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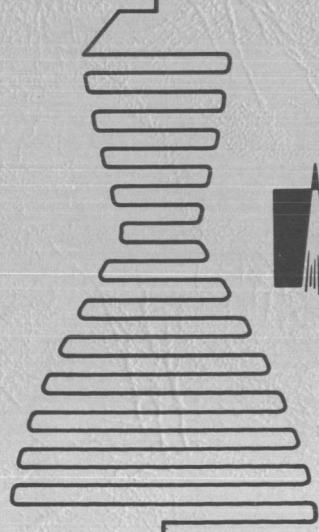
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Hard copy (HC) 300

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FACILITY FORM 602

N 68 26564
 (ACCESSION NUMBER) (THRU)

44
 (PAGES) (CODE)

01-67450
 (NASA CR OR TMX OR AD NUMBER) (CATEGORY)



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LAP 68-9 (RC)

FABRICATION TECHNIQUES FOR
SHROUDED TITANIUM IMPELLER

Second Quarterly Progress Report
For Period Ending 31 December 1967

CONTRACT NAS 8-20761

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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INTRODUCTION AND SUMMARY

During the second quarter, effort on fabrication techniques of a shrouded titanium impeller was directed toward completion of the detail design drawings for full size hardware fabrication. Major effort was also placed on fabrication and diffusion bonding of simulated impeller samples to determine, and then eliminate, possible problem areas that could arise in bonding of the full size impeller assembly.

Detail drawings for the impeller pre-bond assembly have been completed and cost quotations are being obtained. Three trial simulated impellers have been fabricated, the first and third of which have been bonded. Complete filling of the fillet areas did not occur on the first sample, which used 17-4 PH restrainer tooling material. In view of possible excessive restrainer growth on the first sample, new split ceramic restrainer tooling was fabricated and utilized in bonding of the third sample. Complete fillet formation again was not achieved, and therefore the sample will be recycled before core removal.

Fabrication of six test specimens and tooling has been completed to determine the optimum bonding temperature and pressure for titanium alloy (5 Al 2.5 Sn). One of these specimens has been placed through the bonding cycle. Estimated delivery date for titanium forgings to fabricate two complete assemblies is 15 January 1968. The cumulative expenditure to date is approximately 1761 hours and \$38,436.

IMPELLER DETAIL DESIGN AND
TECHNIQUE DEVELOPMENT

IMPELLER DESIGN

Detail drawings for the impeller pre-bond assembly have been completed and are shown in Fig. 1. This impeller will be capable of being tested in the Mark 29 liquid hydrogen pump with minor modifications. Major design parameters are: head rise - 46,100 ft, flowrate - 9754 gpm, speed - 29,800 rpm, blade discharge angle - 37 degrees, number of vanes - 7 full and 7 partial, discharge diameter - 12 inches. The front shroud, back shroud, vanes, and cores will be fabricated as matched assemblies to minimize required tolerances and thus reduce the amount of titanium that must be moved during the bonding cycle. An allowance of 0.040 inch has been added to all passage surfaces to permit removal, by chem-milling, of the interaction layer formed during the bonding process. Cost quotations are being obtained for fabricating two of the pre-bond assemblies shown in Fig. 1.

DIFFUSION BONDING TEST SAMPLES

Three simulated trial impellers have been fabricated, two of which have been bonded. Six specimens for determining the best bonding conditions have been fabricated, and one has been run through the bond cycle.

First Trial Impeller Sample

Figures 2 through 6 are a sequence of photographs showing the sample in various stages of assembly before bonding. Figure 2 shows the simulated impeller front and back shrouds, and vanes. In reference to Fig. 2, the front shroud is represented by the cylindrical ring and the back shroud by the contoured hub. Figure 3 shows the impeller assembly with lower pressure plate, outer shroud, vanes, and cores. The cores are 4340 steel filler material shown between the vanes. Edges of the cores have been rounded to permit formation of vane to shroud fillets while bonding. In reference to Fig. 3, the back shroud has been omitted to show the fillet areas at the edge of the cores that must be filled during the bonding process. Figure 4b shows the cores, upper and lower pressure plates, and outer restraining tooling. Figure 5b shows the impeller and tooling assembly prior to installation in the retort. Fig. 6 shows the completed assembly in the retort ready for the bonding cycle.

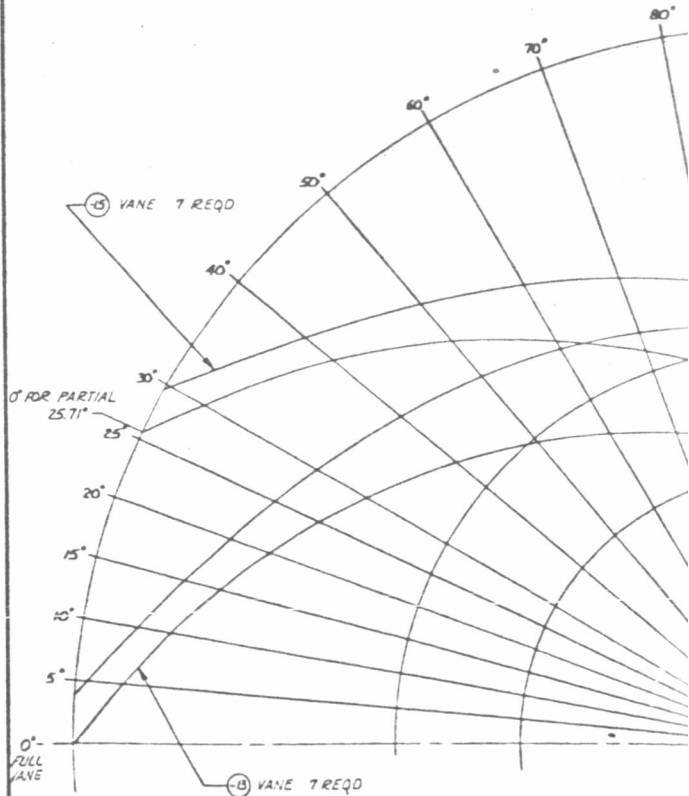
THE AIR FORCE ENGINEERING ESTABLISHMENT
 REPORT NO. 8221A-PP

-3 SHAFT 7-9, -13 & -15		-5 SHROUD 7-9, -13 & -15	
X	Y	X	Y
6.0400		4.150	6.0400
5.6375		4.250	5.9300
5.2900		4.525	5.5775
4.9725		4.975	5.2675
4.6585		5.425	5.0125
.0225	4.3825	.5875	4.7325
.0650	4.1175	.6375	4.5900
.2125	3.6650	.7525	4.2775
.4325	3.2925	.8975	4.0250
.6775	3.0100	1.0525	3.8325
.9450	2.7800	1.2375	3.6725
1.2000	2.6200	1.4775	3.5575
1.4400	2.5025	1.6025	3.4725
1.6625	2.4200	1.7875	3.4125
1.8750	2.3625	1.9725	3.3725
2.0675	2.3250	2.1425	3.3550
2.2475	2.3025	2.3175	3.3475
2.4175	2.2925	2.4825	3.3450
4.1500	2.2925	3.3150	3.3450

COORDINATES FOR -3 SHAFT,
 -5 FRONT SHROUD, -7 & -9
 CORES & -13 & -15 VANES
 MERIDIONAL PROFILE.
 VALUES SHOWN ARE BASIC

θ	PRESSURE SURFACE COORDINATES FOR -7				
	X	Y	X	Y	X
5°	X	0.850	2.100		
	Y	5.8825	5.9620		
10°	X	0.850	2.100	3.350	
	Y	5.5350	5.6000	5.6650	
15°	X	0.850	2.100	3.350	4.600
	Y	5.2225	5.2900	5.3575	5.4250
20°	X	0.850	2.100	3.350	4.600
	Y	4.9325	5.0025	5.0725	5.1425
25°	X	0.850	2.100	3.350	4.600
	Y	4.6475	4.7250	4.8025	4.8820
30°	X	0.850	2.100	3.350	4.600
	Y	4.3750	4.4650	4.5550	4.6450
40°	X	2.100	3.350	4.600	5.850
	Y	3.9425	4.0675	4.1925	4.3175
50°	X	3.350	4.600	5.850	7.100
	Y	3.5225	3.6775	3.8425	4.0075
60°	X	5.850	6.250	6.950	7.650
	Y	3.2500	3.3750	3.5000	3.6250
70°	X	7.875	8.413	8.950	9.488
	Y	3.0000	3.1250	3.2500	3.3750
80°	X	10.225	11.0625	11.945	11.865
	Y	2.7500	2.8750	3.0000	3.1250
90°	X	12.650	13.2954	13.257	13.561
	Y	2.6250	2.7500	2.8750	3.0000
100°	X	15.000	15.228	15.457	15.685
	Y	2.5000	2.6250	2.7500	2.8750
110°	X	17.600	17.782	17.964	18.46
	Y	2.5000	2.6250	2.7500	2.8750
120°	X	19.125	19.253	19.382	19.510
	Y	2.3750	2.5000	2.6250	2.7500
130°	X	2.1025	2.1139	2.1254	2.1368
	Y	2.3750	2.5000	2.6250	2.7500
140°	X	2.3350	2.3428	2.3507	2.3585
	Y	2.3750	2.5000	2.6250	2.7500

VALUES SHOWN ARE BASIC



PLAN VIEW SHOWN
SCALE:

11

10

CORE # -13 VANE

0.50	
1.50	
2.50	1.100
3.50	3.750
4.50	2.85
5.50	3.500
6.50	1.472
7.50	3.350
8.50	1.620
9.50	3.250
10.50	1.8375
11.50	3.375
12.50	2.0025
13.50	3.250
14.50	2.825
15.50	3.250
16.50	2.332
17.50	3.250

θ SUCTION SURFACE COORDINATES FOR -9 CORE # -13 VANE

θ	X	Y	X	Y	X	Y	X	Y
5°	0.850	2.100	3.350					
10°	0.850	2.100	3.350	4.600				
15°	0.850	2.100	3.350	4.600				
20°	0.850	2.100	3.350	4.600				
25°	0.850	2.100	3.350	4.600	5.850			
30°	0.850	2.100	3.350	4.600	5.850			
40°	0.850	2.100	3.350	4.600	5.850			
50°	0.850	2.100	3.350	4.600	5.850			
60°	0.850	2.100	3.350	4.600	5.850			
70°	0.850	2.100	3.350	4.600	5.850			
80°	0.850	2.100	3.350	4.600	5.850			
90°	0.850	2.100	3.350	4.600	5.850			
100°	0.850	2.100	3.350	4.600	5.850			
110°	0.850	2.100	3.350	4.600	5.850			
120°	0.850	2.100	3.350	4.600	5.850			
130°	0.850	2.100	3.350	4.600	5.850			
140°	0.850	2.100	3.350	4.600	5.850			

VALUES SHOWN ARE BASIC

θ PRESSURE SURFACE COORDINATES FOR -9 CORE # -13 VANE

θ	X	Y	X	Y	X	Y	X	Y
5°	0.850	2.100	3.350					
10°	0.850	2.100	3.350	4.600				
15°	0.850	2.100	3.350	4.600				
20°	0.850	2.100	3.350	4.600				
25°	0.850	2.100	3.350	4.600	5.850			
30°	0.850	2.100	3.350	4.600	5.850			
40°	0.850	2.100	3.350	4.600	5.850			
50°	0.850	2.100	3.350	4.600	5.850			
60°	0.850	2.100	3.350	4.600	5.850			
70°	0.850	2.100	3.350	4.600	5.850			
80°	0.850	2.100	3.350	4.600	5.850			
90°	0.850	2.100	3.350	4.600	5.850			
100°	0.850	2.100	3.350	4.600	5.850			
110°	0.850	2.100	3.350	4.600	5.850			
120°	0.850	2.100	3.350	4.600	5.850			
130°	0.850	2.100	3.350	4.600	5.850			
140°	0.850	2.100	3.350	4.600	5.850			

VALUES SHOWN ARE BASIC

θ SUCTION SURFACE

θ	X	Y	X	Y	X	Y	X	Y
5°	0.850	2.100						
10°	0.850	2.100						
15°	0.850	2.100						
20°	0.850	2.100						
25°	0.850	2.100						
30°	0.850	2.100						
40°	0.850	2.100						
50°	0.850	2.100						
60°	0.850	2.100						
70°	0.850	2.100						
80°	0.850	2.100						
90°	0.850	2.100						
100°	0.850	2.100						
110°	0.850	2.100						
120°	0.850	2.100						
130°	0.850	2.100						
140°	0.850	2.100						

VALUES SHOWN ARE BASIC

PARTIAL -7E-9

FOLD

θ

90°

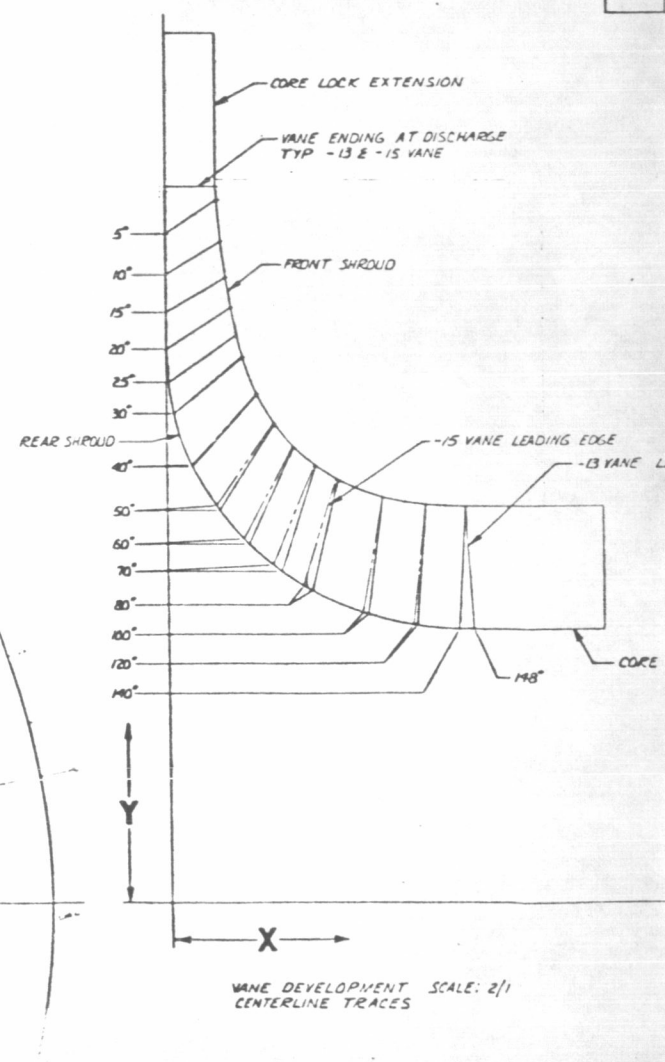
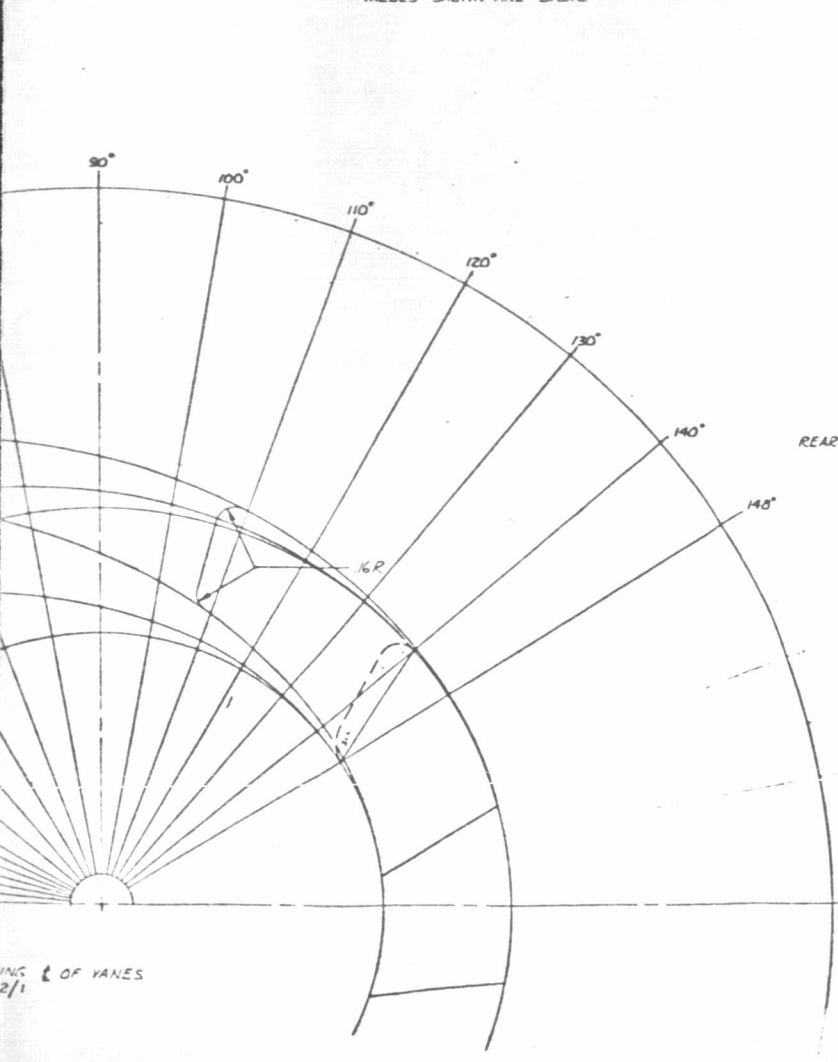
100°

110°

120°

130°

140°



11

10

9

8

COORDINATES FOR -7 CORE & -15 VANE

3350				
57975				
3350	4600			
53650	54525			
3350	4600			
50225	51075			
3350	4600			
47100	47975			
3350	4600	5850		
44100	45125	46150		
4500	5850			
42300	43500			
5850	7100			
38350	39950			
7290	8035	8780	9525	
35000	36250	37500	38750	
9230	9795	10360	10925	
32500	33750	35000	36250	
17385	17865	18345	18825	
31250	32500	33750	35000	
12325	13200	13575	13950	14325
30000	31250	32500	33750	35000

SHOWN ARE BASIC

CUTTING PLANE INTERSECTS BETWEEN CORES FROM -15 VANE LEADING EDGE

T SHROUD		REAR SHROUD	
X	Y	Θ	R
14450	35650	80°(REF)	11625
16400	34775	90°	14225
18275	34150	100°	16500
20125	33725	110°	18775
21825	33575	120°	20800
23550	33475	130°	22750
25200	33475	140°	24550
		148°	25925

VALUES SHOWN ARE BASIC

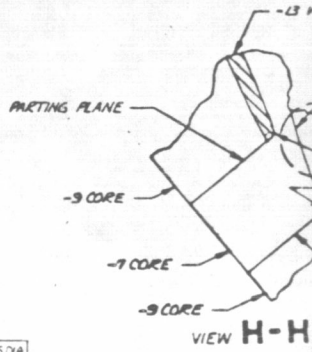
LEADING EDGE

DOC EXTENSION

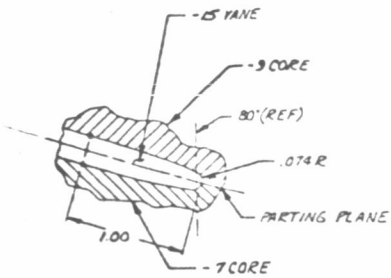
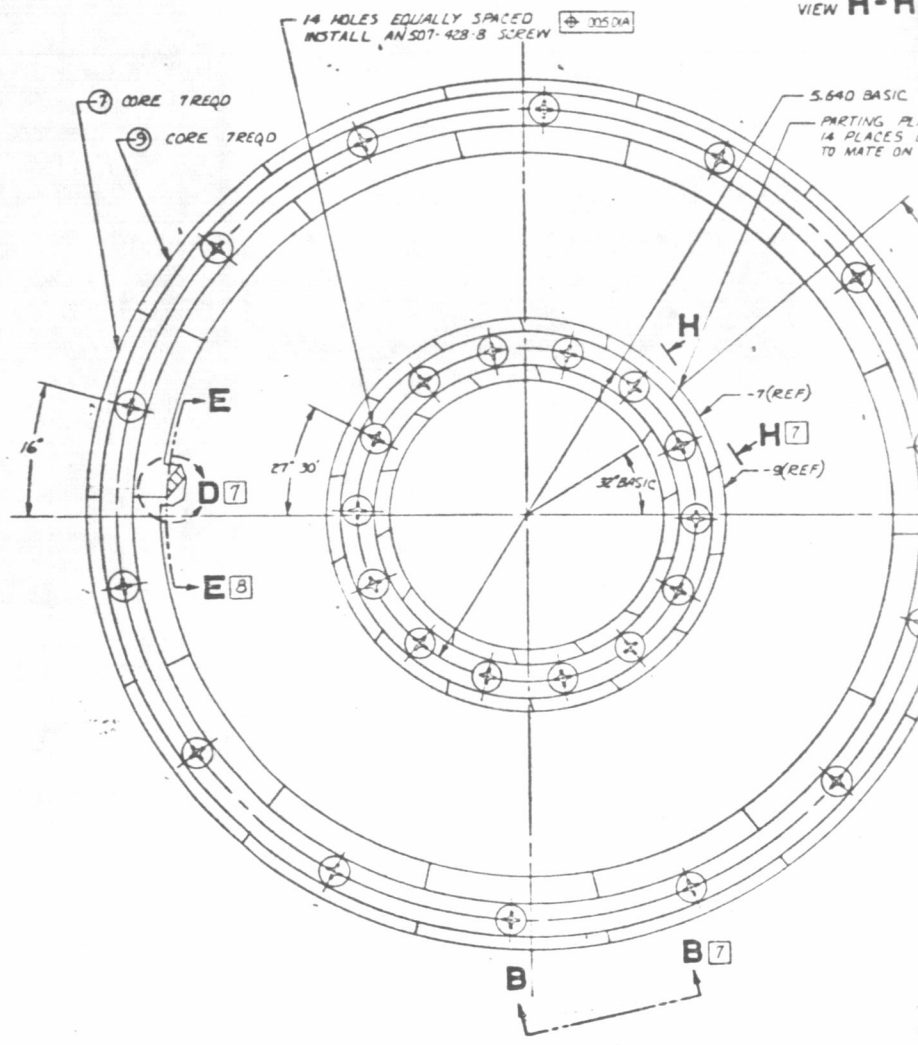


0.15 R TYP -7 & -9 CORES

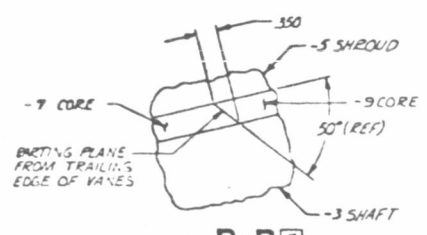
VIEW E-E [8] SCALE: 2/1



VIEW H-H



SECTION C-C [1] SCALE: 2/1
TYP LEADING EDGE -15 VANE
VANE TO FAIR SMOOTHLY FROM LEADING EDGE RADIUS OVER TRUE LENGTH SHOWN



VIEW B-B [7] 14 PLACES EQUALLY SPACED

ISERTONE
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BROOKLYN, CALIFORNIA - BOSTON, MASS.

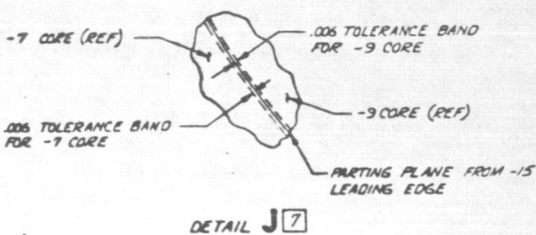
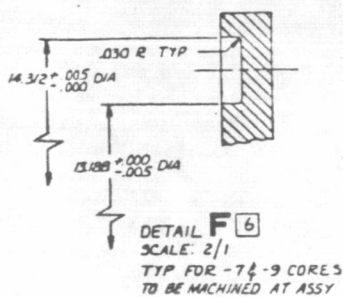
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9

8

WE

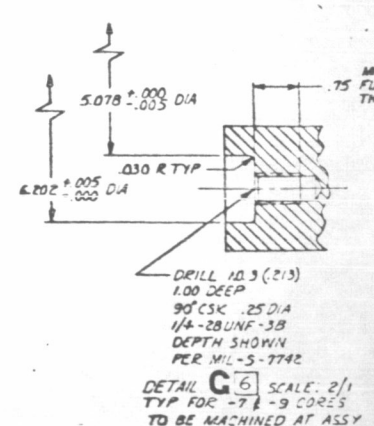
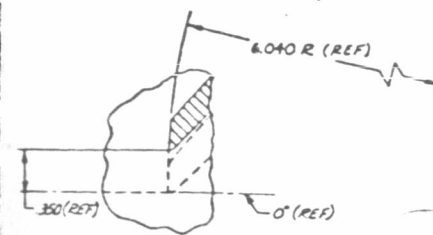
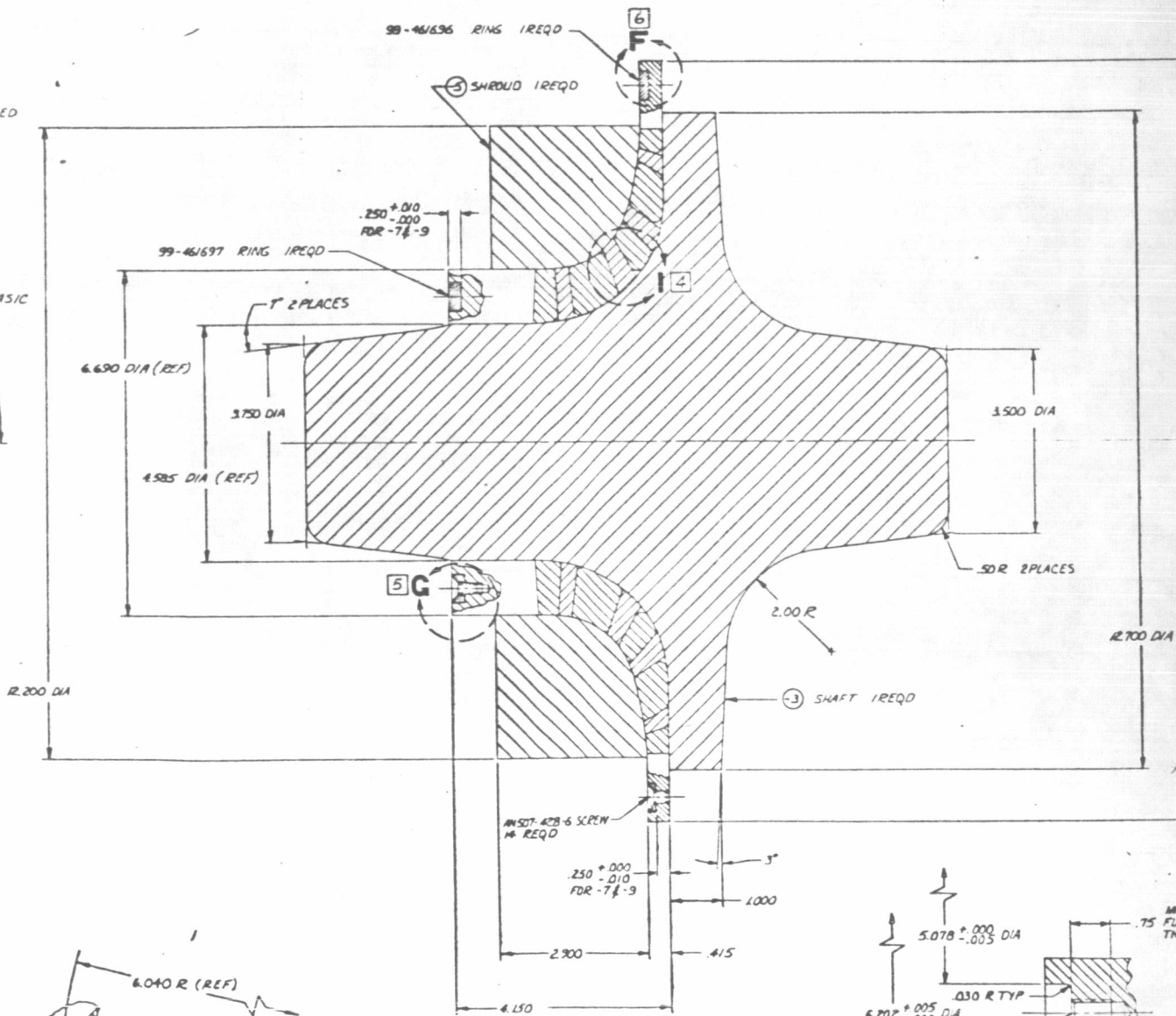
PARTING PLANE FROM
 -15 LEADING EDGE
J 5
 .078 R FOR -7 CORE
 .103 R FOR -7 CORE
 .078 R FOR -9 CORE
 PARTING PLANE



J 7 TYP

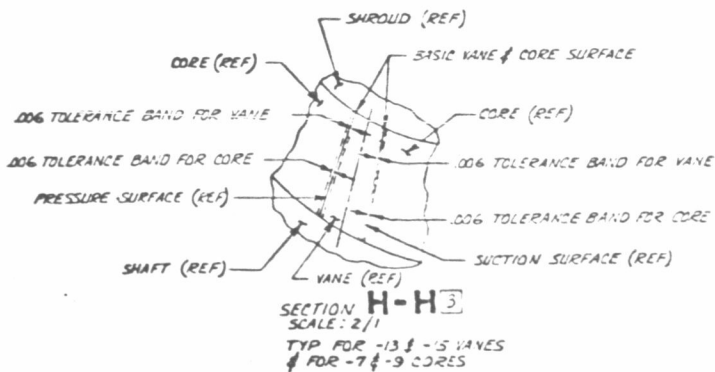
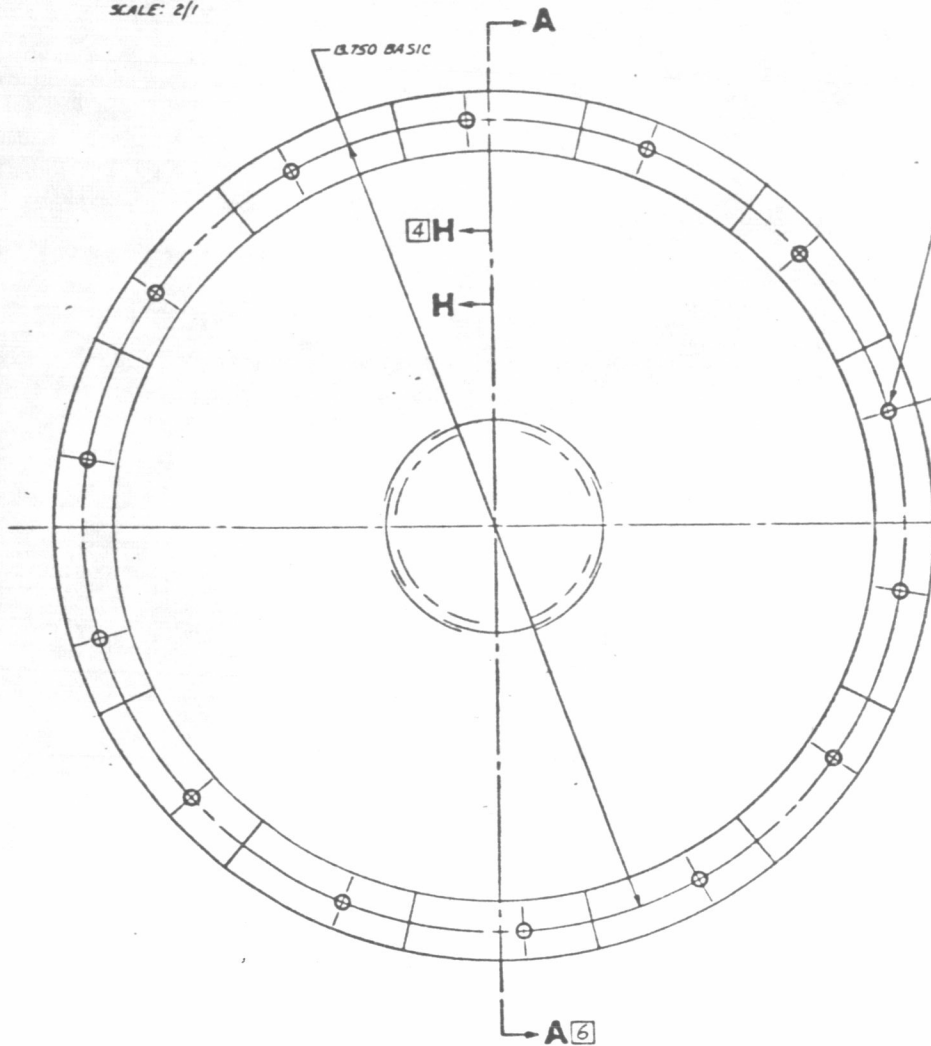
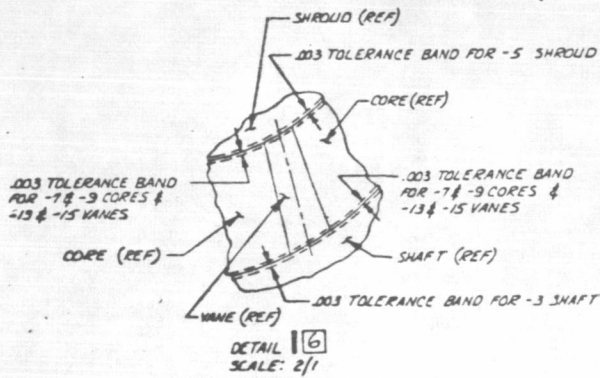
NE
EQUALLY SPACED
ASSY

40° BASIC



SECTION A-A 3

SECRETARY
 & DIVISION
 CODE E



Ø.700 DIA

ZONE	LTR	REVISIONS		DATE	APPROVED
		REV. NO.	DESCRIPTION		
		1. REF. BE REWORKED	3. WELDING CHANGE		
		2. DIMENT. BE REWORKED	4. NEW SHOP PRACTICE		
		5. PARTS MADE ON			

DRILL NO. 3 (.213) THRU
 90° CSK .25 DIA BOTH SIDES
 1/4" - 28 UNF - 38 THRU
 PER MIL-S-7742
 14 PLACES EQUALLY SPACED
 ⊕ .005 DIA
 TO BE MACHINED AT ASSY

(REF)

PARTING PLANE
 14 PLACES EQUALLY SPACED
 TO MATE ON ASSY

- 6 IDENTIFY PER RA0104-008
- 5 VANE TO SHAFT RADIUS ON -7 & -9 CORES WITH RESPECT TO -13 & -15 VANES SHALL BE .015 AT VANE DISCHARGE INCREASING AT A CONSTANT RATE TO .140 AT 3.850 R. RADIUS IS A CONSTANT 1/40 FROM 3.850 R TO 3.250 R & TAPERES TO .036 AT LEADING EDGE
- 4 VANE TO SHROUD RADIUS ON -7 & -9 CORES WITH RESPECT TO -13 & -15 VANES SHALL BE .015 AT VANE DISCHARGE INCREASING AT A CONSTANT RATE TO .075 AT 4.500 R. RADIUS IS A CONSTANT .075 FROM 4.500 R TO 4.070 R & TAPERES TO .040 AT LEADING EDGE MACHINE PER RA0103-002
- 3 ONE FORGING ① WHEN MACHINED VANES 7 EACH -13 & -15
- ② HAND FORGING 14.00 ± .50 DIA X 4.25 ± .25

NOTE: UNLESS OTHERWISE SPECIFIED

HEAT TREAT	NONE
FINISH	
MARK	NOTED

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND APPLY PRIOR TO FINISH	
1/2" BACK SURF ROUGHNESS	
TOLERANCES ON ANGLES ± 1° IF NOTED	
HOLEX NOTED "DRILL"	
Ø	TOLERANCE
8000 .000	+ .0015 - .00
2000 .100	+ .0020 - .00
1000 .200	+ .0025 - .00
5000 .500	+ .0030 - .00
2000 .700	+ .0035 - .00
1000 1.000	+ .0040 - .00
1000 2.000	+ .0045 - .00
DO NOT SCALE PRINT	

-15	Ti-SAL-2.55w	(1)(3)	RB0170-079
-13	Ti-SAL-2.55w	(1)(3)	RB0170-079
-9	H/H TOOL STEEL	15.00 DIA X 4.50	CONV. GRADE
-7	H/H TOOL STEEL	15.00 DIA X 4.50	CONV. GRADE
-5	Ti-SAL-2.55w	(1)	RB0170-079
-3	MAKE FROM XEGR 9355-1		
NO	MATERIAL	SIZE	SPECIFICATION

ROCKETDYNE
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 CANOGA PARK, CALIFORNIA • McCREER, TEXAS

IMPPELLER PRE-BOND ASSEMBLY - DIFFUSION BONDED

SALE CODE DEPT NO: J 02602 99-461698

SCALE 1/1 SHEET 1 OF 1

99-461698

Figure 1. Impeller Pre-Bond Assembly

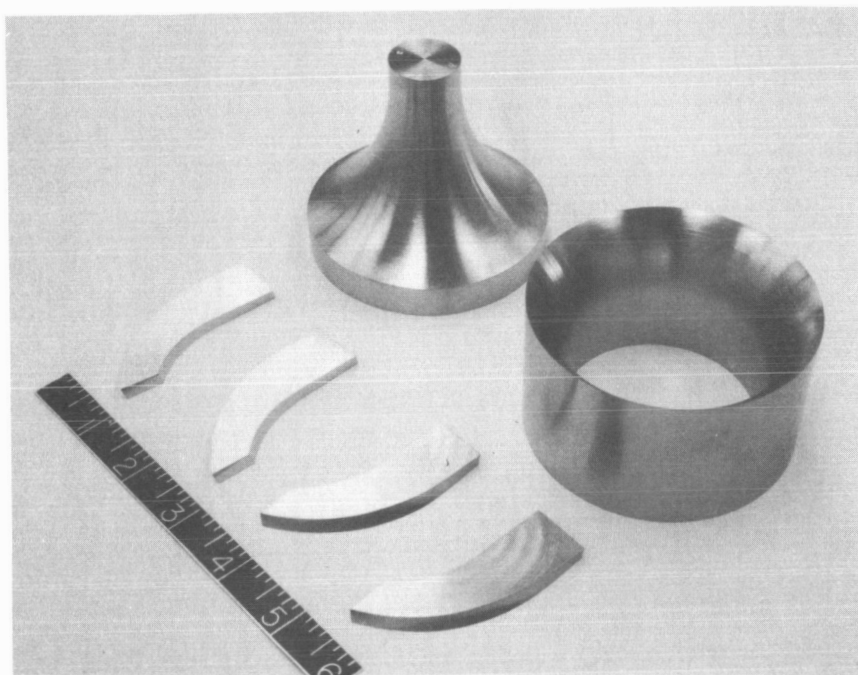


Figure 2a



Figure 2b

Figure 2a & 2b. Simulated Impeller - Trial Sample

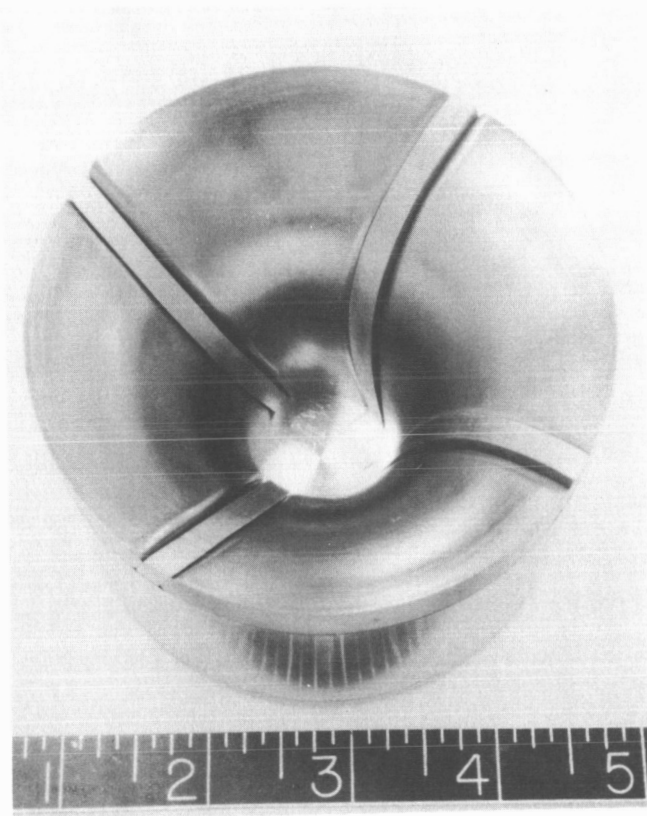


Fig. 3a

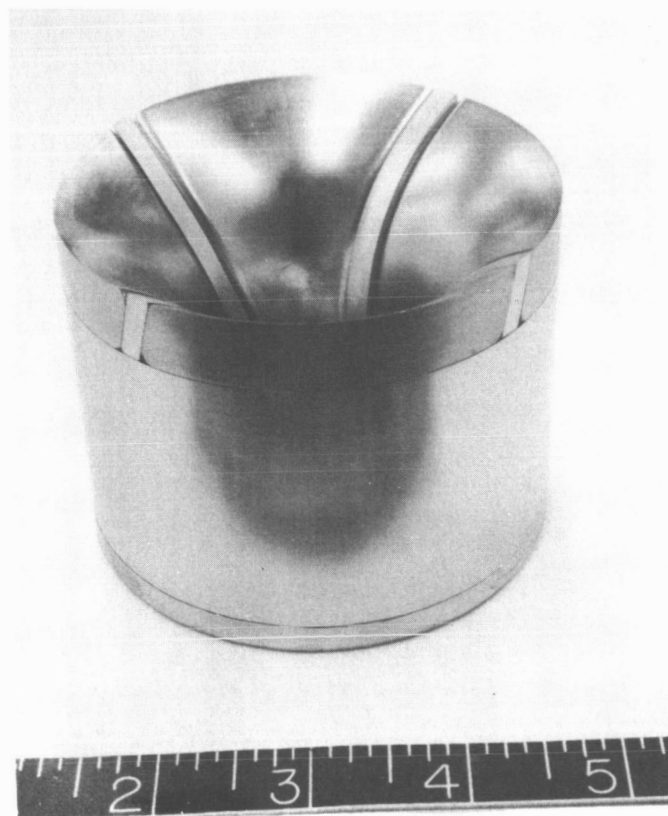


Fig. 3b

Figure 3a & 3b. Simulated Impeller - Assembly with Cores and Lower Pressure Plate (Without Back Shroud)

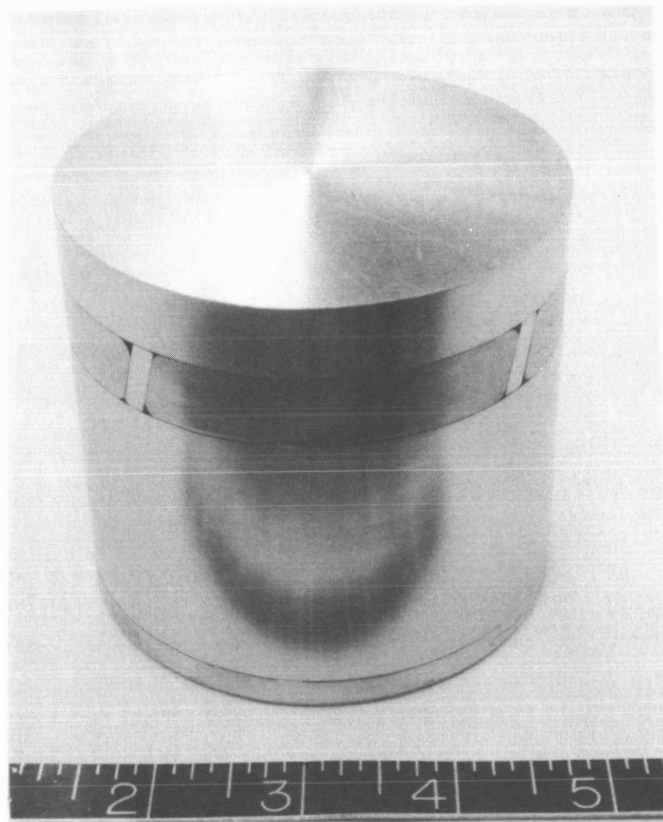


Fig. 4a. Assembly with Back Shroud and Lower Pressure Plate, and Cores

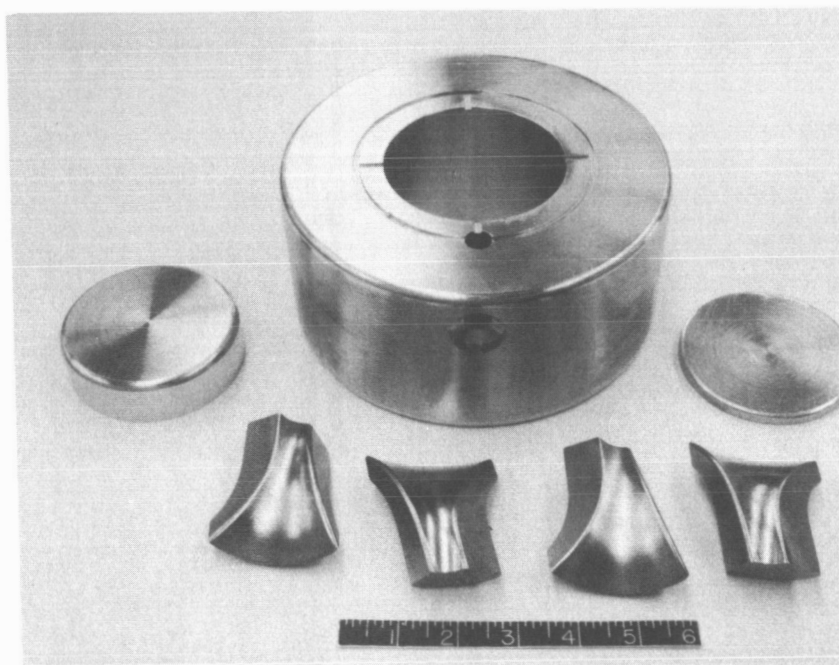


Fig. 4b. Cores, Pressure Plates, and Outer Containment Tooling

Figure 4. Simulated Impeller Assemblies

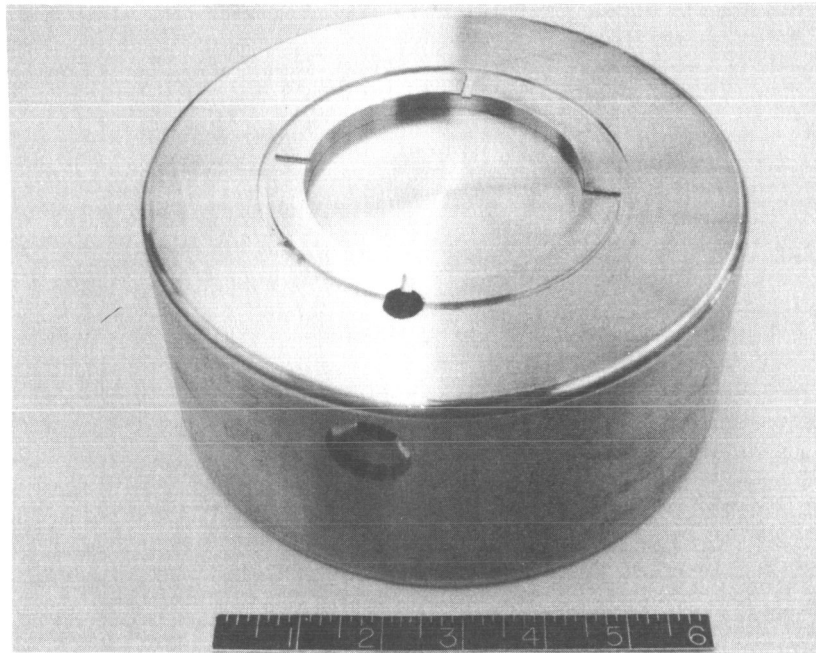


Fig. 5a Assembly Without Upper Pressure Plate

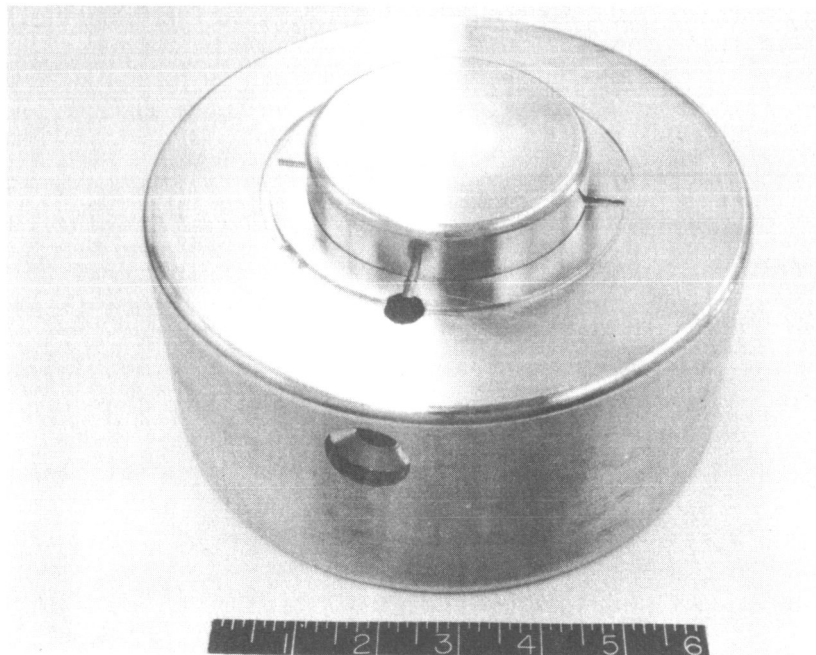


Fig. 5b Assembly With Upper Pressure Plate

Figure 5. Simulated Impeller Assembly



Figure 6. Complete Simulated Impeller Assembly
Ready for Bonding

The first sample was bonded at a temperature of 1750 deg F for a period of 16 hours. Pressure on the pressure plate was varied from 2000 to 4000 psi during the 16 hours. Time at 4000 psi was a minimum of 3 hours. Figures 7 and 8 show the sample after removal from the retort and restrainer tooling. A force of 280,000 pounds was required to remove the sample from the restrainer tooling, due to bonding of 4340 steel cores to the 17-4 PH outer restrainer. As can be seen from the photographs, this caused a slight separation of the tooling and rear shroud. Detail inspection indicated the interaction layer between the cores and impeller to be less than 0.010 inch thick. It was also noted that complete forming of the fillets at the impeller discharge did not occur at all joints. Figures 9, 10, and 11 are different views of the impeller subsequent to a light machine cut for surface clean up. Figures 12(a) and 12(b) show the sample after leaching of the cores and initial chem-milling to remove the interaction layer. As can be seen from Fig. 12(a), a complete formation of the fillets did not occur on the vanes in the impeller passages. Investigation indicates that this may be attributed to growth and yielding of the outer restrainer tooling and/or incorrect length of time and pressure at the bonding temperature. Examination of the fillet area at the impeller eye under a magnification of 250 (see Fig. 13) indicated that a slight notch of 0.004 inch existed after initial chem-milling. Lines existing on Fig. 13 are scratches on the specimen. Additional chem-milling was performed on the part to remove a total of 0.020 inch of material and thus eliminate the notched area. Figure 14(a) and 14(b) show the inner and outer fillet at the impeller eye at a magnification of 40 after total material removal of 0.020 inch on each surface.

Figure 15(a) and 15(b) show the grain structure of the titanium material before and after bonding at a magnification of 250X. As can be seen, grain growth occurred during the bonding process.

Figures 16 through 18 are photographs of the first sample impeller after final chem-milling. Originally it was planned to remove a total of 0.040 inch of material per surface by chem-milling and to section the part for

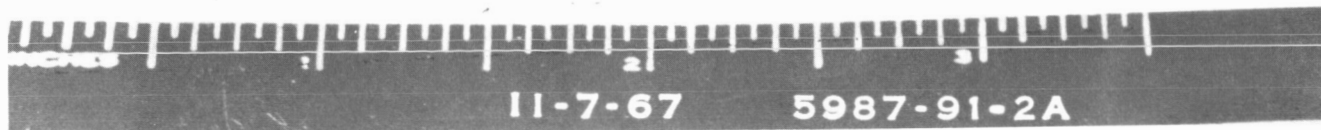
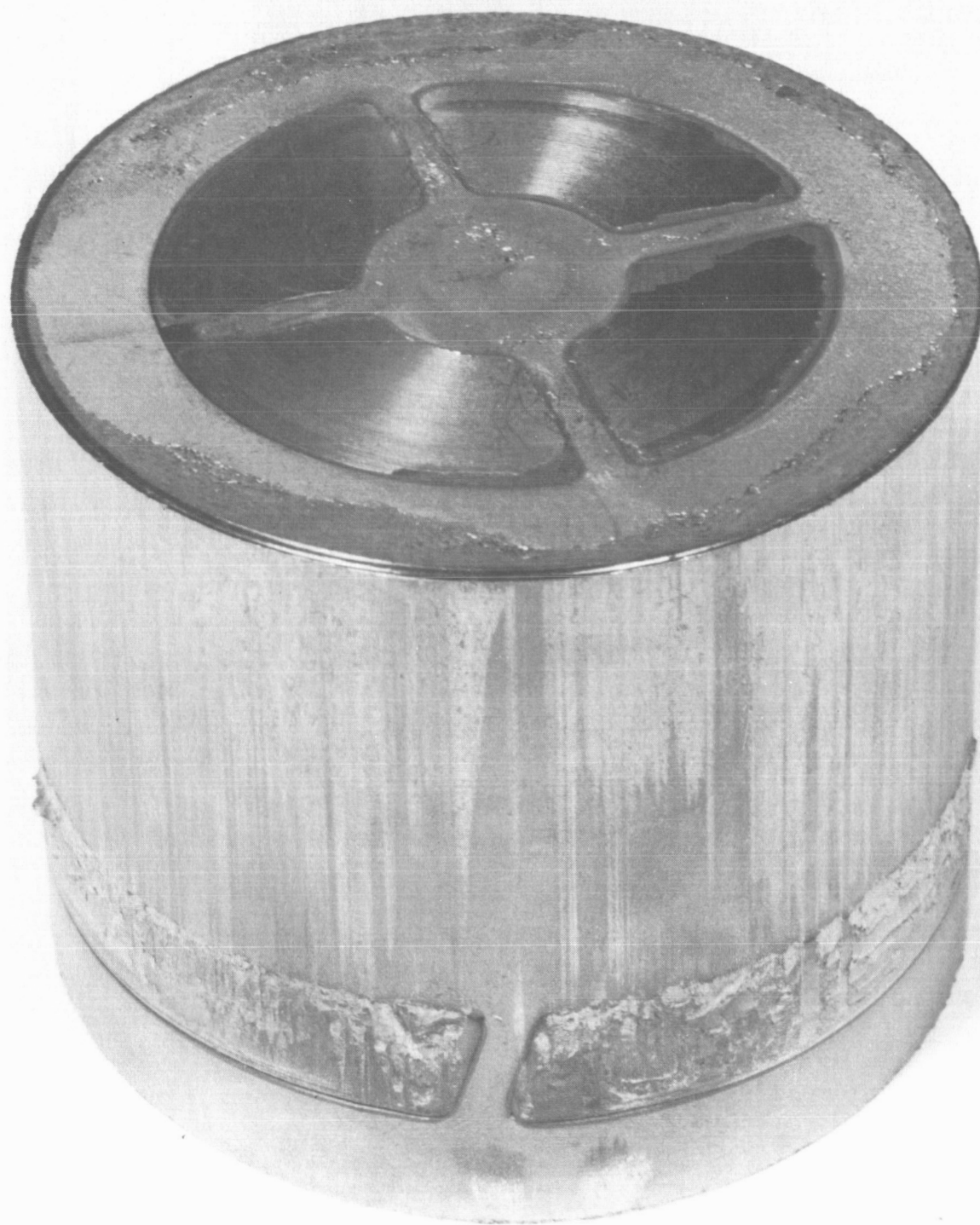


Figure 7. Test Sample After Removal From Restrainer Tooling

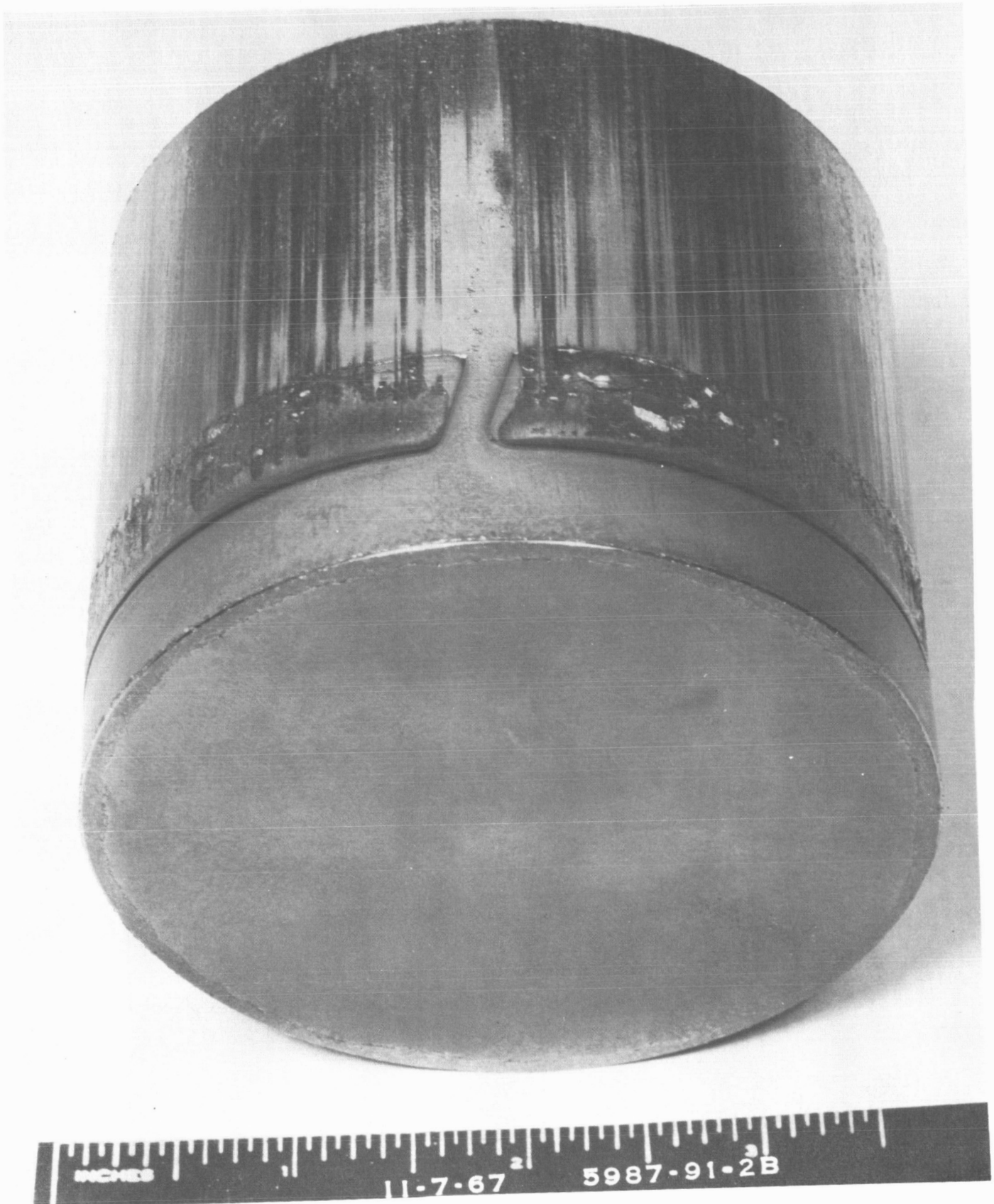


Figure 8. Test Sample After Removal From Restrainer Tooling

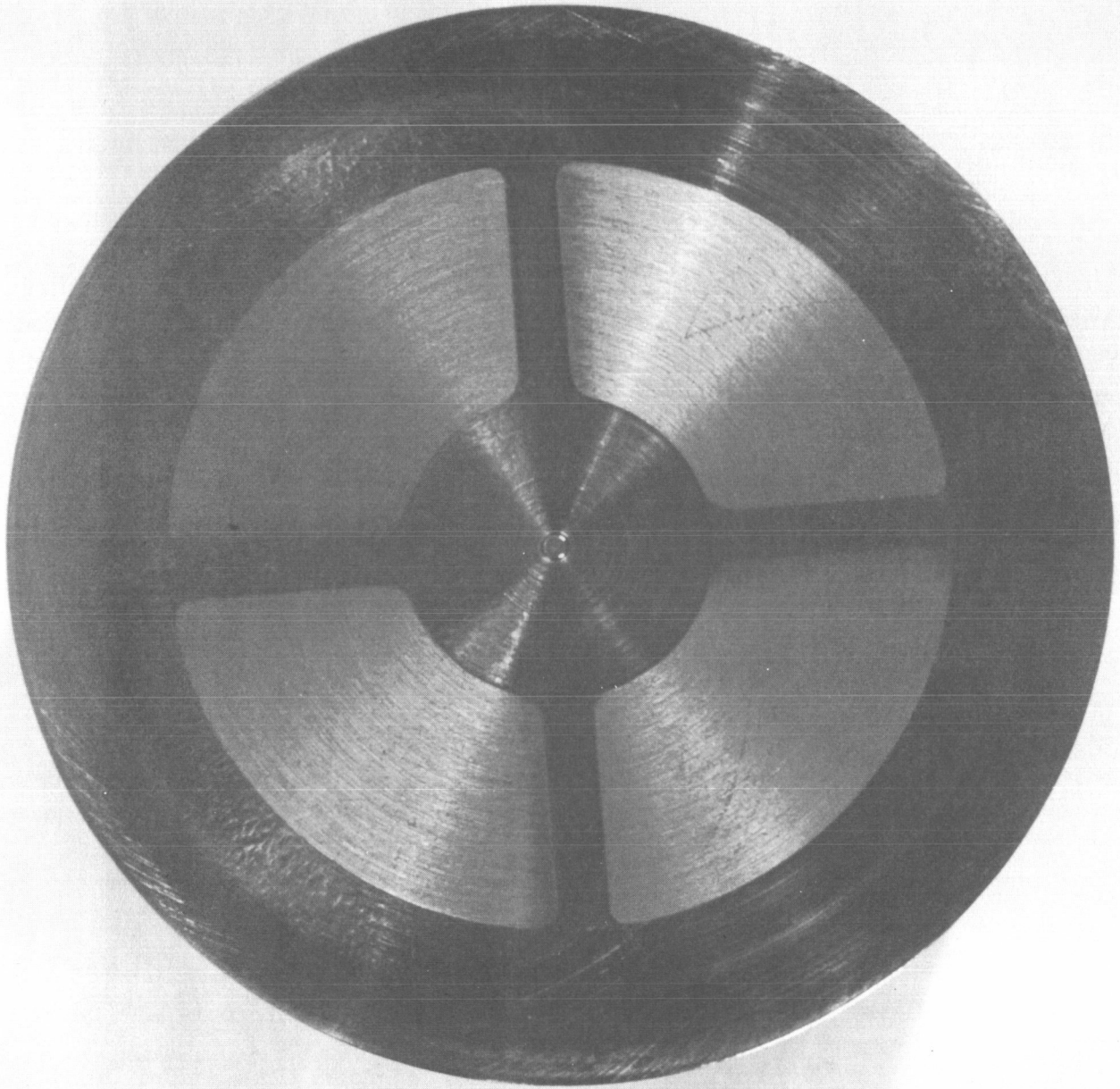


Figure 9. Test Sample After Clean Up Machining - Inlet Eye View

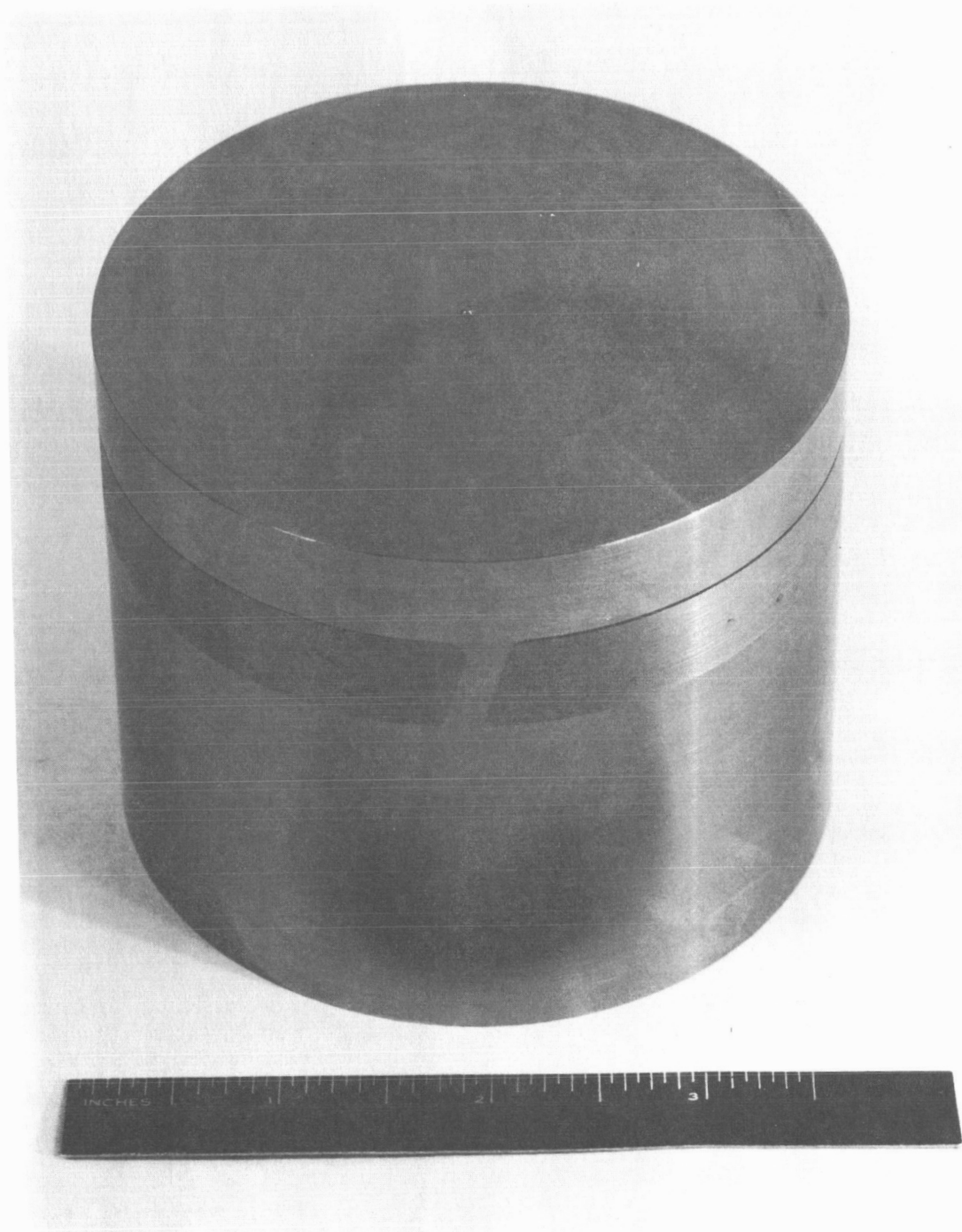


Figure 10. Test Sample After Clean Up Machining - Rear Shroud View

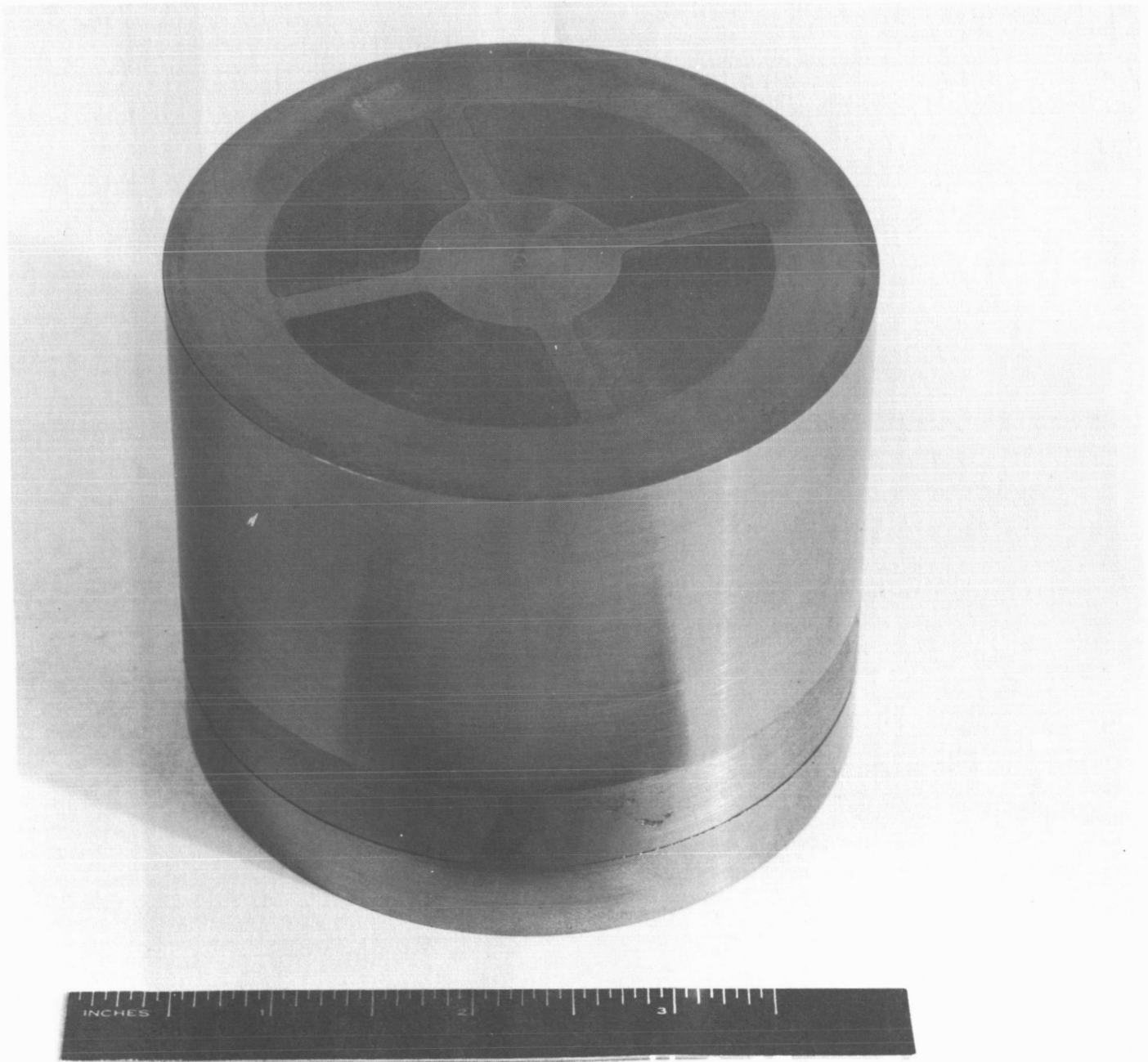


Figure 11. Test Sample After Clean Up Machining - Eye and Discharge View

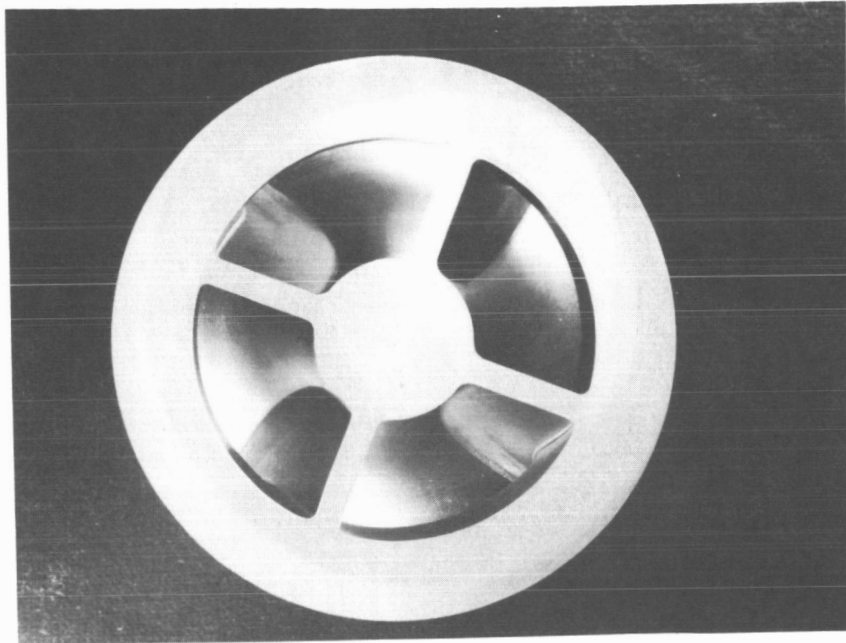


Figure 12(a). Eye View

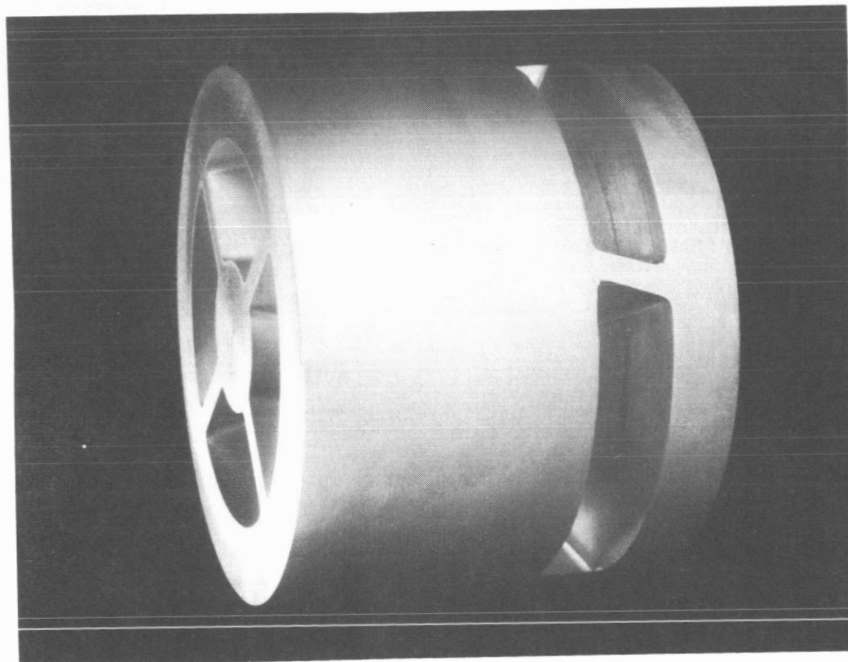


Figure 12(b). Side View

Figure 12. Test Sample After Core Removal

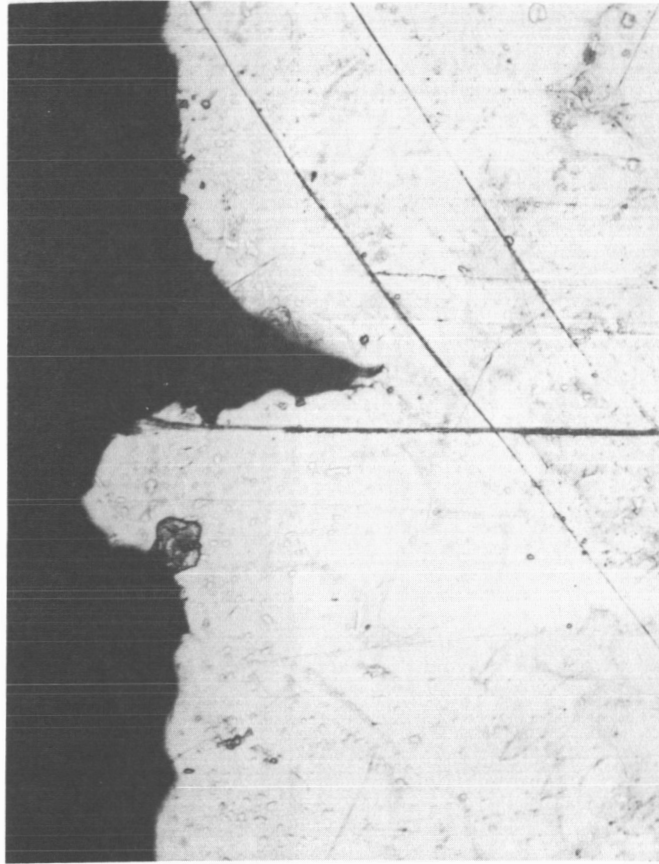


Figure 13. Typical notch at eye vane fillet on first trial sample.
Magnification 250 x - Notch .004 inch deep.

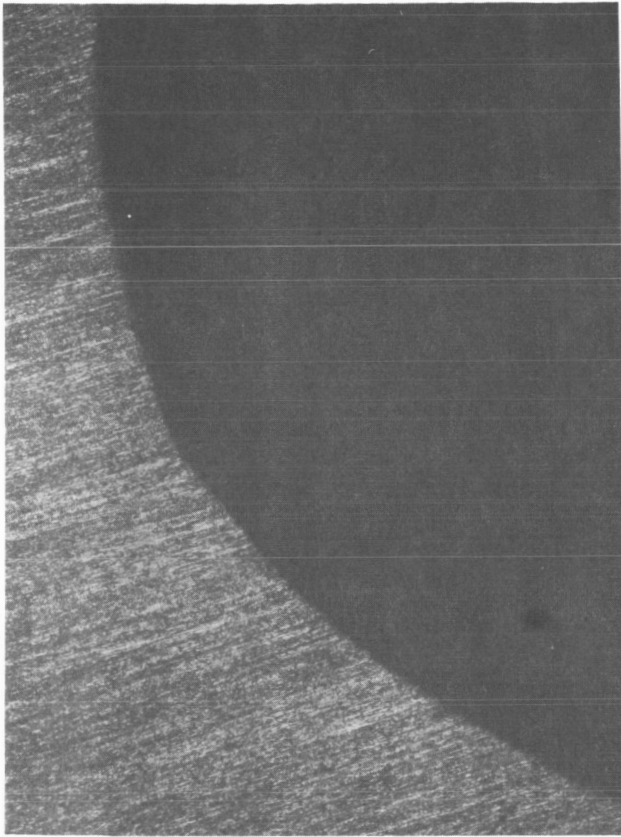


Figure 14(a)

Vane Fillet at Inner Shroud - 40X

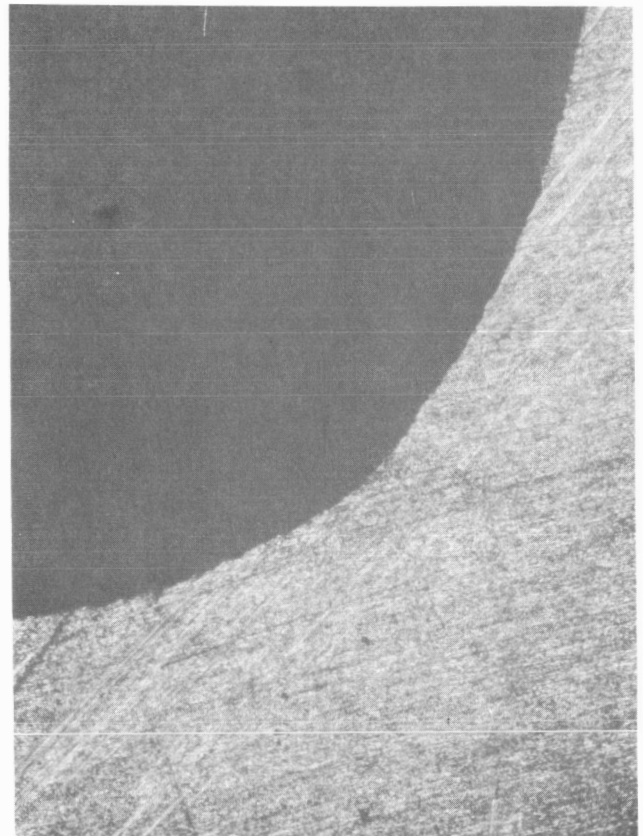


Figure 14(b)

Vane Fillet at Outer Shroud - 40X

Figure 14. Photographs of Vane Fillets at Impeller Eye on First Trial Sample After Chem-milling of 0.020 Inch (Magnification 40X)

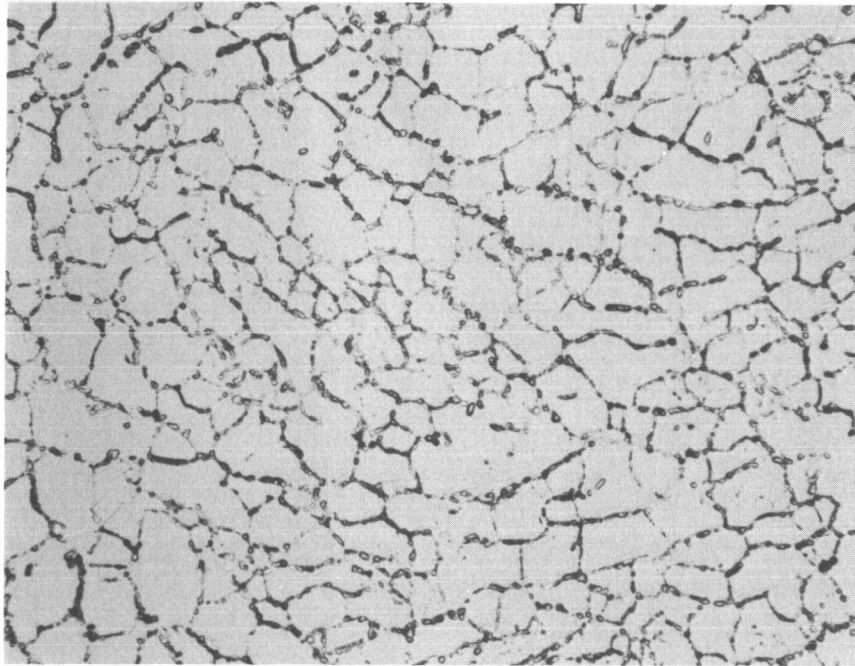


Fig. 15a. Before Bonding or as Received

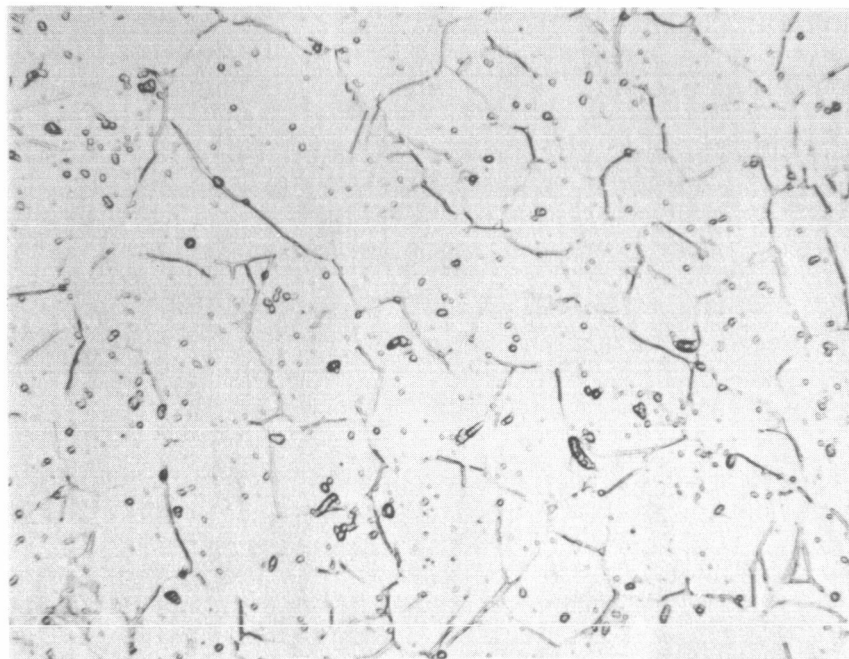


Fig. 15b. After Bonding

Figure 15. Photographs of First Sample Grain Structure Before and After Bonding. Alloy T_1 5AL-2.5 Sn Forging. Magnification 250X.

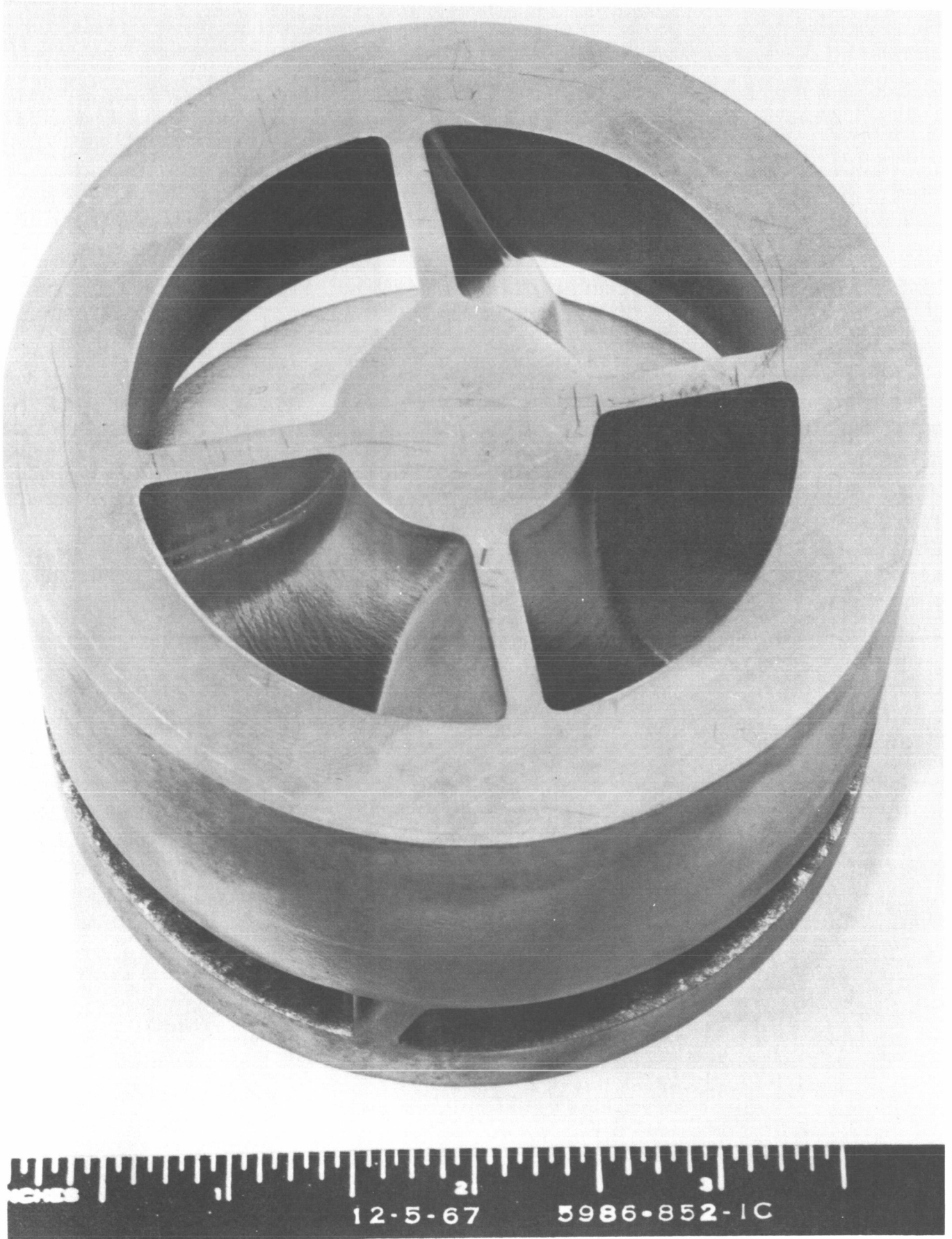


Figure 16. First Trial Sample After Final Chem-Milling - Eye Discharge View

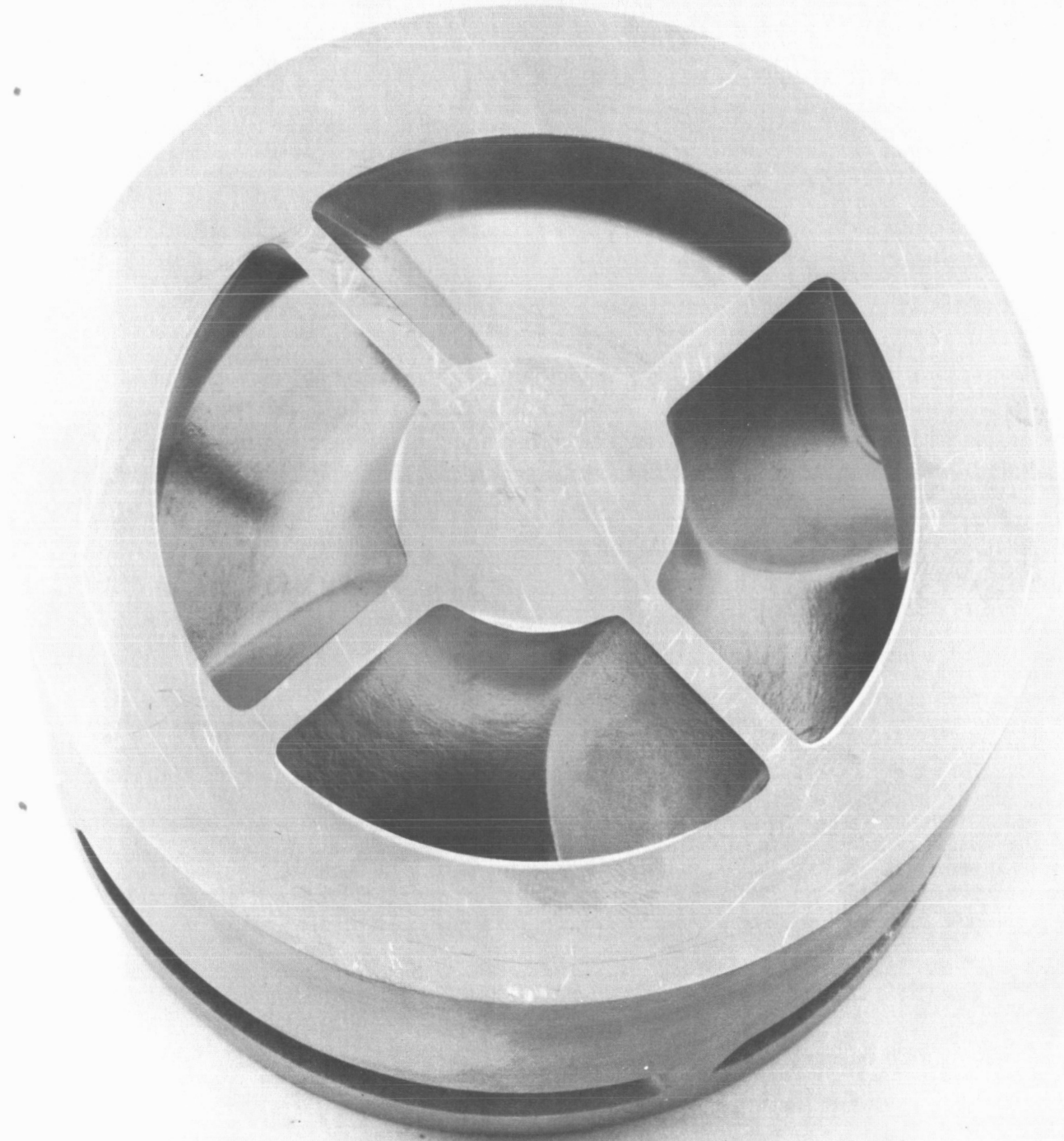


Figure 17. First Trial Sample After Final Chem-Milling - Eye View

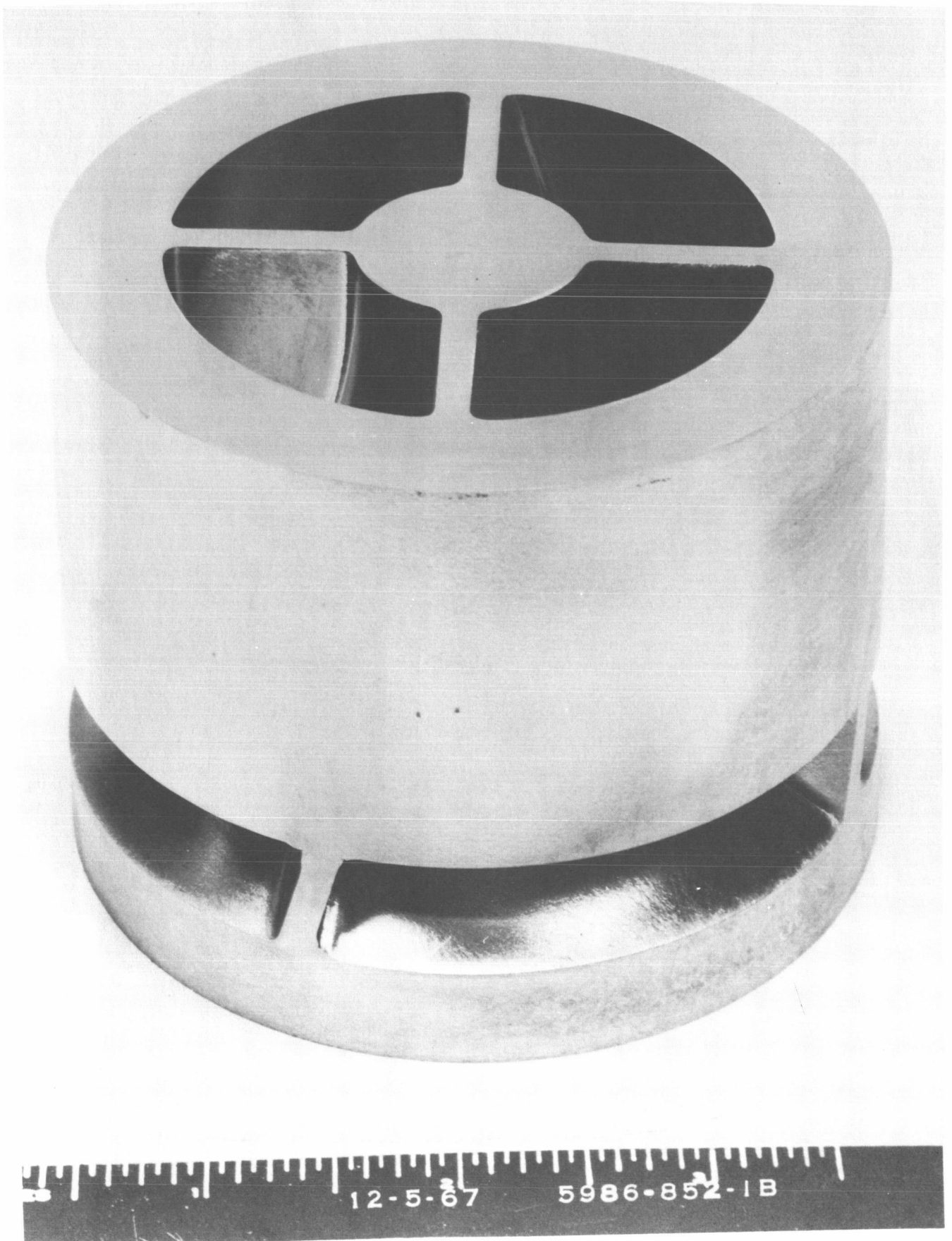


Figure 18. First Trial Sample After Chem-Milling - Discharge View

tensile specimens. However, in order to minimize cost it has been decided to perform this testing on the sample which represents the more optimum bonding conditions. A total of 0.020 inch of material per surface was removed by chem-milling from the first test sample. Dye penetrant inspection of the bond joints after final chem-milling indicates that a localized crack about 1/32 inch deep exists at the edge of the impeller discharge vane fillets.

Second Trial Impeller Sample

The second trial impeller sample is shown in Figs. 19 through 22. The core tooling for the second trial sample has been modified to determine the effect of a core split line on the flow passage wall. Figure 19 shows a disassembled view of the modified core and impeller assembly. Figure 20 shows a partially assembled view with the aft shroud removed. Figure 21 and Fig. 22 show views of the impeller eye and impeller discharge for the assembled unit.

Bonding of this unit has been deferred pending determination of optimum bonding conditions with the six test specimens discussed under Optimum Bonding Condition Determination.

Third Trial Impeller Sample

A third trial impeller was fabricated (at no cost to the program). This sample was identical to the first sample; however, H-11 tool steel was used for core material in lieu of 4340 steel. H-11 tool steel was selected because of its better high temperature characteristics. The third sample has been bonded using new restrainer tooling designed to minimize radial growth during the bonding cycle. This tooling was originally intended for use in bonding the second sample. The new restrainer consists of an inner cylindrical stainless steel liner 1/4 inch thick, an intermediate ceramic cylinder 6 inches in thickness, and an outer retainer of 4340 steel about 3/4 inch thick.

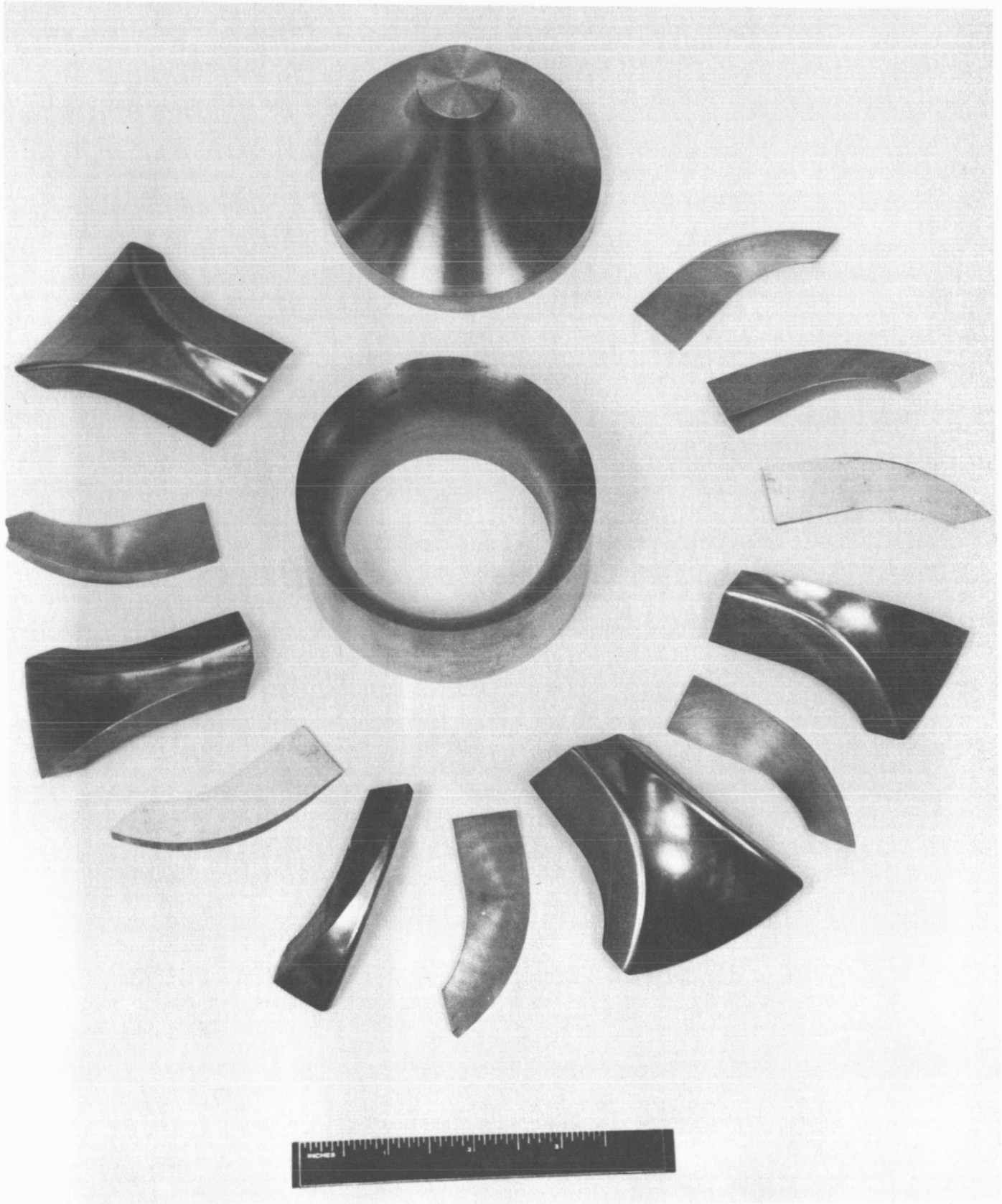


Figure 19. Disassembled View of Second Trial Sample Showing Modified Core

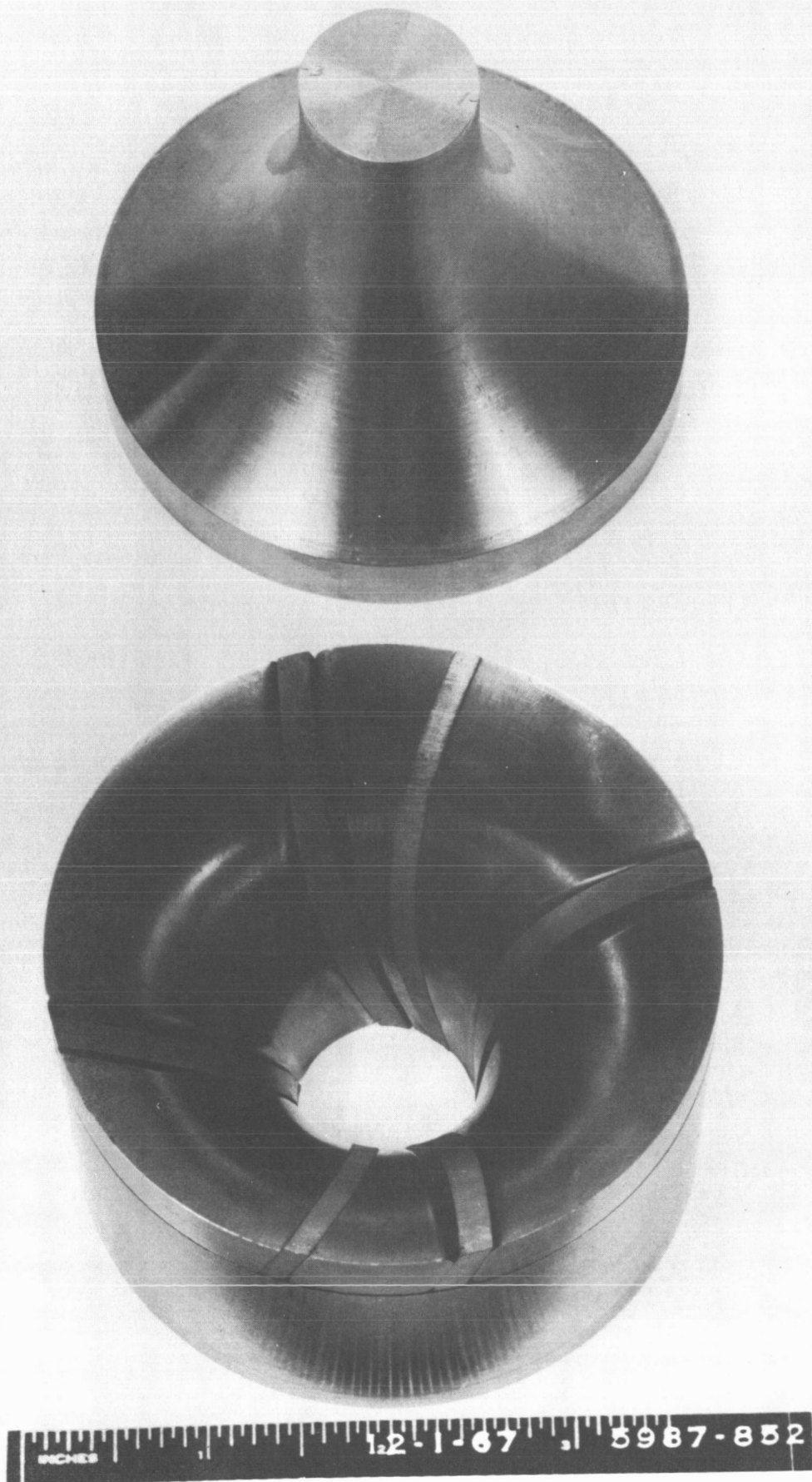


Figure 20. Partially Assembled View of Second Trial Sample Showing Modified Core

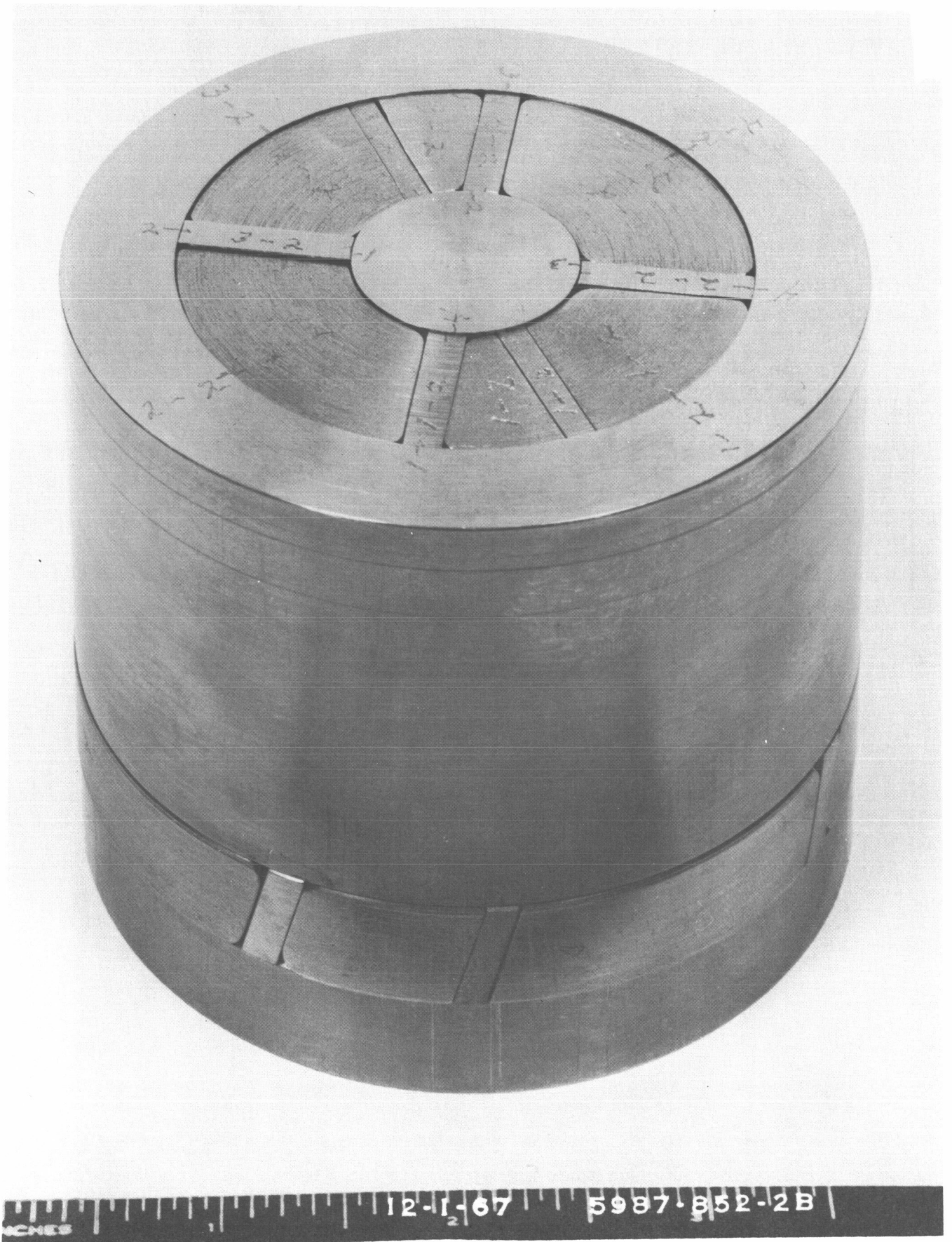


Figure 21. Assembled Eye View of Second Trial Sample

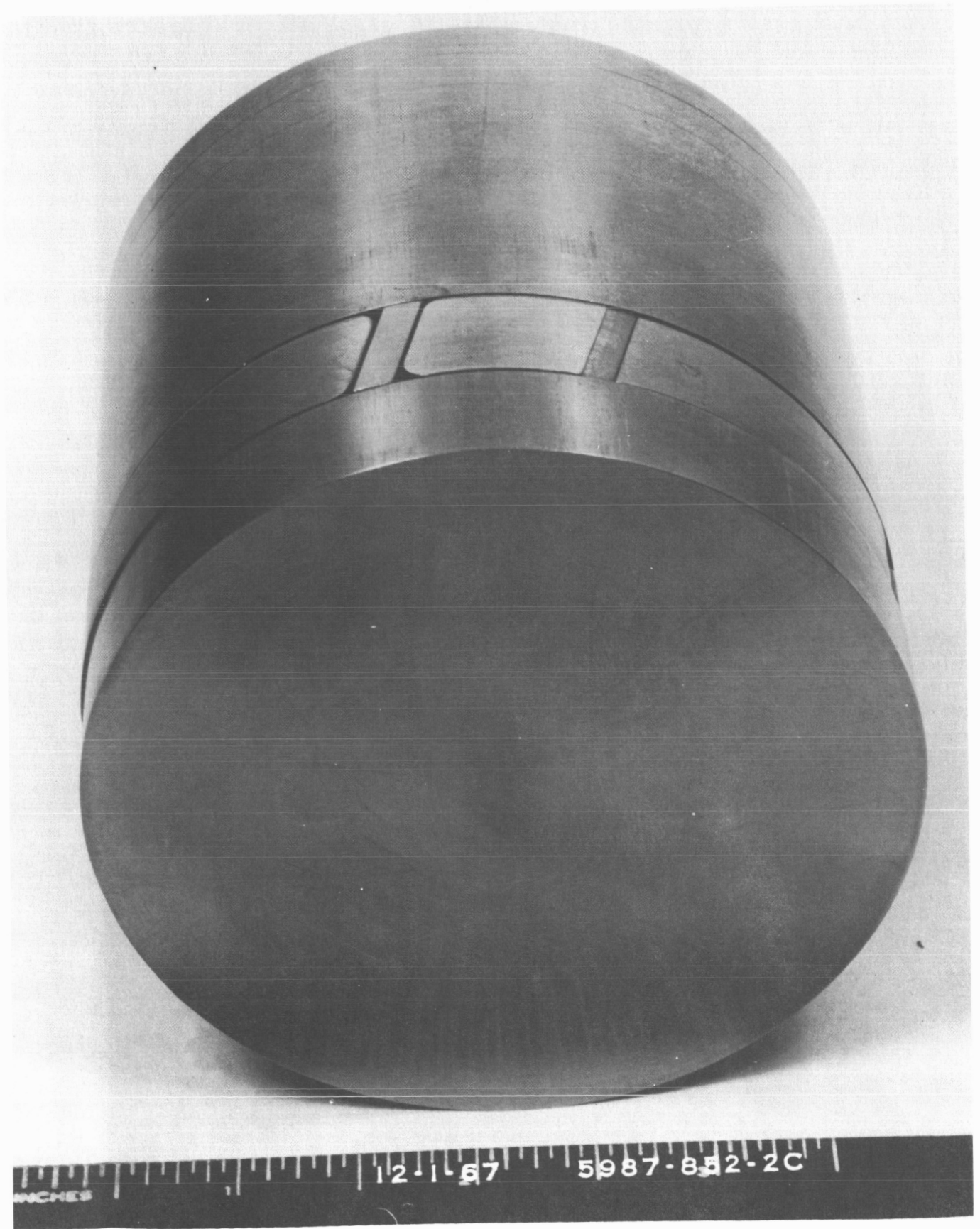


Figure 22. Assembled Discharge View of Second Trial Sample

The ceramic and outer steel restrainer are split to prevent damage to the ceramic during assembly and disassembly. A castable massrock material manufactured by the Glass Rock Products Corporation was used for the ceramic restrainer. This material has low coefficients of thermal expansion and heat transfer.

Figures 23 through 28 are a series of photographs showing the sample in various stages of assembly and disassembly before and after the bonding cycle. The third sample was bonded at a temperature of 1650 deg F for a period of 16 hours with constant pressure of 2000 psi on the pressure plate. It should be noted that the cracks in the ceramic restrainer shown in Fig. 28 after the bonding cycle, are curing cracks and were present before bonding. It is planned to use the same restrainer for the second sample.

Visual inspection of the third trial sample, after removal from retort and tooling, indicates that complete formation of the fillets did not occur. Preliminary investigation indicates that the required axial deformation for complete filling of the fillet areas did not occur. Although the required compression was indicated the reason for not achieving it on the actual part has not as yet been determined. It is planned to fabricate a new retort and restrainer, and recycle the part to achieve complete formation of the fillets.

Optimum Bonding Condition Determination

It has been found that some titanium alloys have an optimum temperature at which the material becomes most plastic and is thus more optimum for bonding. This temperature may also be significantly lower than the beta transition point thus allowing a greater margin between the bonding temperature and the beta transition point, which must be avoided if material properties are to be maintained. As this information is not available on the particular alloy being used (5 Al-2.5 Sn), it has been decided to

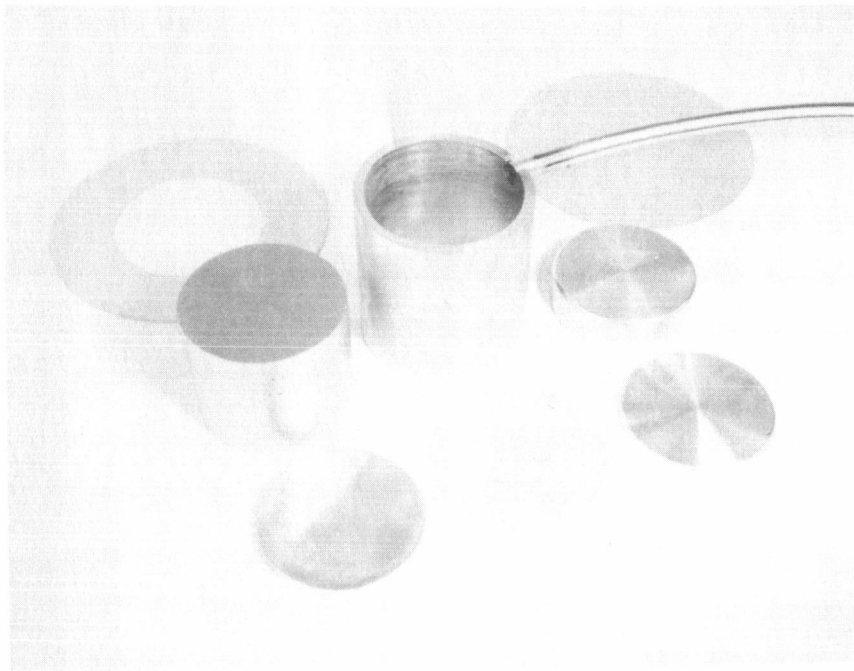


Fig. 23a. Impeller Assembly Outside of Retainer

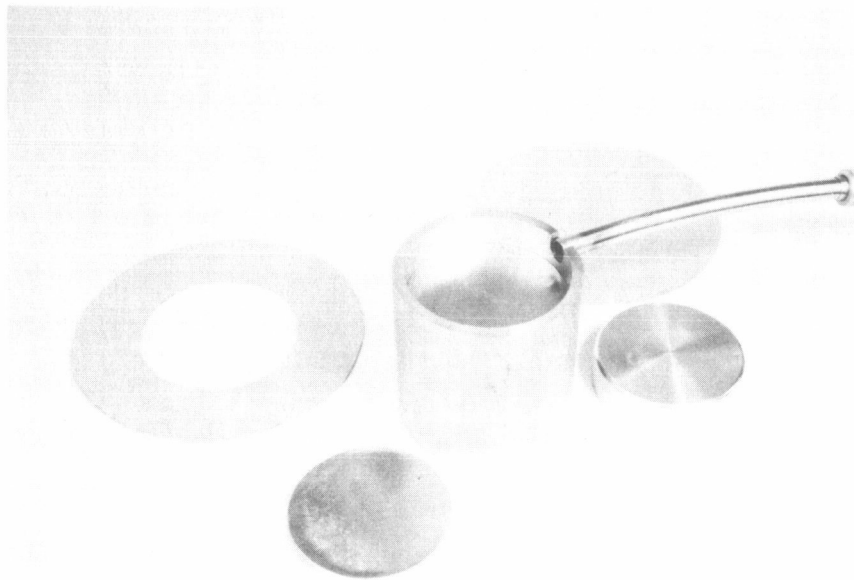


Fig. 23b. Impeller Assembly in Retainer

Figure 23. Third Trial Sample - Partial Assembly Prior to Bonding

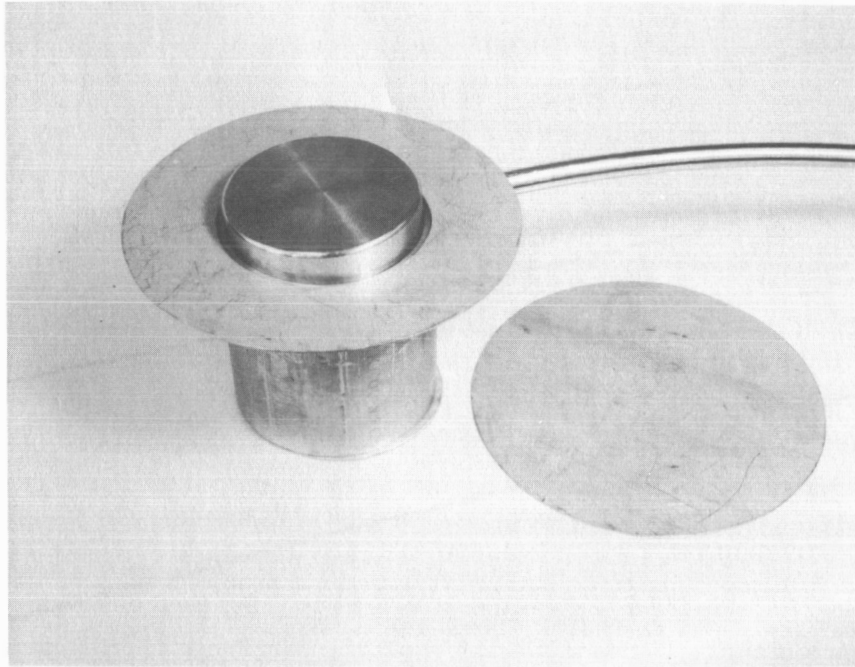


Fig. 24a. Assembly With Retort Cover Removed

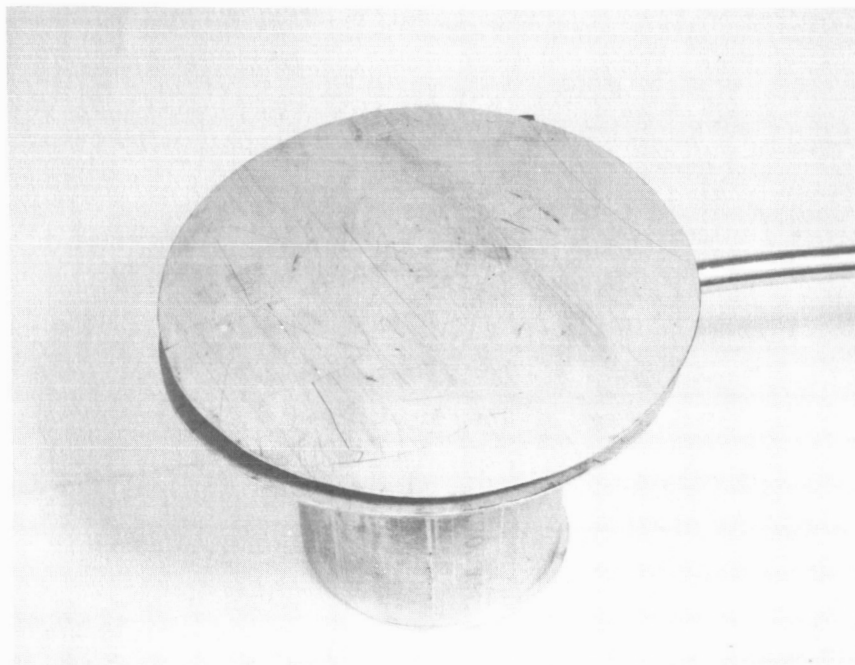


Fig. 24b. Assembly With Retort Cover in Place

Figure 24. Third Trial Sample - Prior to Welding Retort

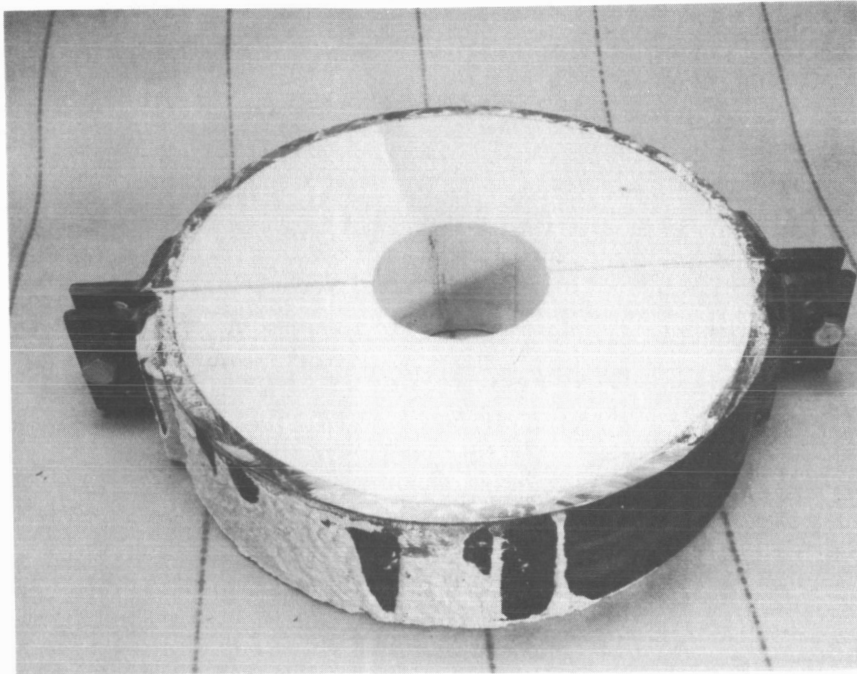


Fig. 25a. Restrainer Without Steel Shims

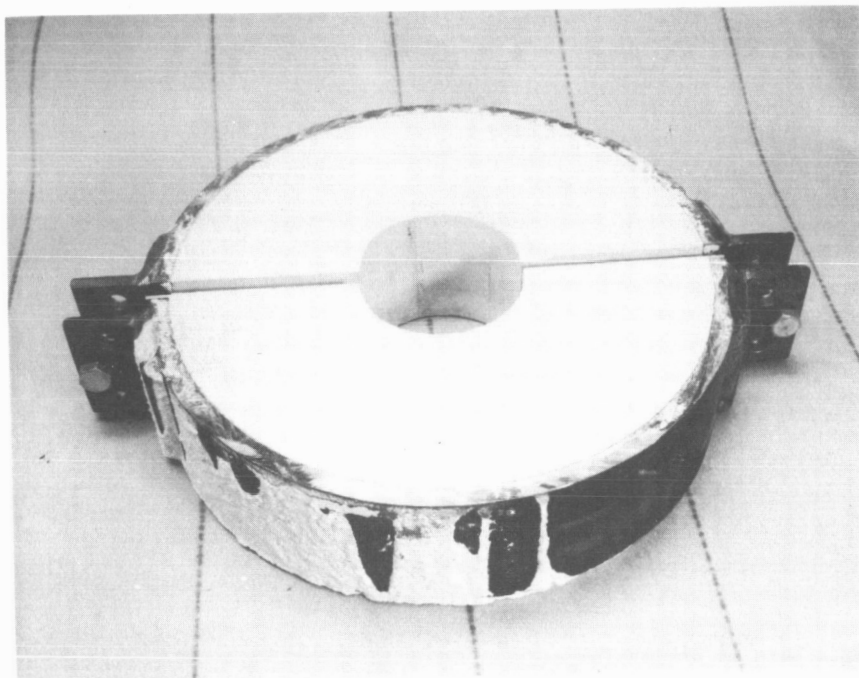


Fig. 25b. Restrainer With Steel Shims in Place

Figure 25. Third Trial Sample Restrainer Tooling

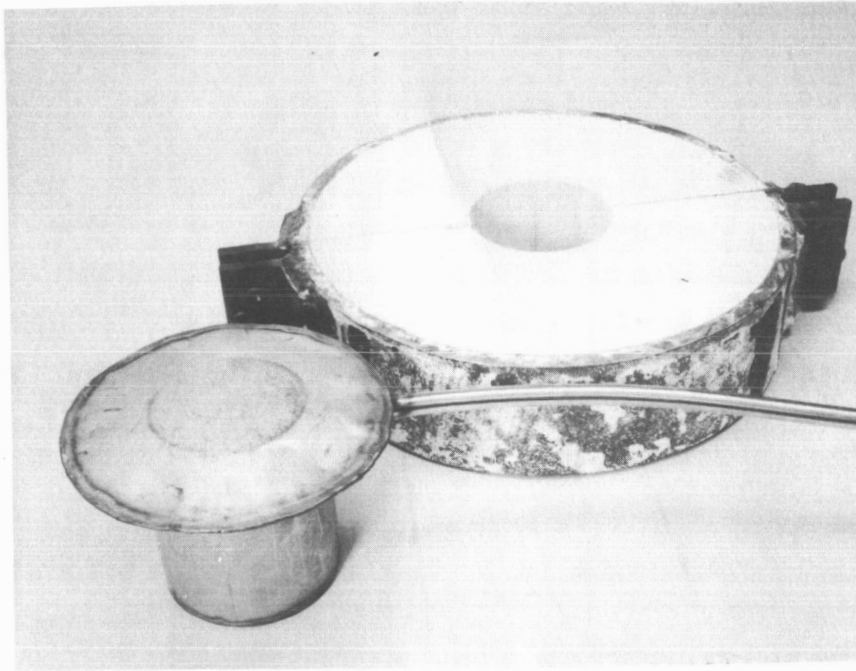


Fig. 26a. Retort Assembly Removed From Restrainer

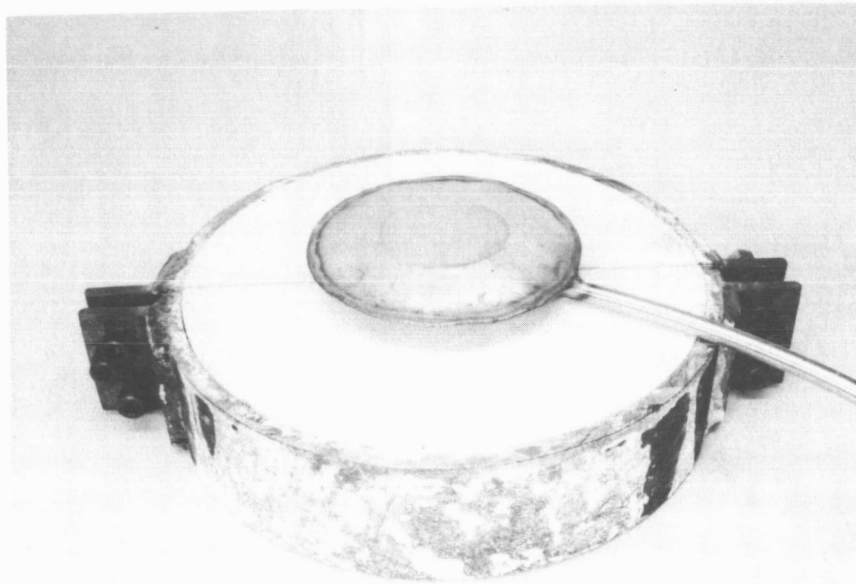


Fig. 26b. Retort Assembly in Restrainer

Figure 26. Third Trial Sample - Retort Assembly and Restrainer Tooling

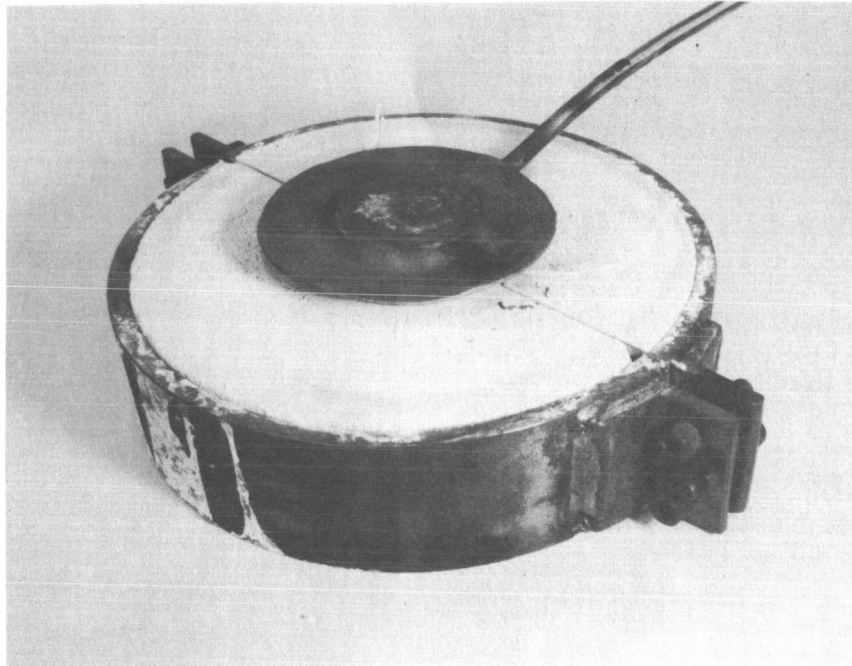


Fig. 27a. Retort Assembly in Restrainer

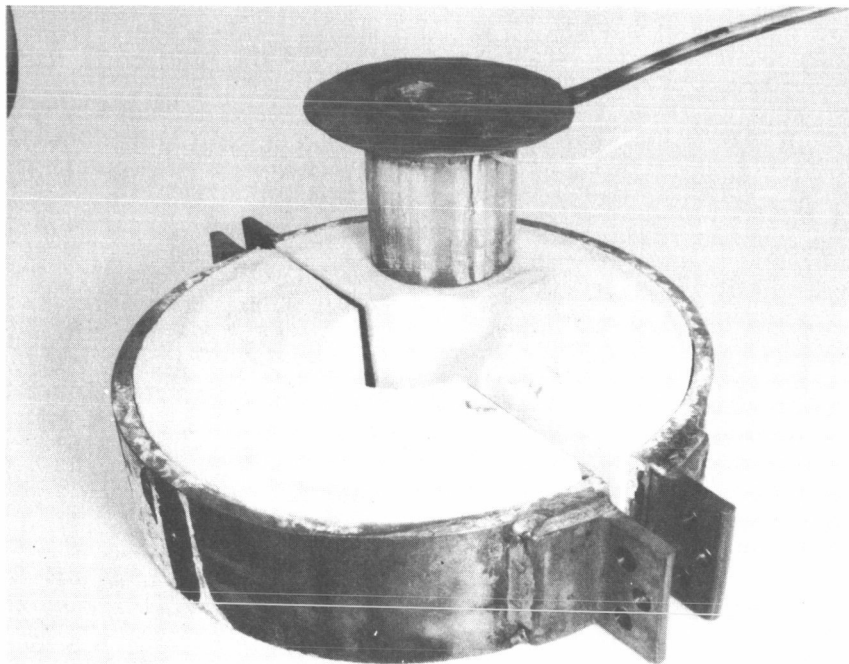


Fig. 27b. Retort Assembly Removed from Restrainer

Figure 27. Third Trial Sample After Bonding

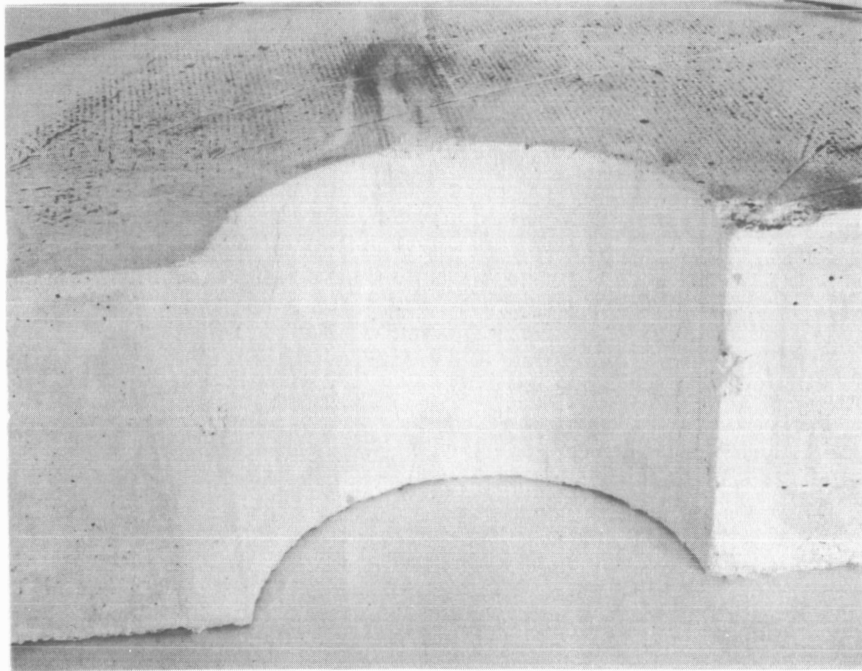


Figure 28. Close-Up View of Ceramic Restrainer - After the Bonding Cycle

determine the best bonding temperature and pressure by performing tests on six small samples fabricated from 7/8 inch diameter rod (alloy 5 Al-2.5 Sn). Fabrication of these samples including tooling has been completed and one specimen has been placed through the bonding cycle. Figures 29 through 32 are a series of photographs showing one of these test specimens in various stages of assembly.

The first specimen was cycled under conditions identical to that of the first impeller test sample. These conditions were selected as a basis for comparison. Figure 33 shows the results of the test on the first specimen. It can be seen that the 4340 steel die deformed and complete filling of the large gap did not occur under the bonding conditions employed. Subsequent tests will employ a lower temperature and pressure. H-11 tool steel will also be tried for the die material to determine if die deformation can be reduced.

FORGING STATUS

Titanium forgings for the front shrouds and vanes and blades have been received. Tensile specimens are being taken from these forgings to determine properties. A new estimated delivery date for the back shroud die forgings is 15 January. Steel forgings for the core material (either 4340 or H-11) will be procured, pending examination of the third trial sample.

PLANS FOR NEXT QUARTER

During the next quarter, bonding of the second impeller sample will be completed. Optimum bonding conditions will be determined with completion of testing on the 7/8 inch diameter (5 Al 2.5 Sn) specimens. Examination and analysis will be completed on the second and third trial impeller samples. Fabrication of the full size impellers will be initiated, pending results of the diffusion bonded samples and review with NASA.

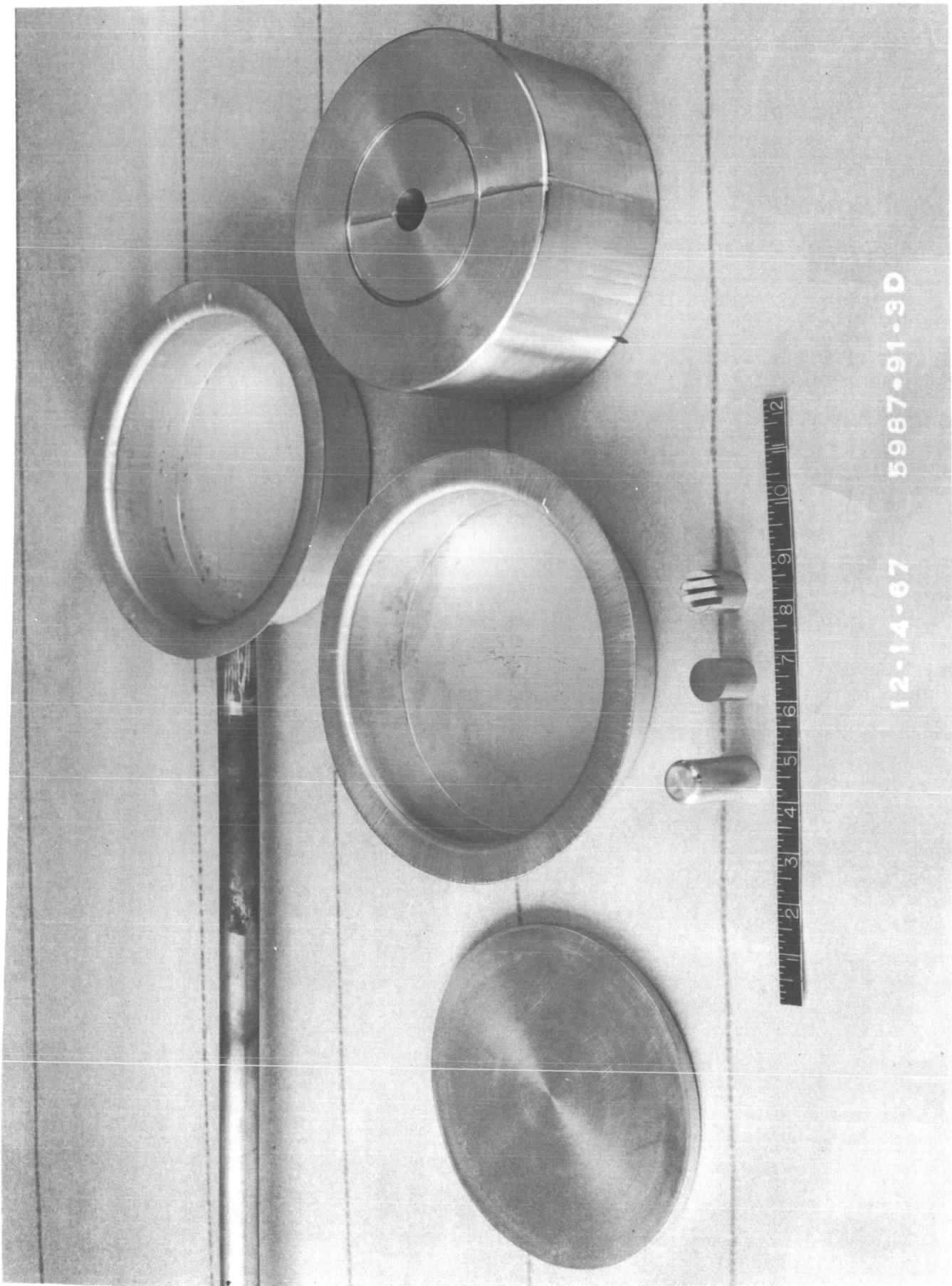


Figure 29. Disassembled View of 7/8 Inch Specimen and Tooling

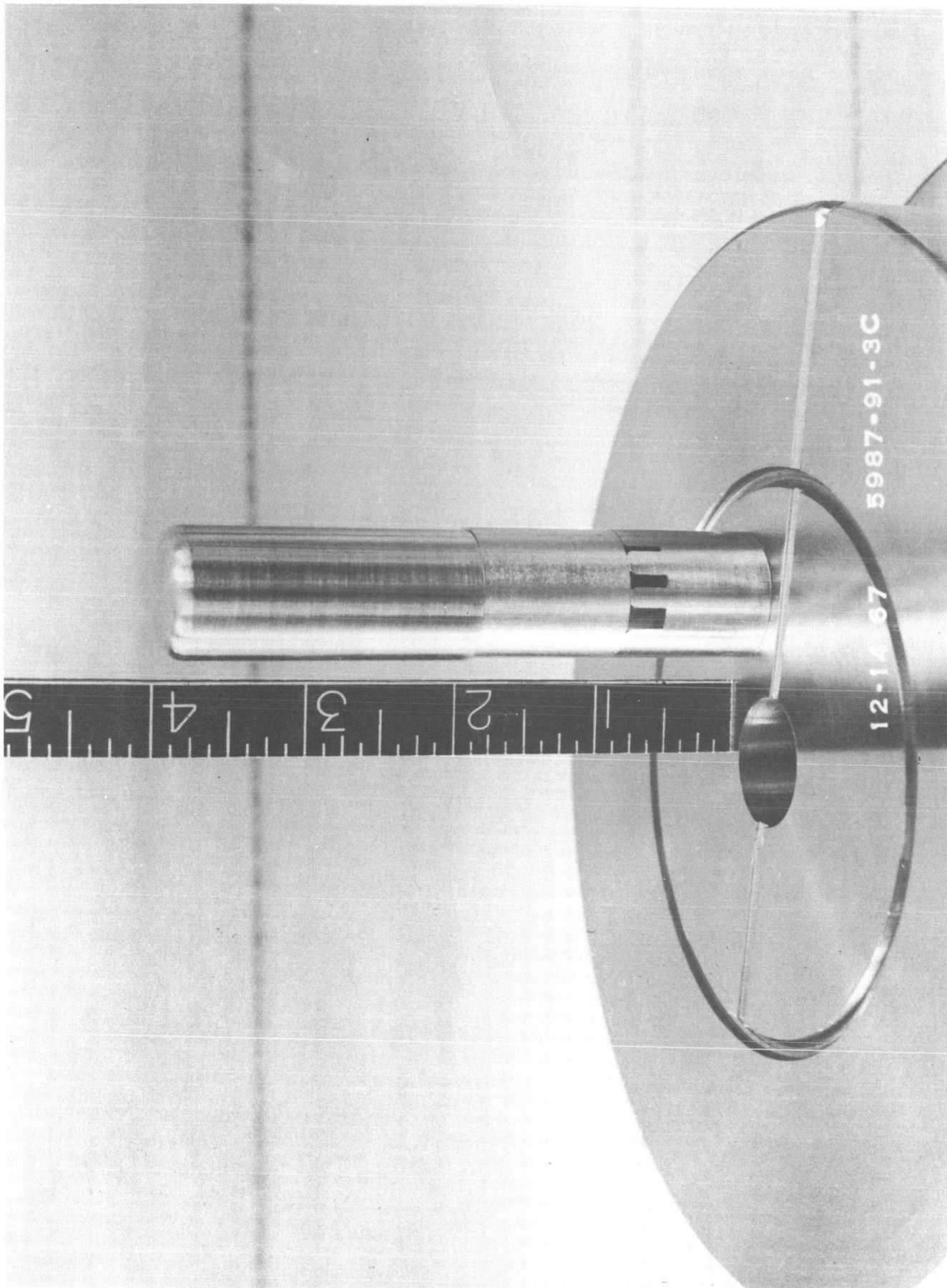


Figure 30. Close-Up View of Restrainer, Die, Plunger and 7/8 Inch Specimen.

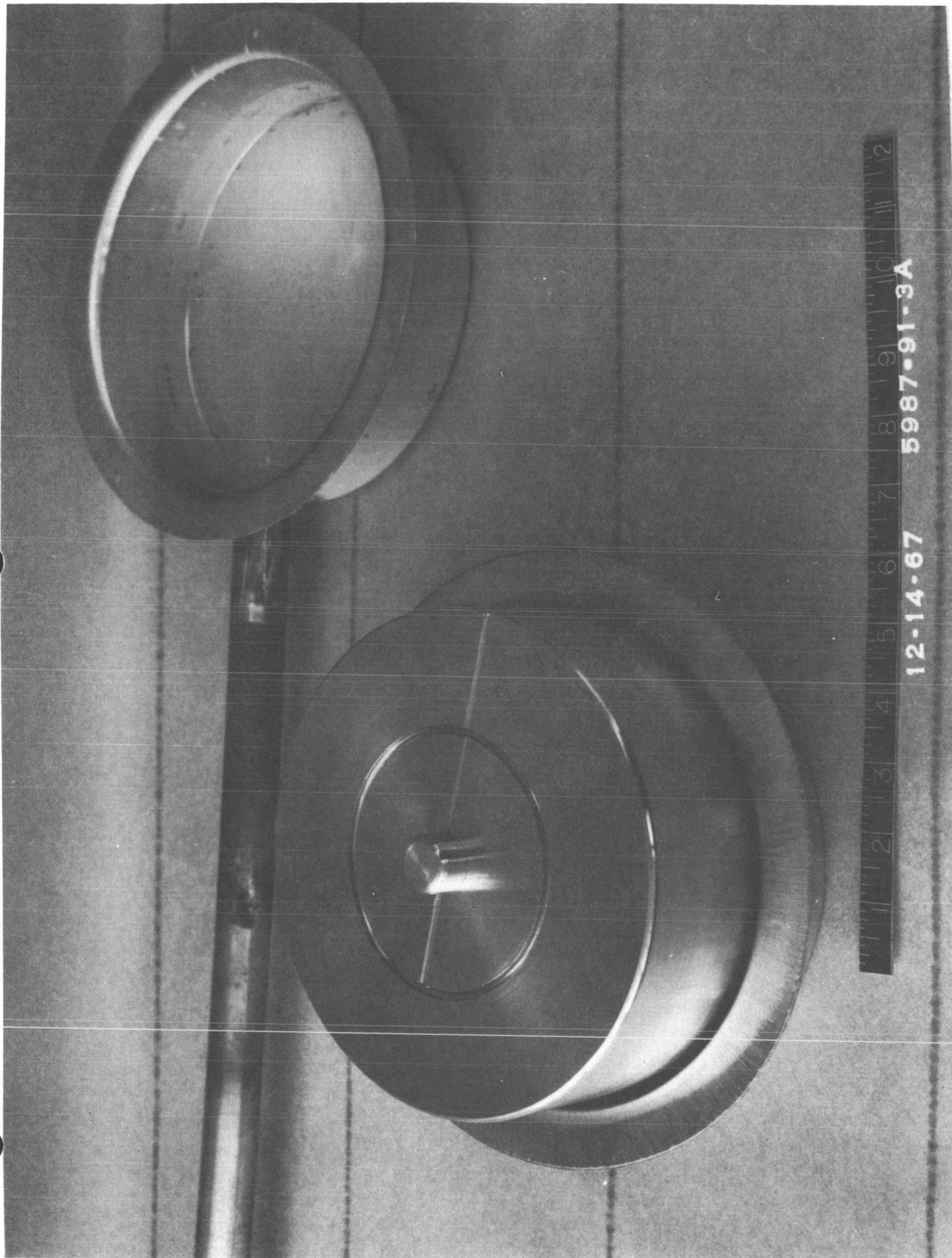


Figure 31. Assembled Views of 7/8 Inch Test Specimen and Tooling With Retort Cover Removed

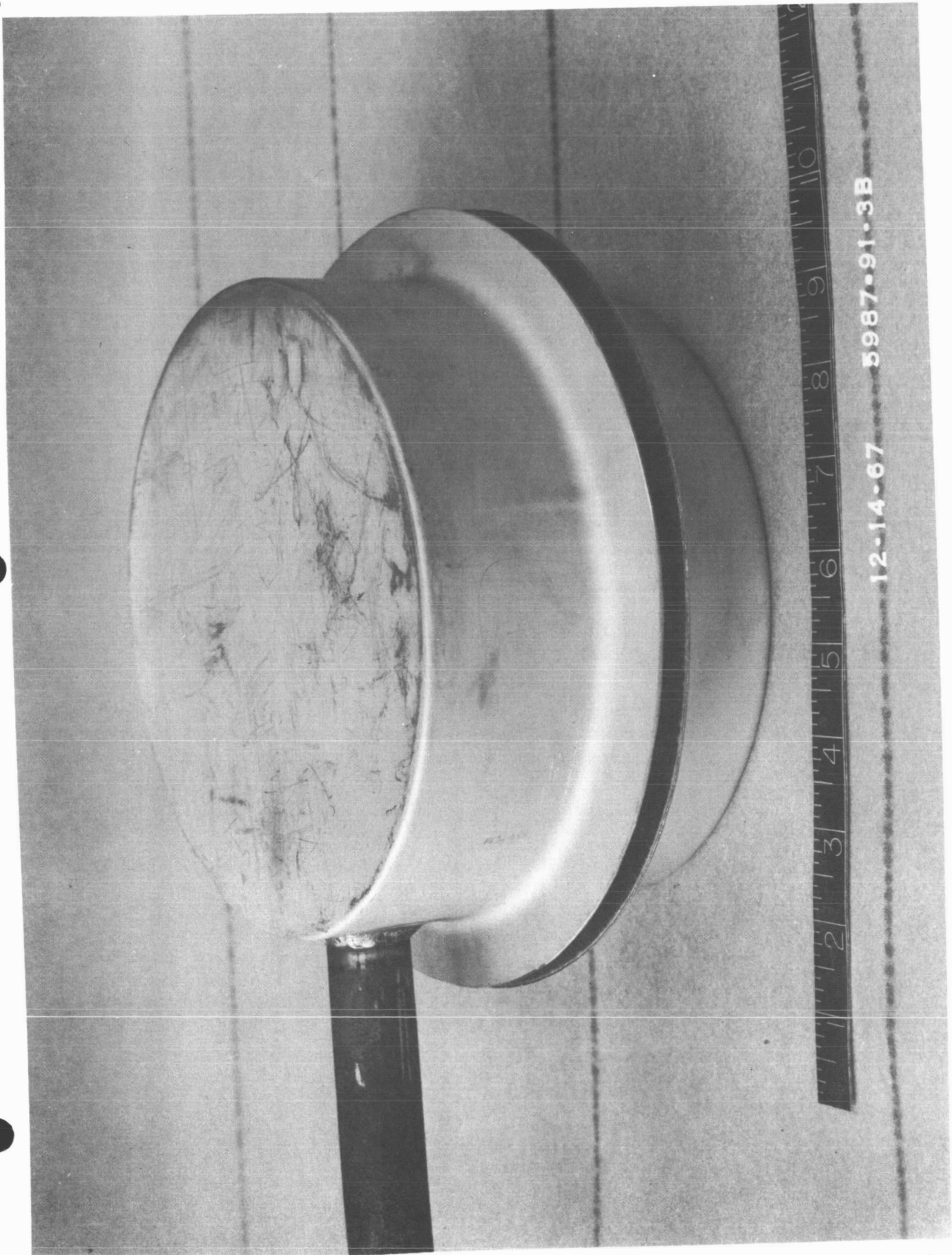
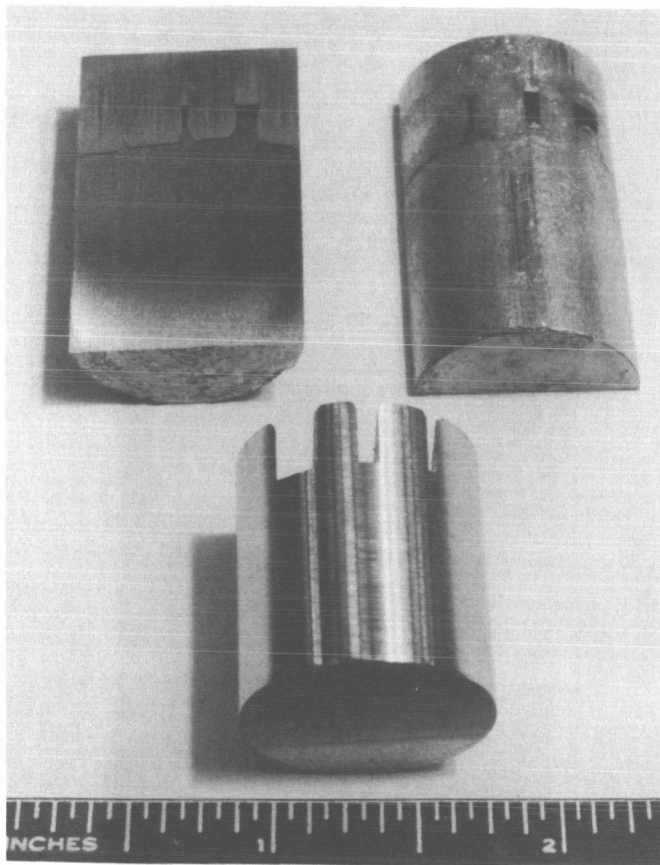
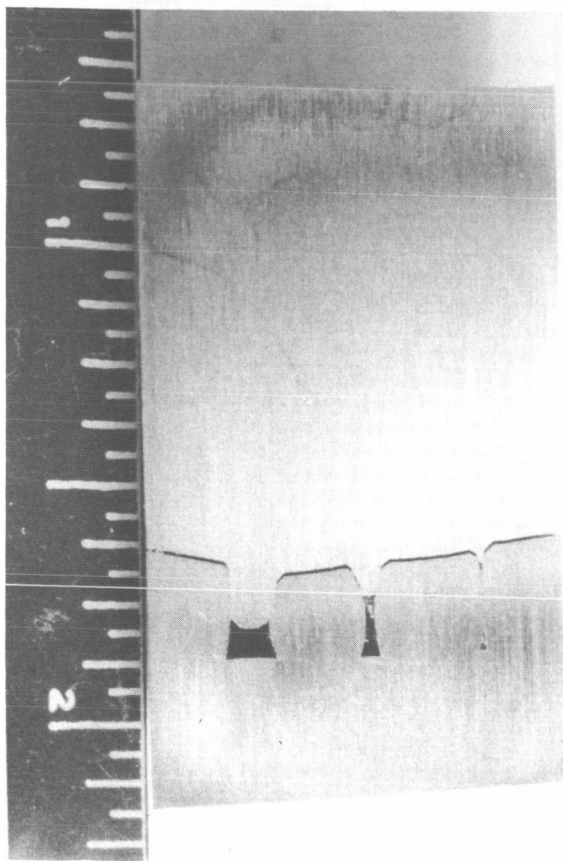


Figure 32. Assembled View of 7/8 Inch Test Specimen and Tooling With Retort Cover in Place



33a. View Comparing Sectioned Part After Pressing and New Tooling



33b. Close-up View Showing Tooling and Titanium Deformation

Figure 33. Sectioned View of First 7/8 inch Test Specimen After Simulated Bonding Cycle