FABRICATION OF LARGE DIAMETER SPHERES BY THE ARDEFORM PROCESS

JANUARY 22, 1965

PREPARED UNDER NASA MANNED SPACECRAFT CENTER

CONTRACT NAS 9-2648

FINAL REPORT

ARDE-PORTLAND, INC.
580 WINTERS AVENUE
PARAMUS, NEW JERSEY

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ARDE-PORTLAND, INC.
580 Winters Avenue
Paramus, New Jersey

Prepared by: J. J. Cioffi
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Project Engineer

FOREWORD

The cryogenic stretch-forming (ARDEFORM) technique described in this report was investigated and demonstrated to be sound under a company-funded research program. This work was done prior to undertaking contracts for the Department of Defense and NASA.

This technique which has been designated the ARDEFORM process is the property of ARDE-PORTLAND and forms the basis of a Patent Application presently pending in the United States Patent Office.

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I. INTRODUCTION

A. The ARDEFORM Process

The ARDEFORM process consists of fabricating an undersized vessel (preform) from work-hardenable material while the material is still in an annealed condition. In this condition the material is readily welded, machined and formed. After the undersized vessel is fabricated, the entire vessel is strengthened by stretching cryogenically in liquid nitrogen to the full size required. This fabrication technique was investigated under a company-funded research program and continued under various Defense Department contracts.

The present contract was granted to further demonstrate the feasibility of the process for the fabrication of large diameter spherical pressure vessels for space applications.

B. Cryogenic Stretch Facility

In order to accomplish the cryogenic stretchforming operation, ARDE-PORTLAND has invested heavily in a facility used to cold-work steels at cryogenic temperatures (-320°F) to produce high strength-to-weight vessels. The facility consists of a large liquid-nitrogen forming tank; a high-pressure pumping system, with appropriate controls and valves; and a liquid-nitrogen low-pressure storage system. The facility is remotely operated from a control room through a system of control valves, is instrumented with pressure and temperature sensors, as well as safety devices necessary for a very-high-pressure system. Operating pressures, which are functions of the vessel configuration and wall thickness, range from 1,000 psia to 30,000 psia.

C. Contract Scope of Work

Fabricate and deliver six units of a high-strength oxygen sphere storage vessel, utilizing the ARDEFORM process.

II. SUMMARY

The feasibility of fabricating large diameter spheres by the ARDEFORM process was demonstrated successfully. Six units were delivered in accordance with contract terms.

III. CONCLUSION

1. Large diameter spherical vessels can be fabricated by the ARDEFORM process.
2. These vessels can be fabricated to a predetermined size even though a sizing die is not used.
3. A high-strength-to-weight ratio vessel will result from the process.

IV. WORK ACCOMPLISHED

A. Design

The detail design of the 25" sphere is shown in the following illustrations which are at the end of the report.

IV. WORK ACCOMPLISHED (cont'd)

SKE 1428F-25" NASA Spherical Oxygen container Ardeformed.

E 3188-25" NASA Spherical Oxygen Container Assy-Preform.

E 103741 A - Head Hemispherical with Boss Cut Out.

C 103755 A - Internal Support Hemispherical.

C 103756 A - Induction Boss - Hemispherical.

The design was agreed upon by NASA and ARDE-PORTLAND personnel for the purpose of determining the feasability of the ARDEFORM process as applicable to large diameter vessels. It will be noted that two types of bosses were used in the vessels. This was done in order to evaluate the possibility of incorporating an internal structural support as well as a pressurizing port. An additional decision was to spin and then machine the hemispherical heads. Accordingly, tolerances were set within commercially available limits.

The engineering analysis for this design was based on prior experience with smaller diameter spheres. In particular, four spheres having a preform diameter of 6.95" were studied. These spheres were fabricated from A1S1 301 material, heat number E-73413 purchased from Eastern Stainless Steel. The results of cryoginially stretching and hydrostatic testing of these spheres are shown on Graph A as triangles. These practical results indicated a ± .006 inches per inch strain tolerance on the theoretical curve as shown on the graph.

The 25" spheres were conservatively guaranteed for a minimum ultimate strength of 240,000 psi at room temperature. In order to assure this criteria, to keep the weight down and to allow for some leeway in sizing, the design was actually based on a 260,000 psi ultimate tensile strength.

IV. <u>WORK ACCOMPLISHED</u> (cont'd)

Utilizing the above information and the equation S = PD/4t, where S = ultimate tensile strength, p = pressure, D = Internal Diameter and t = thickness of the sphere, an average final thickness for the sphere was obtained.

$$t_{f\ avg.} = \frac{1508 \times 25.10}{4 \times 260{,}000} = .0364"$$

Introducing a ± .005" tolerance on this thickness resulted in a t_f min = .0314" and t_f max = .0414".

To obtain a thickness of material prior to stretching the following equation was used

$$t_o = t_f \times \delta$$

Where t_o = Original Thickness of Material

t_f = Final Thickness of Material

δ = Strain factor which is equal to inches per inch of strain plus 1.

From the theoretical stress-strain curve the inches/inch of strain is .068 at a stress level of 260,000 psi. If the ±.0066"/" of strain tolerance is included the strain factor becomes .074"/" maximum to .062"/" minimum. Including these strain tolerances plus the minimum and maximum thicknesses in the above equation results in an original thickness of material = .0478" max to .0354" min. It was therefore, decided that the detail dimension should be .042± .002 inches thick, well within the minimum and maximum dimensions calculated. The calculation of the preform diameter was similarly accomplished, except that the diameter is a uniaxial growth and, therefore, the strain factor is not squared i.e. $D_o = \frac{D_f}{\delta}$

IV. WORK ACCOMPLISHED (cont'd)

Where D_o = Original Diameter of preform.

D_f = Final Diameter of preform.

The resulting drawing dimension was 23.500± .005".

B. Manufacture

1. Hemispherical Heads

This component was fabricated from a .375 inch thick annealed AISI 301 steel plate which was then spun into a rough contour to resemble the hemispherical head. During spinning the fabricator was allowed to anneal as often as he thought necessary provided a final anneal at 1925°F±25°F was performed immediately before final machining. The rough contour was then machined inside and out on a contour lathe to drawing dimensions.

2. Bosses

Bosses were machined from the same heat of material as the hemispherical heads except that 1-1/2" thick sheet bar was used. The machining was done parallel to the grain structure in order to minimize the chances of porosity occurring.

Figures 1-6 at the end of this section describe the remaining manufacturing areas. It will be noted that all welding was performed by the heliarc process in one pass. After welding spheres are cryogenically stretched to approximately 1510 psi. The vessels were then aged at a temperature of 790°F±10°F for twenty hours and then passivated in a solution of heated nitric acid and sodium dichromate. At each stage of processing rigid quality control was maintained and an inspection was performed.

IV WORK ACCOMPLISHED (cont'd)

C. Hydrotesting

Each completed sphere was subjected to a proof pressure test as shown in Figures 7 and 8. The target proof pressure was 1350 psig. In addition, each sphere was instrumented with two strain gages near the girth weld, one perpendicular to the weld, the other parallel to it. Results of strain gage data are shown in Figures 10 to 16A. One sphere was taken to burst. The resulting burst pressure was 1560 psig. as compared to the design burst pressure of 1508 psig.

D. Problem Areas

1. Machining of Hemispherical Heads

During the machining operation two problems were encountered. (1) Flaking occurred on the outside surface of the hemisphere. (2) Voids and porosity due to the spinning operation occurred at the polar region. The first problem was eliminated by machining off less material per cut. Upon investigation it was determined that the voids at the polar region were in an area that would be removed in order to weld the bosses and, therefore, would not be detrimental to the finished vessel. Photographs from the metallurgical report are shown in Figures 17 through 19.

2. Cryogenic Bursting of Spheres

Of the initial three spheres fabricated two burst in the cryogenic stretch operation. Stress levels achieved were theoretically 191,000 and 203,000 psi. Metallurgical investigations were conducted to explain these failures. A report of these investigations follows.

IV. WORK ACCOMPLISHED (cont'd)

METALLURGICAL REPORT ON SPHERE S/N 552

1. General Observation

The fracture surface in one hemisphere exhibited a brittle failure mode for a distance of 4 or 5 inches from the girth weld. As the fracture progressed further in the same hemisphere, a ductile shear, 45° fracture occurred. The fracture appearance in the other hemisphere was completely of the ductile shear type.

2. Specimen Location

Metallographic specimens were taken from several locations of interest along the fracture. These locations were as follows:

a. The brittle fracture region.

b. The ductile fracture region.

c. The girth weld area.

3. Factors Investigated

The specimens were prepared for investigation of the following factors:

a. Inclusion size, orientation and distribution, and relation to prior austenite grain boundaries.

b. Grain boundary carbide precipitation.

c. Prior austenite grain size and anisotropy.

IV. WORK ACCOMPLISHED (cont'd)

METALLURGICAL REPORT ON SPHERE S/N 552 (cont'd)

4. Results of Investigation

The metallographic examination, which revealed information pertinent to the causes of failure in the sphere, is discussed below. The location and orientation of the metallographic specimens is shown in Figure 20. In the discussion below, locations and directions refer to those shown in Figure 20.

a. Inclusions

The inclusions in the material taken from the brittle fracture region show an orientation parallel to the path of the fracture. Figure 21 shows a view at c, in which the inclusions appear as small dots. Figure 22 shows a view at "b" in which slight elongation of the inclusions is apparent. Although this material can certainly not be characterized as a clean material, it does not appear that the inclusions were the primary cause of failure of the vessel. No drastic differences in appearances and quantity of inclusion were observed between those in the shear fracture region, the brittle fracture region and the weld area.

b. Prior Austenite Grain Boundaries

Transformation of the austenite to martensite occurs during the cryogenic stretch forming process. In order to determine the causes of failure it is valuable to investigate the material for conditions which existed prior to transformation. During the stretching of annealed material with equiaxed austenite grains, it has been observed that original austenite grain boundaries retain their equiaxed form. For example, Figures 23 and 24 are photomicrographs of the structure of a tensile specimen cryogenically stretched about 17%. These photographs, show the structure in the transverse and longitudinal directions. The similarity of the two photographs indicates that structural isotropy is retained even for large plastic deformations by stretching.

Examination of the metallographic specimens from the sphere, however, indicates definite structural anisotropy in the region of brittle fracture. Figures 25 and 26 are photomicrographs with the line of sight parallel and perpendicular to the fracture direction, respectively. Figure 25 shows view "d" and Figure 26 shows view "a" as indicated in Figure 20. Note that in Figure 25 that the grain structure is elongated parallel to the fracture. A view at "b", showing elongated grains and at "c" showing the equiaxed ends of these grains is shown in Figures 27 and 28, respectively. The grain elongation parallel to the fracture is evident only in locations near the brittle fracture region. A view at "f" Figure 29, shows essentially equiaxed grains, in the vicinity of the ductile fractures. Figure 29 should be compared with a view "d" in Figure 30 at the same magnification.

c. Carbides

Some carbide precipitation was noted in the prior austenite grain boundaries at all locations. The greatest amount of carbide precipitation, however, was noted at view "d", near the weld. Although some precipitation is to be expected in the vicinity of the weld, the extent of precipitation far exceeded that ordinarily noted. By comparison, the precipitation noted at location "e" at the beginning of the weld carbide zone on the other side of the weld, was very slight. In fact, precipitation at locations "b" and "c", removed from the weld, but near the brittle fracture region, were more extensive than that noted in the carbide zone at "e". View "f", Figure 29 at the ductile fracture region shows only a small amount of precipitation.

IV. WORK ACCOMPLISHED (cont'd)

METALLURGICAL REPORT ON SPHERE S/N 552 (cont'd)

5. Conclusions

Based on the previous observations, it is apparent that the sphere failure occurred as a result of embrittlement by precipitated carbides. The part was solution treated and quenched while it was approximately 3/8" thick, and then machined to the required wall thickness. Apparently, a combination of improper steps were involved. First, and most likely, the annealing temperature or time at annealing temperature was too low. This probably resulted in incomplete solution of the carbides in the brittle fracture region, this is pointed up by the presence of elongated grains. Second, the quenching time may have been insufficiently rapid, permitting reprecipitation of those carbides which did manage to dissolve during the heat treatment. The existence of a ductile and brittle region on the same head could have occurred as a result of several possible conditions. For example, the equiaxed grains in the ductile region can be explained by considering that the material remaining after machining had been close to the surface of the 3/8" thick blank during the annealing and quenching cycle. The brittle fracture region may have been close to the center of the blank metal thickness. This would result in an unannealed region near the girth and an annealed region near the pole of the hemisphere.

6. Recommendations

Anneal heads after machining or after welding. A proper anneal and quench is more readily controlled in the thinner material. The precise location of failure was difficult to pin point because of some rubbing of the fracture surface during shipment of the failed vessel to the laboratory.
A photograph of the fracture surface at the suspected failure

origin is shown in Figure 31. The origin appears to be in the "carbide zone" on the bad side of the weld. This is not unreasonable under the circumstances since the carbides precipitated during welding merely increased the amount already present as a result of improper annealing and quenching.

7. Action

The recommendations outlined above were followed with the result that all additional spheres were stretched successfully.

E. Discussion of Program Results

Referring to Figure 32 which summarizes the results of the program, it will be noted that all design goals were achieved or exceeded with the exception of the diameter and volume. These two parameters were intentionally sacrificed in the interest of determining repeatability. They could have easily been brought within print requirements by straining the material to a lower cryogenic stretch pressure. The resulting sphere would have had a slightly lower ultimate strength level but would have exceeded all design goals by a considerable margin. This larger volume and diameter is due to the difference in the behavior of the heat of material actually used, which is shown on Graph B, versus the heat of material on Graph A which was used for the theoretical calculations. It will be noted by looking at the uniaxial stress-strain curve that this is a "looser" heat i.e. for the same stress condition the strain is greater. It was recognized in conducting the calculations that there might be a difference between the two heats of material; however in the interest of time, it was decided that a chance would be taken. The alternative of changing the stretch pressure to accommodate for any difference in strain characteristics would always be available.

IV. WORK ACCOMPLISHED (cont'd)

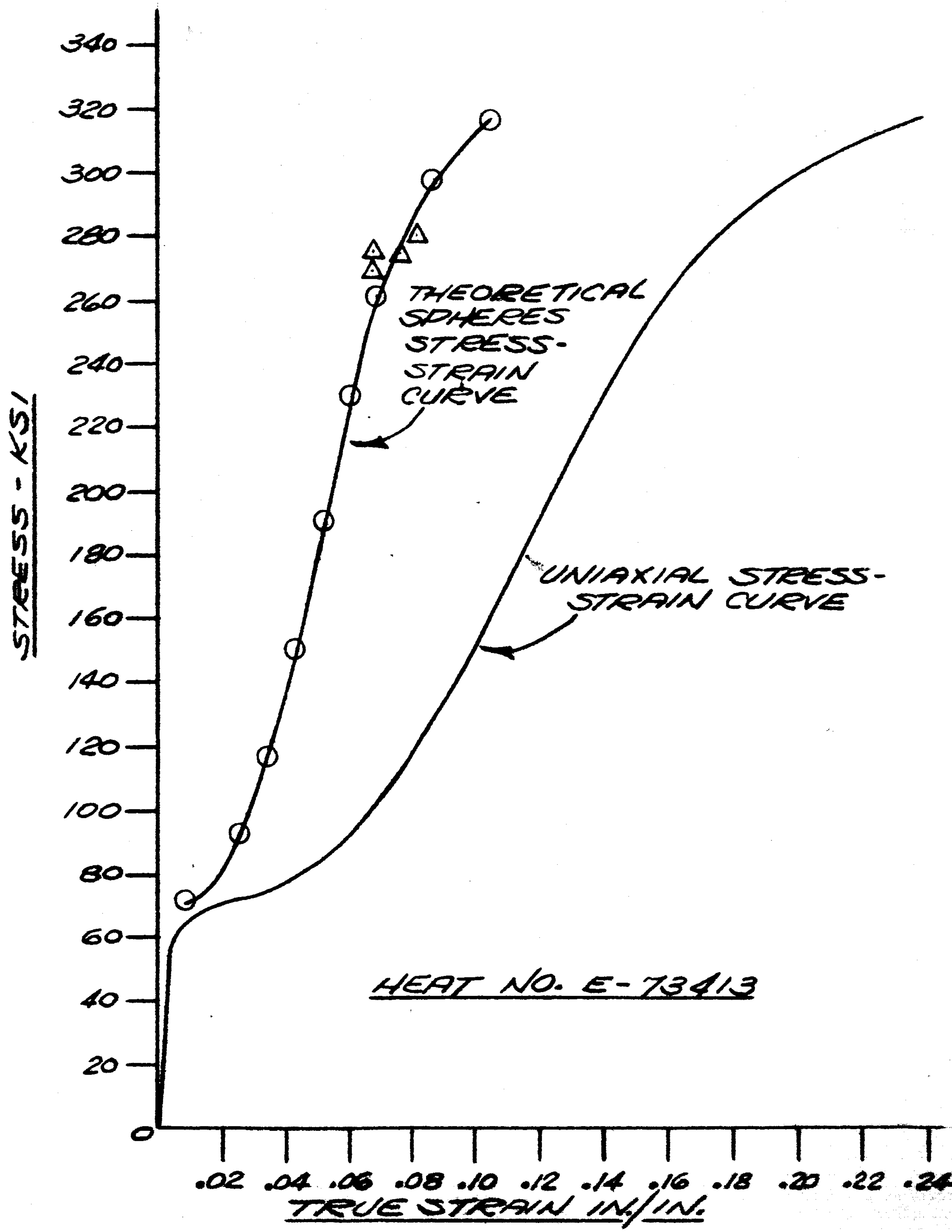
E. Discussion of Program Results (cont'd)

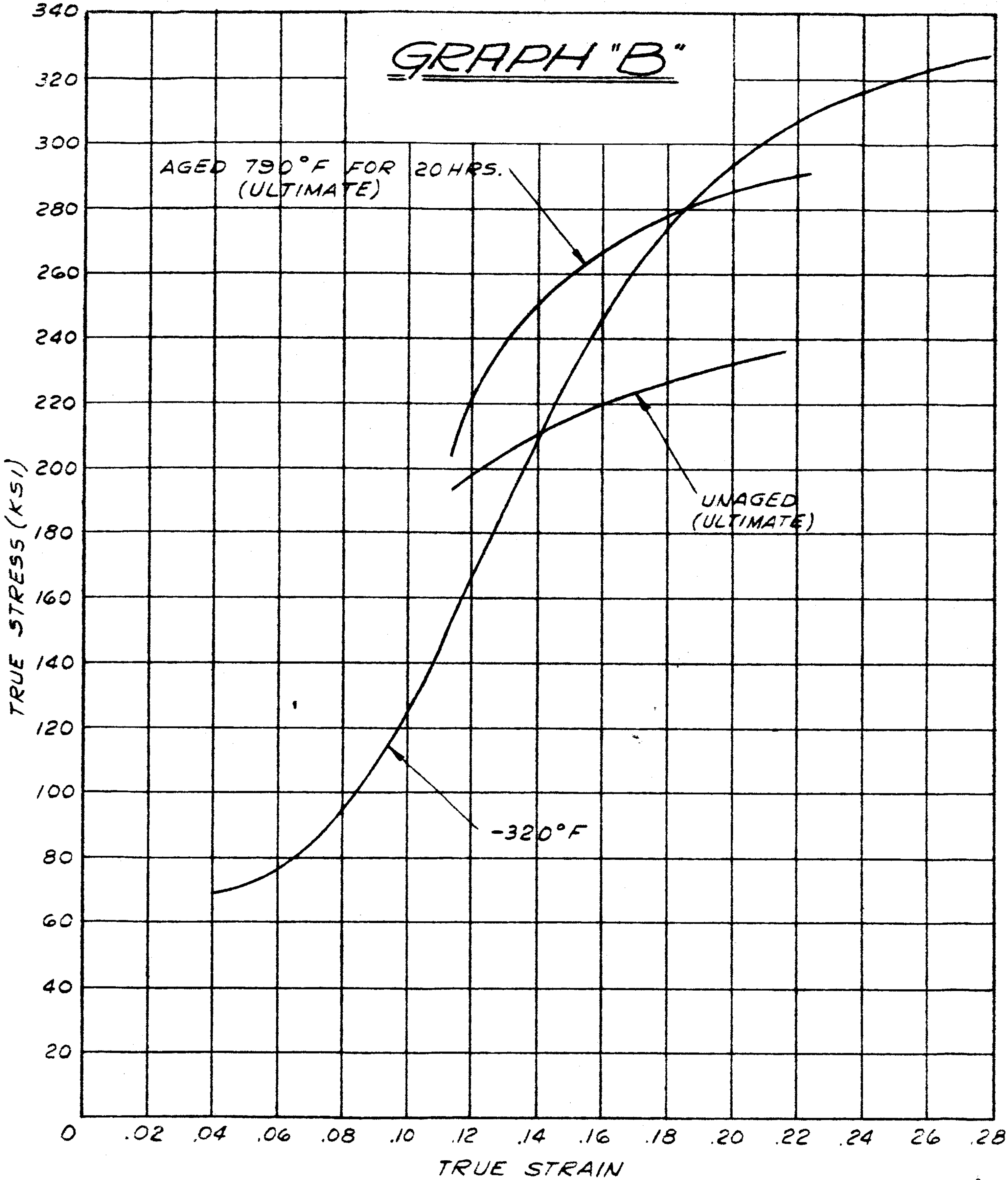
It is interesting to note in Figure 32, that there was a slight increase in volume after proof-testing although no deterioration of pressure wasobserved when the proof pressure was held for five minutes as indicated in Figures 10 through 16A. This increase varied from sphere to sphere. It is felt that this variation is primarily due to the accuracy of the measuring equipment. A realistic engineering estimate is that the volume increase is approximately .1% or nine cubic inches. If the measuring equipment is considered accurate, it will be found that the total variation in volume from the minimum to the maximum sphere is 155 cubin inches after proof-testing as compared to a maximum variation of 100 cubin inches theoretical. It therefore becomes apparent that a wider tolerance should be used in any future designs. This tolerance should be in the neighborhood of 2%. The maximum spread in diameters is .168" as called for on the drawing, if we analyze the minimum and maximum dimensions achieved among all sphere. This results in a .170" spread which is close enough if we consider measuring accuracy. If PI tape results are discountered, this tolerance spread is .117" well within design limits.

Figure 32 indicates that a total of ten spheres were fabricated. Two of these failed to survive the cryogenic stretch operation and a third sphere was processed as far as the preform stage. The cause of failure for the first two spheres was determined to be an improper anneal during the spinning operation. A detailed metallurgical investigation was performed regarding this improper anneal and several remedies proposed. The results of this investigation are detailed in Section IV-D of this report. The unprocessed sphere was to be used as an alternate solution to the annealing problem as recommended in Section IV-D. Due to the successful treatment of subsequent spheres manufactured, it became unnecessary to make use of this item.

V. LIST OF GRAPHS AND FIGURES

GRAPH "A"


340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
STRESS - KSI
THEORETICAL SPHERES STRESS-STRAIN CURVE
UNIAXIAL STRESS-STRAIN CURVE
HEAT NO. E-73413
.02 .04 .06 .08 .10 .12 .14 .16 .18 .20 .22 .24
TRUE STRAIN IN./IN.



UNIAXIAL
TENSILE PROPERTIES
OF HEAT #E-73597

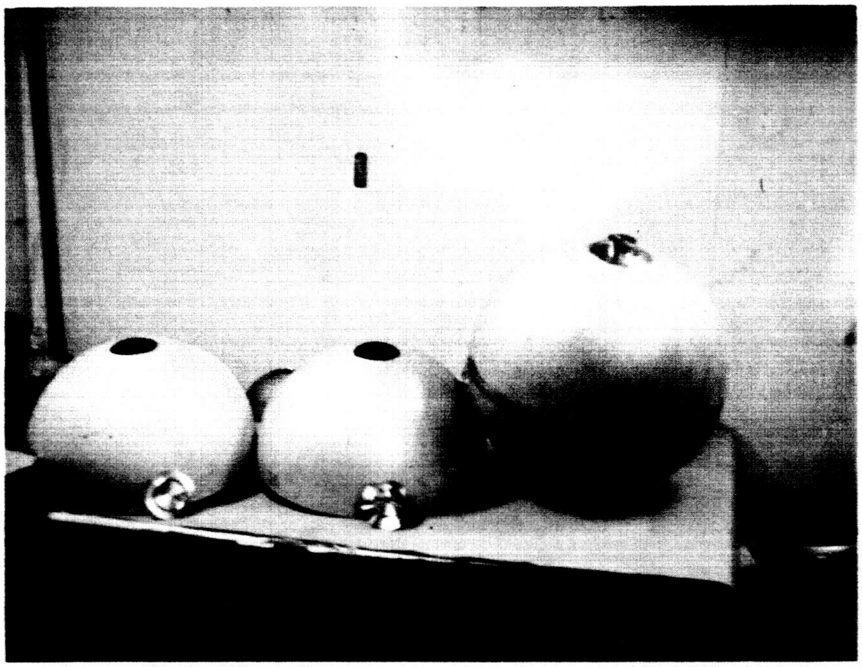


FIGURE 1
25" SPHERE-WELDED PREFORM AND COMPONENTS

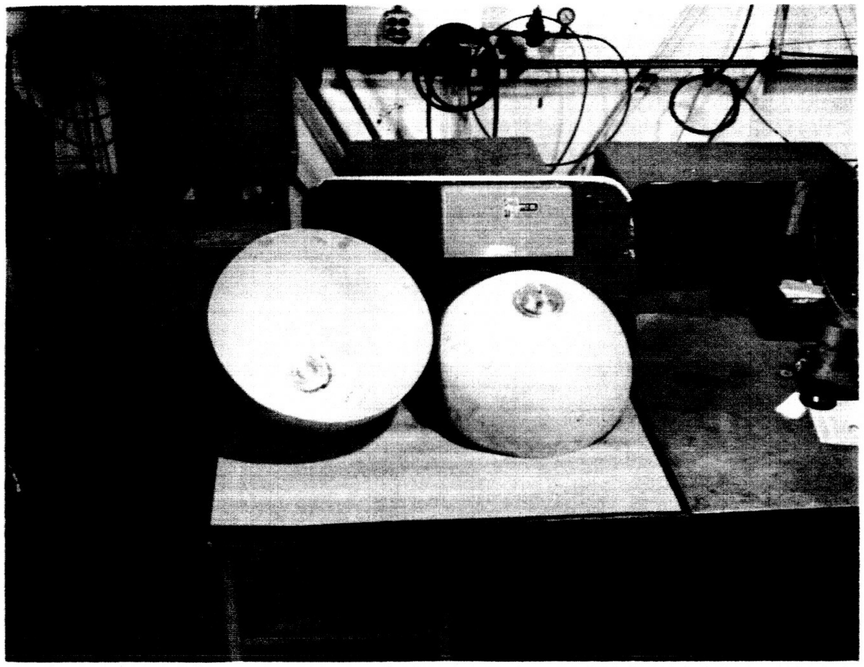


FIGURE 2

25" SPHERE-BOSSES WELDED TO HEMISPHERICAL HEADS

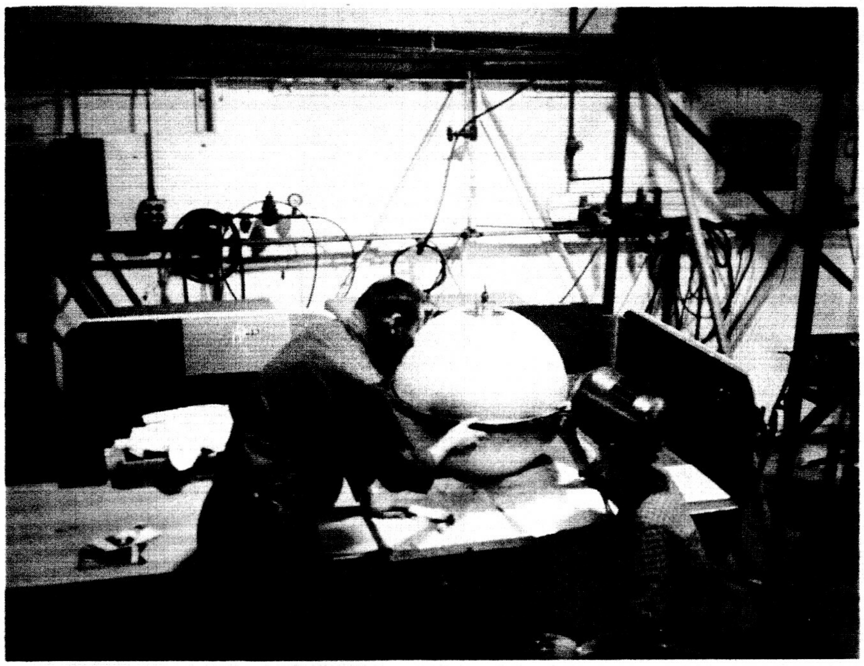


FIGURE 3
25" SPHERE - TACK WELDING OF HEMISPHERES

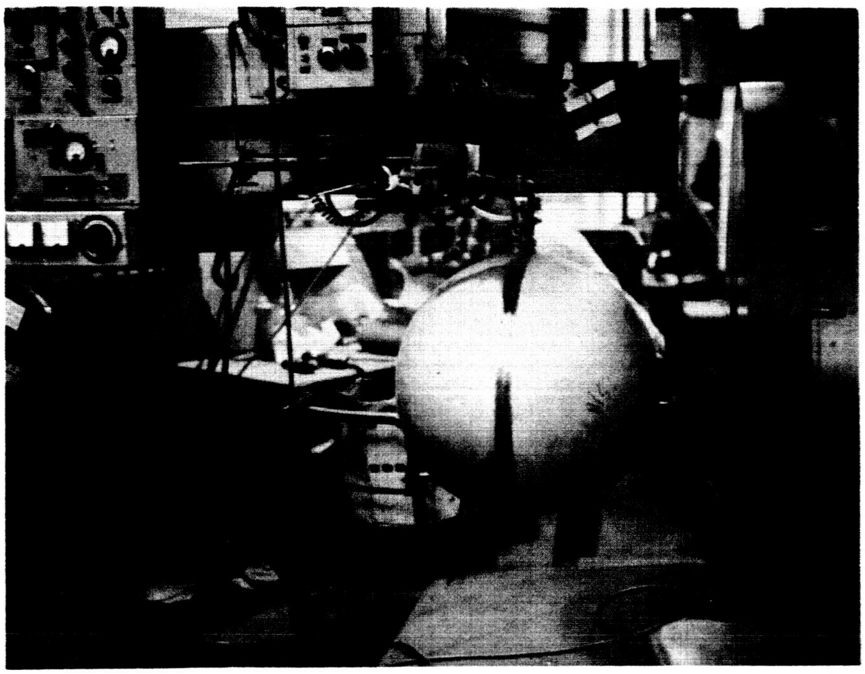


FIGURE 4

25" SPHERE - GIRTH WELDING OF SPHERE

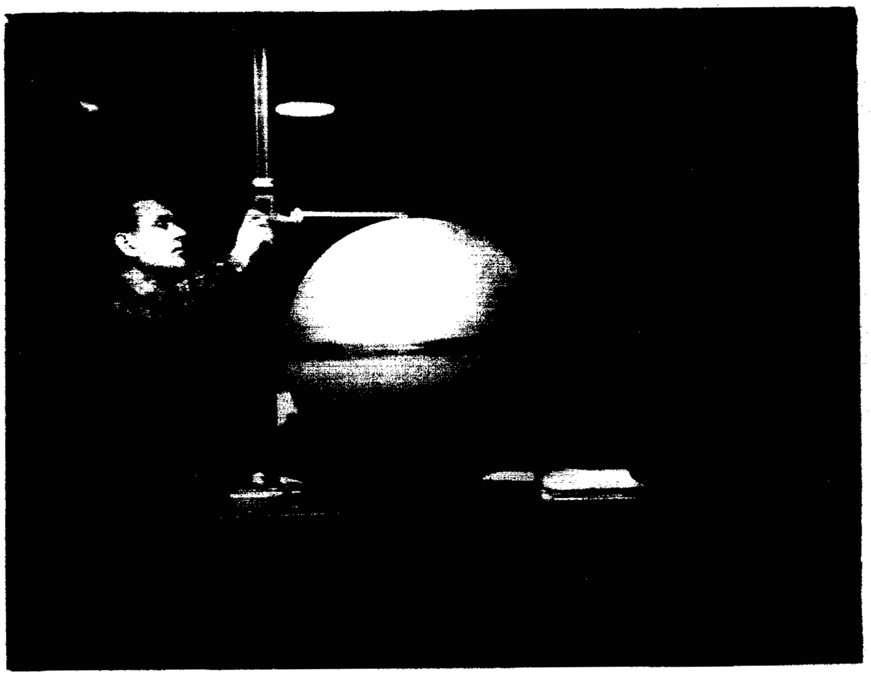


FIGURE 5
25" SPHERE-INSPECTION OF SPHERE

FIGURE 6

25" SPHERE - IDENTICAL SPHERES BEFORE AND AFTER CRYOGENIC STRETCH

FIGURE 7

TEST EQUIPMENT SET-UP SHOWING HYDROTEST PRESSURE GAGE AND STRAIN GAGE INSTRUMENTATION

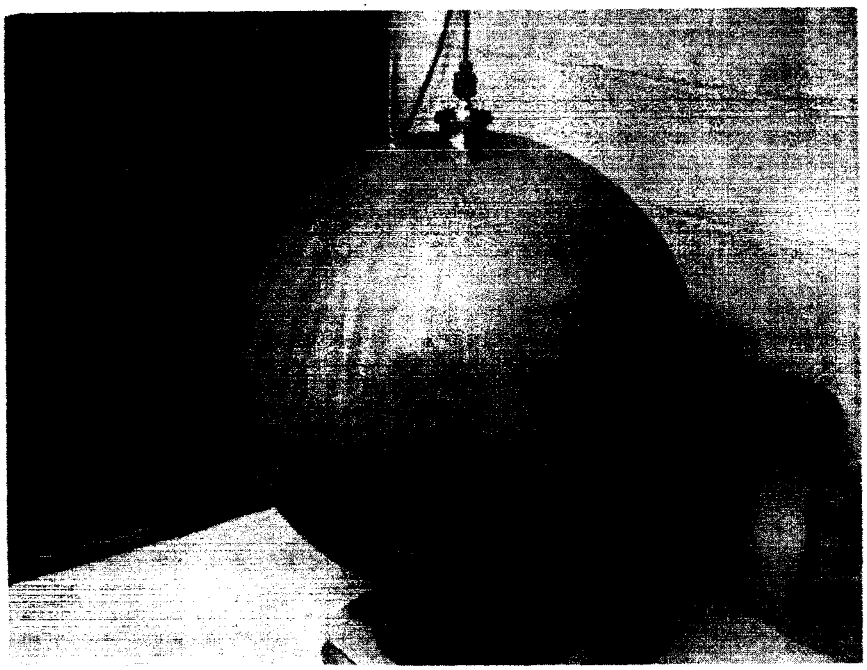


FIGURE 8

25" SPHERE-UNDERGOING PROOF PRESSURE CHECK

FIGURE 9

25" SPHERE-AFTER BURST TEST AT 1560 PSIG

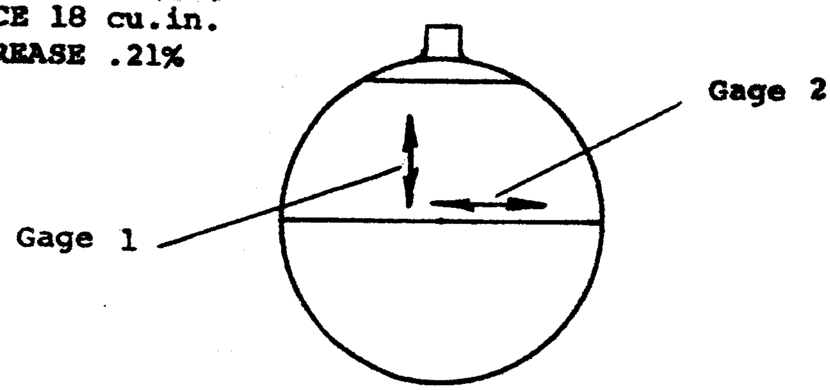
TEST REPORT

S/N 550

25" AGED SPHERE

WEIGHT - 23 lbs.

VOLUME AFTER PRESSURE TEST - 8357 cu. in.
VOLUME BEFORE TEST-8339 cu.in.
VOL.DIFFERENCE 18 cu.in.
VOLUME % INCREASE .21%



PRESSURE	Gage 1	Gage 2
	MICROINCH READINGS	
0	10970	9800
300	11890	10690
500	12500	11320
700	13120	11970
900	13770	12650
1000	14050	12970
1200	14710	13720
*1350	15180	14300

* HELD FOR 3 MINUTES

500 PSI TEST FOR FINAL LEAKAGE CHECK.

11-6-64

FIGURE 10

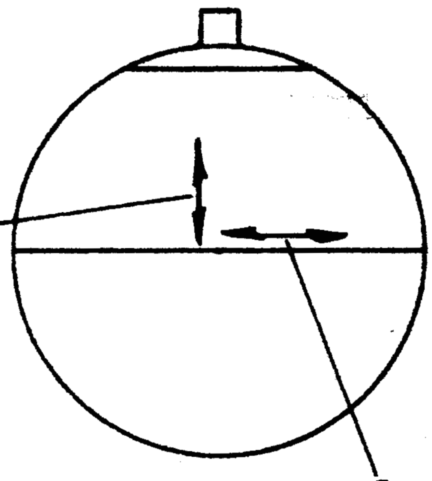
TEST REPORT

S/N 554

25" AGED SPHERE

WEIGHT - 21.92 lbs.

VOLUME (AFTER TESTING) - 8395 cu. in.
" (BEFORE TESTING) - 8390 cu. in.
" DIFFERENCE - 5 cu. in.
" % INCREASE - .06%



PRESSURE	Gage 1	Gage 2
	MICROINCH READINGS	
0	11000	10490
500	EXERCISE GAGES	
0	11000	10530
300	11970	11480
500	12620	12090
700	13330	12710
• 900	14050	13240
*1000	14400	13400
*1200	15160	13960
*1350	15690	14250
0	11190	

* #2 GAGE FALLING OFF, READINGS INCONCLUSIVE.

FIGURE 11

1-18-65

TEST REPORT

S/N 555

25" AGED SPHERE

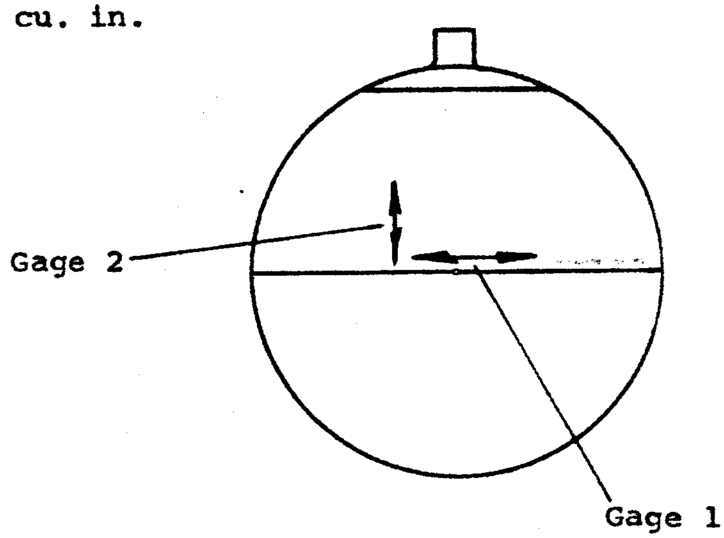
WEIGHT - 22.01 lbs.

VOLUME (AFTER TESTING) - 8366 cu. in.

" (BEFORE TESTING) - 8360 cu. in.

" DIFFERENCE - 6 cu. in.

" % INCREASE - .07%



PRESSURE	Gage 1	Gage 2
	MICROINCH READINGS	
0	12300	10500
500	- EXERCISE GAGES -	
0	12320	10490
300	12900	11350
500	13350	11990
*700	13760	12550
*900	14240	13180
•1000	14400	13480
*1200	14850	14150
*1350	15150	14640

* BOTH GAGES DROPPING - READINGS INCONCLUSIVE

FIGURE 12

1-18-65

TEST REPORT

S/N 556

25" AGED SPHERE

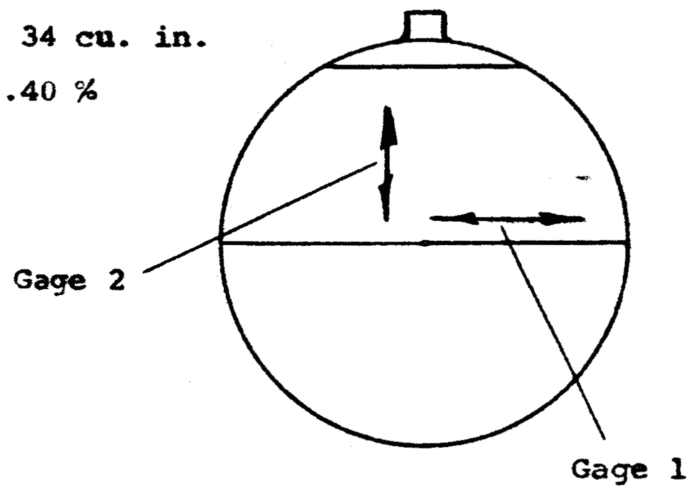
WEIGHT - 22.07 lbs.

VOLUME (AFTER TESTING) - 8512 cu. in.

" (BEFORE TESTING) - 8478 cu. in.

" DIFFERENCE - 34 cu. in.

" % INCREASE - .40 %



PRESSURE	Gage 1	Gage 2
	MICROINCH READINGS	
0	10500	12040
300	11670	13220
500	12520	14020
700	13410	14830
900	14390	15710
1000	14910	16140
1100	15400	16550
1200	15920	16990
*1350	16700	17670

*HELD FOR 5 MINUTES - NO PRESSURE LOSS

FIGURE 13

1/26/65

TEST REPORT

S/N 557

25" AGED SPHERE

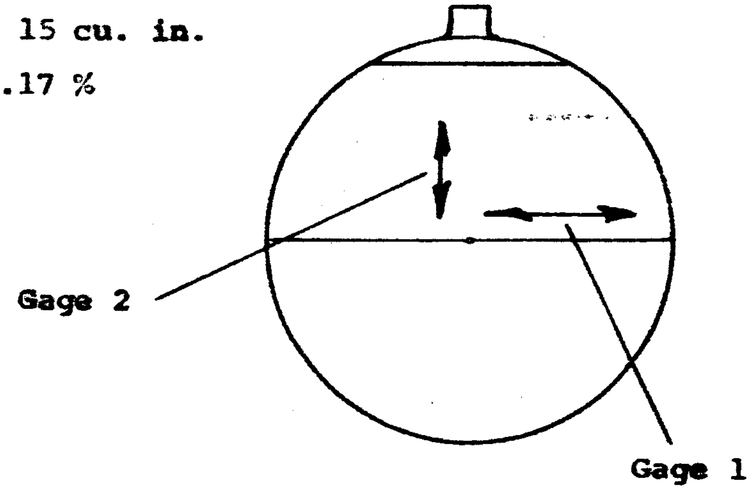
WEIGHT - 22.79 lbs.

VOLUME (AFTER TESTING) - 8398 cu. in.

" (BEFORE TESTING) - 8383 cu. in.

" DIFFERENCE - 15 cu. in.

" % INCREASE - .17 %



PRESSURE	Gage 1	Gage 2
	MICROINCH READINGS	
0	10650	10630
300	11510	11840
500	12110	12640
700	12780	13520
900	13500	14470
1000	13850	14920
1100	14250	15430
1200	14630	15910
*1350	15210	16620

*HELD FOR 5 MINUTES - NO PRESSURE LOSS

FIGURE 14

1/26/65

TEST REPORT

S/N 558

25" AGED SPHERE

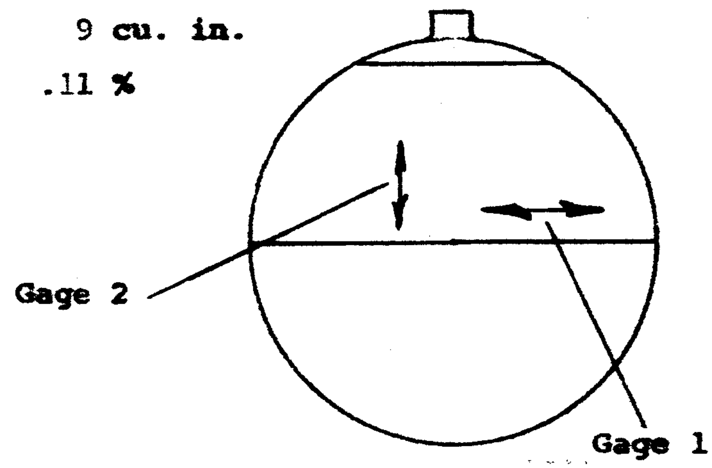
WEIGHT - 21.92 lbs.

VOLUME (AFTER TESTING) - 8488 cu. in.

VOLUME (BEFORE TESTING) - 8479 cu. in.

" DIFFERENCE - 9 cu. in.

" % INCREASE - .11 %



PRESSURE	Gage 1	Gage 2
	MICROINCH READINGS	
0	10840	10680
300	12020	11860
500	12840	12650
700	13700	13470
900	14670	14360
1000	15130	14790
1100	15630	15230
1200	16110	15690
*1350	16850	16360

*HELD FOR 5 MINUTES - NO PRESSURE LOSS

FIGURE 15

1/26/65

TEST REPORT

S/N 559

25" AGED SPHERE

WEIGHT - 22.94 lbs.

VOLUME (AFTER TESTING) - 8386 cu. in.

" (BEFORE TESTING) - 8381 cu. in.

" DIFFERENCE - 5 cu. in.

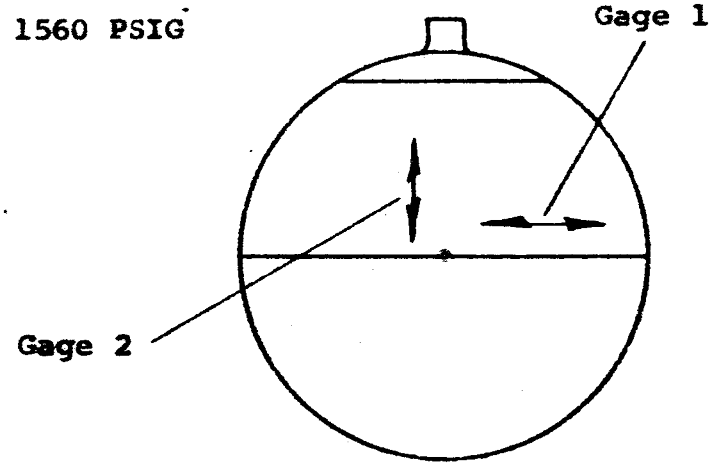
" % INCREASE - .06 %

" AFTER HOLDING @ 1560 PSIG FOR 2 MIN. - 8568 cu. in.

" DIFFERENCE - 187 cu. in.

" % INCREASE - .22 %

BURST PRESSURE - 1560 PSIG



PRESSURE	Gage 1	Gage 2
	MICROINCH READINGS	
0	11040	10960
300	12020	12080
500	12710	12860
700	13440	13670
900	14190	14520
1000	14600	14970
1100	14990	15380
1200	15390	15840
*1350	16000	16510

*HELD FOR 5 MINUTES - NO PRESSURE LOSS

FIGURE 16

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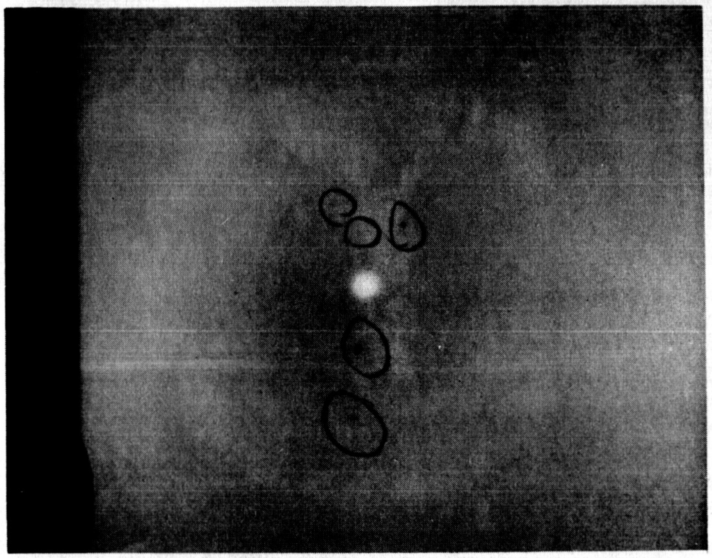


FIGURE 17

RADIOGRAPH OF S/N 1007 HEAD AT THE POLE AREA 2/3X

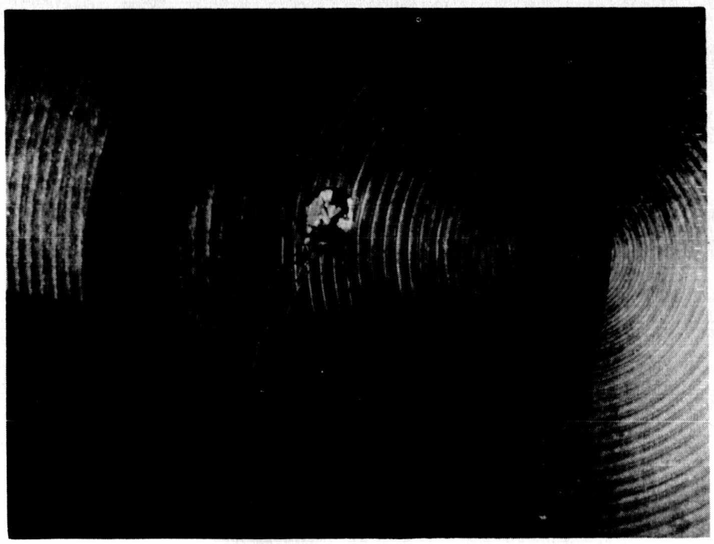


FIGURE 18

HOLE ON THE OUTSIDE SURFACE OF THE POLE AREA OF S/N 1010 HEAD 10X

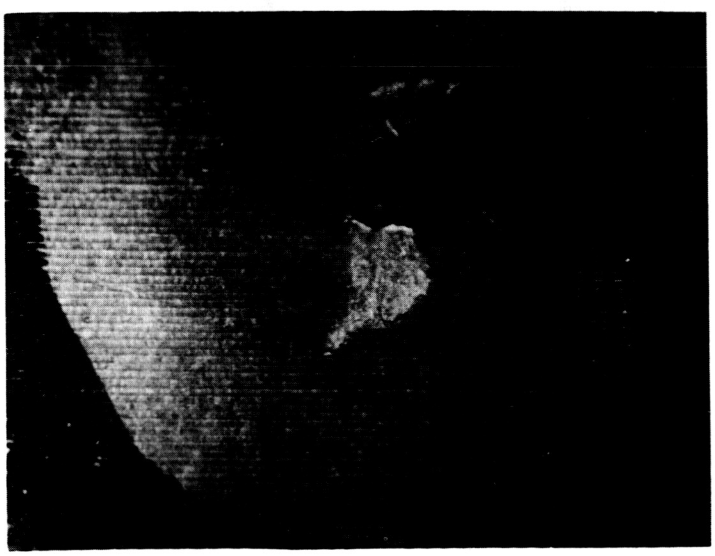
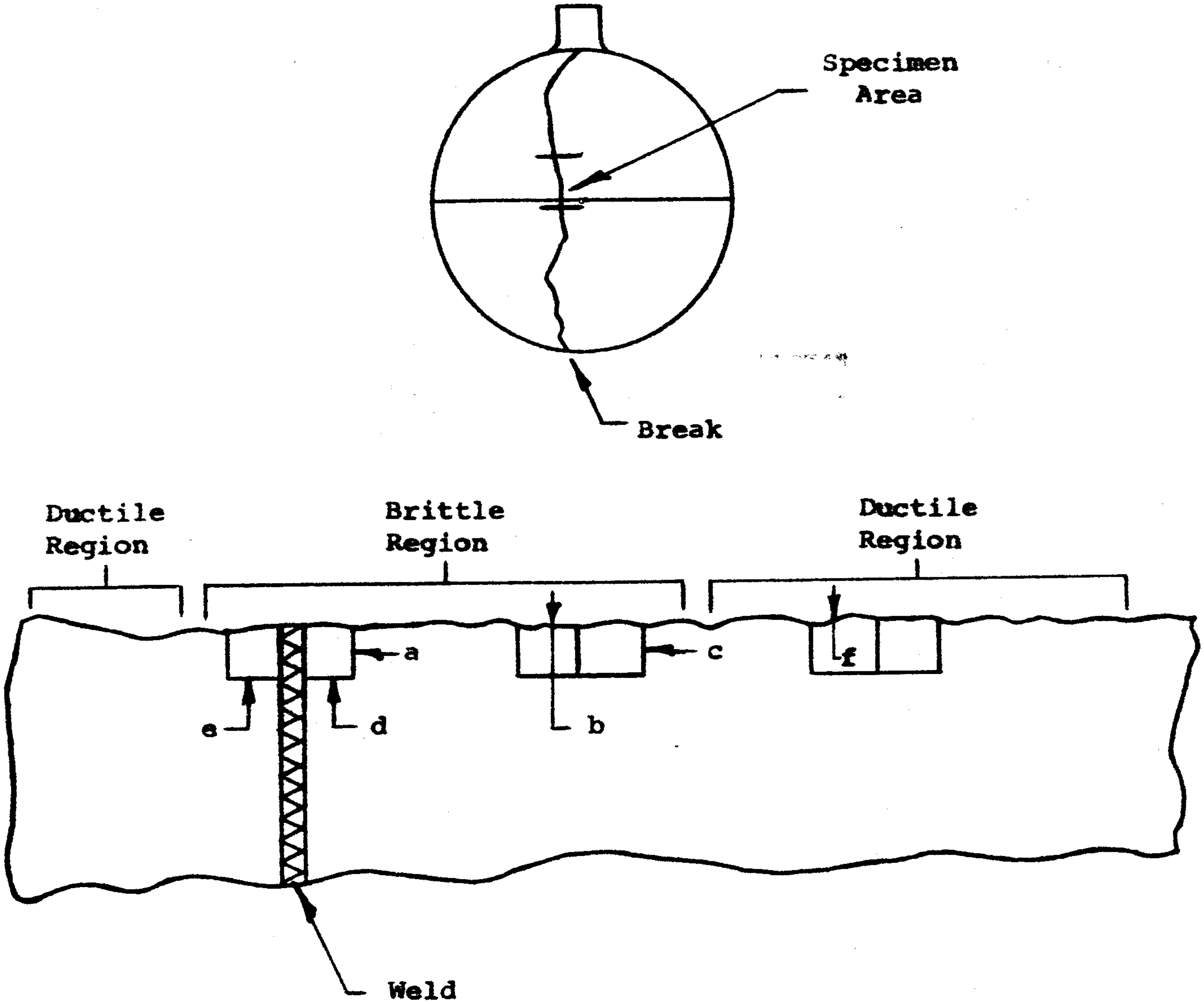


FIGURE 19

FLAKED AREA ON THE OUTSIDE SURFACE OF S/N 1010 HEAD 6-1/2X

S/N 552



METALLURGICAL SPECIMEN LOCATION

FIGURE 20

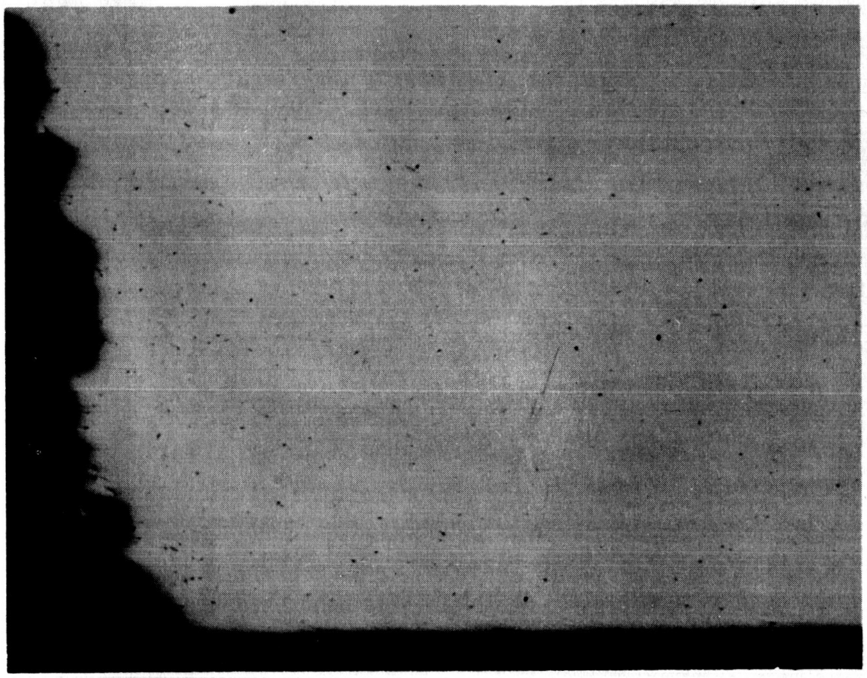


FIGURE 21

METALLOGRAPH SHOWING INCLUSIONS 100X

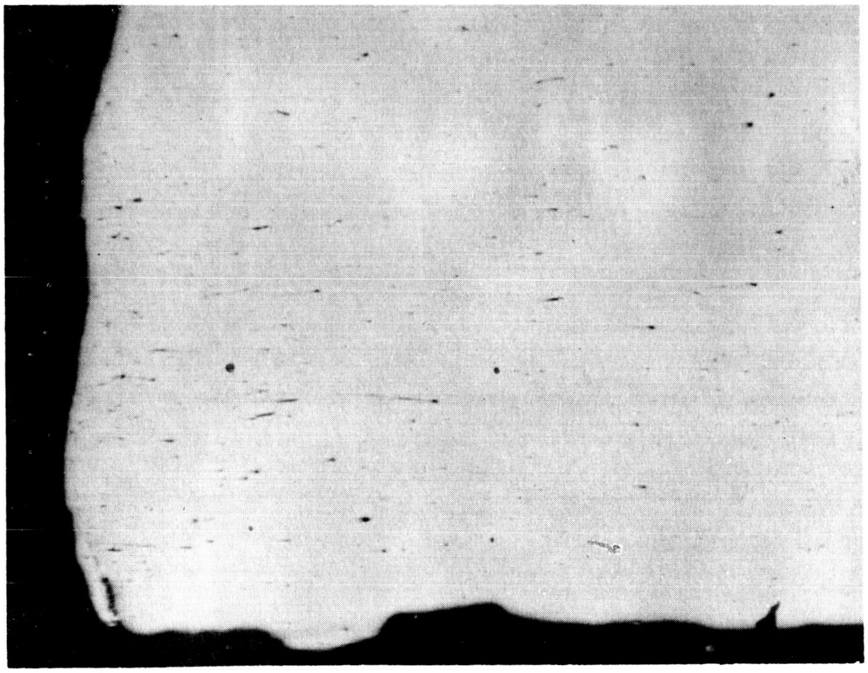


FIGURE 22

METTALLOGRAPH SHOWING INCLUSION ELONGATION 100X

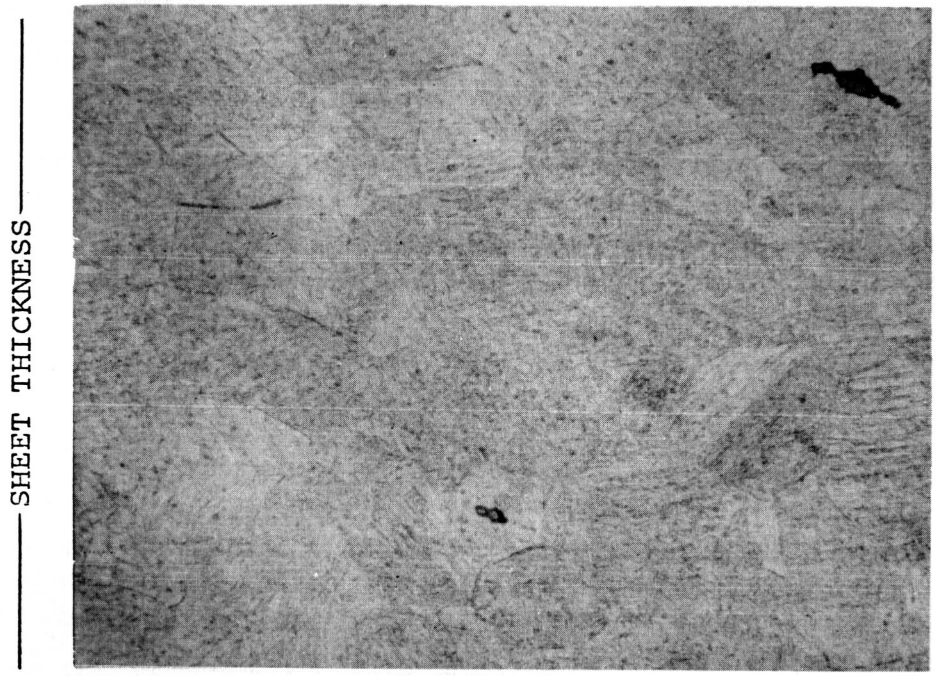


FIGURE 23

GRAIN STRUCTURE - TENSILE SPECIMEN - 17%
CRYOGENIC STRETCH - LONGITUDINAL DIRECTION
540X

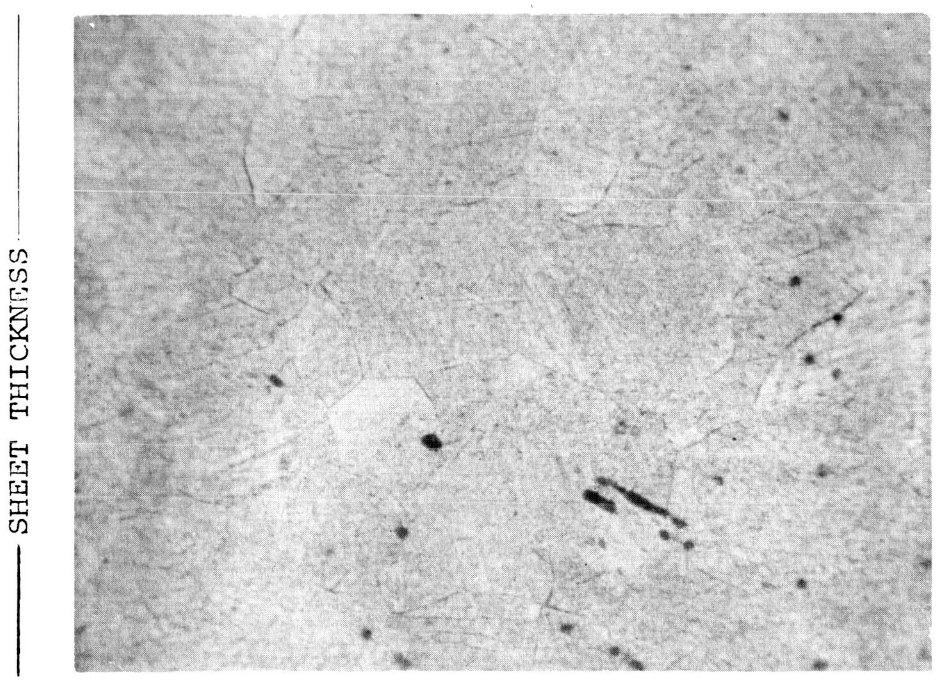


FIGURE 24

GRAIN STRUCTURE - TENSILE SPECIMEN -17%
CRYOGENIC STRETCH - TRANSVERSE DIRECTION
540X

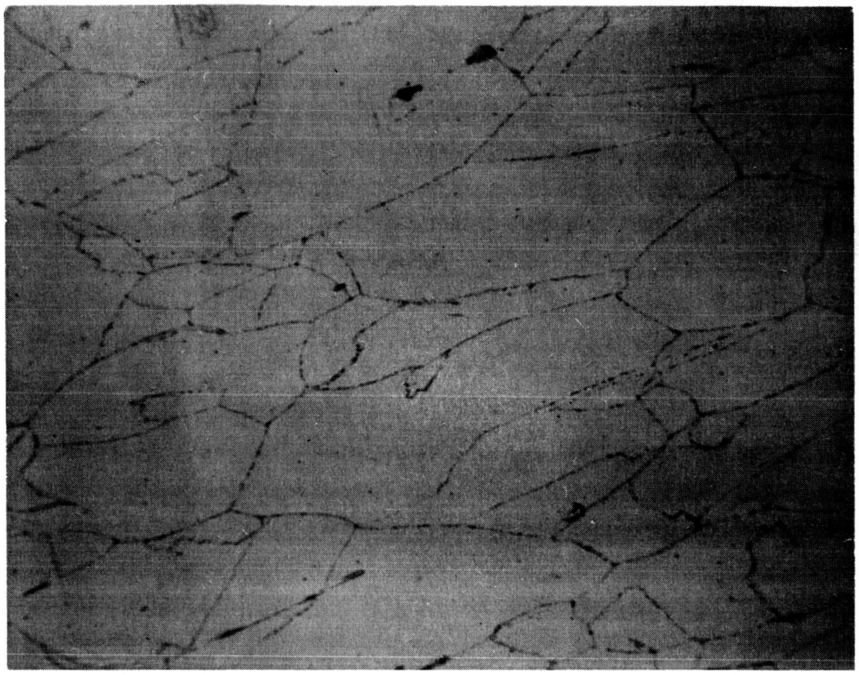


FIGURE 25

GRAIN STRUCTURE ELONGATED
PARALLEL TO THE FRACTURE 540X

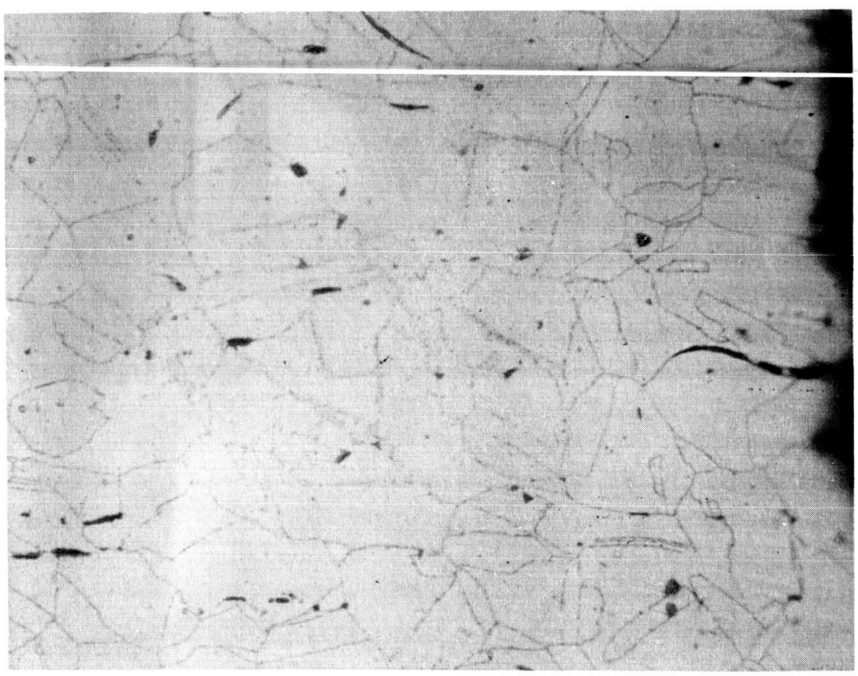


FIGURE 26

GRAIN STRUCTURE PERPENDICULAR
TO FRACTURE DIRECTION 540X

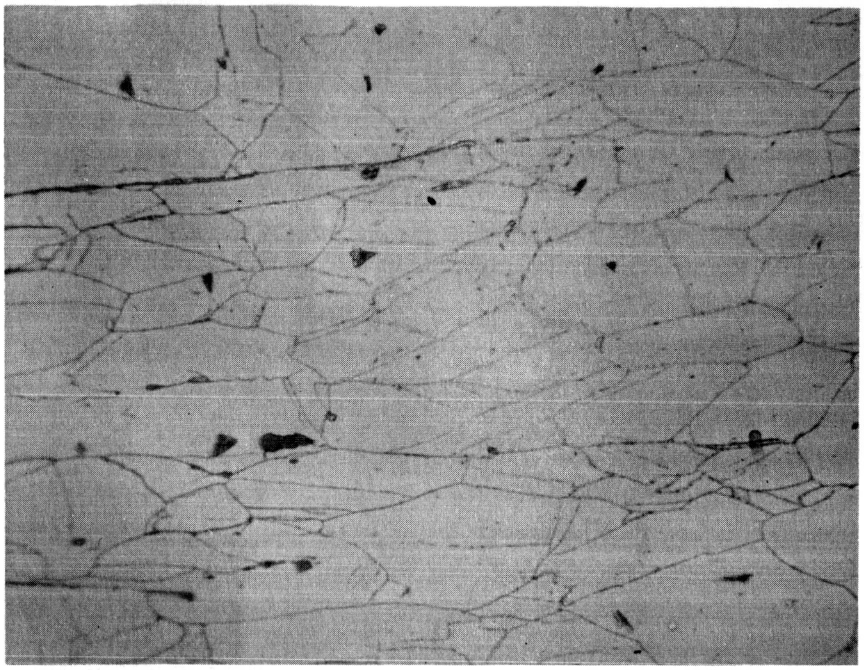


FIGURE 27

GRAIN STRUCTURE SHOWING ELONGATED GRAIN 540X

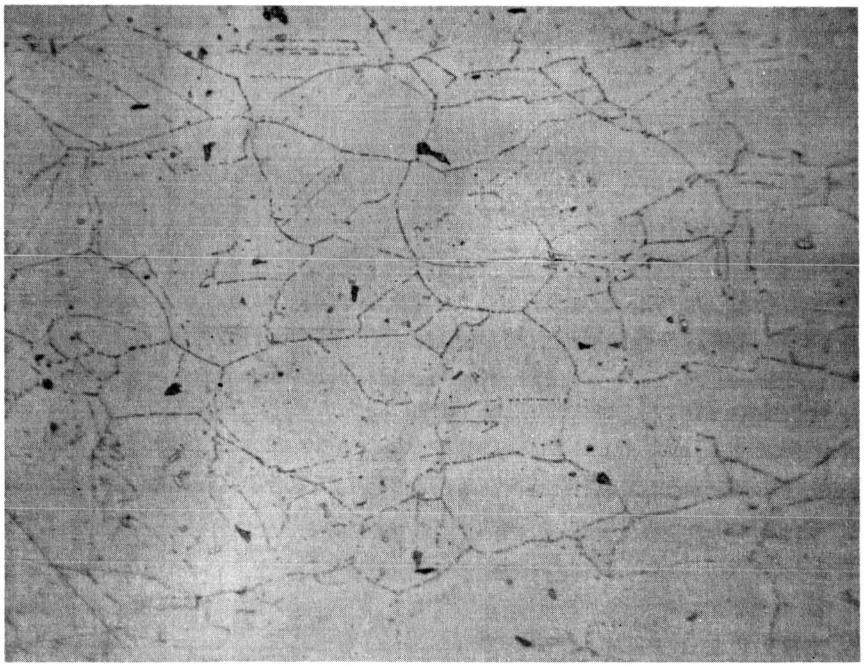


FIGURE 28

END GRAIN STRUCTURE OF GRAINS SHOWN IN FIGURE 8
540X

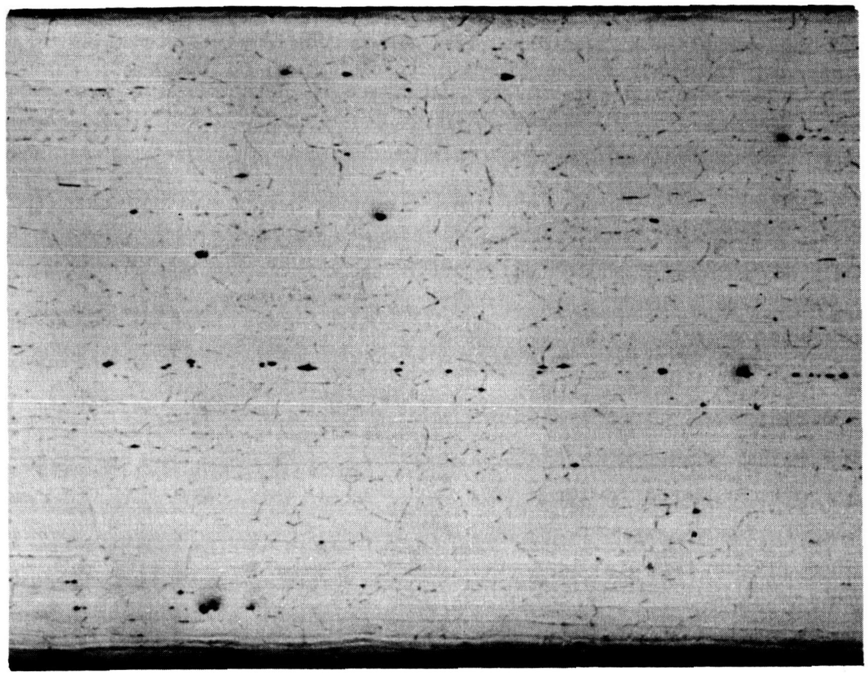


FIGURE 29

EQUIAXED GRAIN STRUCTURE IN
REGION OF DUCTILE FAILURE 100X

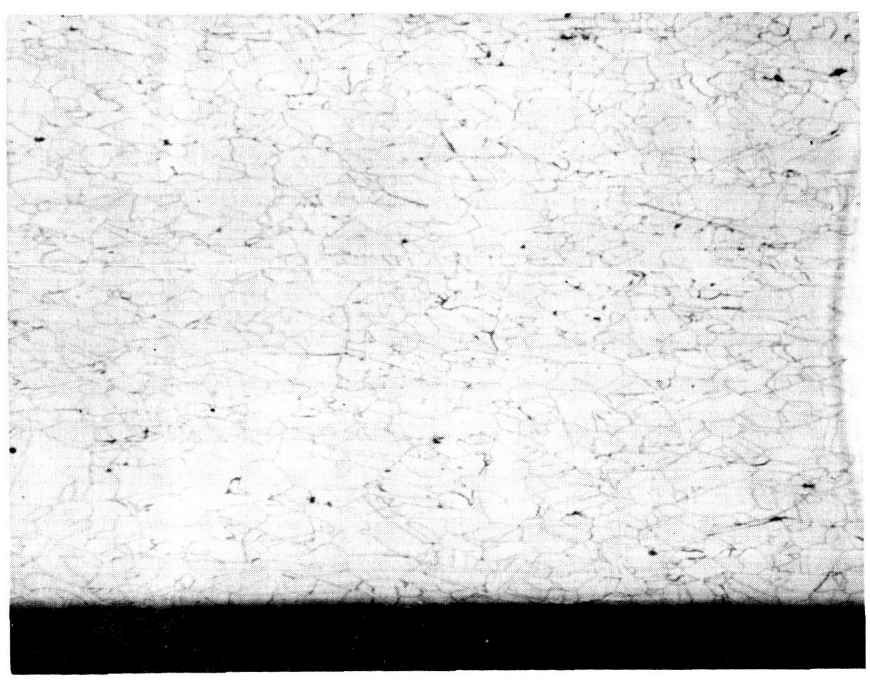


FIGURE 30

ELONGATED GRAIN STRUCTURE IN
REGION OF BRITTLE FAILURE 100X

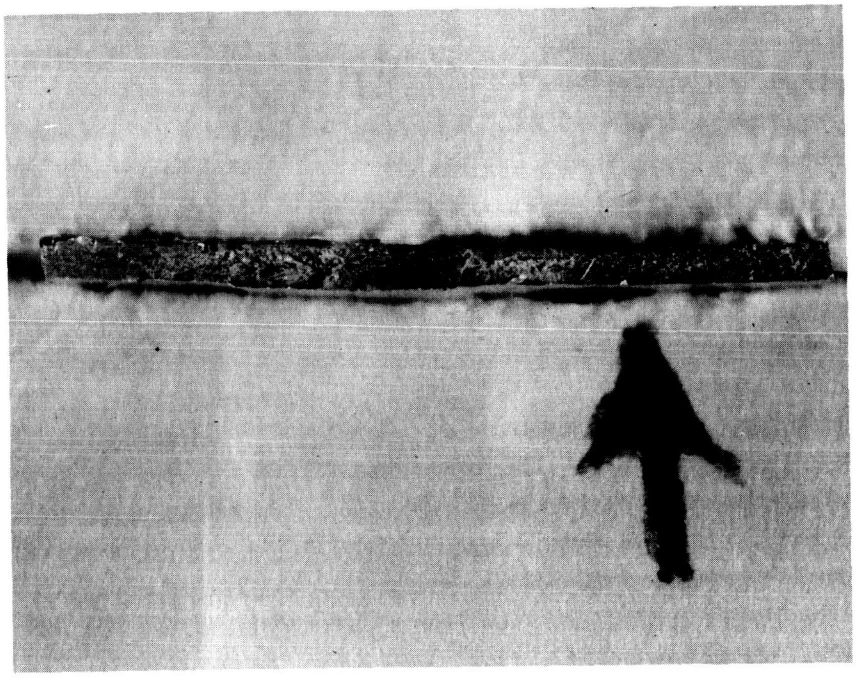


FIGURE 31

FRACTURE SURFACE AT SUSPECTED ORIGIN OF FAILURE 5X

DESIGN GOALS		240,000	1347±10	214,375	8230 - 8330		25.090-25.258	26.5	240,000
VESSEL SERIAL NUMBER	-320°F STRETCH PRESSURE PSIG	(1) -320°F STRESS LEVEL ACHIEVED PSIG	R.T. PROOF PRESSURE TEST PSIG	(1) R.T. PROOF PRESSURE STRESS PSIG	VOLUME PRIOR TO PROOF TEST-IN^3	VOLUME AFTER PROOF TEST IN^3	(2) OUTSIDE DIAMETER INCHES	WEIGHT LBS.	BURST STRENGTH PSI
550	1520	258,538	1350	229,621	8339	8357	25.254	23.0	(1) 267,328
551	(4) 1150	191,000	-	-	-	-	-	-	-
552	(4) 1240	203,000	-	-	-	-	-	-	-
553	NOT STRETCHED - WAS TO BE USED FOR ALTERNATE ANNEALING SALVAGE METHOD								
554	1515	258,179	1350	230,063	8390	8395	25.302	21.92	(1) 266,957
555	1510	256,898	1350	229,677	8360	8366	25.260	22.01	(1) 265,632
556	1510	258,571	1350	231,173	8478	8512	(3) 25.424	22.07	(1) 267,362
557	1510	257,632	1350	230,333	8383	8398	(3) 25.331	22.79	(1) 266,391
558	1510	258,041	1350	230,698	8479	8488	25.371	21.92	(1) 266,814
559	1510	257,184	1350	229,933	8381	8386	25.287	22.94	266,000 ACTUAL

NOTES:

(1) THEORETICAL CALCULATIONS.

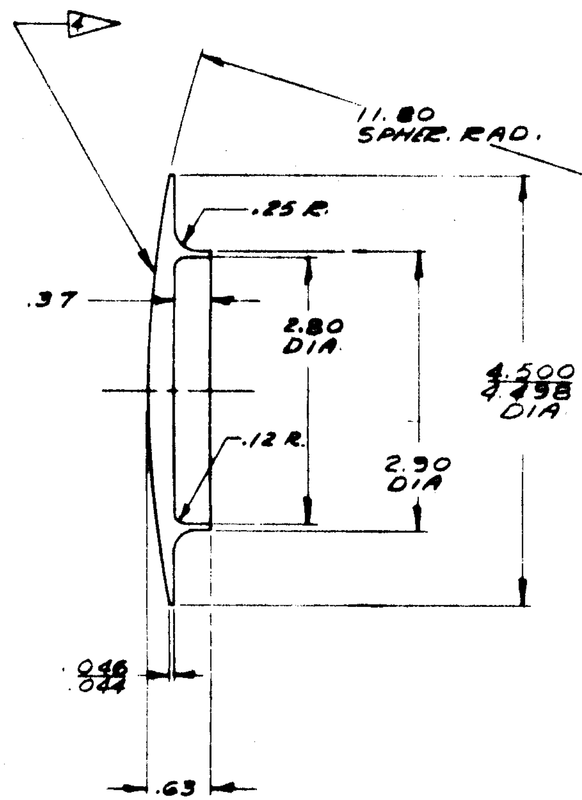
(2) AVERAGE OF THREE READINGS

(3) THESE DIMENSIONS TAKEN WITH A PI TAPE.

(4) BURST

FIGURE 32

E O NO	SYM	ZONE	DESCRIPTION	DATE	APPROVED
3644			ORIGINAL RELEASE		
3644	A		63 WAS 125	3-3-64	



NOTES:

1 — GENERAL HANDLING REQUIREMENTS PER SPEC. NO. ARC-1800

2 — VENDOR TO USE MAT'L. PROVIDED BY ARDE-PORTLAND ONLY.

3 — CLEAN PER SPEC. NO. AP-C-1200 REV. 2.

4 MARK PART NO. & CHANGE LETTER APPROX. 1/8 HIGH LETTERS WITH PERMANENT INK.

5 ST. ST'L AISI TYPE 301 PER SPEC. NO AP-C-2000 HEAT NO. E 73597

C103755 A

				ITEM NO.	CODE IDENT	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
						C103755	INTERNAL SUPPORT	5	5
QTY REQD PER DASH NO.									

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES
.X = ±.030, .XX = ±.010, .XXX = ±.005
ANGULAR ±30'
BREAK SHARP EDGES .003-.015
ALL SMALL FILLETS .020-.040R
THREADS PER FED. HNDBK H-28 AND SUPPLEMENTS.
DIMENSIONING PER MIL-STD-8
WELD SYMBOLS PER JAN-STD-19
SURFACE ROUGHNESS SYMBOLS PER MIL-STD-10
ALL FINISHED SURFACES 63

NEXT ASSEMBLY

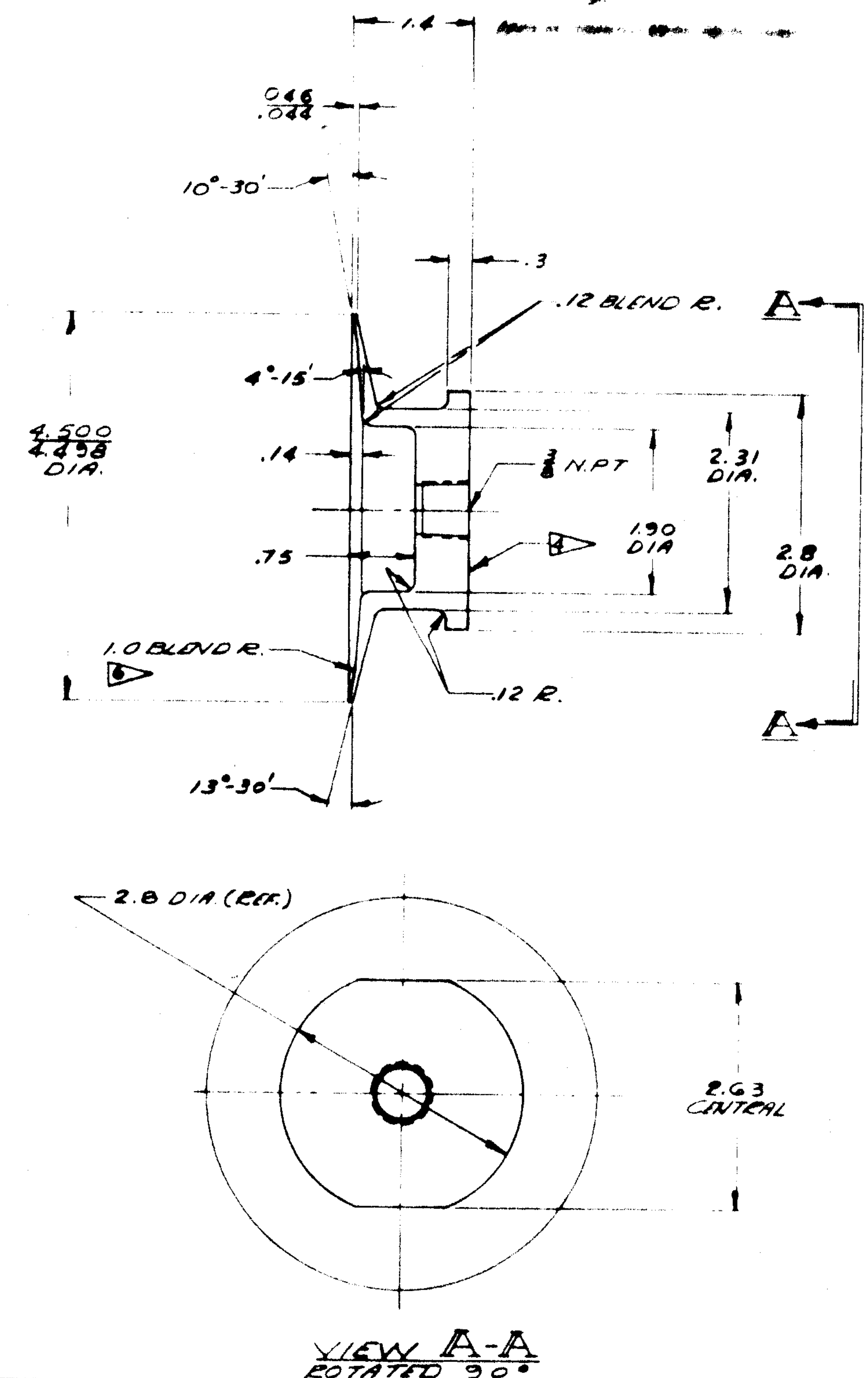
DRAWN BY	ARDE/WALDEN	5-4-64
CHECKER		
STRESS ENG'R		
AERO THERMO		
DES. ENG'R		
PROJ. ENG'R		5-14-64

ARDE-PORTLAND, INC.
PARAMUS, NEW JERSEY — SOUTH PORTLAND, MAINE

TITLE: INTERNAL SUPPORT - HEMISPHERICAL

CODE IDENT NO.	SIZE	
12218	C	C103755
SCALE FULL		SHEET

F.O. NO	SYM	ZONE	DESCRIPTION	DATE	APPROVED
3644			ORIGINAL RELEASE		
3644	A		63 WAS 125		



NOTES:

1— GENERAL HANDLING REQUIREMENTS PER SPEC NO. AP-C-1800.

2— VENDOR TO USE MATL PROVIDED BY ARDE-PORTLAND ONLY.

3— CLEAN PER SPEC. NO. AP-C-1200 REV 2.

4 MARK PART NO & CHANGE LETTER APPROX 1/8 HIGH LETTERS WITH PERMANENT INK.

5 ST STL AISI TYPE 301 PER SPEC NO AP-C-2000 HEAT NO. E73597

6 NO UNDERCUT IS PERMITTED IN THIS AREA. MINIMUM THICKNESS SHALL BE .063

QTY REQD PER DASH NO.	ITEM NO	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
			C103756	INDUCTION BOSS	5	5

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES .X ± .030 .XX ± .010 .XXX ± .005
ANGULAR ± 30'
BREAK SHARP EDGES .003 .015
ALL SMALL FILLETS .020 .040R
THREADS PER FED. HNDBK H-28 AND SUPPLEMENTS
DIMENSIONING PER MIL-STD-8
WELD SYMBOLS PER JAN-STD-19
SURFACE ROUGHNESS SYMBOLS PER MIL-STD-10
ALL FINISHED SURFACES 63

NEXT ASSEMBLY

DRAWN BY ARDE HALDEN 5-4-64
CHECKER
STRESS ENG'R
AERO THERMO
DES. ENG'R
PROJ. ENG'R 5-14-64

ARDE-PORTLAND, INC.
PARAMUS, NEW JERSEY — SOUTH PORTLAND, MAINE

TITLE: INDUCTION BOSS - HEMISPHERICAL

CODE IDENT NO. 12218 | SIZE C | C103756
SCALE FULL | SHEET

C103756 A

S/N 559

25" SPHERE

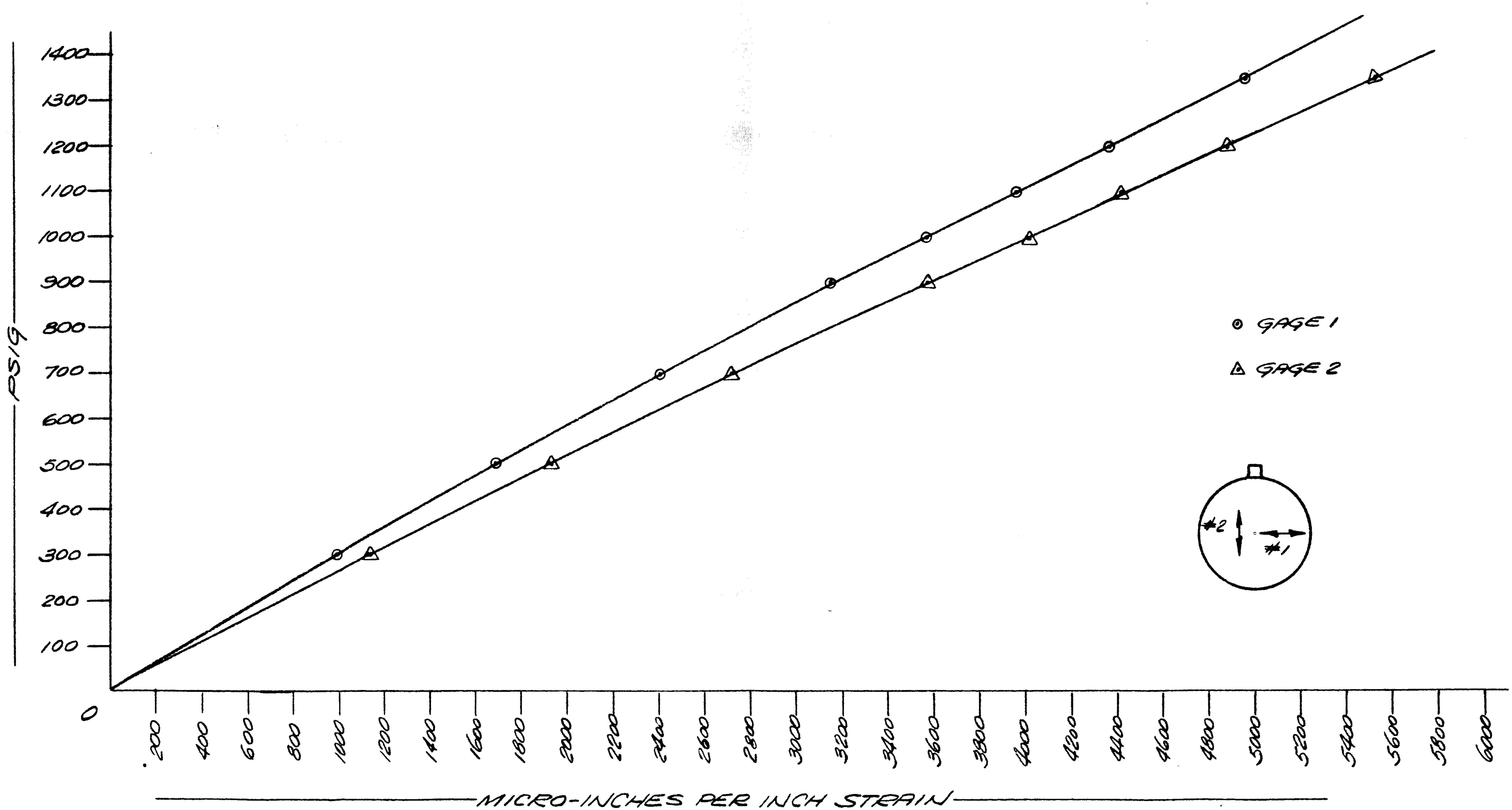


FIGURE 16A
1-27-65

S/N 558

25" SPHERE

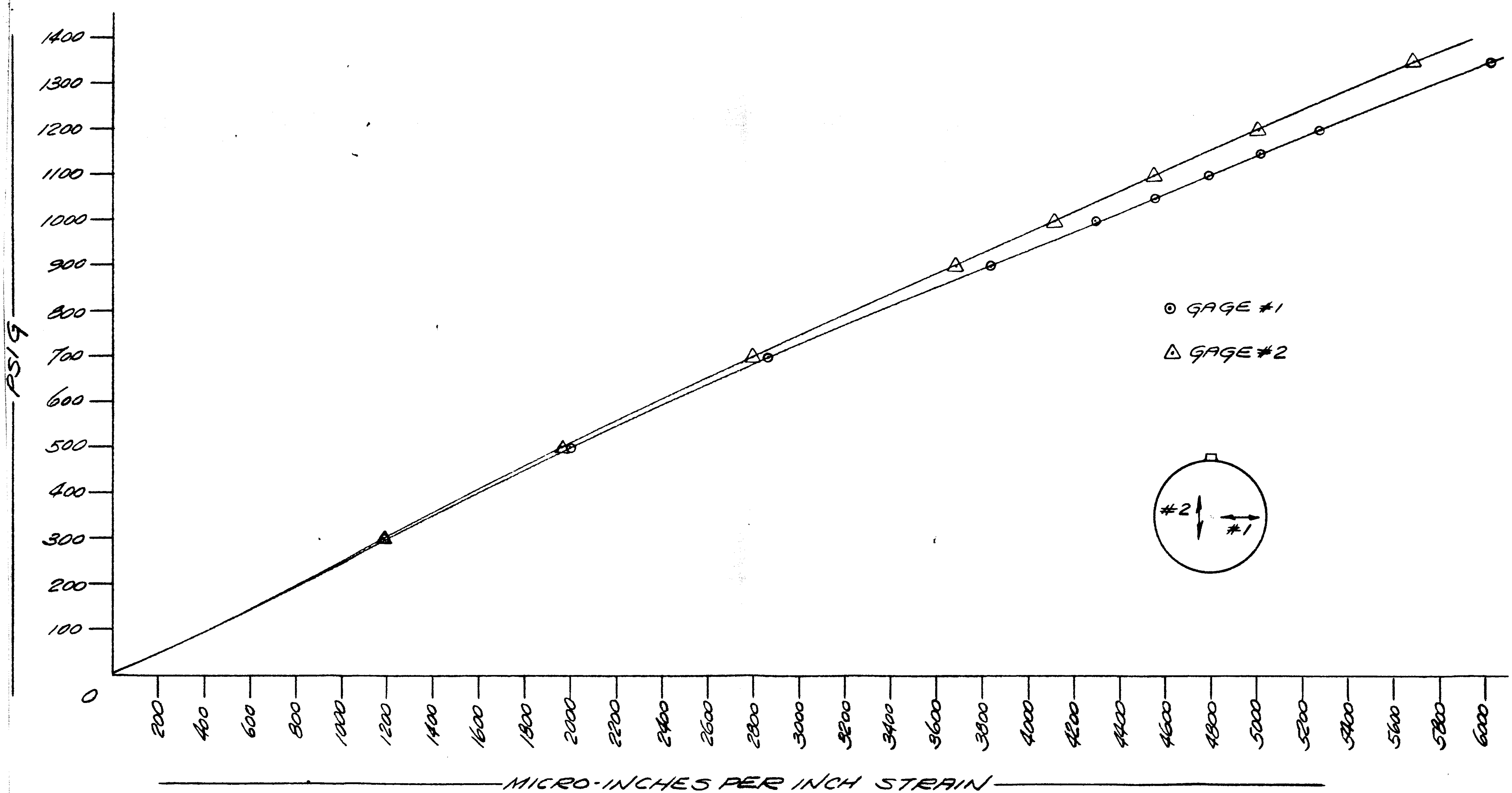


FIGURE 15A
1-26-65

S/N 557

25" SPHERE

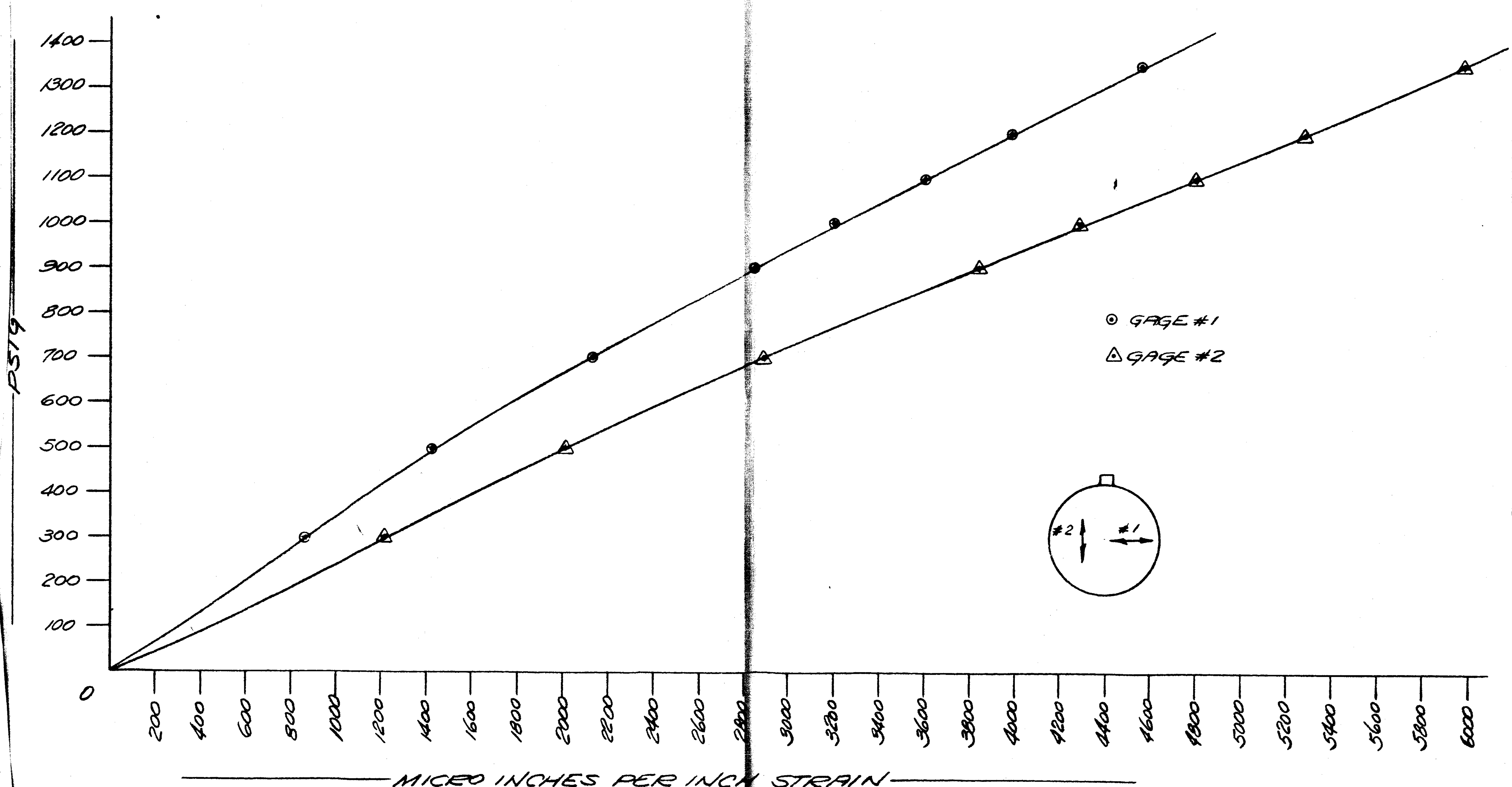


FIGURE 14A
1-26-65

S/N 556

25" SPHERE

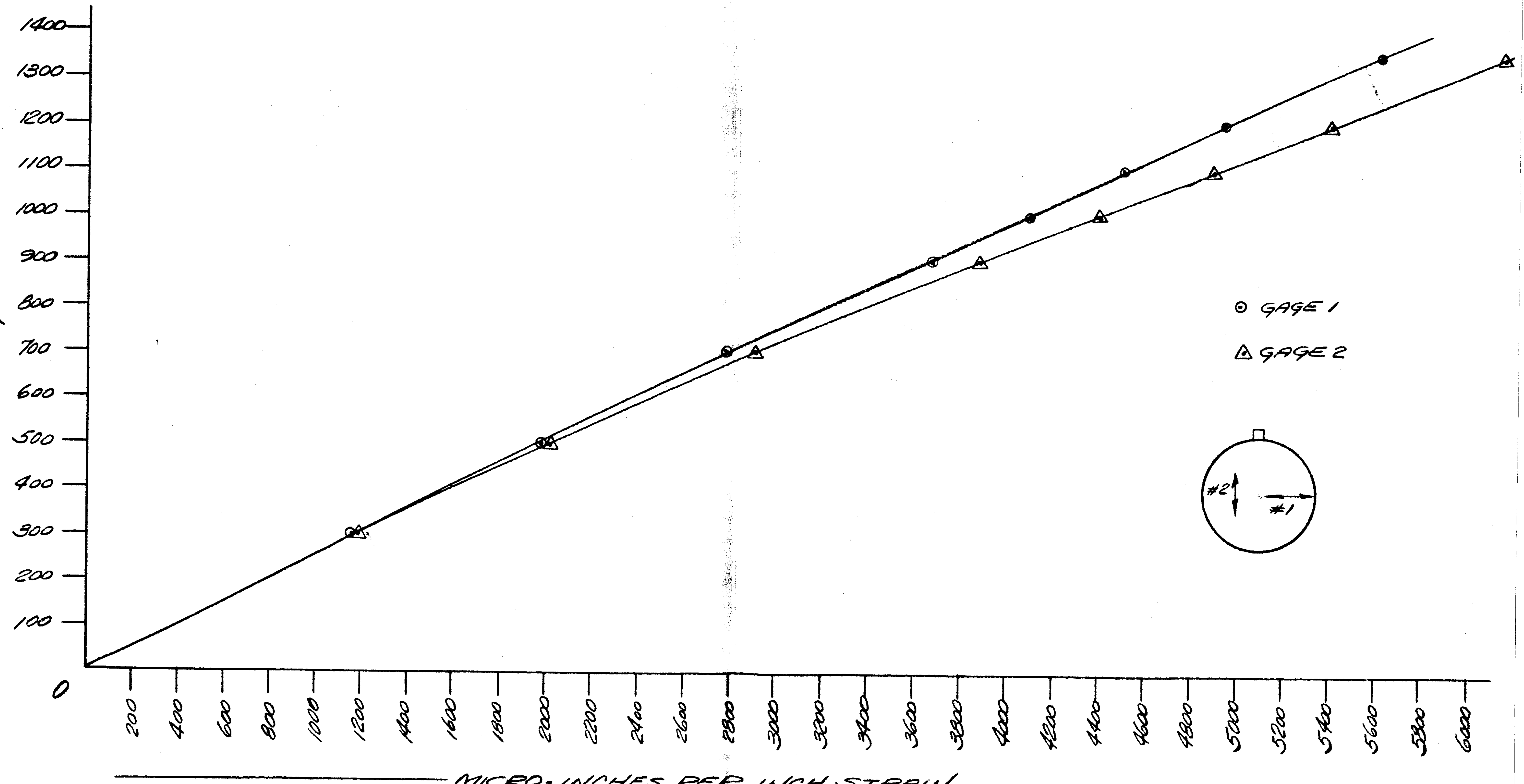


FIGURE 13A
1-26-65

S/N 555

25" SPHERE

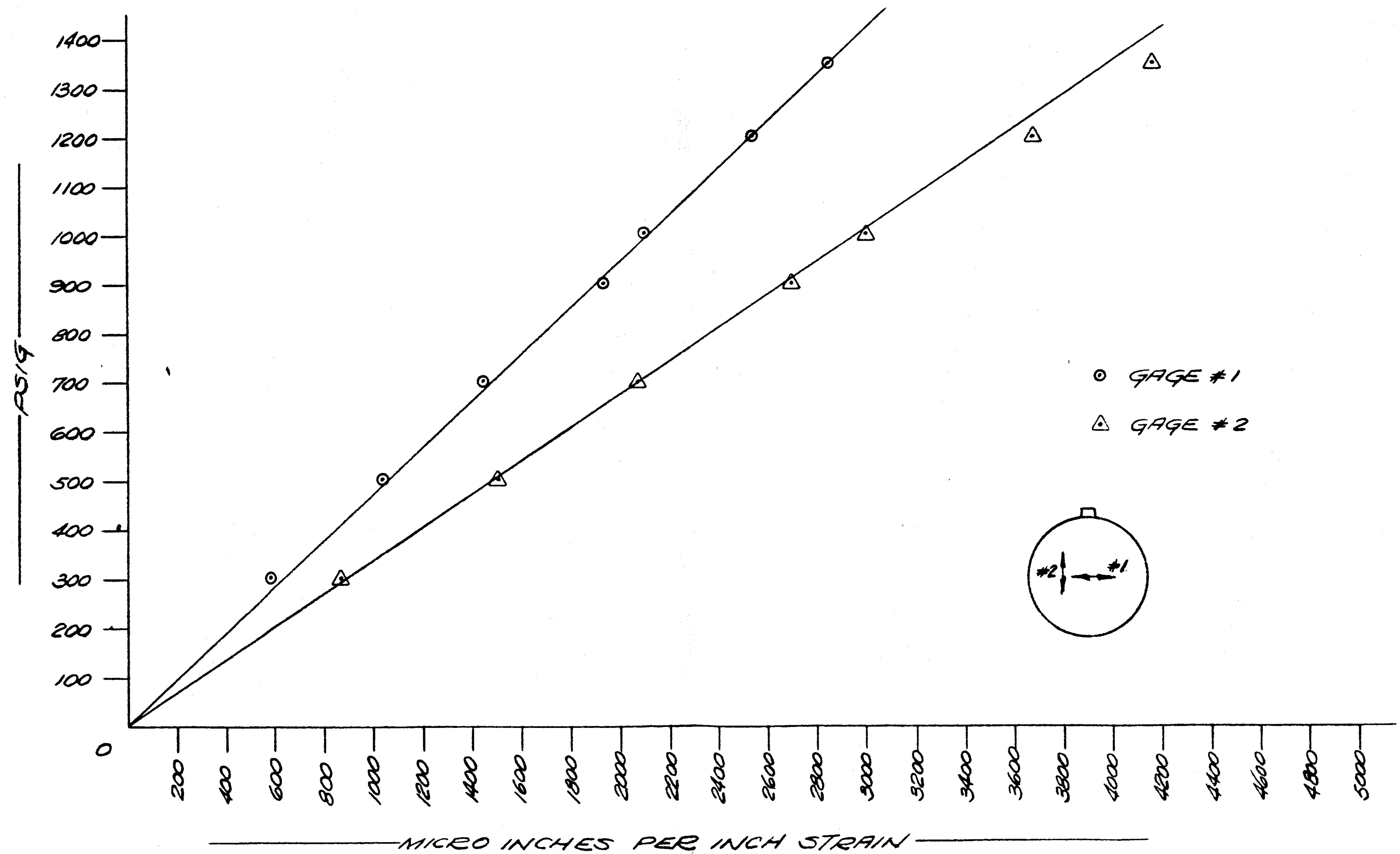


FIGURE 12A
1-18-65

S/N 554

25" SPHERE

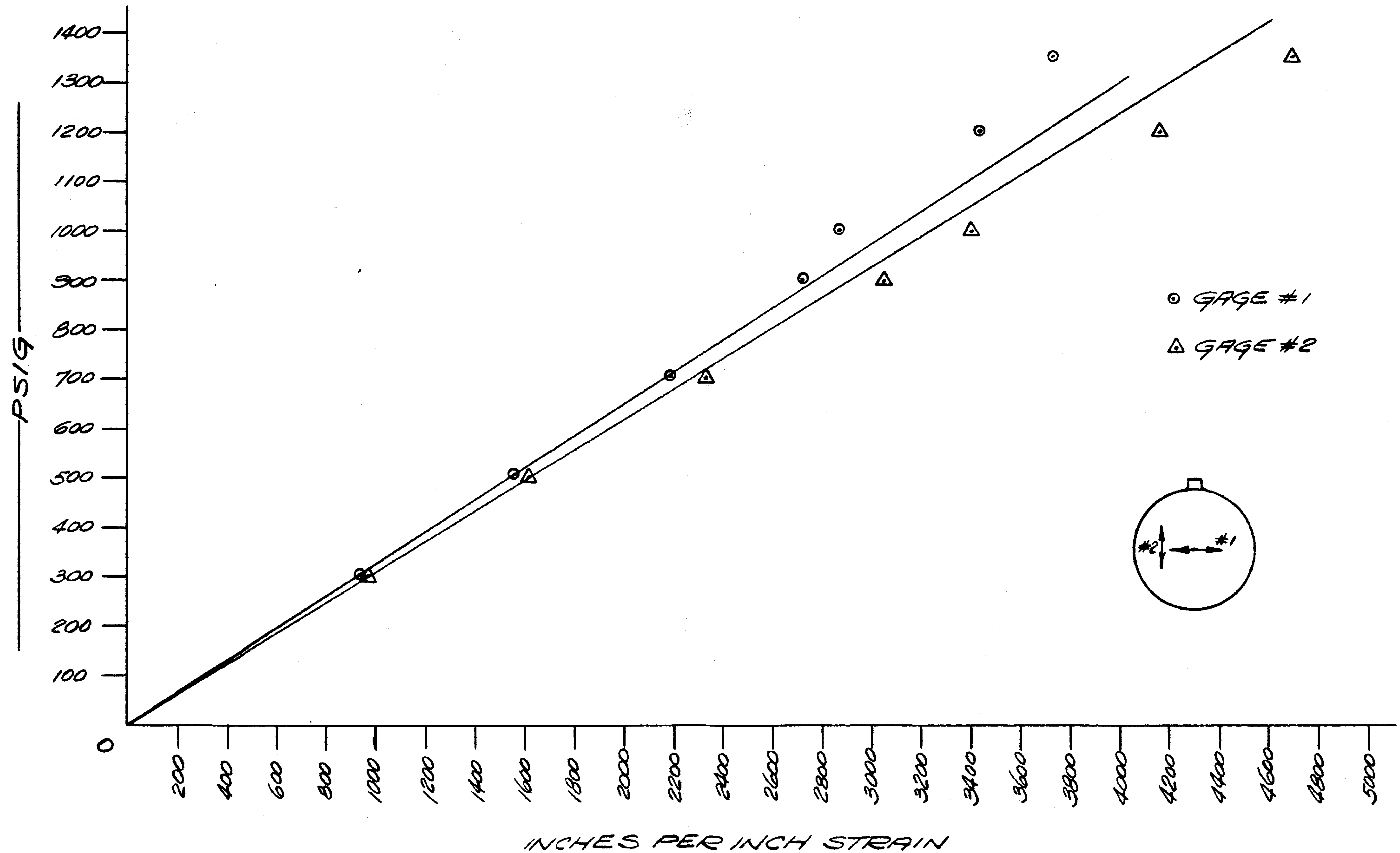


FIGURE 11A
1-18-65

S/N 550

25" SPHERE

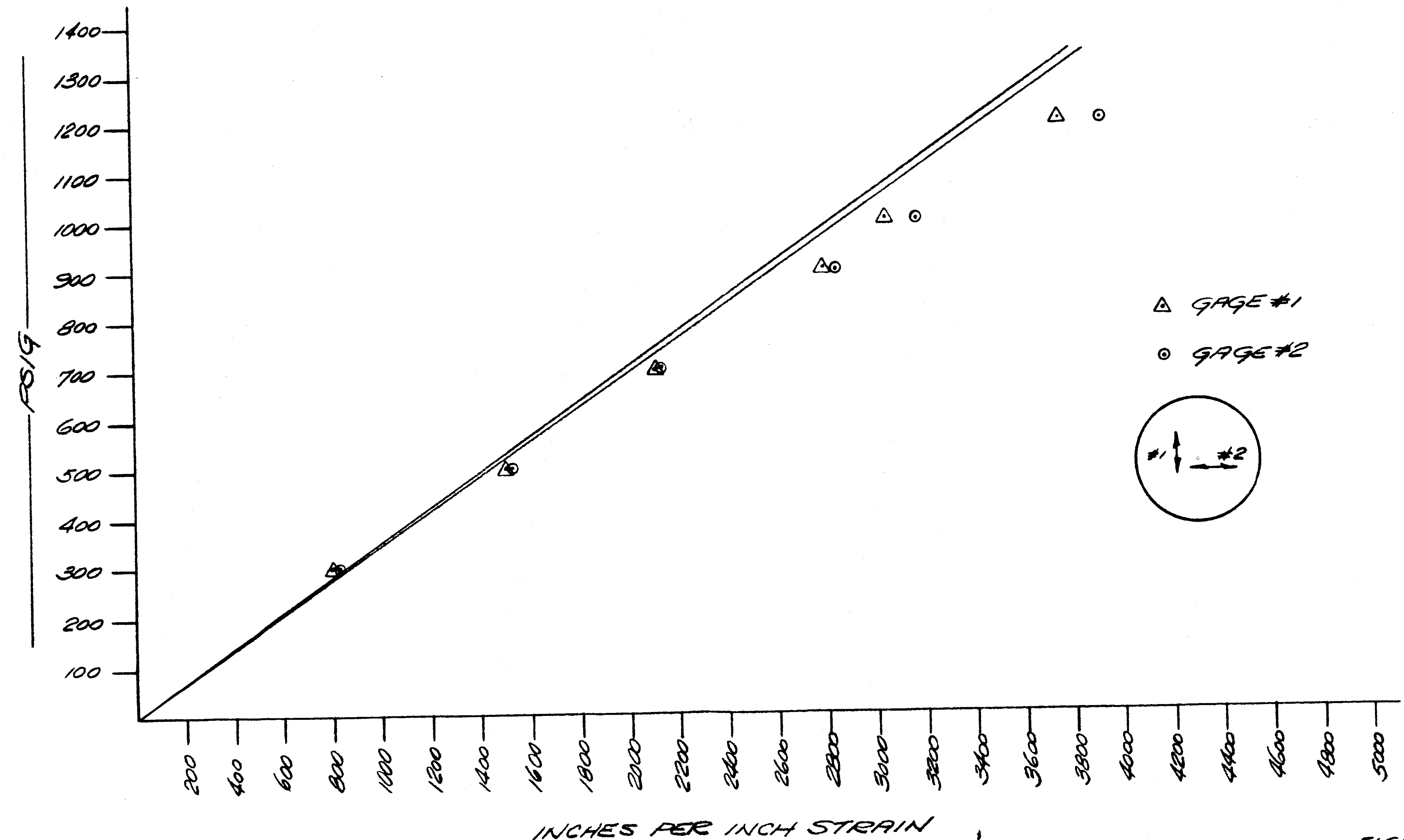
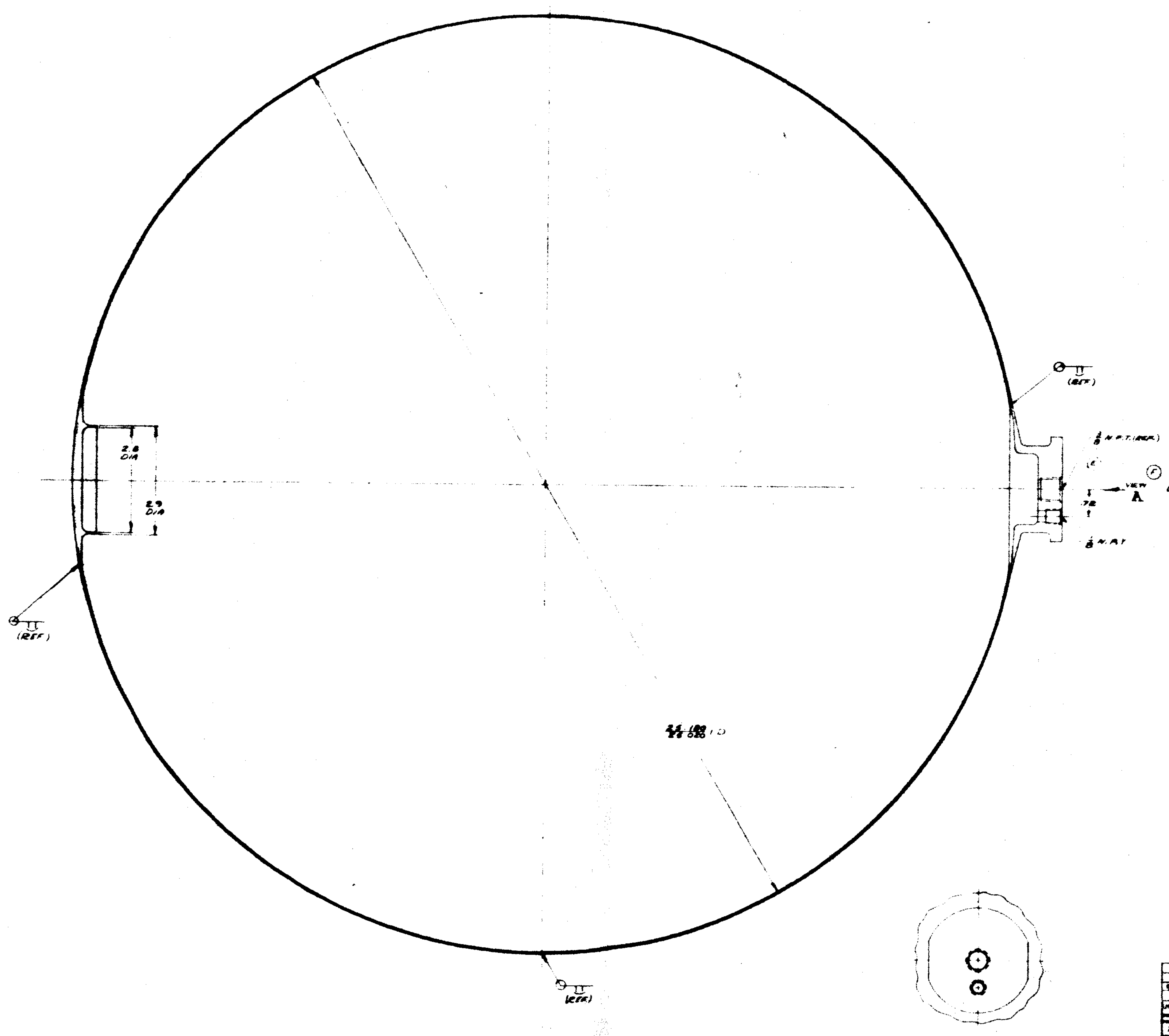


FIGURE 10A
11-6-64

I.O. NO.	SYM	ZONE	DESCRIPTION	DATE	APPROVED
1900			ORIGINAL RELEASE		
[illegible]	A		REVISED NOTES & BOSS	[illegible]	[illegible]
PO[illegible]	B		REVISED DWG. & NOTES	[illegible]	[illegible]
[illegible]	C		10 WAS 1/4 ZINC'D STEEL [illegible] 4 LBS TO NOTE 3 BOSS MAX. [illegible]	[illegible]	[illegible]
3644	D		REVISED NOTES	[illegible]	[illegible]
3644	E		[illegible] BOSS REMOVED [illegible] REMOVED. [illegible] REMOVED. NEW BOSS [illegible] .72 [illegible] ADDED	[illegible]	[illegible]
3644	F		ADDED VIEW A	[illegible]	[illegible]



NOTES:-

1— PROOF PRESSURE 1387 PSIG @ 70°F WITH NO SIGN OF PERMANENT DEFORMATION.

MINIMUM BURST PRESSURE 1808 PSIG @ 70°F

2— MAXIMUM WEIGHT INCLUDING BOSS 26.5 LBS

3 ARDEFORMED A.I.S.I. 301 ST STL AGED AT 790°F±10°F FOR 20 MIN.

4— IN ACCORDANCE WITH ARDE PORTLAND PROPOSAL NO. [illegible]

5— DESIGNED STRENGTH LEVELS
ULTIMATE 240,000 PSI @ ROOM TEMPERATURE
PROOF 208,000 PSI @ ROOM TEMPERATURE

6— INTERNAL VOLUME AT 70°F ±10°F SHALL NOT BE LESS THAN 8230 CU IN. OR MORE THAN 8330 CU IN. EXCLUDING BOSS VOLUME.

7— HYDROSTATICALLY TEST TO 1347±10 PSIG @ 70°F AND HOLD FOR THREE MINUTES AFTER STRETCHING AND AGING BUT BEFORE FINAL MACHINING OF BOSS

8 — AFTER FINAL MACHINING AND PRIOR TO SHIPMENT SPHERE SHALL BE CLEANED AND PASSIVATED IN ACCORDANCE WITH SPEC NO AP-C-1200 THEN PACKED AND SEALED IN A POLYETHYLENE BAG OR EQUAL.

VIEW A (F)

SKE 1428 F

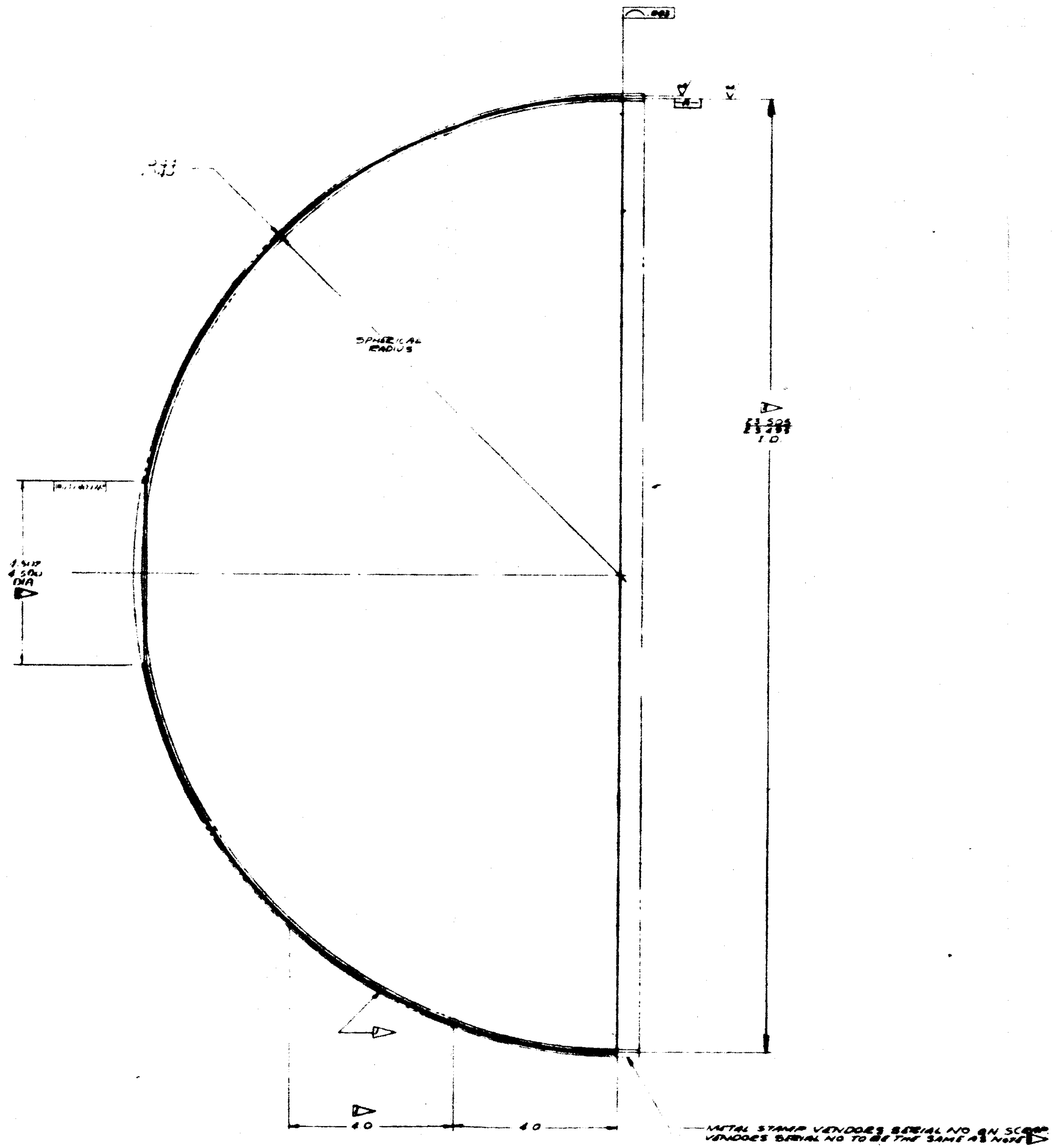
SKE 1428	25" NASA Container		
LIST OF MATERIAL OR PARTS LIST			

ARDE-PORTLAND, INC.

25" NASA SPHERICAL OXYGEN CONTAINER ARDEFORMED

12218 E SKE 1428

SCALE 1:1



NOTES:

1. MARK PART NO & CHANGE LETTER, VENDORS SERIAL & LOT NOS. APPROX. ⅛ HIGH LETTERS WITH PERMANENT INK IN AREA SHOWN.
2. DIAMETER TOLERANCE & CONCENTRICITY APPLIES WHEN ROUNDED IN FIXTURE.
3. ST STL AISI TYPE 301 HEAT NO E 78415.
4. PROCESSING AND QUALITY CONTROL FOR SPUN AND MACHINED PARTS PER TEMPORARY AEROFORM SPECIFICATION NO 0006.
6. GENERAL HANDLING REQUIREMENTS PER SPEC NO AP-C-1800.
7. VENDOR TO USE MAT'L PROVIDED BY AERO-PORTLAND ONLY.

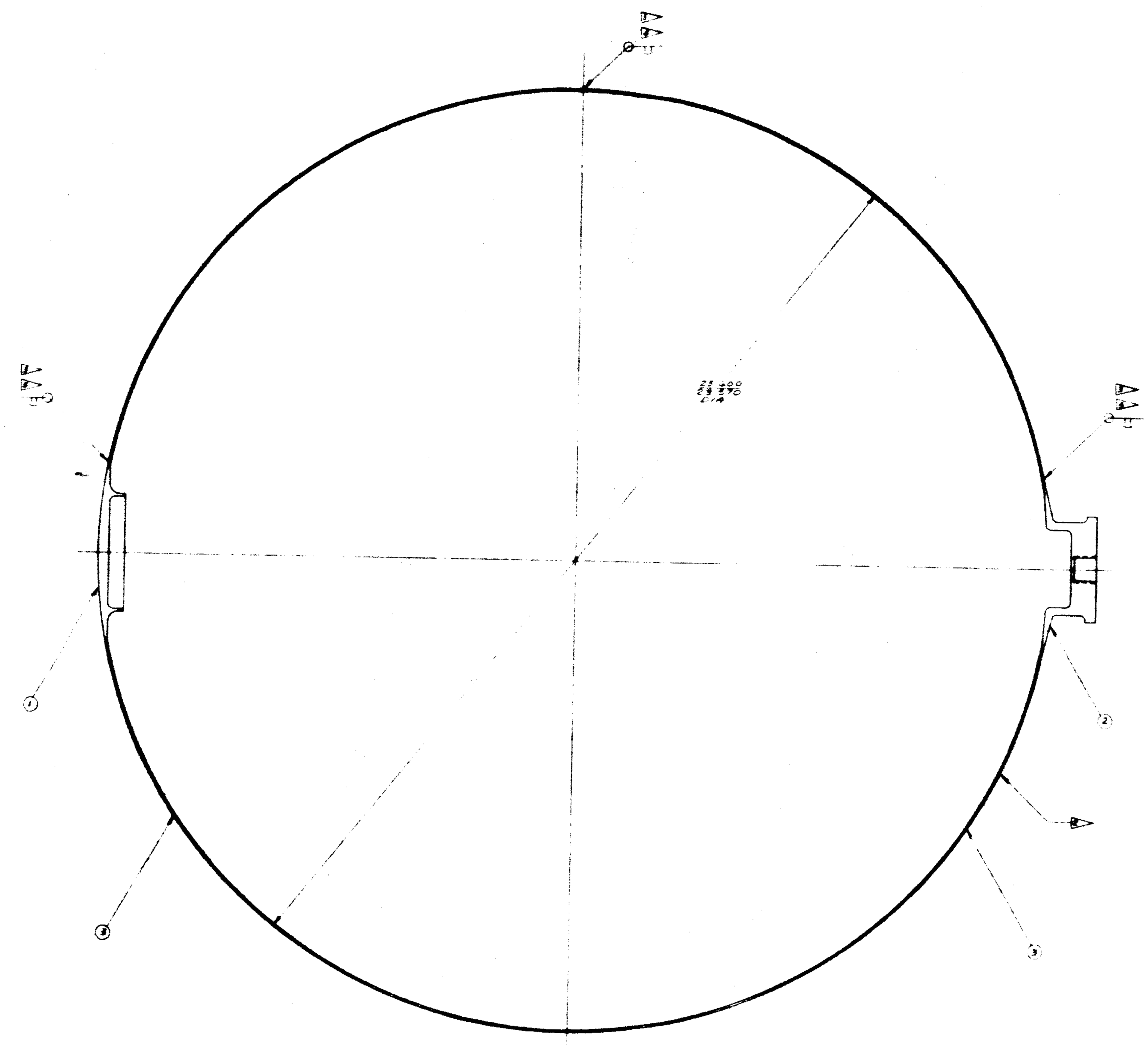
LIST OF MATERIAL OR PARTS LIST

AERO-PORTLAND, INC.

HEAD - HEMISPHERICAL WITH BOSS CUT OUT

12208 | E103741

ORIGINAL RELEASE



NOTES:

1 — GENERAL MARKING REQUIREMENTS PER SPEC NO AP-C-1800

2 MARK PART NO, CHANGE LETTER & SERIAL NO APPROX 1/8 HIGH LETTERS WITH PERMANENT INK

3 WELD PER SPEC NO AP-C 1000

4 MAXIMUM ALLOWABLE WELD MISMATCH .008

5 MAXIMUM ALLOWABLE WELD MISMATCH .004

QTY REQD PER DASH NO				ITEM NO	CODE IDENT	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL	SPECIFICATION
			2	4		E-0374			
				2		3756			
				1		C103755			
						88	25 NASA		

LIST OF MATERIAL OR PARTS LIST

UNLESS OTHERWISE SPECIFIED

NEXT ASSEMBLY: E1E 1228

DRAWN 4-5-64

CHECKED

STRESS ENGR

AERO THERMO

DES ENGR

PROJ ENGR

ARDE-PORTLAND, INC.

TITLE: 25 NASA SPHERICAL OXYGEN CONTAINER ASSEMBLY PREFORM

CODE IDENT NO 12218 | SIZE E | E3188

SCALE

SHEET