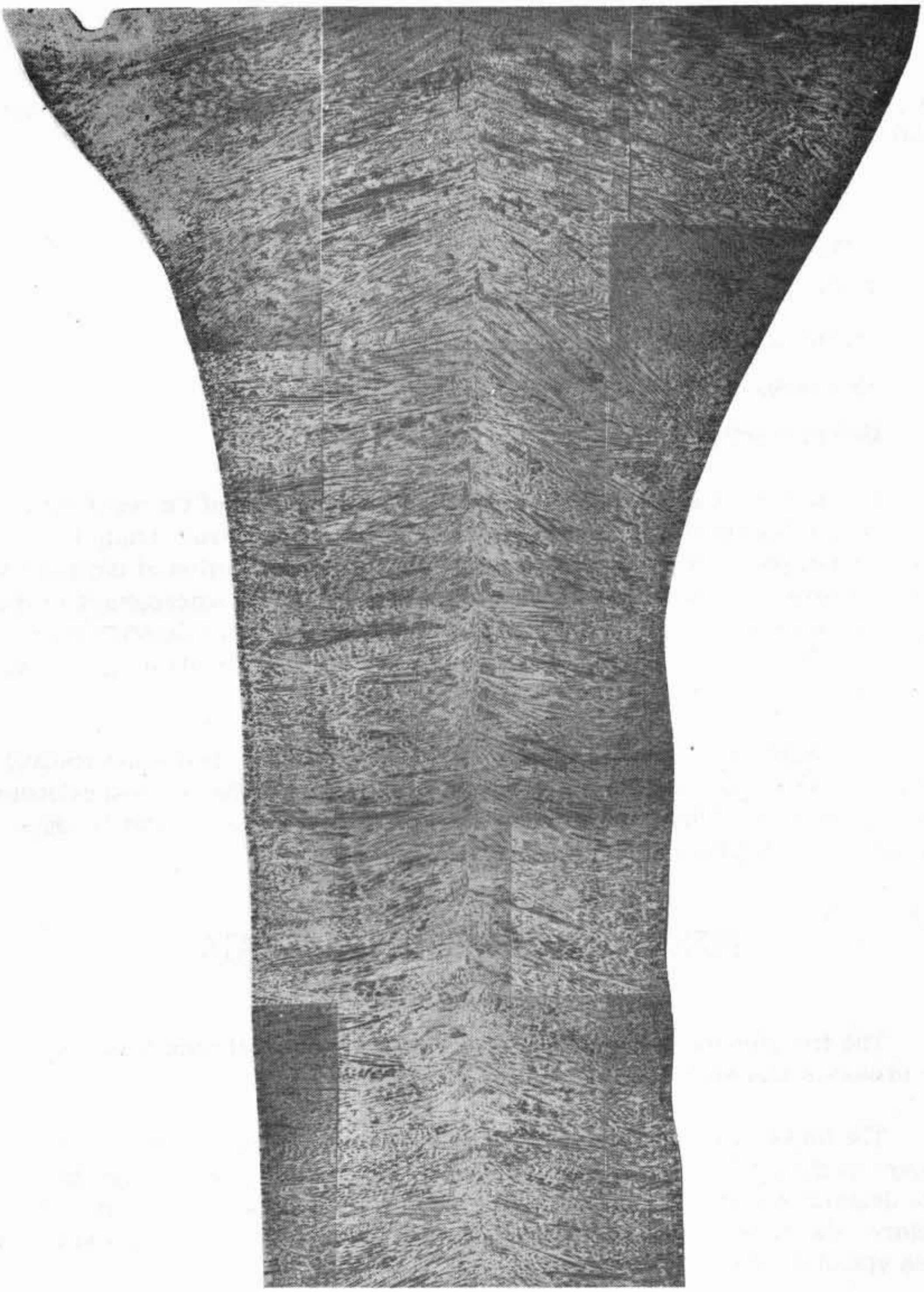
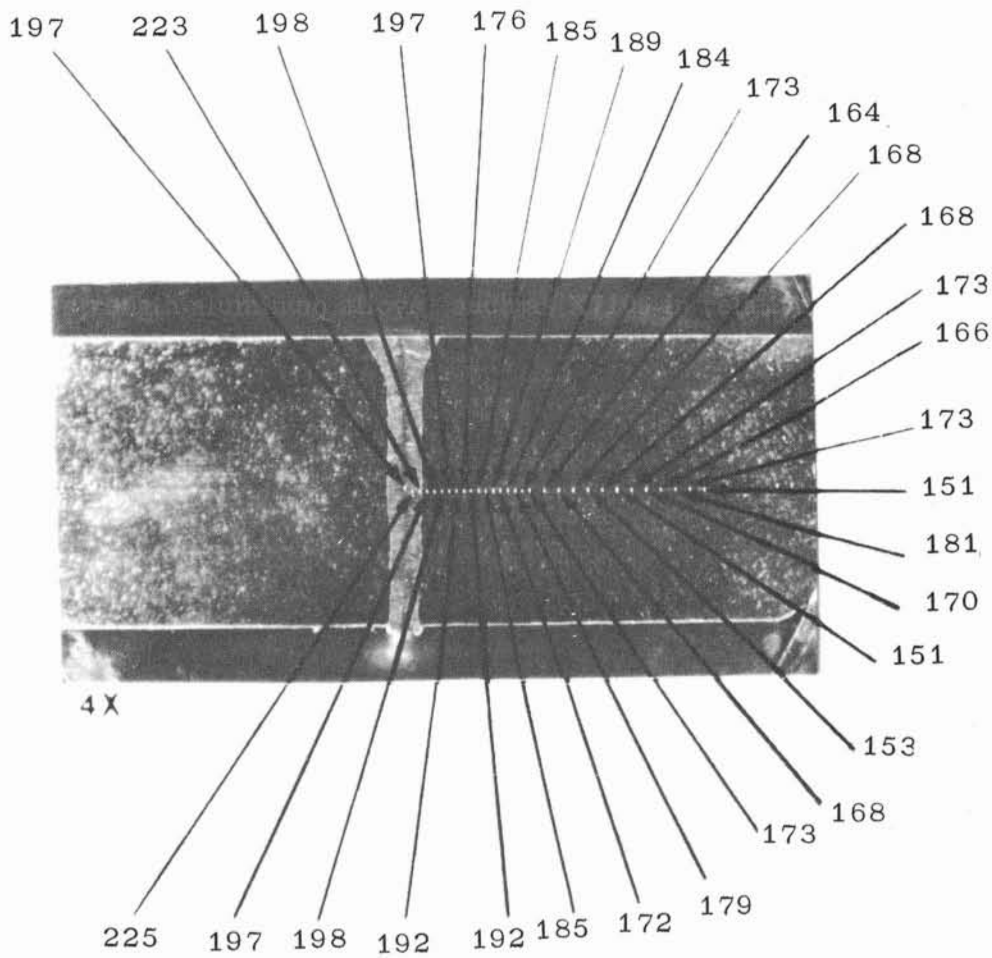


FIGURE 15. CROSS-SECTION OF TAILOUT AS WELDED IN 304 STAINLESS STEEL PLATE



NOTE: KNOOP HARDNESS VALUES ARE GIVEN FOR POSITIONS INDICATED FROM CENTER OF WELD INTO PARENT METAL

FIGURE 16. ELECTRON BEAM WELD IN 3/8-INCH THICK 304 STAINLESS STEEL PLATE

CONCLUSIONS AND RECOMMENDATIONS

Explosive Forming

1. Explosive forming is an acceptable technique for the production of acceptable quality plenum tank bulkheads from stainless steels, such as 304, and high strength aluminum alloys, such as X7106 in relatively thick sections.

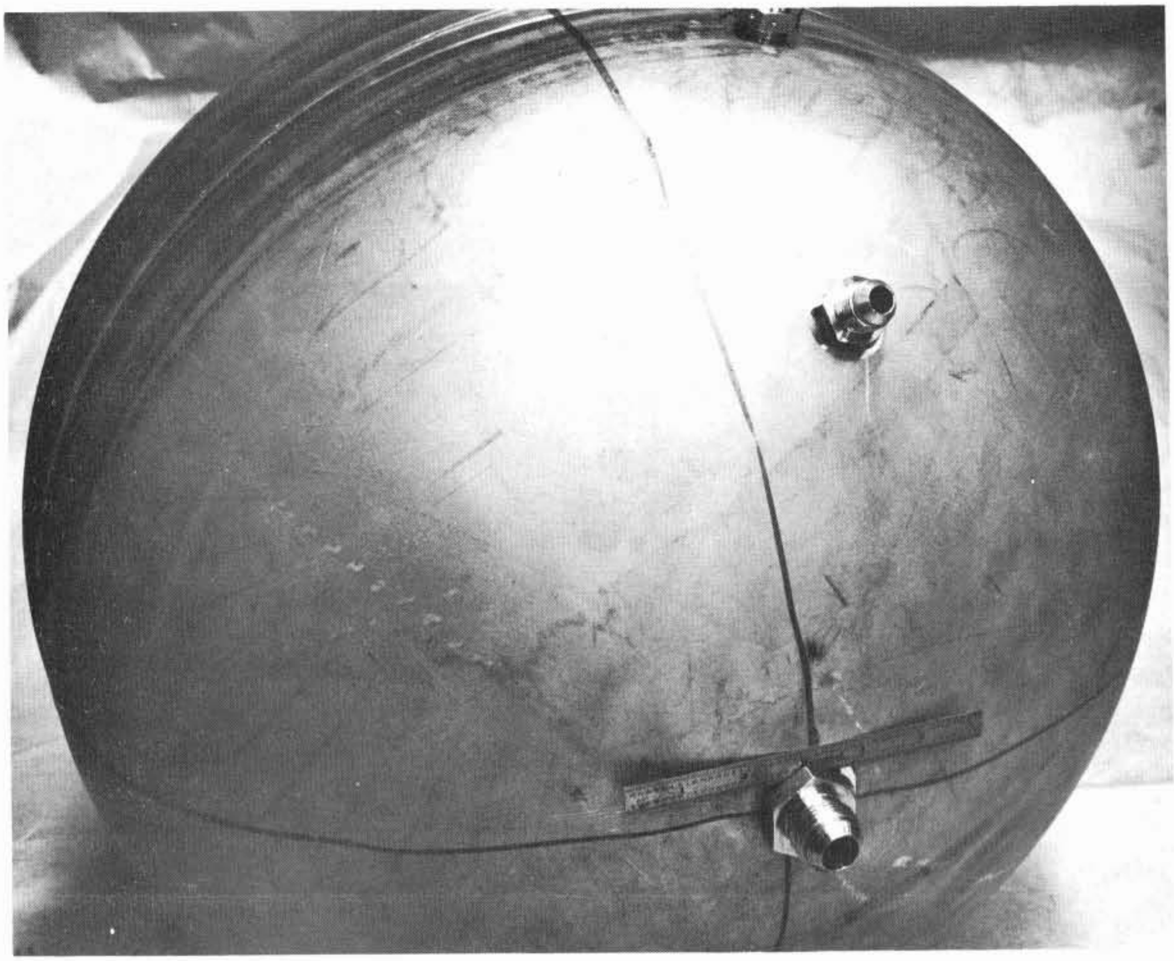


FIGURE 17. WELDED 304 STAINLESS STEEL
PLENUM TANK (END VIEW)

2. The use of explosives in forming 304 stainless steel increases the yield strength by approximately 30 percent, by work hardening the material.

3. The metal gathering technique of explosive forming is recommended for forming thick materials into configurations such as:

$$\frac{x^2}{2} + \frac{y^2}{1} = 1 .$$

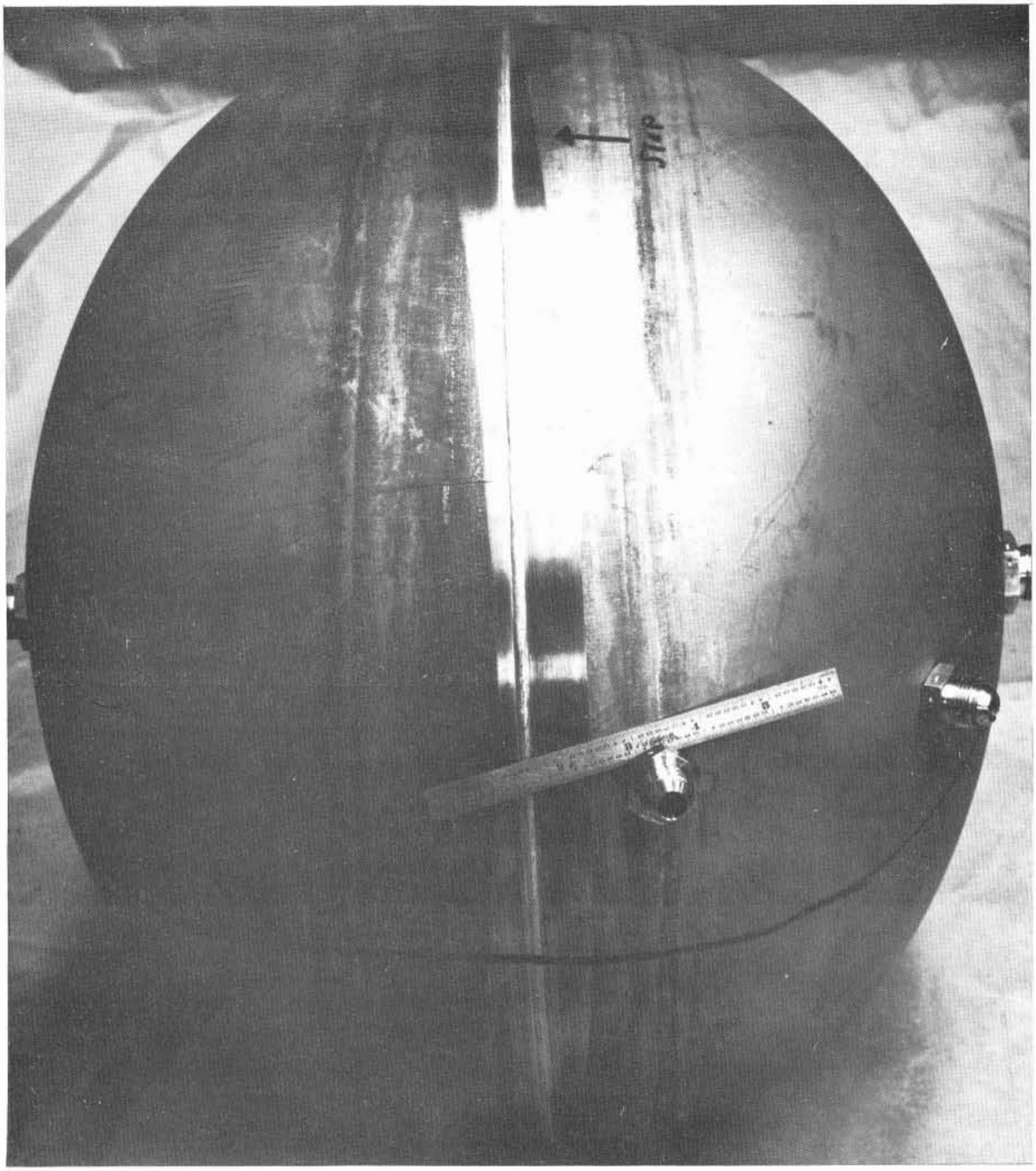


FIGURE 18. WELDED 304 STAINLESS STEEL PLENUM TANK
(SIDE VIEW)

Electron Beam Welding

1. The use of a vapor shield or suppressor is necessary for successful welding of X7106-T63 aluminum using the electron beam.

2. By the electron beam technique, 304 stainless steel is readily welded.

APPENDIX A.
EXPLOSIVE FORMING CHARTS

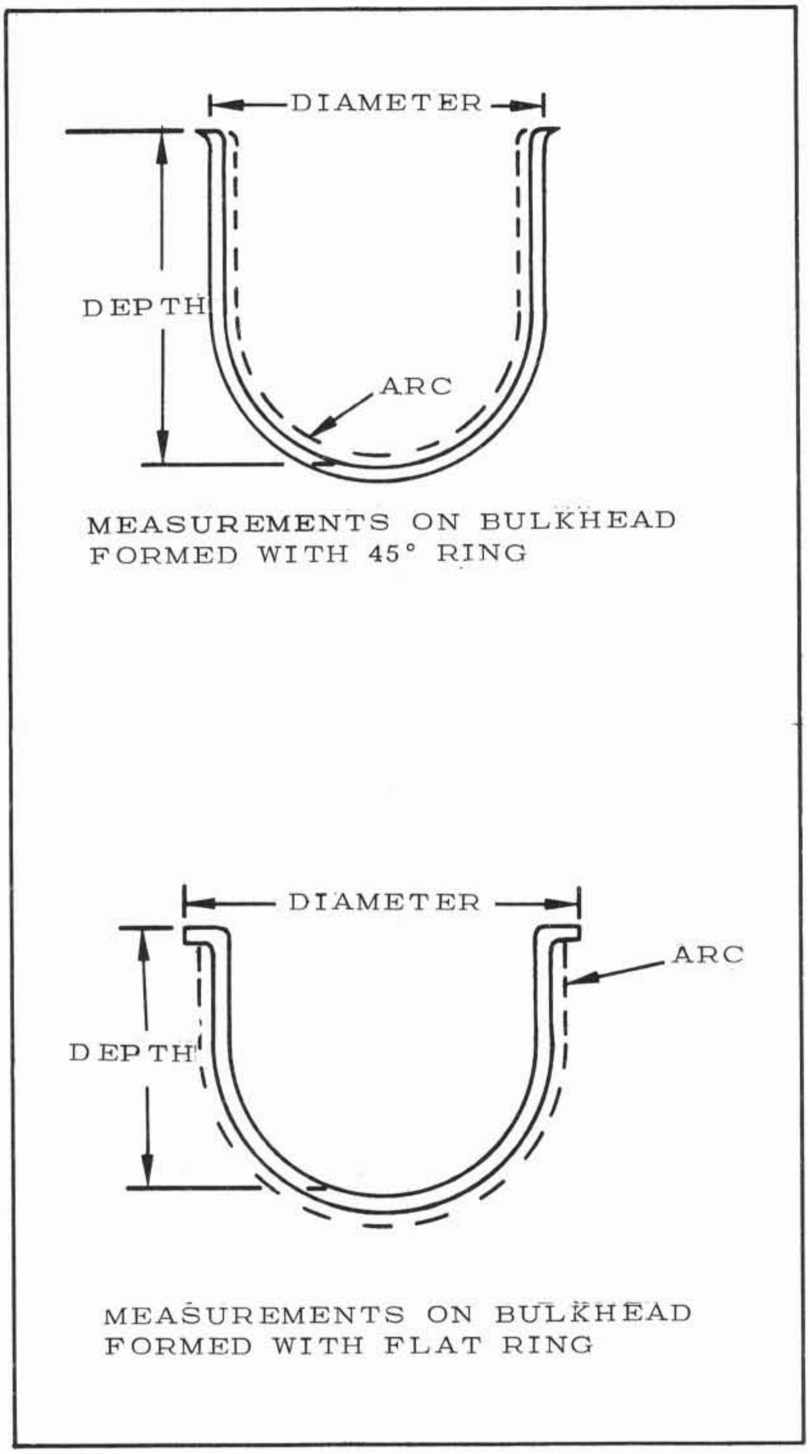


FIGURE A-1. POSITIONS OF ARC, DIAMETER AND DEPTH MEASUREMENTS USED IN FORMING CHARTS

EXPLOSIVE FORMING CHARTS

SHEET 1 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL 304 STAINLESS STEEL (29 IN. DIA. x 1/4 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFORMATION
1-SS	1	Primacord	523 Grains	20 In. Dia. Circle	4	29	27-3/4	29	* 30-3/8	4.3	--	3-11/16	
	2					27-3/4	27-1/8	30-3/8	* 29-5/8	2.3	---	4-3/4	
	3				3	27-1/8	27	29-5/8	30	0.4	0.4	5-1/4	
	4		471 Grains	18 In. Dia. Circle	2-1/2	27	26-5/8	30	30-1/8	0.5	0.4	5-3/4	
	5	Primacord	942 Grains		3	26-7/8	26-1/2	30-1/8	30-1/2	1.0	1.0	6-9/16	
	6					26-1/2	26-3/16	30-1/2	31	1.2	0.8	7	
	7		1256 Grains	18 In. and 6 In. Dia. Circle	3-Flange 3-Apex	26-3/16	26	31	31-1/4	0.7	0.8	7-1/2	
	8					26	25-1/2	31-1/4	21-1/2	1.9	0.8	8-1/16	
	9			16 In. and 8 In. Dia. Circle	4-Flange 3-Apex	25-1/2	25-1/8	31 1/2	32	1.5	1.6	8-5/16	
	10	Primacord Comp. C4	2064 Grains	16 In. Dia. Circle Ball	4-Flange 4-Apex	25-1/8	23-5/8	32	Bottom of Die	6.0	--	9-5/8	
	11	Primacord	1464 Grains	(2) 14 In. Dia Circle	1-Draw R 4-Draw R	Part to template configuration except 1/16 in. at 20 inch diameter.							

* Blank edges pulled away from 45° draw ring. Arc measurements are incorrect - Shot No.'s 1 and 2.

% DRAW - 18.5%

% STRETCH - 5.3%

REMARKS: 1. The draw ring of 45 degrees with a 1-inch draw radius was used on this test.

2. Bulkhead was sectioned for metallurgical properties and these properties are included in an appendix of this report.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 2 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL 304 STAINLESS STEEL (29 IN. DIA. x 1/4 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFOR-MATION
2-SS	1	Primacord	1042 Grains	20 In. Dia. Circle	4	29	26-7/8	29	29-3/4	7.3	2.6	3-1/2	
	2					26-7/8	Dimensions were not recorded.						
	3					26-7/8	26-7/8	No draw - all stretch indicated					
	4					26-7/8	26-5/8	29-3/4	29-3/4	0.9	-	5-3/4	
	5		942 Grains	18 In. Dia. Circle	3-From Apex	26-5/8	26-1/4	29-3/4	30-1/2	1.4	2.5	6-1/2	
	6	Primacord Comp. + C4	2064 Grains	16 In. Dia. Circle Ball	4-Flange 4-Apex	26-1/4	24-5/8	30-1/2	31-5/8	6.2	3.7	8-7/16	
	7		1621 Grains			24-5/8	24	31-5/8	32-1/4	2.5	2.0	8-7/8	
	8					24	23-1/8	32-1/4	33	3.6	2.3	9-8/16	
	9	Primacord	1152 Grains	12 In. Dia. Circle 16 In. Dia. Circle	5-Flange 1-Flange	Part to template contour except 1/16 inch at 20-inch diameter.							

% DRAW - 20.3%

% STRETCH - 10.2%

REMARKS: 1. A 45 degree draw ring with a 1 inch draw radius was used on this test.

2. Bulkhead held for tests, as required.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 3 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL 304 STAINLESS STEEL (31 IN. DIA. x 3/8 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFORMATION
3-SS	1	Primacord	515 Grains	20 In. Dia. Circle	4	31	30-5/8	31	31-1/4	1.2	0.8	2-5/8	
	2		1030 Grains			30-5/8	29-1/4	31-1/4	31-5/8	4.5	1.2	4-1/4	
	3		1875 Grains	18 In. Dia. Circle		29-1/4	28-3/8	31-5/8	32	3.0	1.1	5-5/8	
	4		1875 Grains			28-3/8	28-1/8	32	32-1/2	0.9	1.6	6-3/8	
	5		1875 Grains			28-1/8	27-7/8	32-1/2	32-3/4	0.9	0.4	7	
	6	"Detasheet"	3102 Grains	(2) 8 In. Dia. Disks		27-7/8	27	32-3/4	33-1/2	3.1	2.3	8-1/4	
	7	Primacord	2000 Grains	5 Ft. Spiral Pattern	2-1/2	27	26-5/8	33-1/2	33-3/4	1.4	0.7	8-5/8	
	8	"Detasheet"	3102 Grains	(2) 8 In. Dia. Disks	4	26-5/8	26	33-3/4	34-3/8	2.3	1.9	9-3/8	
	9		4653 Grains	(3) 8 In. Dia. Disks		26	24-1/2	34-3/4	35-1/4	5.8	1.4	10-1/2	
	10		4653 Grains			No measurements taken - part not removed from die.							
	11	Primacord	400 Grains	14 In. Dia. Circle	3		Sizing Shot						
	12	Primacord "Detasheet"	3425 Grains	12" Dia. Circle 12" O.D. x 8" I.D.	4 3	24-1/2	21-3/4	35-1.4	37-5/16	11.2	6.0	12	

% DRAW - 29.8

% STRETCH - 20.3

REMARKS: 1. 45-degree draw ring with a 3-inch draw radius was used on this test.

2. Part machined and held for future tests, as required.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 4 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL 304 STAINLESS STEEL (31 In. Dia. x 3/8 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE			STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFOR-MATION
		TYPE	WT.	CONFIGURATION									
4-SS	1	Primacord	1030 Grains	20 In. Dia. Circle	4	31	29-5/8	31	31-1/4	4.4	2.4	3-3/4	
	2		1030 Grains			29-5/8	29	31-3/4	31-7/8	2.1	0.4	4-3/4	
	3		1875 Grains	18 In. Dia. Circle		29	28-1/2	31-7/8	32-1/4	1.7	1.2	6	
	4	"Detasheet"	3102 Grains	(2) 8 In. Dia. Disks		29-1/2	27-1/2	32-1/4	32-15/16	3.5	2.1	7-1/2	
	5		4653 Grains	(3) 8 In. Dia. Disks		27-1/2	26-1/8	32-15/16	34	5.0	3.0	8-7/8	
	6		6204 Grains	(4) 8 In. Dia. Disks		26-1/8	24-3/8	34	35-3/8	4.8	4.0	10-1/2	
	7		4653 Grains	(3) 8 In. Dia. Disks		No Measurements Taken							
	8		3877 Grains	4" Wide Strip 10" Dia. Disks	4-Side 2-Apex	24-3/8	21-1/2	35-3/8	37	12.0	5.0	11-7/8	

% DRAW - 30.6

% STRETCH - 19.7

REMARKS: 1. 45° draw ring with 3-inch draw radius used in this test.

2. Part machined and held for tests, as required.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 5 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL 304 STAINLESS STEEL (31 IN. Dia. x 3/8 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches	% DRAW $\frac{D-dF}{D}$ x 100	% STRETCH $\frac{LF-li}{li}$ x 100	PART DEPTH (Inches)	MISC. INFOR-MATION
55.5	1	Primacord	1030 Grains	20 In. Dia. Circle	4	31	29-9/16	31	31-1/2	4.6	1.6	3-3/4	
	2		2060 Grains			29-9/16	28-3/4	31-1/2	32	2.7	1.9	5-1/2	
	3		1875 Grains	18 In. Dia. Circle		28-3/4	28-1/4	32	32-1/2	1.7	1.6	6-1/4	
	4	"Detasheet"	9690 Grains	10 In. Dia. Disk		28-1/4	25-1/4	32-1/2	34-3/4	10.6	7.0	9-5/8	
	5		3625 Grains			25-1/4	24-1/2	34-3/4	35-1/2	3.0	2.2	10-3/8	
	6		3940 Grains	(2) 9 In. Dia. Disks		24-1/2	23-1/4	35-1/2	36-1/4	5.0	2.0	11-1/4	
	7		1308 Grains	6 In. Dia. Disks	3		Sizing Shot to Seat Part Into Die						
	8		7270 Grains	(2) 10 In. Dia. Disks	4	22-3/4	21-1/2	-	-	5.5	-	-	

% DRAW - 30.6

% STRETCH - 17.0

REMARKS: 1. 45° draw ring with a 3-inch draw radius used.

2. Part machined and held for study, as required.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 6 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL 304 STAINLESS STEEL (31 IN. DIA. x 3/8 INCH THICK) DIE - 20 INCH DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE			STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA.(dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFOR-MATION
		TYPE	WT.	CONFIGURATION									
6-SS	1	Primacord	1030 Grains	20 In. Dia. Circle	4	31	29-1/2	31	31-1/2	4.8	1.6	3-3/8	
	2		2060 Grains			29-1/2	28-5/8	31-1/2	32	3.0	1.6	5-1/2	
	3		1875 Grains	18 In. Dia. Circle	3	28-1/2	28-1/2	32	32-3/8	1.8	1.2	6-1/2	
	4	"Detasheet"	6208 Grains	10 In. O.D. x 6 In. I. D. Ring	4	28-3/8	26-3/8	32-3/8	34-1/8	6.2	6.0	8-7/8	
	5		7270 Grains	(2) 10 In. Dia. Disks		26-3/8	24	Not Measured		9.0	-	10-9/16	
	6		7270 Grains			No Measurements Taken.							
	7		400 Grains	10 In. O.D. x 6 In. I. D. Ring	5	24	21-3/8	34-1/8	37-5/8	10.9	10.2	12-1/16	

% DRAW - 27.8

% STRETCH - 21.4

REMARKS: 1. 45° draw ring with a 3-inch draw radius used.

2. Part machined and held for test, as required.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 7 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL X7106-0 ALUMINUM (32 IN. DIA. x 1 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFOR-MATION
4 AL	1	Primacord	2297 Grains	22 In. Dia. Circle	4	32	30	32	31-3/4	6.6	7.0	4-5/16	
	2	"Detasheet"	10,082 Grains	(2) 10 In. Disk (4) 10 In. O.D.		32	29-5/16	31-3/4	34-7/8	14.8	9.8	10	
				x 8 In. I.D. Strips									
In process annealed.													
	3	"Detasheet"	8776 Grains	(2) 10 In. Disk (3) 10 In. O.D.	10-Above Apex	Sides not to die configuration						13/16 From Die	
				x 8 In. I.D. Strips								Bottom	
	4				6-Above Apex							Bottomed Out	
	5	Primacord	1046 Grains	10 In. Dia Circle	1-Below Draw R.	29-9/16	20-1/4	34-7/8	38-3/4	21	10	13-7/8	

% DRAW - 36.7

% STRETCH - 22.05

REMARKS: 1. A 45° ring with a 3-inch draw radius was used on this and all subsequent tests.
2. Part to template contour, heat treated and aged to T-63 condition.
3. Metallurgical properties are reported in Appendix C.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 8 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL X7106-0 ALUMINUM (32 IN. DIA. x 1 INCH THICK)						DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$							
PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFOR-MATION
5 AL	1	Primacord	2297 Grains	22 In. Dia. Circle	4	32	29-1/4	32	31-3/4	8.6	0.8	4-3/4	
	2	"Detasheet"	13,814 Grains	(3) 10 In. Disk (5) 10 In. O.D.		29-1/4	25-1/4	31-3/4	33-3/4	13.7	6.0	9-1/4	
				x 8 In. I.D. Strips									
				In process annealed									
	3	"Detasheet"	11,788 Grains	(2) 10 In. Disks (3) 8 In. Disks	9-Above Apex	25-1/4	22	33-3/4	36-1/2	12.9	8.1	11-3/4	
	4	Primacord	1046 Grains	10 In. Dia. Circle	2-Below Draw R.	Part to bottom of die - sides not filled out.						12-1/8	
	5	"Detasheet"	8383 Grains	(3) 10 In. Disks	6-Above Apex	22	20-1/8	36-1/2	39	8.5	6.8	13-3/8	

% DRAW - 37.1

% STRETCH - 18.8

REMARKS: 1. Part is to template contour.

2. Machined and treated to T-63 condition for weld study.

SHEET 9 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL X7106-0 ALUMINUM (32 IN. DIA. x 1 INCH THICK) DIE - 20 INCH DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (S) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D}$ x 100	% STRETCH $\frac{LF-li}{li}$ x 100	PART DEPTH (Inches)	MISC. INFOR-MATION
10 AL	1	Primacord	2297 Grains	22 In. Dia. Circle	4	32	29-1/4	32	31-3/4	8.9	0.8	4-15/16	
					In Process Annealed								
	2	"Detasheet"	11,788 Grains	(2) 10 In. Disk (3) 8 In. Disk		29-3/4	25	31-3/4	34-3/8	13.3	7.6	10-1/8	
	3	"Detasheet"	9596 Grains	(2) 10 In. Disk (2) 8 In. Disk	4-1/2 Above Apex	25	20-1/2	34-3/8	38-1/8	22	10.1	12-7/8	
	4	Primacord	1232 Grains	12 In. Dia. Circle	2-Below Draw R.	No measurements - part of bottom of die.							
	5		800 Grains	8 In. Dia. Circle	Even to Draw R.	Part now to template contour.						13-1/4	

% DRAW - 36.0

% STRETCH - 20.5

REMARKS: 1. Part machined and treated to T-63 condition for weld study.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 10 of SHEETS 12

TD-47 E. P. -5080

MATERIAL X7106-0 ALUMINUM (32 IN. DIA. x 1 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFOR-MATION
11 AL	1	Primacord	2297 Grains	22 In. Dia. Circle	4	32	29-1/2	32	31-5/8	8.0	1.2	4-1/2	
	2	"Detasheet"	11,788 Grains	(2) 10 In. Disk (3) 8 In. Disk		29-1/2	24-3/4	31-5/8	34-1/2	16.1	9.1	10-1/8	
						In Process Annealed							
	3	"Detasheet"	8481 Grains	(3) 10 In. Disk	4	24-3/4	21	34-1/2	38	15.2	10.1	12-1/4	
	4	Primacord	836 Grains	8 In. Dia. Circle	9-Above Apex	No detected dimensional changes.							
	5		1218 Grains	12 In. Dia. Circle									
	6		1218 Grains		2-Below Draw R.	21	20	38	40-1/8	4.8	5.6	13-1/8	

% DRAW - 37.5

% STRETCH - 26.9

REMARKS: 1. Shots 4 and 5 were sizing shots, to expand part to the die maximum diameter.

2. Part trimmed and treated to T-63 condition.

3. Part held for study, as required.

EXPLOSIVE FORMING CHARTS (Cont'd)

SHEET 11 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL X7106-0 ALUMINUM (32 IN. DIA. x 1 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches)	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFOR-MATION
15 AL	1	Primacrod	6903 Grains	(3) 22 In. Dia. Circle	4	32	28	32	32-1/3	12.5	0.8	7-3/8	
	2	"Detasheet"	8482 Grains	(5) 10 In. Dia. Disks		28	25	32-1/4	35	10.7	8.5	10-1/4	
					In Process Annealed								
	3	"Detasheet"	6056 Grains	(4) 10 In. Dia. Disks	4	25	23-3/4	35	35-1/2	5.0	1.4	11-15/16	
					In Process Annealed								
	4	"Detasheet"	4846 Grains	(2) 10 In. Dia. Disks	4	23-3/4	21	35-1/2	38-1/2	5.3	8.4	13	
	5	Primacord "Detasheet"	2916 Grains)	10" Dia. Circle 2" Wide Strip	5-From Apex	21	20	38-1/2	38-3/4	4.8	0.6	13-1/2	

% DRAW - 37.5

% STRETCH - 20.2

REMARKS: 1. Part machined and treated to T-63 condition. (Maximum machined thickness 3/4-inch.)

2. Vidigage thickness measurements. $\frac{\text{Apex}}{0.560}$ $\frac{1\text{ In.}}{0.585}$ $\frac{4\text{ In.}}{0.725}$ $\frac{8\text{ In}^*}{0.820}$ $\frac{16\text{ In.}}{0.785}$ * Micrometer reading = 0.784

EXPLOSIVE FORMING CHARTS (Concluded)

SHEET 12 of SHEETS 12

TD-47 E. P. - 5080

MATERIAL X7106-0 ALUMINUM (32-1/4 IN. DIA. x 1 INCH THICK) DIE - 20 IN. DIA. CONFIGURATION $\frac{x^2}{2} + \frac{y^2}{1} = 1$

PART NO.	SHOT NO.	EXPLOSIVE TYPE	EXPLOSIVE WT.	EXPLOSIVE CONFIGURATION	STAND OFF (Inches)	INITIAL DIA. (D) (Inches)	FINAL DIA. (dF) (Inches)	INITIAL ARC (li) (Inches)	FINAL ARC (LF) (Inches	% DRAW $\frac{D-dF}{D} \times 100$	% STRETCH $\frac{LF-li}{li} \times 100$	PART DEPTH (Inches)	MISC. INFORMATION
16 AL	1	Primacord	2300 Grains	22 In. Dia Circle	4	32-1/4	29-5/8	32-1/4	33-1/8	16.0	2.7	4-5/8	
	2	"Detasheet"	4630 Grains	(3) 8 In. Dia. Disk		29-5/8	27-5/16	33-1/8	34-3/4	6.8	5.0	8-1/8	
	In Process Annealed												
	3	"Detasheet"	9695 Grains	(4) 10 In. Dia. Disks	4-3/4	27-15/16	24-3/4	34-3/8	37	9.3	7.6	10-7/8	
	In Process Annealed - 1 1/2 Inch - Cut off O.D. of 45° Flange.												
	4	"Detasheet"	2916 Grains	10 In. O.D. x 6 In. I.D. Circle	8-From Apex	No measurements taken because of reduced O.D.							
	5		4653 Grain	(3) 8 In. Dia. Disk	6								
	6	Primacord	800 Grain	8 In. Dia. Circle	Draw Radius	Part to template configuration.							

% DRAW -

% STRETCH -

REMARKS: 1. Part treated to T-63 condition, machined and held for future use.

2. Vidigage thickness measurements:

Apex	4 In.	8 In.	12 In.	* 16 In
0.585	0.735	0.830	0.880	0.775

* Micrometer reading 0.775

APPENDIX B.
METALLURGICAL EXAMINATION OF 304 STAINLESS STEEL

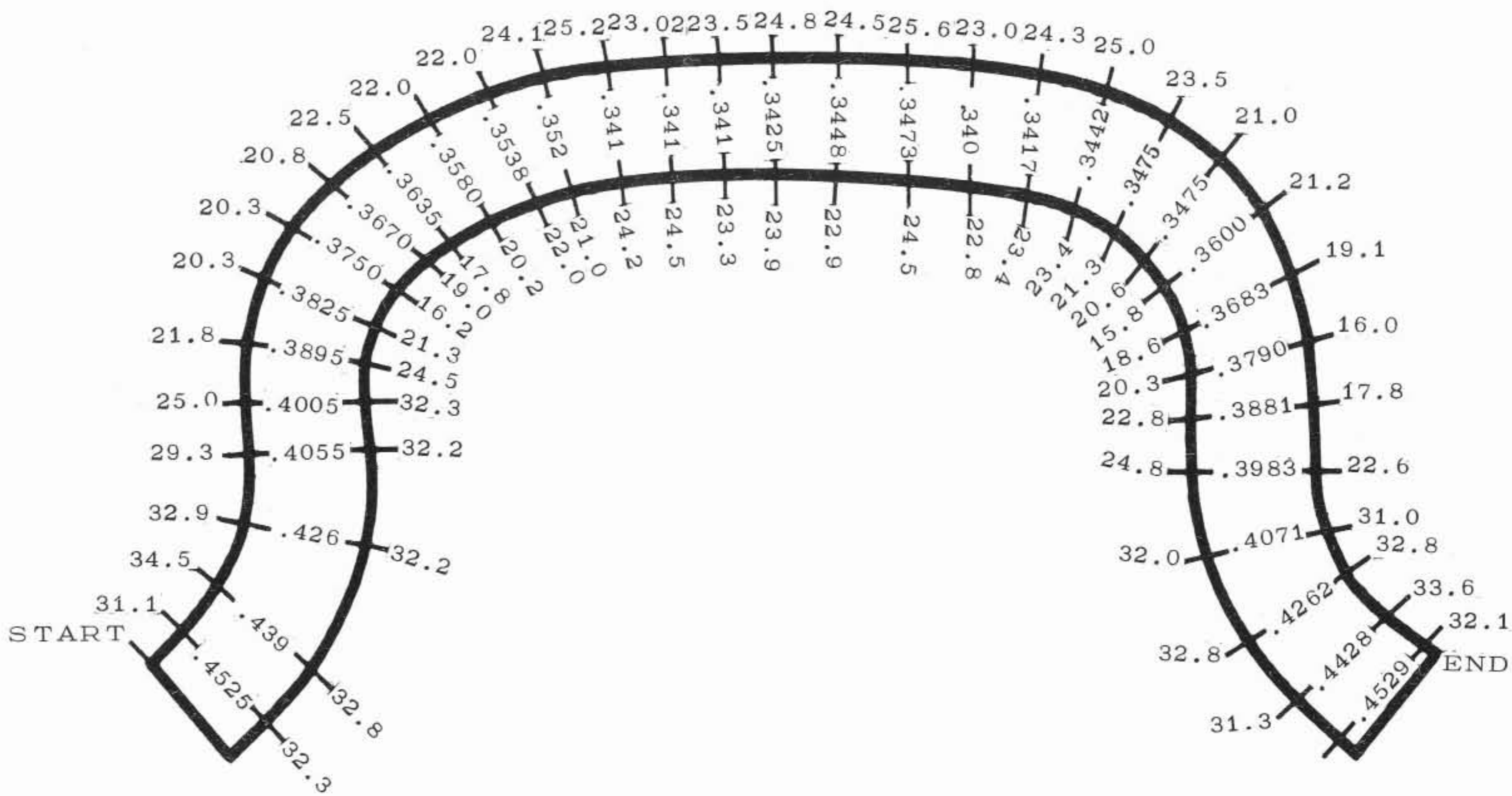
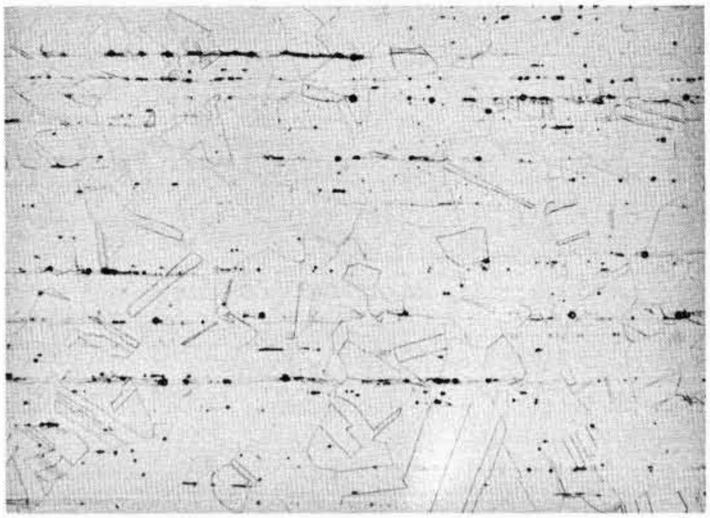


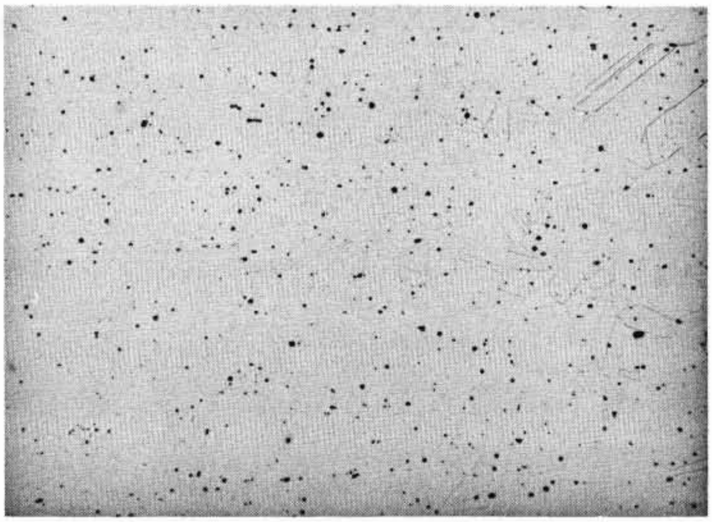
FIGURE B-1. HARDNESS MEASUREMENTS OF 304 STAINLESS STEEL EXPLOSIVELY FORMED BULKHEAD



100X FERRIC CHLORIDE ETCH

LONDITUDINAL

FIGURE B-2. TYPICAL MICRO STRUCTURES OF 304 STAINLESS STEEL AS RECEIVED



100X ETCHED ELECTROLYTICALLY IN 5 PERCENT OXALICACID

TRANSVERSE

FIGURE B-3. TYPICAL MICRO STRUCTURE OF 304 STAINLESS STEEL AS RECEIVED

APPENDIX C.
PHOTOMICROGRAPHS OF EXPLOSIVELY FORMED DOME OF X7106 ALUMINUM

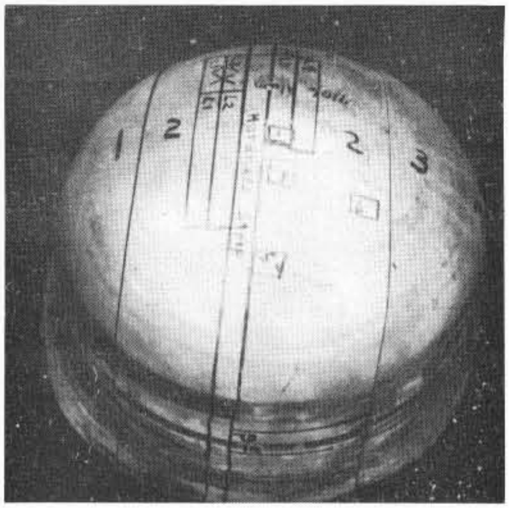


FIGURE C-1. OUTSIDE VIEW OF THE DOME SHOWING THE LOCATION OF SPECIMENS 1, 5, 6, AND 7

FIGURE C-2. OUTSIDE VIEW OF THE DOME SHOWING THE LOCATION OF SPECIMENS 2, 3, AND 4

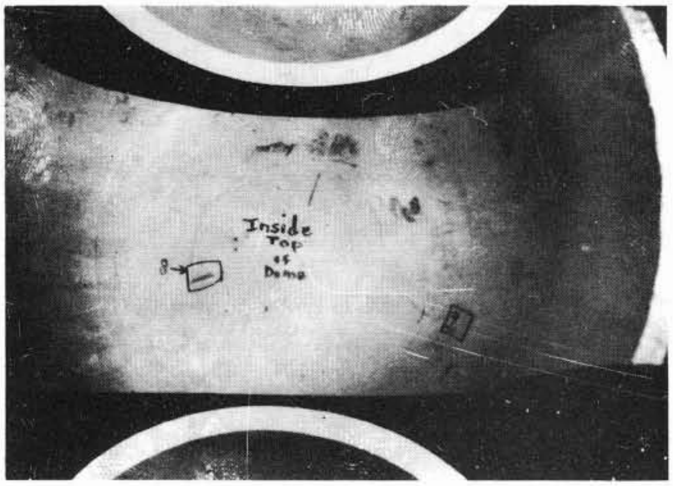
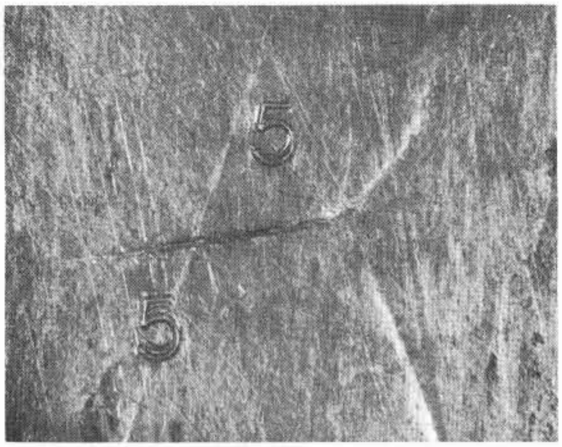
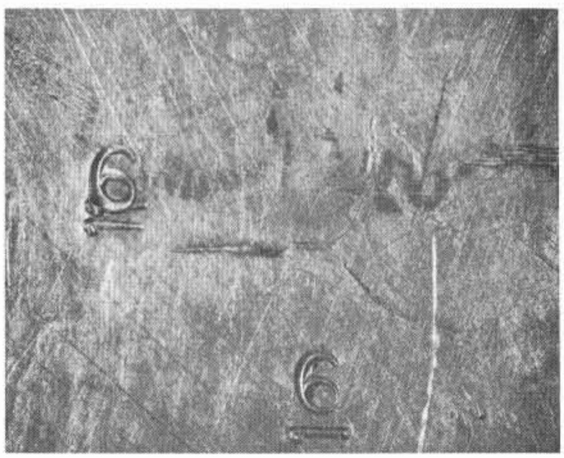


FIGURE C-3. INSIDE VIEW OF THE DOME TOP SHOWING
THE LOCATION OF SPECIMENS 8 AND 9



50X

FIGURE C-4. PHOTOMICROGRAPH OF THE OUTSIDE SURFACE OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 5

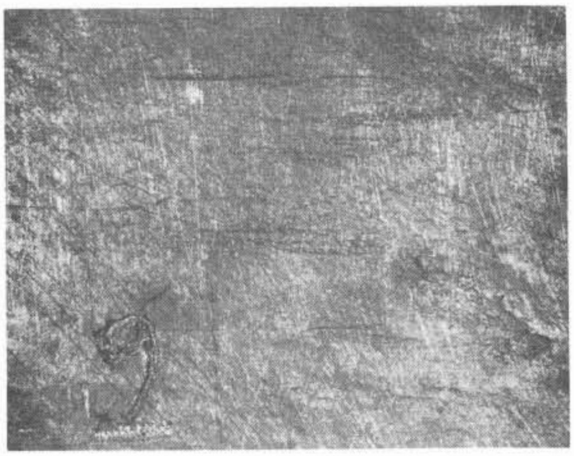


50X

FIGURE C-5. PHOTOMICROGRAPH OF THE OUTSIDE SURFACE OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 6

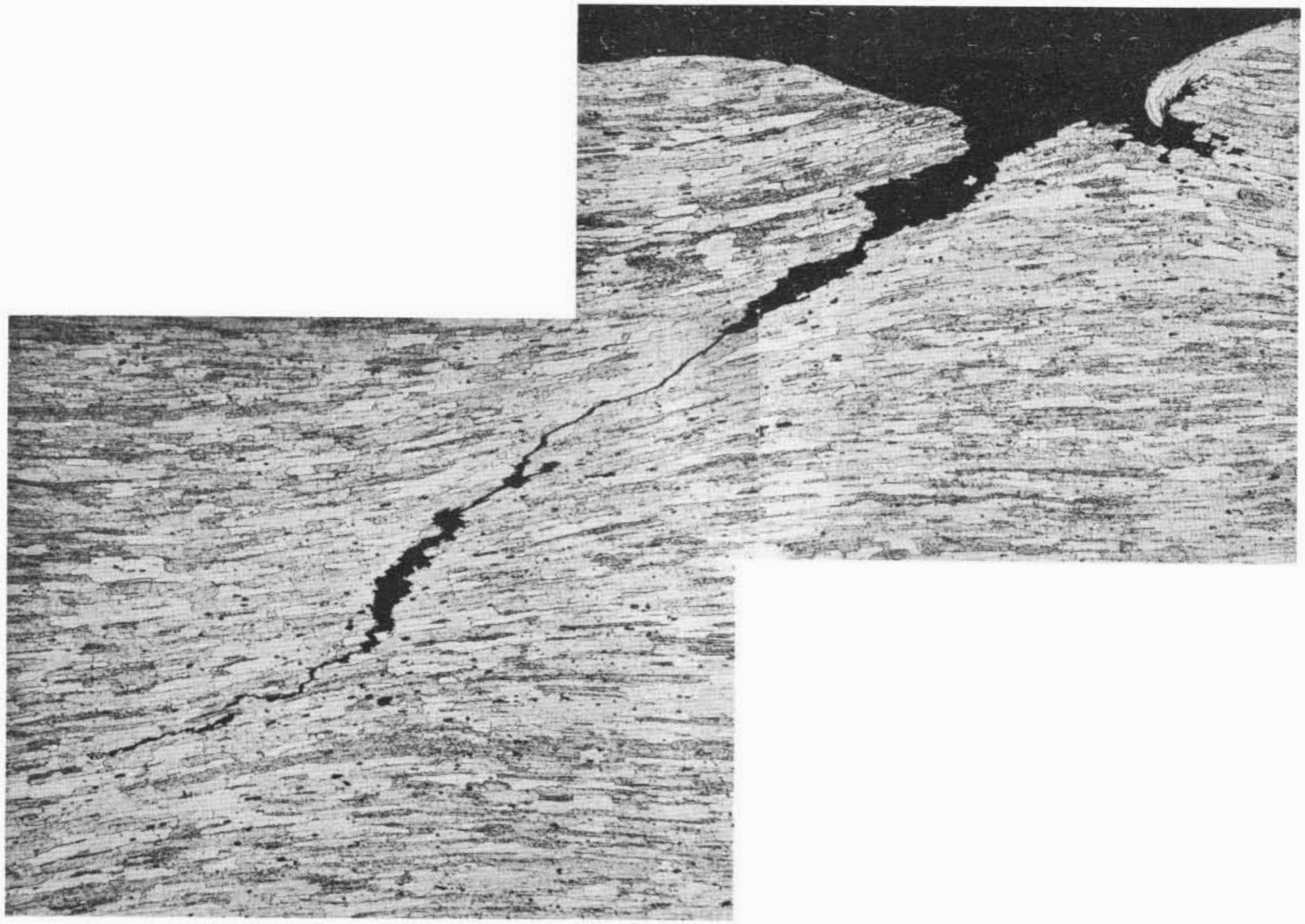
50X

FIGURE C-6. PHOTOMICROGRAPH OF THE OUTSIDE SURFACE OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 7



50X

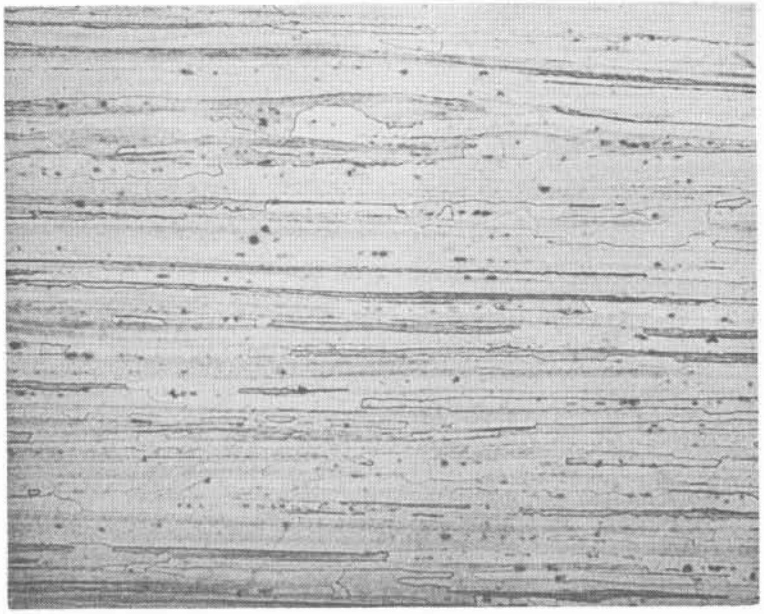
FIGURE C-7. PHOTOMICROGRAPH OF THE OUTSIDE SURFACE OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 9



100X

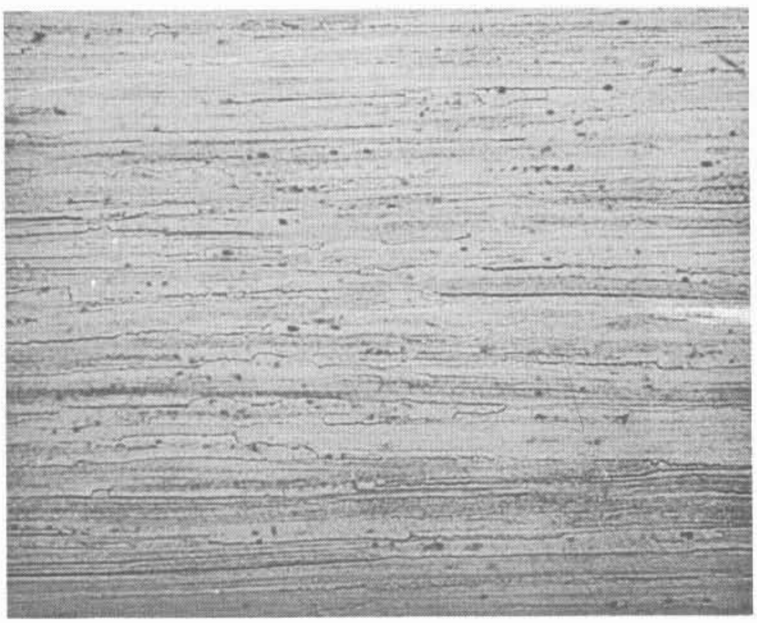
KELLER'S ETCH

FIGURE C-8. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. THE CRACK MEASURES APPROXIMATELY 0.037 INCH DEEP FROM THE SURFACE. TOTAL LENGTH IS APPROXIMATELY 0.060 INCH LONG. TOTAL WIDTH OF SPECIMEN IS 0.500 INCH. SPECIMEN NUMBER 1



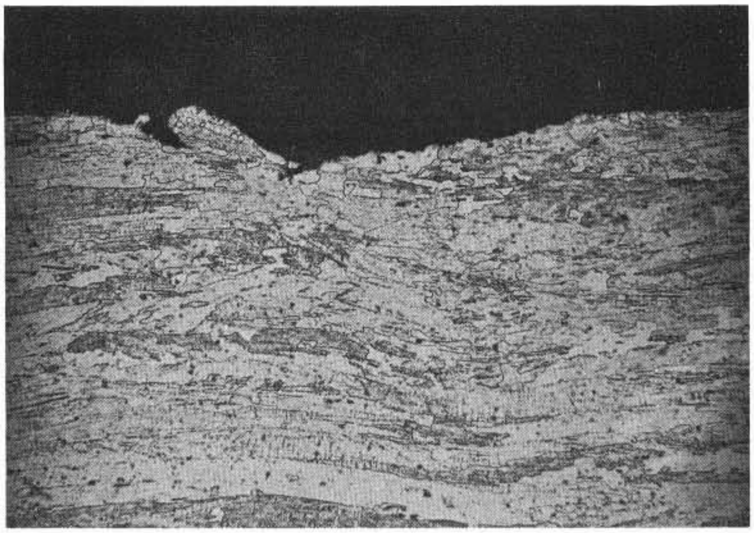
100X KELLER'S ETCH

FIGURE C-9. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 2



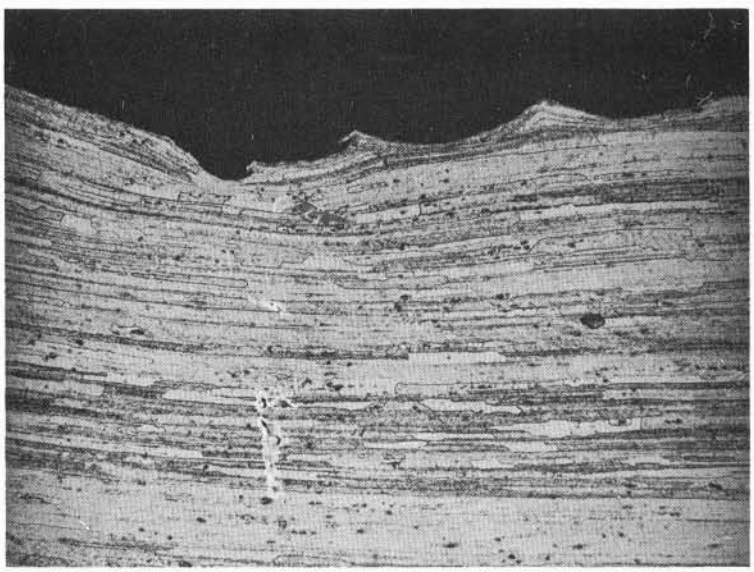
100X KELLER'S ETCH

FIGURE C-10. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 3



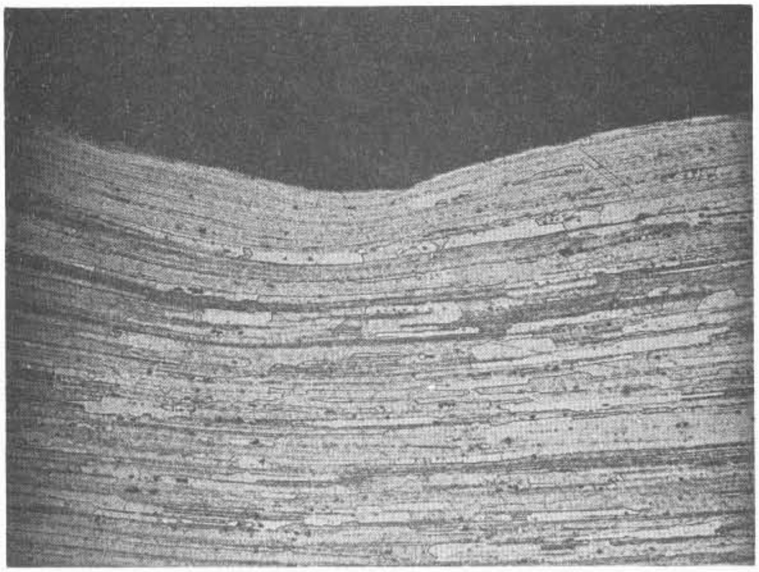
100X KELLER'S ETCH

FIGURE C-11. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 4



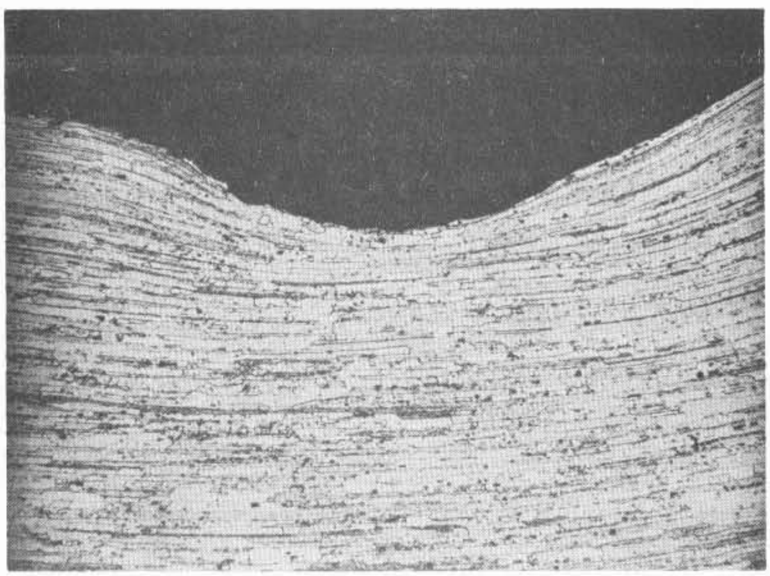
100X KELLER'S ETCH

FIGURE C-12. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 5



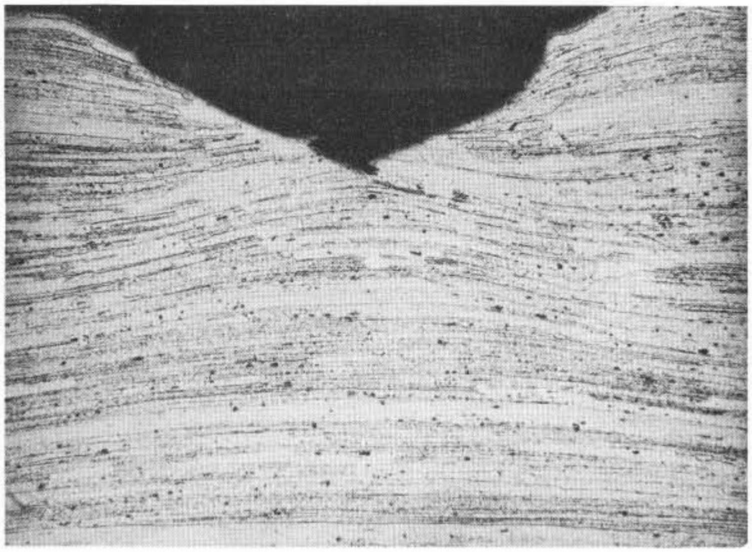
100X KELLER'S ETCH

FIGURE C-13. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 6



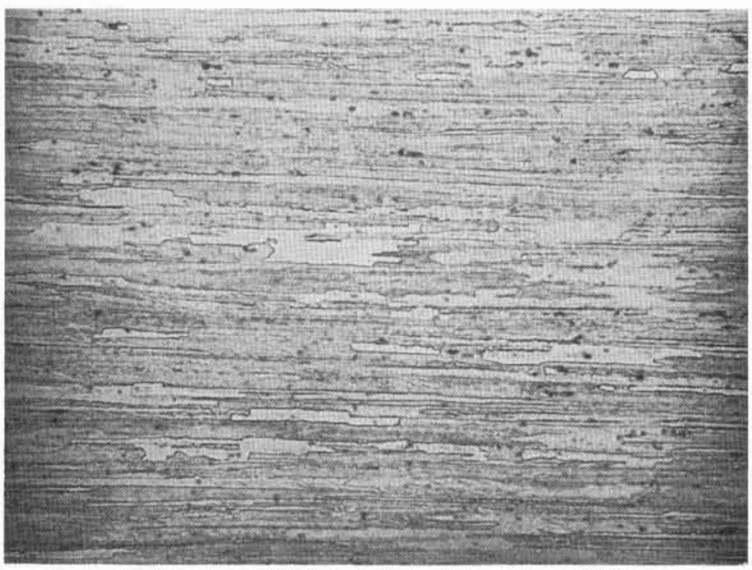
100X KELLER'S ETCH

FIGURE C-14. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 7



100X KELLER'S ETCH

FIGURE C-15. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 8



100X KELLER'S ETCH

FIGURE C-16. PHOTOMICROGRAPH OF THE EXPLOSIVELY FORMED DOME OF X7106-T63 ALUMINUM ALLOY. SPECIMEN NUMBER 9

REFERENCE

1. "Steels for Low Temperature Applications," U. S. Steel, 585 William Penn Place, Pittsburgh 30, Pennsylvania.

R-ME-DIR
Mr. Kuers
Dr. Siebel
Mr. Wuenscher

R-ME-A
Mr. Nowak
Mr. Schwinghamer

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R-ME-RE
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R-ME-T
Mr. Franklin

R-ME-X
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