NNF-DOC-014

NEAR-NET FORGING TECHNOLOGY DEMONSTRATION PROGRAM

FINAL REPORT

October 1996

Prepared By
I. Keith Hall

Approved By
David B. Sisk

(This work was sponsored by NASA Marshall Space Flight Center through contract NAS8-39935)

LOCKHEED MARTIN

FOREWORD

The work presented in this report was performed by Lockheed Martin Astronautics, Huntsville, AL, under Contract No. NAS8-39935, for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Marshall Space Flight Center, AL. David Sisk served as the Lockheed Martin Astronautics program manager. Keith Hall served as principal engineer on the program and was given the responsibility of managing all day-to-day activities.

Many people made significant contributions to this program. We would be remiss in not recognizing these people and expressing our thanks for their contributions. Specifically from NASA Marshall Space Flight Center we would like to recognize the efforts of Timothy Vaughn who served as the NASA Contracting Officer's Technical Representative (COTR). Our thanks also go out to Bill Stanton and Paul Schuerer for their support and cooperation. From Lockheed Martin Astronautics we would like to express our gratitude to Hugh McCutchen who performed the stress analysis work on this program; to Gerry Björkman who performed the weldability evaluation; and to Richard Webb and Stephanie Cain who performed the necessary contracts, finance, and procurement functions. We also wish to recognize the significant contributions made by the principal subcontractors. Specifically, we thank Dan Avery and Chuck Sample from Wyman Gordon who managed the ingot conversion and cylindrical blocker fabrication tasks. We also thank Mr. David Furrer, project manager at the Ladish Company, who was assisted by Mr. Rick Hoffman in performing all the near-net forging development work on this program. A special note of recognition goes out to the hourly personnel at Ladish and Wyman Gordon for their skillful hands-on contributions to this program. Finally, we express thanks to Michael Kahn of Allied Engineering and Production Corporation who managed the steel drum tool machining task.

TABLE OF CONTENTS

SECTION PAGE

FOREWORD ... iii

TABLE OF CONTENTS ... iv

LIST OF FIGURES ... vii

LIST OF TABLES ... xi

SUMMARY ... xiii

1. INTRODUCTION ... 1-1
   1.1 BACKGROUND ... 1-1
   1.2 NEAR-NET FORGING PROCESS DESCRIPTION ... 1-2
   1.3 BENEFITS ... 1-6
   1.4 GOVERNMENT / INDUSTRY COOPERATIVE PROGRAM ... 1-7

2. NEAR-NET FORGING PROGRAM DESCRIPTION ... 2-1
   2.1 DESIGN ... 2-2
      2.1.1 Machined Y-ring Adapter Design ... 2-2
      2.1.2 Near-Net Forging Design ... 2-4
      2.1.3 Preform Design ... 2-6
   2.2 TOOLING ... 2-7
      2.2.1 Contour Preform Tools ... 2-7
      2.2.2 Near-Net Forging Tools ... 2-7
      2.2.3 Drum Tool Fill Level Sensors ... 2-11
      2.2.4 Extraction Tooling Aids ... 2-11
   2.3 INGOT CONVERSION / BACK EXTRUSION OF CYLINDRICAL BLOCKERS ... 2-13
   2.4 CONTOUR PREFORM RING ROLLING ... 2-17
      2.4.1 Contour Preform SN #1 ... 2-17
      2.4.2 Contour Preforms SN's #2-4 ... 2-19
   2.5 NEAR-NET FORGING PRODUCIBILITY ENHANCEMENT TASKS ... 2-22
      2.5.1 2-D Finite Element Near-Net Forging Computer Model ... 2-22
      2.5.2 Clay Modeling Simulations ... 2-22

TABLE OF CONTENTS (Cont'd)

SECTION PAGE

2.6 NEAR-NET FORGING OF "PATHFINDER" Y-RING ADAPTER 2-23
2.6.1 Drum Rolling 2-23
2.6.2 Results 2-23
2.7 NEAR-NET FORGING OF "MECHANICAL PROPERTIES" Y-RING ADAPTER 2-30
2.7.1 Drum Rolling 2-30
2.7.2 Results 2-30
2.8 MANUFACTURE OF TWO "REPLACEMENT" CONTOUR PREFORMS 2-32
2.8.1 Tooling Modifications 2-33
2.8.2 Machining Of The Two Additional Contour Preforms 2-33
2.9 NEAR-NET FORGING OF "FLIGHT QUALITY" Y-RING ADAPTERS 2-33
2.9.1 Near-Net Forging The SN #5 Y-Ring Adapter 2-34
2.9.1.1 Results 2-34
2.9.2 Near-Net Forging Of SN #6 Y-Ring Adapter 2-36
2.9.2.1 Results 2-36

3. RECURRING COST SUMMARY 3-1
3.1 RECURRING COST MODEL SUMMARY OUTPUT 3-1
3.2 ACHIEVABLE NEAR TERM NEAR-NET FORGING COST REDUCTIONS 3-2
3.3 MATERIAL UTILIZATION 3-3

4. WELDING EVALUATION 4-1
4.1 WELD EVALUATION OBJECTIVE 4-1
4.2 APPROACH 4-1
4.3 WELD SET-UP 4-2
4.4 RESULTS 4-2
4.5 WELD EVALUATION CONCLUSIONS AND RECOMMENDATIONS 4-5

TABLE OF CONTENTS (Cont'd)

SECTION	PAGE
5. CONCLUSIONS AND RECOMMENDATIONS	5-1
APPENDIX A. INGOT CERTIFICATION	A
APPENDIX B. LADISH FINAL PROGRAM REPORT	B
APPENDIX C. REPORT OF PRELIMINARY 2195-T8 NEAR-NET FORGING WELD EVALUATION	C

LIST OF FIGURES

FIGURE PAGE

Figure 1-1. Potential applications of near-net forgings on space launch vehicles......1-1

Figure 1-2. Ingot conversion and back extrusion operations. 1-3

Figure 1-3. Contoured preform forming operations. 1-4

Figure 1-4. Near-net forging and extraction operations. 1-5

Figure 1-5. Thermal mechanical processing and machining operations. 1-5

Figure 1-6. Propellant tank assembly using near-net forged components......1-6

Figure 1-7. A 50% overall reduction in cost is the goal for near-net forging when mature......1-7

Figure 1-8. Government / Industry cooperative near-net forging development programs......1-8

Figure 2-1. The objective of this program was to demonstrate scale-up of the near-net forging process by producing four 170-inch diameter y-ring adapters. Two of these adapters will be included in an advanced technology cryogenic propellant tank. 2-1

Figure 2-2. Sketch of as-near-net forged, heat treated and stretched, y-ring adapter (2195-T8)......2-2

Figure 2-3. Axial-radial plane cross section of near-net forged, and machined, y-ring adapter (not final released)......2-3

Figure 2-4. Axial-circumferential plane view of near-net forged, and machined, y-ring adapter (not final released)......2-4

Figure 2-5. LMA engineering drawing of near-net forged y-ring adapter......2-5

Figure 2-6. Contour preform design......2-6

Figure 2-7. Ladish designed near-net forging drum tool......2-8

Figure 2-8. Stiffener cavity slot being milled in 4340 steel "drum tool" blank......2-9

Figure 2-9. Near-net forging drum tool. 2-9

Figure 2-10. Close-up showing machined "stiffener" slots in near-net forging drum tool......2-10

LIST OF FIGURES (Cont'd)

FIGURE PAGE

Figure 2-11. The lower pre-heat flame is directed at the contour idler mandrel. The second flame up from the bottom is directed at the drive roller. *2-10*

Figure 2-12. Fill level sensor holes were drilled into the drum tool to intersect with the apex of selected stiffener cavities. *2-12*

Figure 2-13. Lockheed Martin provided "centering wedges" to aid in part extraction. *2-12*

Figure 2-14. Jack screw block keep near-net forging from cocking in drum tool during extraction. *2-13*

Figure 2-15. Upset conversion of Al-Li 2195 ingot. *2-14*

Figure 2-16. Back extruded cylindrical blocker preform drawing. *2-15*

Figure 2-17. 45 .0 inch outside diameter X 31.3 inch inside diameter X 43 inch tall Al-Li 2195 back extruded cylinder. *2-16*

Figure 2-18. Blocker preform. *2-16*

Figure 2-19. Contour preform, SN #1, contour not completely formed / partially flattened during contour rolling. *2-18*

Figure 2-20. Contour preform, SN #1, contour not completely formed / partially flattened during contour rolling. *2-18*

Figure 2-21. Contour preform, SN #3, contour not completely formed / partially flattened during contour rolling. *2-20*

Figure 2-22. Contour preform, SN #3, contour not completely formed / partially flattened during contour rolling. *2-20*

Figure 2-23. Contour preform, SN #4, contour not completely formed / partially flattened during contour rolling. *2-21*

Figure 2-24. Contour preform, SN #4, contour not completely formed / partially flattened during contour rolling. *2-21*

Figure 2-25. Contour preform SN #4 machining drawing provides 0.200 inch extra thickness at key locations to improve stiffener fill rate uniformity. *2-24*

LIST OF FIGURES (Cont'd)

FIGURE PAGE

Figure 2-26. Contour preform SN #4 machining drawing provides 0.200 inch extra thickness at key locations to improve stiffener fill rate uniformity 2-25

Figure 2-27. Near-net forging of y-ring adapter on Ladish's large ring mill 2-26

Figure 2-28. Close-up of y-ring adapter being near-net forged 2-26

Figure 2-29. Fill sensor probe being used to verify stiffener fill (demonstrated after near-net forging in this photo) 2-27

Figure 2-30. Flash is chiseled-off from both ends of the drum tool / near-net forged y-ring adapter as it cools 2-27

Figure 2-31. Flash is ground-off from both ends of the drum / near-net forged y-ring adapter assembly as it cools 2-28

Figure 2-32. A gap emerges between Al-Li near-net forging and steel drum tool as they cool 2-28

Figure 2-33. Centering wedges are tapped into gap between Al-Li near-net forging and steel drum tool 2-29

Figure 2-34. Photograph of 170-inch diameter, Al-Li near-net forged, "process pathfinder" y-ring adapter, SN #4 2-29

Figure 2-35. Photograph of 170-inch diameter, Al-Li near-net forged "mechanical properties", y-ring adapter, SN #1 2-31

Figure 2-36. Close-up photograph of near-net forged, "mechanical properties" y-ring adapter, SN #1 near bottom of adapter (oriented up in this photo) 2-31

Figure 2-37. Close-up photograph of near-net forged, "mechanical properties" y-ring adapter at the stiffener-to-test ring/flange intersection 2-32

Figure 2-38. A slight under-fill of the stiffeners on near-net forged y-ring adapter, SN #5, can be observed 2-35

Figure 2-39. An arc section of approximately 8 stiffeners only filled to about half height on near-net forged y-ring adapter SN #5 2-35

Figure 2-40. Photograph of 170-inch diameter, Al-Li 2195 near-net forged adapter, SN #6 2-37

LIST OF FIGURES (Cont'd)

<u>FIGURE</u> <u>PAGE</u>

Figure 2-41. Lap defect at stiffener-to-test ring/flange location is severe on SN #5 and #6. .... *2-37*

Figure 3-1. Al-Li near-net forging recurring cost reduction potential. *3-2*

Figure 3-2. Near-net forging a y-ring adapter uses 63% less raw material than machining one from a seamless rolled ring forging. *3-3*

Figure 4-1. 0.320 inch thick, 2195-RT70 plate-to-plate VPPA weld baseline (PLT-M01) 12.5 X magnification. *4-4*

Figure 4-2. 0.320 inch thick, 2195-T8 near-net forged "membrane" panel VPPA welded to 2195-RT70 plate (Panel B-M01) 12.5 X magnification. *4-4*

Figure 4-3. 0.320 inch thick, 2195-T8 near-net forged "membrane" panel VPPA welded to 2195-RT70 plate (Panel A-M01) 12.5 X magnification. *4-5*

LIST OF TABLES

TABLE PAGE

Table 3-1. Recurring cost model calculated values to produce the Titan oxidizer barrel section using conventional machining versus near-net forging for aluminum and Al-Li alloys..........................3-1

Table 4-1. Averaged room temperature tensile data for 2195-T8 VPPA welds...4-3

SUMMARY

Significant advantages in specific mechanical properties, when compared to conventional aluminum (Al) alloys, make aluminum-lithium (Al-Li) alloys attractive candidate materials for use in cryogenic propellant tanks and dry bay structures. However, the cost of Al-Li alloys is typically five times that of 2219 aluminum. If conventional fabrication processes are employed to fabricate launch vehicle structure, the material costs will restrict their utilization. In order to fully exploit the potential cost and performance benefits of Al-Li alloys, it is necessary that near-net manufacturing methods be developed to off-set or reduce raw material costs.

Near-net forging is an advanced manufacturing method that uses elevated temperature metal movement (forging) to fabricate a single piece, near-net shape, structure. This process is termed "near-net" because only a minimal amount of post-forge machining is required. The near-net forging process was developed to reduce the material scrap rate (buy-to-fly ratio) and fabrication costs associated with conventional manufacturing methods. The goal for the near-net forging process, when mature, is to achieve an overall cost reduction of approximately 50 percent compared with conventional manufacturing options for producing structures fabricated from Al-Li alloys.

This NASA Marshall Space Flight Center (MSFC) sponsored program has been a part of a unique government / industry partnership, coordinated to develop and demonstrate near-net forging technology. The objective of this program was to demonstrate scale-up of the near-net forging process. This objective was successfully achieved by fabricating four integrally stiffened, 170-inch diameter by 20-inch tall, Al-Li alloy 2195, Y-ring adapters.

Initially, two 2195 Al-Li ingots were converted and back extruded to produce four cylindrical blockers. Conventional ring rolling of the blockers was performed to produce ring preforms, which were then contour ring rolled to produce "contour preforms". All of the contour preforms on this first-of-a-kind effort were imperfect, and the ingot used to fabricate two of the preforms was of an earlier vintage. As lessons were learned throughout the program, the tooling and procedures evolved, and hence the preform quality. Two of the best contour preforms were near-net forged to produce a process pathfinder Y-ring adapter and a "mechanical properties pathfinder" Y-ring adapter. At this point, Lockheed Martin Astronautics elected to procure additional 2195 aluminum-lithium ingot of the latest vintage, produce two additional preforms, and substitute them for older vintage material non-perfectly filled preforms already produced on this contract. The existing preforms could have been used to fulfill the requirements of the contract. However, LMA desired to produce the best near-net forged adapters possible to ensure the success of the subsequent cryogenic tank test program. The two additional contour preforms were provided to the program at the sole discretion of LMA.

These last two contour preforms were then near-net forged. Subsequently, on other contracts, these two (of four) near-net forged adapters will be machined and welded to end domes and a barrel section to produce an advanced structural technology demonstration tank. This cryogenic propellant tank, which will be produced entirely from near-net technologies and alloy 2195 aluminum-lithium, is projected to be assembled and tested at NASA MSFC. The overall integrated near-net forging development and demonstration effort has clearly been a successful example of a Government / Industry Partnership working efficiently and effectively to develop a new technology.

SECTION 1

INTRODUCTION

1.1 BACKGROUND

The existing fleet of launch vehicles was designed for maximum performance. In contrast, a future vehicle will be designed to meet performance objectives while minimizing system cost. The development of new designs, materials, and processes is requisite if these cost and performance objectives are to be achieved.

Aluminum-Lithium (Al-Li) alloys offer a significant improvement in specific mechanical properties when compared to conventional aluminum (Al) alloys such as alloy 2219. Lower density, higher strength, and higher elastic modulus make Al-Li alloys attractive candidate materials for use in cryogenic propellant tanks and dry bay structures. When compared to 2219, Al-Li alloys typically reduce the weight of these structures by 10 to 15 percent. The resulting weight savings can used directly to increase launch vehicle payload capability, or be "spent" to add design margins, and or reduce the cost of other vehicle systems.

However, the cost of Al-Li alloys is approximately five times that of 2219 aluminum. If conventional fabrication processes are employed to produce launch vehicle structures from Al-Li the material costs will restrict their utilization. To fully exploit the potential cost and performance benefits of Al-Li alloys, it is desirable to develop near-net manufacturing technologies.

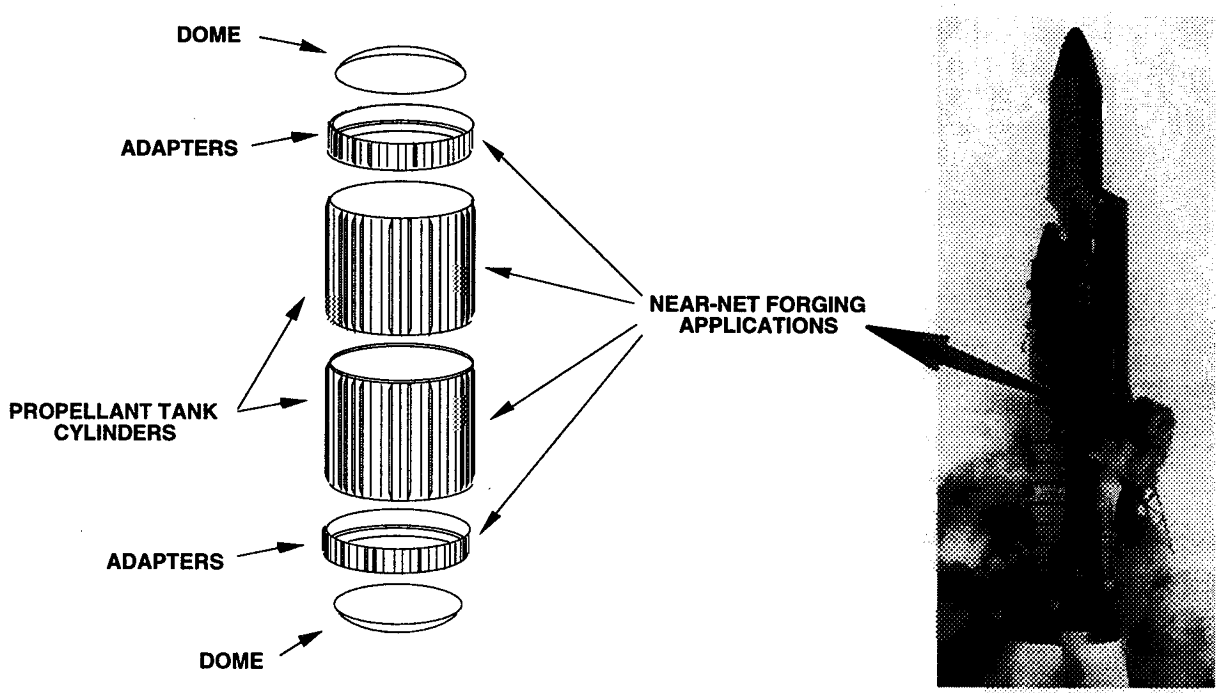


Figure 1-1. Potential applications of near-net forgings on space launch vehicles.

Near-net technologies are a class of manufacturing methods that use elevated temperature metal movement techniques (extrusion, forging, spin forming), as opposed to material removal (machining, chemical milling), to form integral features (stiffeners, frames, weld lands, etc.). The aerospace industry is interested in the aluminum-lithium/near-net manufacturing technology combination for production of light weight, low cost launch vehicle structures. A Titan launch vehicle highlighting the structures that will potentially benefit from near-net manufactured aluminum-lithium technology is shown in Figure 1-1. Progress in the development of the near-net forging process for 2195 aluminum-lithium integrally stiffened cylinders is the subject of this report.

1.2 NEAR-NET FORGING PROCESS DESCRIPTION

The conventional approach to produce an integrally stiffened aluminum or Al-Li cylinder for a launch vehicle propellant tank or dry bay structure is to machine panels from thick plate. Depending on the desired finished diameter, between four and eight panels are then formed and welded together on elaborate assembly fixtures to produce a complete cylinder. Typically 95% of the starting material is converted into worthless chips using this method. Additionally, significant recurring costs are incurred from forming, welding, and inspection during assembly.

In contrast, the net forging process is a new manufacturing approach which can be used to produce single-piece, integrally stiffened aluminum or Al-Li cylinders up to 30 feet in diameter and 10 feet in length on commercially available equipment. Near-net forging is an adaptation of the conventional ring rolling process which is used to produce seamless aluminum rings for today's launch vehicles and aircraft.

The near-net forging process can be logically subdivided into four elements including ingot conversion, preform fabrication, drum rolling, and secondary processing. These elements are illustrated in Figures 1-2 through 1-5 and described in the following paragraphs.

Ingot Conversion. Conventional hot forging operations are employed to convert a rectangular ingot slab into a back extruded cylindrical "blocker". Conversion operations are illustrated in Figure 1-2. The thick walled blocker is approximately the same height as the final part will be after near-net forging. Hot working the metal in all three orientations facilitates the desired shape change and serves to break down the as-cast grain structure of the starting ingot. A refined grain structure improves mechanical properties in the finished part.

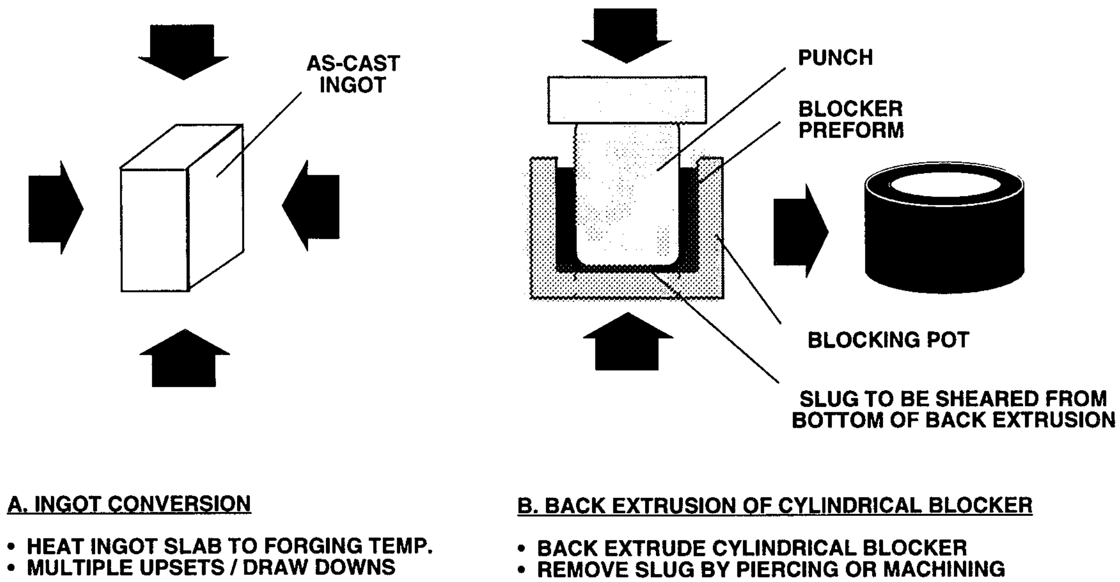


Figure 1-2. Ingot conversion and back extrusion operations.

Preform Fabrication. The next step in the process is to increase the diameter of the blocker to near finished size and move material axially along the cylinder to accommodate circumferential features in the finished part. The resulting rough shape is refered to as a "preform". Preform fabrication is illustrated in Figure 1-3.

As illustrated in figure, the cylindrical blocker is first ring rolled in the conventional manner to an intermediate diameter. A standard cylindrical drive roll and mandrel are used for this "pre-pass" rolling operation to produce a uniform rectangular ring cross section. Next, contoured drive roll and mandrel sleeves are installed on the ring mill and rolling is continued. The contour mandrels are machined with the reverse image of the desired cross sectional geometry of the aluminum ring. Depending upon the acuteness of the circumferential features to be formed during the near-net forging process, multiple contour rolling operations using a series of contour rolling mandrels may be required. Each successive mandrel is machined with a progressively more acute contour than its predecessor so that a gentle contour is initially formed, progressing to the final contour with each contour rolling operation. At the end of the contour rolling step the preform is slightly smaller than that targeted for the finished near-net forged part.

Contour preform fabrication is a delicate balancing act. During rolling, the diameter of the aluminum ring is growing at the same time that material is being moved and gathered axially. The goal is to reach the desired diameter and cross section at the same time. If the proper cross section is achieved too early there is a risk that material will be drawn back out of the thicker areas in the cross section to feed further diameter growth. Drawing material from the thicker areas results in incomplete fill of these areas.

After contour rolling the preform is cold sized to make it as round as possible. It is then machined on all surfaces to expose clean metal for near-net forging and to precisely control the contour going into the forging operations. Uniformity of fill during near-net forging is dependent upon the accuracy of the preform contour.

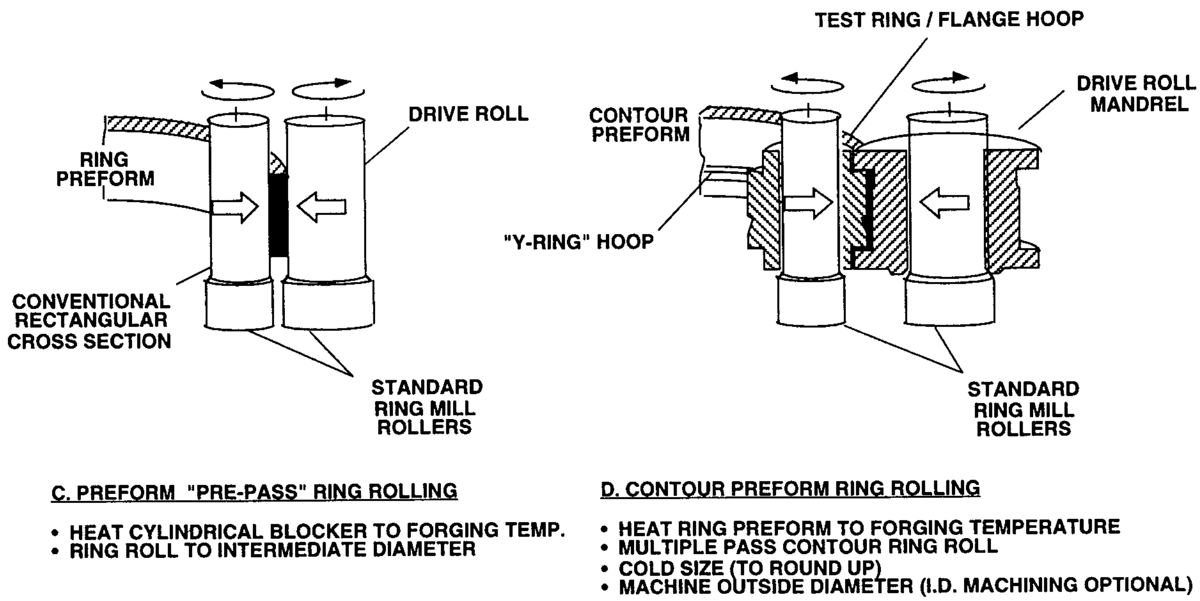


Figure 1-3. *Contoured preform forming operations.*

Near-net forging. The aluminum contour preform is placed into a ring shaped steel drum tool which has the desired external stiffening pattern of the near-net forged part machined into its inside diameter. The contour preform and ring tool are rolled at elevated temperature on conventional ring rolling equipment. During rolling, the aluminum is forged into the steel ring tool cavities, forming the external features on the aluminum cylinder. Due to the contoured shape of the rolling mandrel, which matches the contour of the inside surface of the preform, the internal circumferential aluminum features on the part are maintained during the drum rolling operation. Drum rolling and near-net forging refer to the same operation and are used interchangeably in this report.

After near-net forging, the aluminum cylinder is extracted from the steel drum tool. Aluminum has a higher coefficient of thermal expansion (contraction) than steel. During cooling the aluminum forging shrinks away from the steel drum tool. Once the tool and forging have cooled sufficiently the drum tool is simply lifted off of the forging. The near-net forging and extraction operations are illustrated in Figure 1-4.

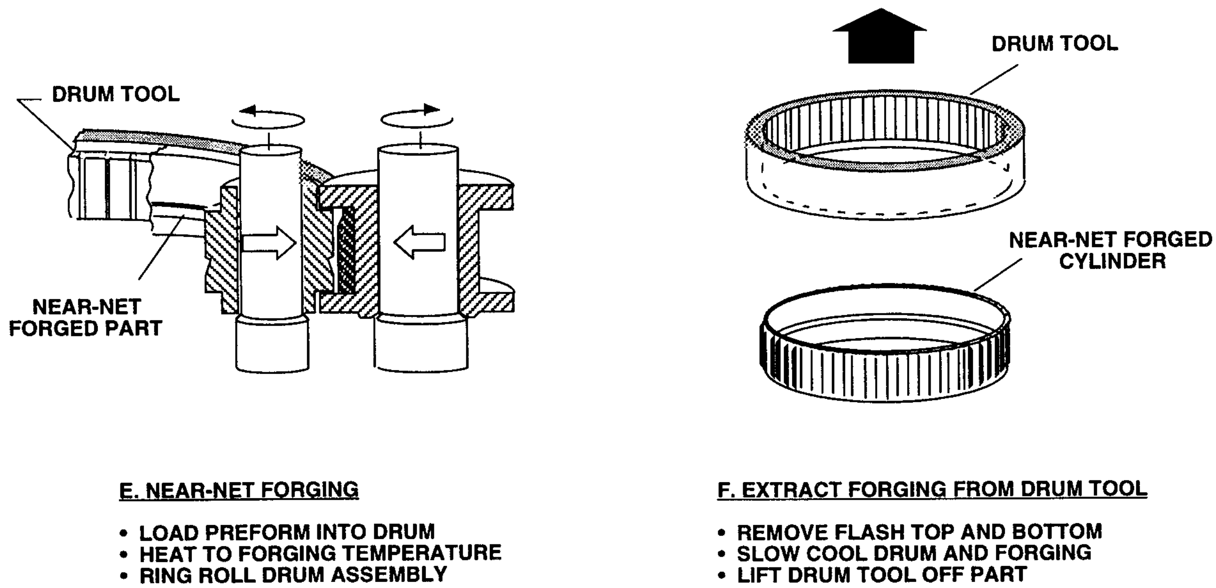


Figure 1-4. *Near-net forging and extraction operations.*

Secondary processing. To enhance mechanical properties, round, and increase diameter to the finished dimension the near-net forged cylinder is solution heat treated, quenched, and cold stretched. Conventional lathe turning of the inside surfaces and milling of the outside reduce part thickness to the desired final dimensions. This forging process is referred to as "near-net" because a minimal amount of post-forge machining is required. As a result, near-net forging uses less raw matemal and a higher material utilization percentage is achieved. The secondary processing steps are illustrated in Figure 1-5.

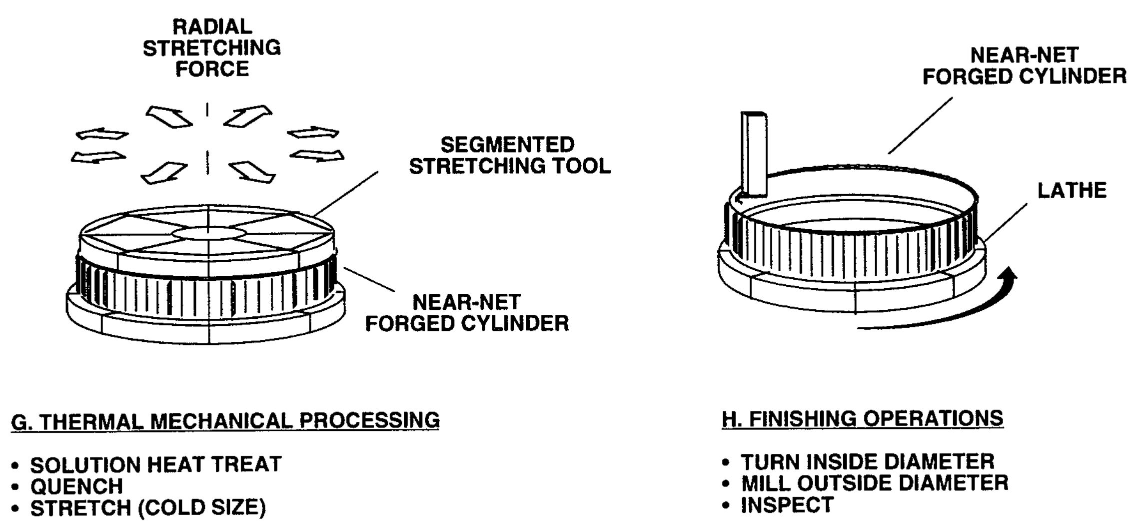


Figure 1-5. *Thermal mechanical processing and machining operations.*

Near-net forged cylinders of varying lengths can be welded together and with closure domes to produce a launch propellant tank as illustrated in Figure 1-6. Near-net forging can also be used to produce integrally stiffened non-pressurized structures such as adapters.

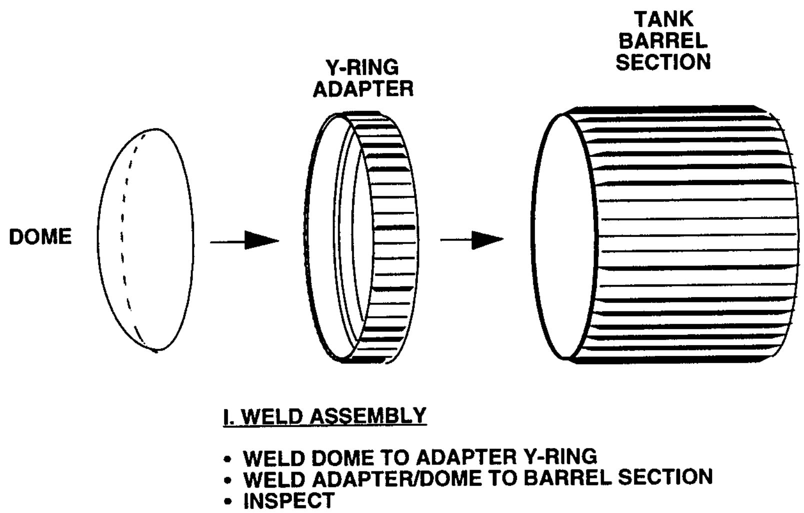


Figure 1-6. Propellant tank assembly using near-net forged components.

1.3 BENEFITS

As shown in Figure 1-7, the ultimate goal for the near-net forging process, when mature, is to achieve an overall cost reduction of approximately 50 percent compared with conventional manufacturing options for producing structures fabricated from Al-Li alloys. Cost savings of this magnitude will be achieved through a significant reduction in raw material requirements, resulting from a higher material utilization percentage / lower scrap rate. Furthermore, due to a reduced part count, and the elimination of labor intensive assembly operations, associated tooling, and quality inspections, additional cost savings will be realized.

Although a cost analysis of the near-net forging process was not a required task on this contract, a brief recurring cost summary is included in Section 3 of this report.

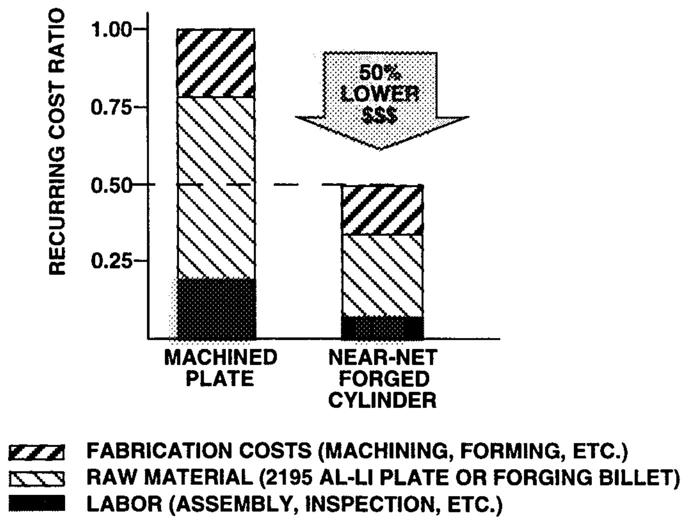


Figure 1-7. A 50% overall reduction in cost is the goal for near-net forging when mature.

1.4 GOVERNMENT / INDUSTRY COOPERATIVE PROGRAM

As illustrated in Figure 1-8, the near-net forging process is being developed under a unique government / industry cooperative partnership. Government partners include NASA Marshall Space Flight Center (MSFC) and NASA Langley Research Center (LaRC). Industry partners include: Lockheed Martin Astronautics, Huntsville, Alabama, the prime contractor responsible for system design, program management, and secondary processing; Wyman Gordon, Houston, Texas, who performed the ingot conversion and blocker preform back extrusion operations for the full scale near-net forging program; the Ladish Company, Cudahy, Wisconsin, responsible for preform fabrication and near-net forging on all programs; and the Shultz Steel Company, South Gate, California, who performed the thermal mechanical processing operations on the full scale near-net forgings.

Feasibility of the near-net forging process was demonstrated previously by Lockheed Martin Astronautics and Ladish Company on IRAD funding. An integrally isogrid stiffened 33-inch diameter subscale cylinder was produced using aluminum alloy 2219. Further development of the near-net forging process, using Al-Li alloy 2195, was performed on a NASA LaRC sponsored contract (NAS1-19242, Task 7). This development work included basic process definition, tool design, parameter development (forging temperature, strain, strain rate, and total strain for each operation), parameter optimization, and cost analysis.

This NASA MSFC sponsored contract was the next step in the development of the near-net forging process. To demonstrate the viability of near-net forging full scale hardware, four 170-inch diameter adapters were manufactured using the processing parameters and tooling concepts developed on the NASA LaRC subscale program. Subsequently, on other contracts, two of the four near-net forged adapters will be machined and welded to end domes and a barrel section to produce an advanced structural technology demonstration tank. This cryogenic propellant tank, which will be produced entirely from near-net technologies and alloy 2195 aluminum-lithium, is projected to be assembled and tested at NASA MSFC.

The integrated near-net forging development and demonstration effort is a very successful example of a Government / Industry Partnership working effectively and efficiently to develop a new technology.

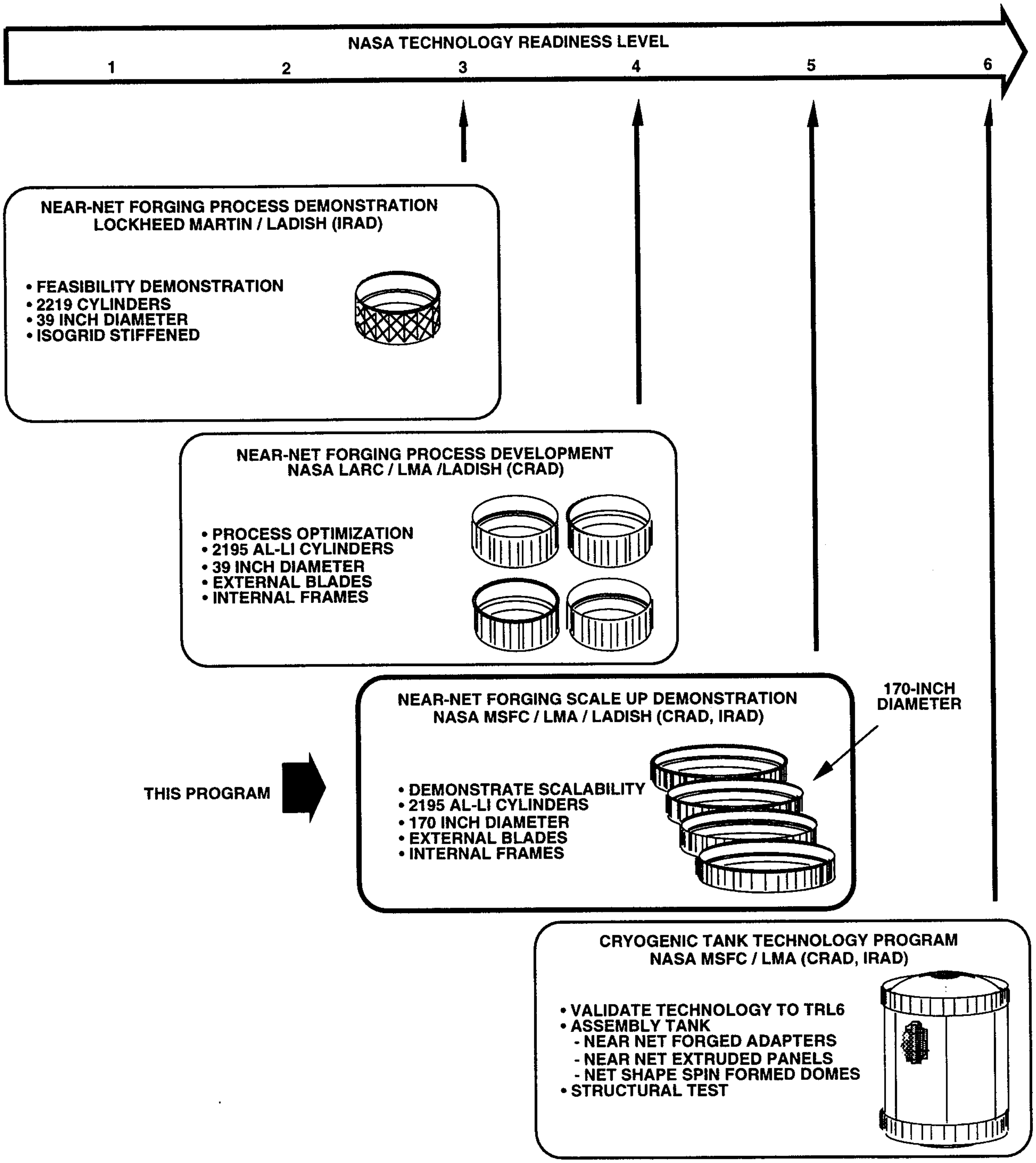


Figure 1-8. Government / Industry cooperative near-net forging development programs.

SECTION 2

NEAR-NET FORGING PROGRAM DESCRIPTION

The objective of this NASA Marshall Space Flight Center (MSFC) sponsored program was to demonstrate scale-up of the near-net forging process by fabricating integrally stiffened Al-Li structures directly applicable to space launch vehicles. Specifically, four 170-inch diameter, integrally stiffened, y-ring adapters were manufactured using Al-Li alloy 2195.

The first two y-ring adapters manufactured were designated pathfinders. The first pathfinder was used to proof the tooling and near-net forging processing parameters. The second pathfinder was used for mechanical properties testing and weldability evaluations. Lessons learned from the pathfinders were incorporated into the tools and processing parameters. Two "flight quality" adapters were then near-net forged. Subsequently, the two flight quality adapters will be welded to net shape spin formed domes and a barrel section assembled from near-net extruded panels to form an advanced technology cryogenic propellant tank. Tank assembly will be accomplished under a government/industry cooperative effort known as the Cryogenic Tank Technology Program (CTTP). The CTTP tank and one of the near-net forged y-ring adapters is illustrated in Figure 2-1.

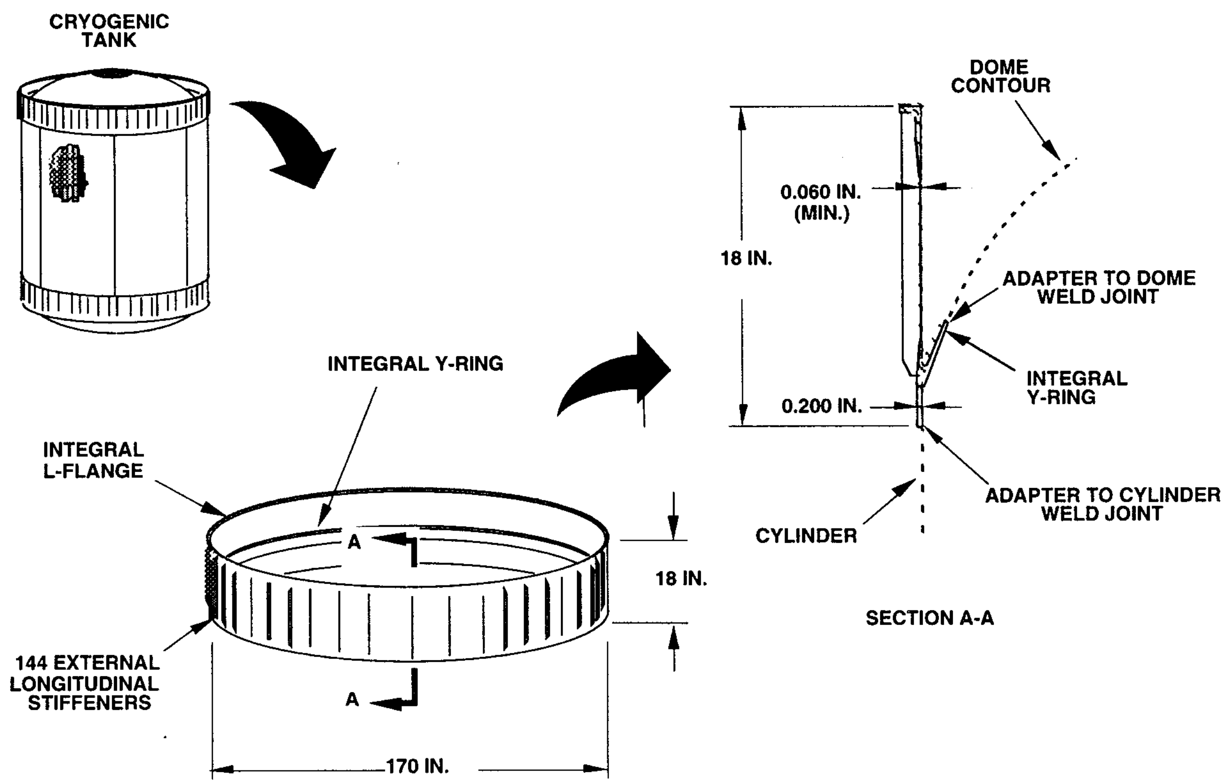


Figure 2-1. The objective of this program was to demonstrate scale-up of the near-net forging process by producing four 170-inch diameter y-ring adapters. Two of these adapters will be included in an advanced technology cryogenic propellant tank.

Weldability evaluations of near-net forged 2195 aluminum-lithium material were also performed on this contract. Thermal mechanical processing, mechanical testing, and finish machining of the y-ring adapters is being funded by other contracts. Results from these activities will be reported elsewhere.

Descriptions of the near-net forging tasks performed on this contract are presented in this section. A copy of the final report produced by Ladish, documenting all their work is included in Appendix B. Results of the weldability investigation is summarized in Section 4.

2.1 DESIGN

The design process for a near-net forged component progresses backwards along the steps of the manufacturing approach. The process begins with the desired configuration of the finished part. A design for the rough near-net forging can then be defined based on tolerances, stretching requirements, and forging considerations. In turn, near-net forging configuration requirements, machining tolerances, and forging considerations dictate the design of the contoured preform. Achieving the finished preform on this program required an intermediate diameter and a finished diameter shape. Therefore there we actually had two preform designs. The following sub-sections summarize each of these steps for the 170-inch diameter y-ring adapters.

The machined y-ring adapter and the required near-net forging were designed by Lockheed Martin Astronautics with forging related producibility insight provided by the Ladish Company. Once the y-ring adapter near-net forging design was established, the contour preform and near-net forging tools were designed by the Ladish Company. Part extraction tooling aides were designed and fabricated by Lockheed Martin and supplied to Ladish.

2.1.1 Machined Y-ring Adapter Design

A sketch showing the near-net forging, from which the Y-ring adapter will be machined, is included in Figure 2-2. Portions of the initial released machined Y-ring drawing are included in Figures 2-3 and 2-4.

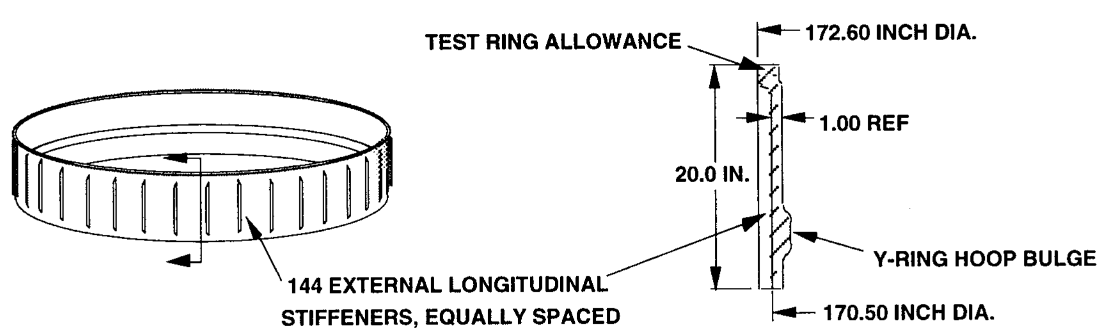


Figure 2-2. Sketch of as-near-net forged, heat treated and stretched, y-ring adapter (2195-T8).

As shown on the drawings, the test ring will be parted-off from the top flange area of the adapter. The inside diameter will be fully machined. The y-ring will be machined to extend inward and upward at a 16 degree angle. The outside diameter will be lathe turned at the bottom portion of the adapter to form an adapter-to-barrel weld land. The flange on the opposite end will be machined to design thickness and 288 equally spaced, 1/4 inch diameter, holes will be drilled around the circumference. The entire outside surface, including the stiffeners and the membrane pocket between stiffeners, will then be milled. The minimum membrane thickness will be 0.060 inch. Design of the machined Y-ring adapter was accomplished under LMA IRAD. Final release of the machined adapter drawing will occur after completion of a mechanical properties test program and final stress analysis; both being performed on IRAD funding.

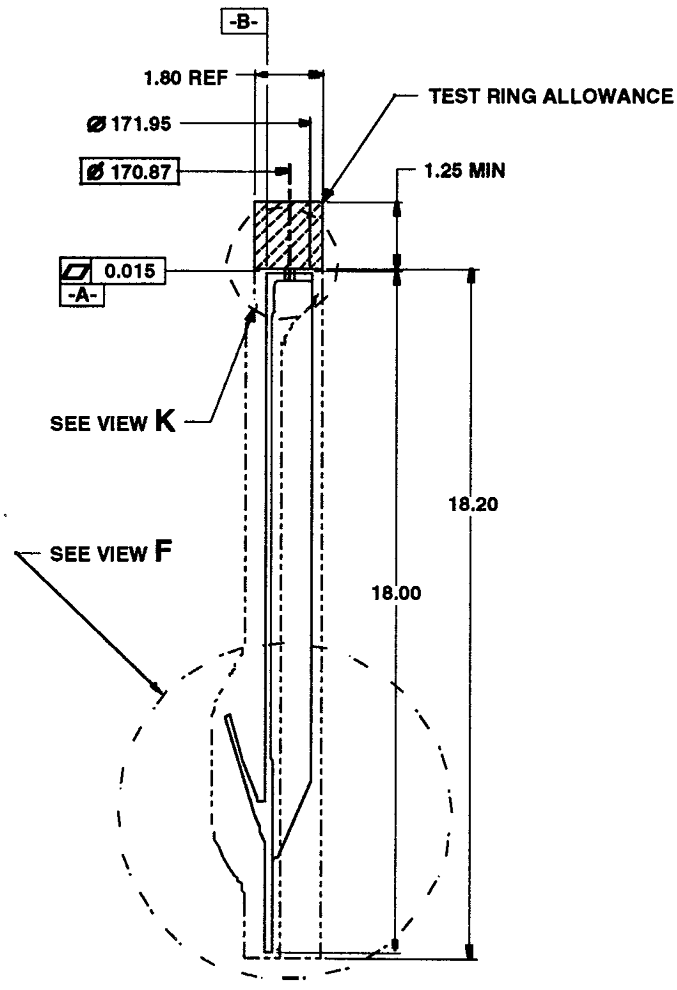


Figure 2-3. Axial-radial plane cross section of near-net forged, and machined, y-ring adapter (not final released).

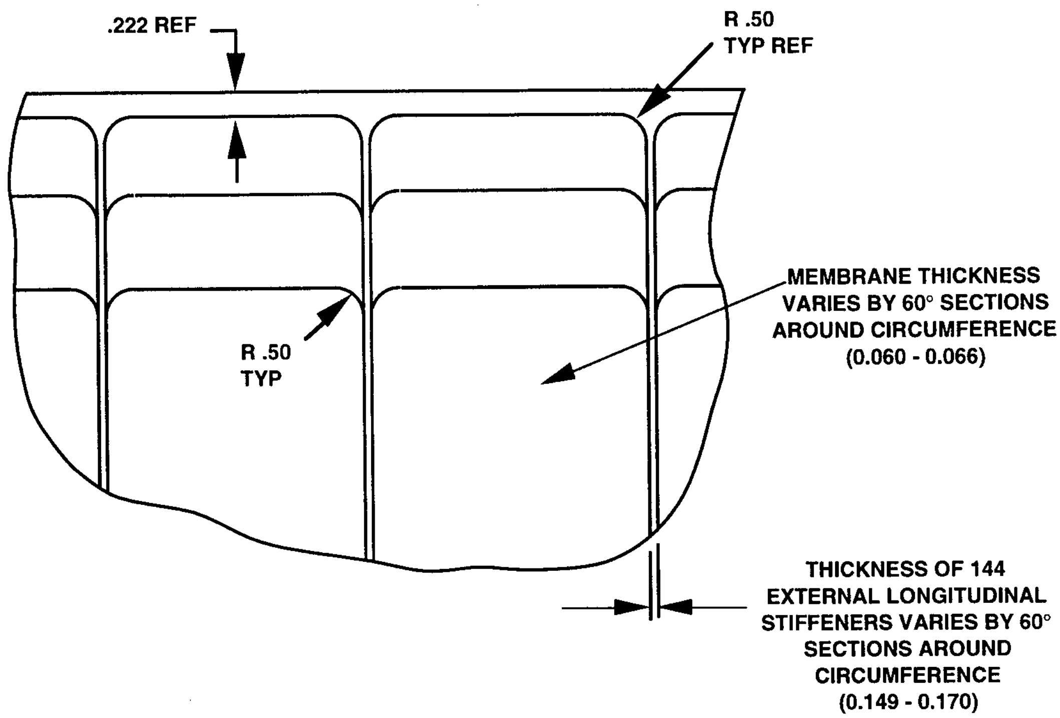


Figure 2-4. *Axial-circumferential plane view of near-net forged, and machined, y-ring adapter (not final released).*

2.1.2 Near-Net Forging Design

Originally it had been planned that the NASA LaRC sub-scale near-net forging development program would be completed prior to this full scale effort. However, since the LaRC program ended up over-lapping this program, design producibility considerations such as minimum preform thickness and optimum stiffener design geometry, were not available when the schedule required that the full scale adapter be designed. To assure that quality near-net forged adapters could be produced on this first-of-a-kind program, no attempt was made to minimize the preform thickness. Additionally, the stiffeners were designed with generous draft angles and a generous forging envelope.

The y-ring adapters were near-net forged per LMA engineering drawing No. NNF-D-002, included in Figure 2-5. After heat treatment and cold stretch the near-net forged y-ring adapter is a ring, 170.50 inches at the outside diameter of the membrane by 20 inches tall. Around the outside circumference 144 evenly spaced, integral blade stiffeners extend axially along the length of the cylinder. The stiffeners merge into a flange on the top end of the adapter forging. The volume of material provided for the flange also includes a surplus ring of material. This ring serves as a tag end for mechanical property verification testing. A single hoop or bulge exists on the inside circumference of the adapter. The dome-to-adapter y-ring flange will be machined from this localized allocation of material.

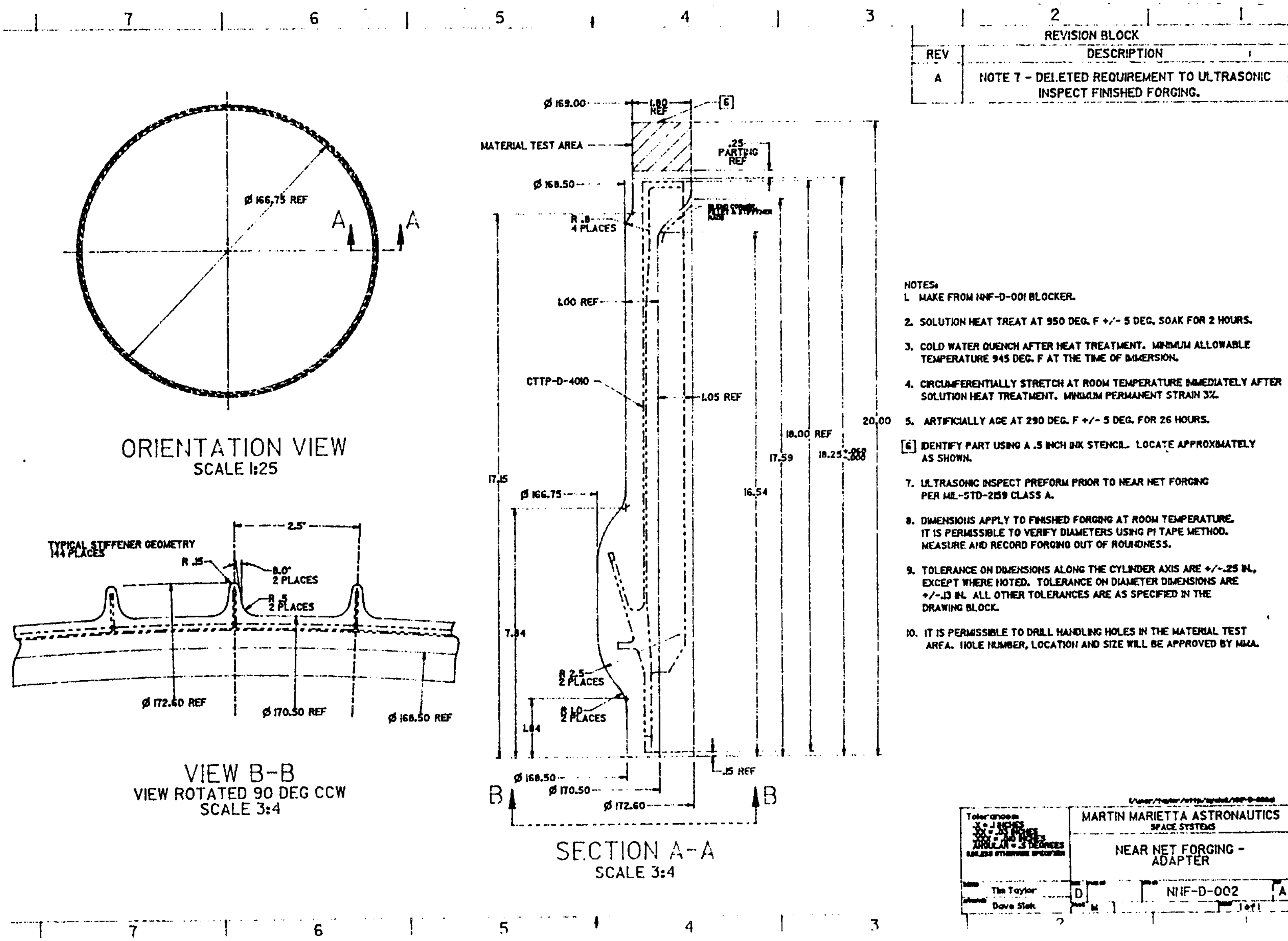


Figure 2-5. LMA engineering drawing of near-net forged y-ring adapter.

2.1.3 Preform Design

LMA and Ladish designed the preform used to produce the y-ring adapter near-net forgings. A drawing of the y-ring adapter contour preform is included in Figure 2-6.

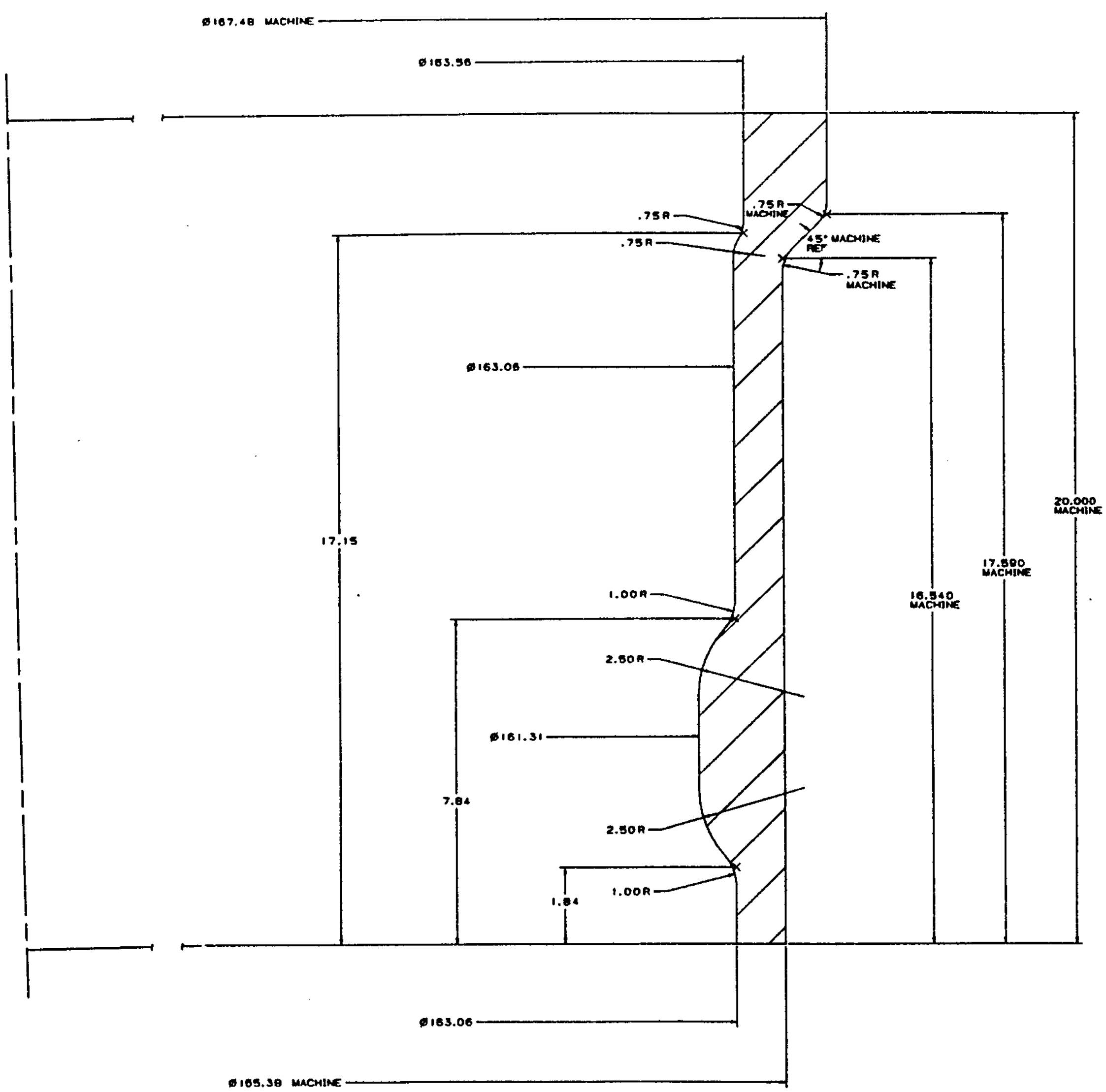


Figure 2-6. Contour preform design.

2.2 TOOLING

The tooling requirements for this program were broken down into two categories, 1) tools required to produce the contour preforms, and 2) tools required for the near-net forging operation. The tools will be briefly defined in the following sub-sections. The sub-sections are ordered consistent with the order of the use of the tools in the manufacturing process.

The forging contractor (Ladish) agreed to use universal mandrels and modify existing tooling where possible to reduce program cost while still meeting design requirements. Upon completion of the program, the Ladish provided mandrels were refurbished to their original condition and remain as Ladish property.

2.2.1 Contour Preform Tools

The baseline contour preform rolling process consists of three separate rolling operations and two sizing operations.

The initial or "pre-pass" roll is a conventional ring rolling operation which utilizes a conventional cylindrical mandrel to produce a ring with a rectangular cross section. This operation is illustrated in Figure 1-3 (C). The next operation, designated as the "first pass" contour rolling operation, employs a gently contoured idler mandrel which begins the formation of internal bulge features at the y-ring and test ring/flange locations. In the baseline process, the test ring/flange bulge is partially transferred to the outside circumferential surface during an intermediate hot sizing operation which uses conventional sizing dies. Final forming, including filling of the hoop bulges, occurs during a "second pass" contour rolling operation. The contour rolling operation was illustrated in Figure 1-3 (D). Finally, the preform is cold sized, using contour die segments, to round it up and ensure that it is at the proper diameter prior to machining to fit into the drum tool.

To support these contour rolling operations, Ladish designed and fabricated a "first pass" idler mandrel, a "second pass" idler mandrel, a "second pass" drive roller, and contour sizing dies.

2.2.2 Near-Net Forging Tools

A 176 inch diameter 4340 steel rolled ring was purchased by the Ladish Company to produce the drum tool. This ring was shipped to Allied Engineering and Production Corporation (AEPC), Alemeda, CA, for machining. A drawing of the drum tool is included in Figure 2-7. A stiffener cavity slot being milled is shown in Figure 2-8. The finished machined drum tool is shown in Figures 2-9 and 2-10.

In addition to the drum tool, Ladish designed and fabricated both a contour idler mandrel and a drive roller to support the near-net forging operation. The drive roller resembles a "spool". Lips on both ends of the drive roller extend across the drum tool wall and over the top of the contour idler mandrel; effectively locking the drum tool in place. This prevents the drum tool from climbing in the ring mill during the drum rolling operation. The contour idler mandrel and drive roller are shown in Figure 2-11, as-installed in the ring mill prior to drum rolling.

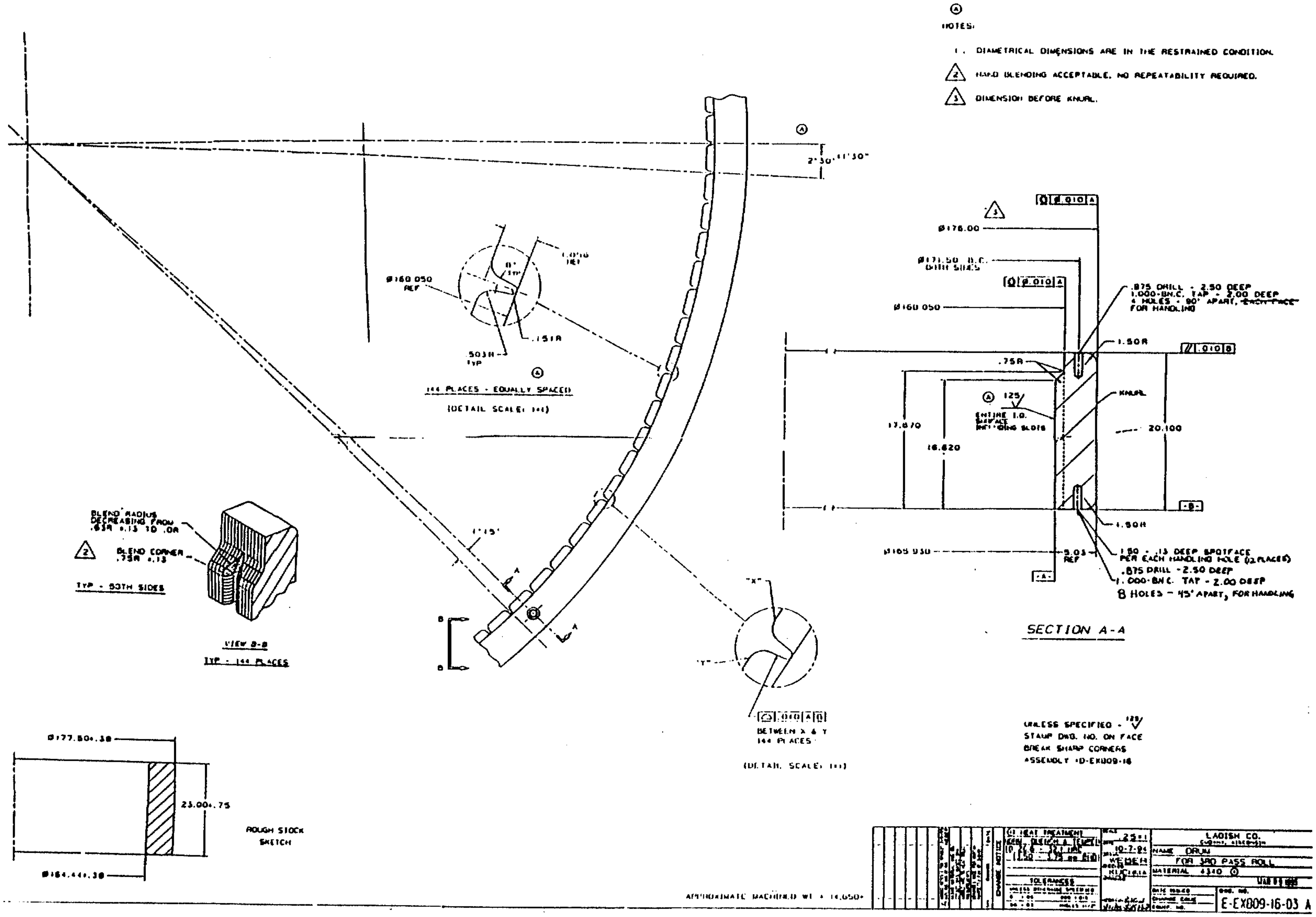


Figure 2-7. Ladish designed near-net forging drum tool.

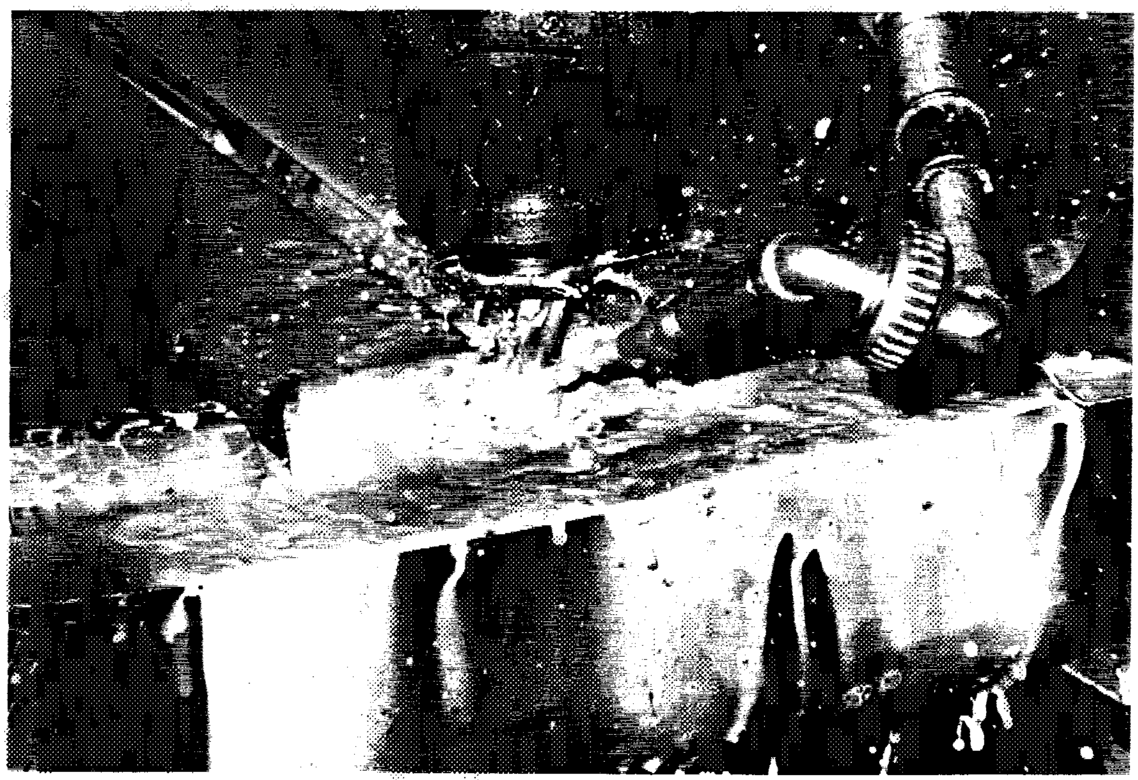


Figure 2-8. Stiffener cavity slot being milled in 4340 steel "drum tool" blank.

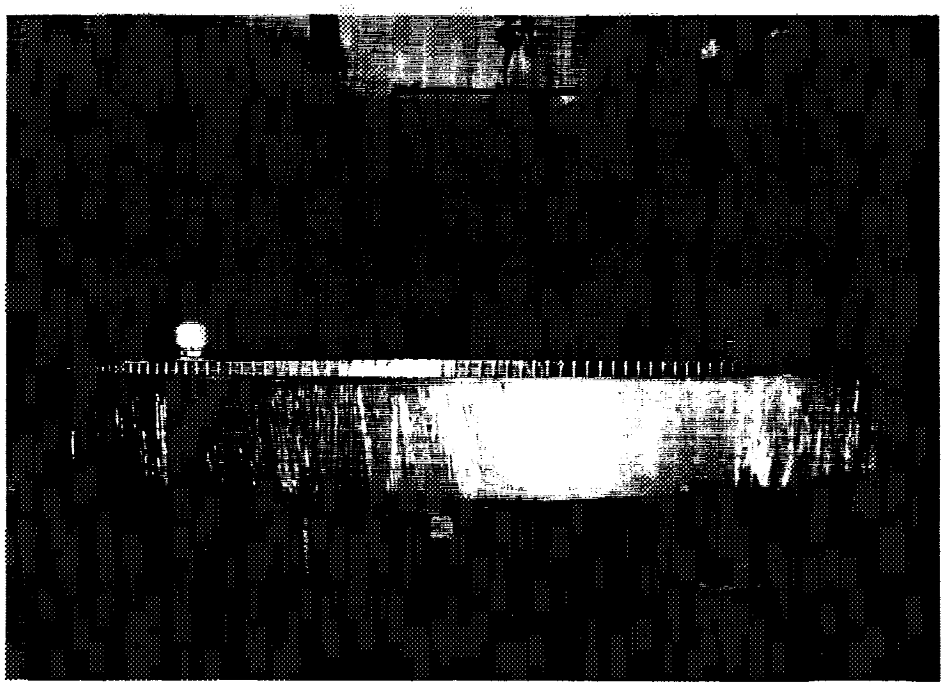


Figure 2-9. Near-net forging drum tool.

Figure 2-10. *Close-up showing machined "stiffener" slots in near-net forging drum tool.*

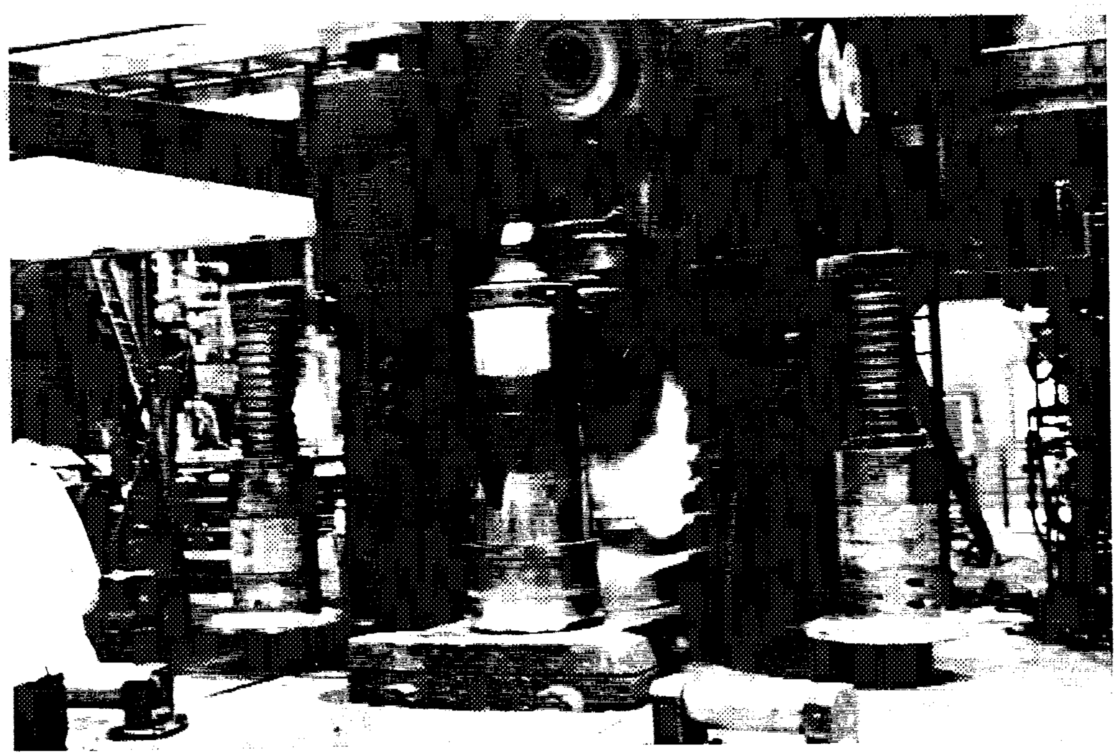


Figure 2-11. *The lower pre-heat flame is directed at the contour idler mandrel. The second flame up from the bottom is directed at the drive roller.*

2.2.3 Drum Tool Fill Level Sensors

As shown in the drawing included in Figure 2-12, six fill level sensor holes were drilled radially through the drum tool wall to intersect the apex of selected stiffeners. The fill level sensors were located at two circumferential locations and were axially located to be over the test ring/flange-to-stiffener intersection, over the y-ring bulge, and over the membrane areas. Periodically during drum rolling a fill level probe is inserted into the holes in the drum tool to check the near-net forged fill level of the stiffeners; much like a dipstick is used to check oil level in an automobile engine. The fill sensors allow a quick in-process stiffener fill rate comparison to be made between the test ring/flange, membrane, and y-ring bulge locations. The fill sensors also allow a determination to be made as to when the blade cavities are filled, thus avoiding over or under rolling of the near-net forged part.

2.2.4 Extraction Tooling Aids

Due to the thermal contraction deferential between the Al-Li part and the steel drum tool as they cool, and owing to the large diameter of the y-ring adapters, problems extracting the near-net forged part from the drum tool were not anticipated.

Nevertheless, jack screw block assemblies and several “centering wedges” were fabricated by Lockheed Martin under IRAD funding and donated to this program for use in extracting the near-net forged parts from the drum tool. These extraction aids were not required to meet the requirements of this contract. They were provided to the program at the sole discretion of Lockheed Martin.

After drum rolling and removal of the end flash, several of the long thin centering wedges are tapped into place between the near-net forged part and the inside diameter surface of the drum tool. The wedges assure that the y-ring adapter contracts uniformly away from the internal circumference of the drum. A design sketch of the centering wedges is included in Figure 2-13.

Additionally, jack screw block assemblies, shown in the design sketch included in Figure 2-14, are bolted to one end of the drum tool and are used to make sure the near-net forged part remains level during extraction and does not cock and bind in the drum tool.

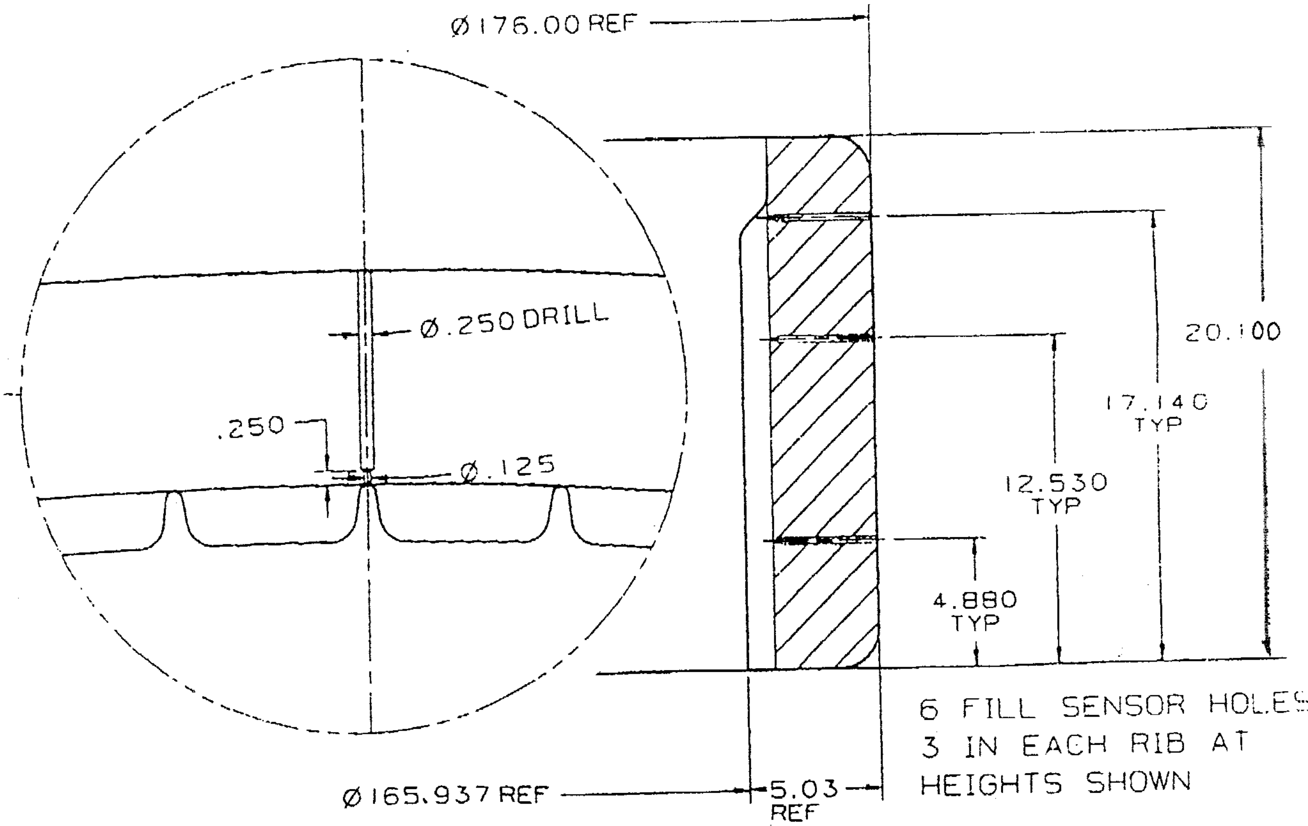


Figure 2-12. Fill level sensor holes were drilled into the drum tool to intersect with the apex of selected stiffener cavities.

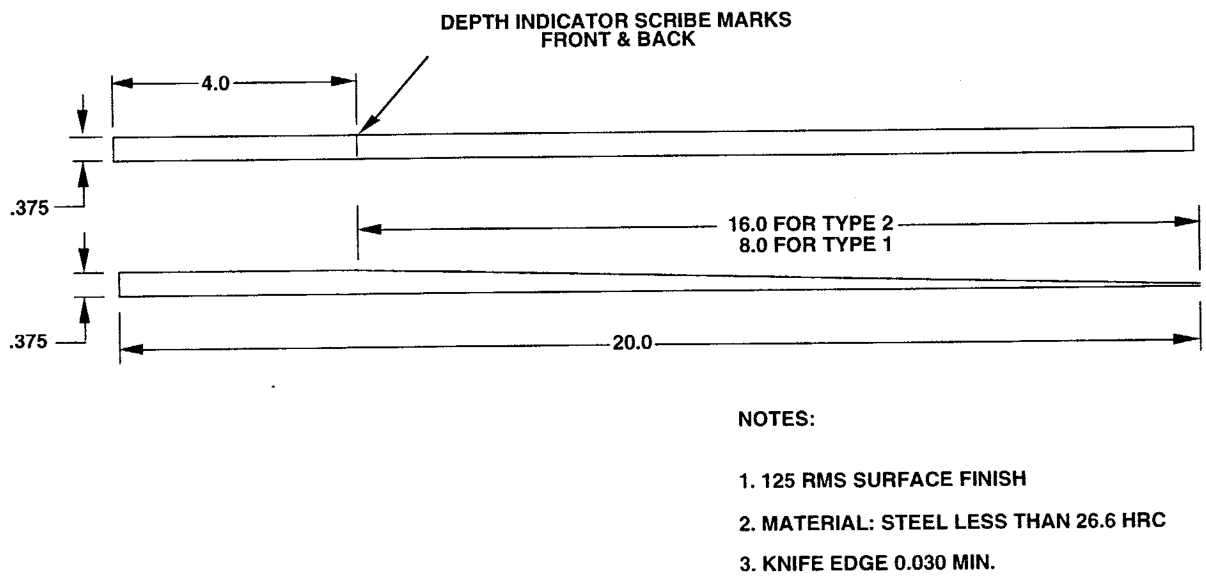


Figure 2-13. Lockheed Martin provided "centering wedges" to aid in part extraction.

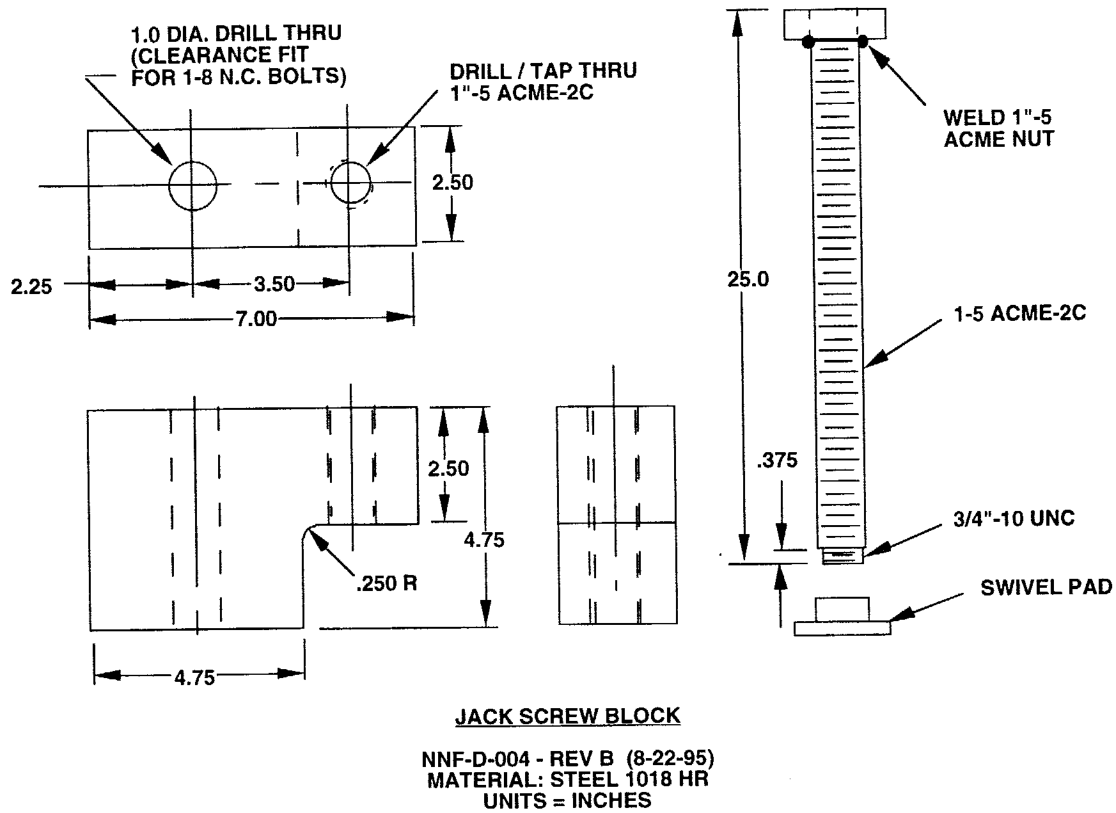


Figure 2-14. Jack screw block keep near-net forging from cocking in drum tool during extraction.

2.3 INGOT CONVERSION / BACK EXTRUSION OF CYLINDRICAL BLOCKERS

Two rectangular Al-Li alloy 2195 scalped ingots were purchased from Reynolds Metals Company (RMC) for use on the Y-ring adapter near-net forging program. The thickness and width dimensions of both ingots were 14 3/8 inches (ST) by 54 1/4 inches (LT), respectively. One ingot was 47 3/4 inches long (L), the other was 50.1 inches long (L). The orientation designations shown in parenthesis refer to the as-cast ingot orientations. The approximate weights of the ingots were 3,650 and 3,787 pounds respectively. Certifications for the ingots, Mill Heat No's. RYC940Z423A and RYC114027A, are included in Appendix B.

The ingot was shipped to Wyman Gordon in Houston Texas. Wyman Gordon was contracted to perform the ingot conversion and back extrusion operations to produce four cylindrical blocker preforms from the two ingots.

Ingot must be hot worked to break-up the as-cast structure producing a uniform fine grain structure. Details of the ingot conversion and back extrusion processes employed by Wyman Gordon are considered confidential and therefore are not included in this report (the Wyman Gordon work is documented in a Lockheed Martin Proprietary Contact Report, No. CTTP-LIB-1350).

In summary, however, 850°F was established as the preheat and wash heat temperatures for the ingot conversion and back extrusion operations; all forging operations were performed in the 850°F to 750°F range. All tooling was heated to above 500°F and was lubricated with a proprietary oil/graphite mixture. The ingot was upset in multiple orientations, as shown in Figure 2-15, and was forged to produce a round "biscuit" billet. The billet was then back extruded to produce the 45 inch outside diameter by 31.3 inch inside diameter by approximately 43-inch tall cylindrical blocker shown in Figures 2-16 and 2-17. The 43-inch tall cylinder was parted in half to produce two blocker preforms, each approximately 21.5-inches tall, as shown in Figure 2-18. Two cylindrical blockers were produced from each ingot for a total of four blockers.

It should also be noted that the axial orientation, or back extrusion axis, of the cylindrical blocker corresponds to the transverse orientation of the as-cast ingot.

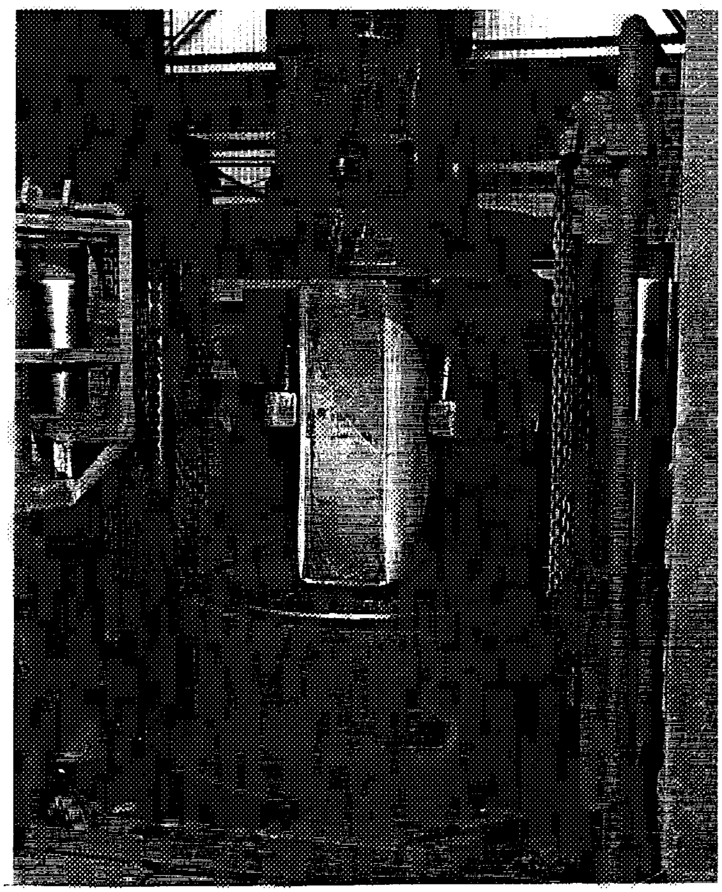
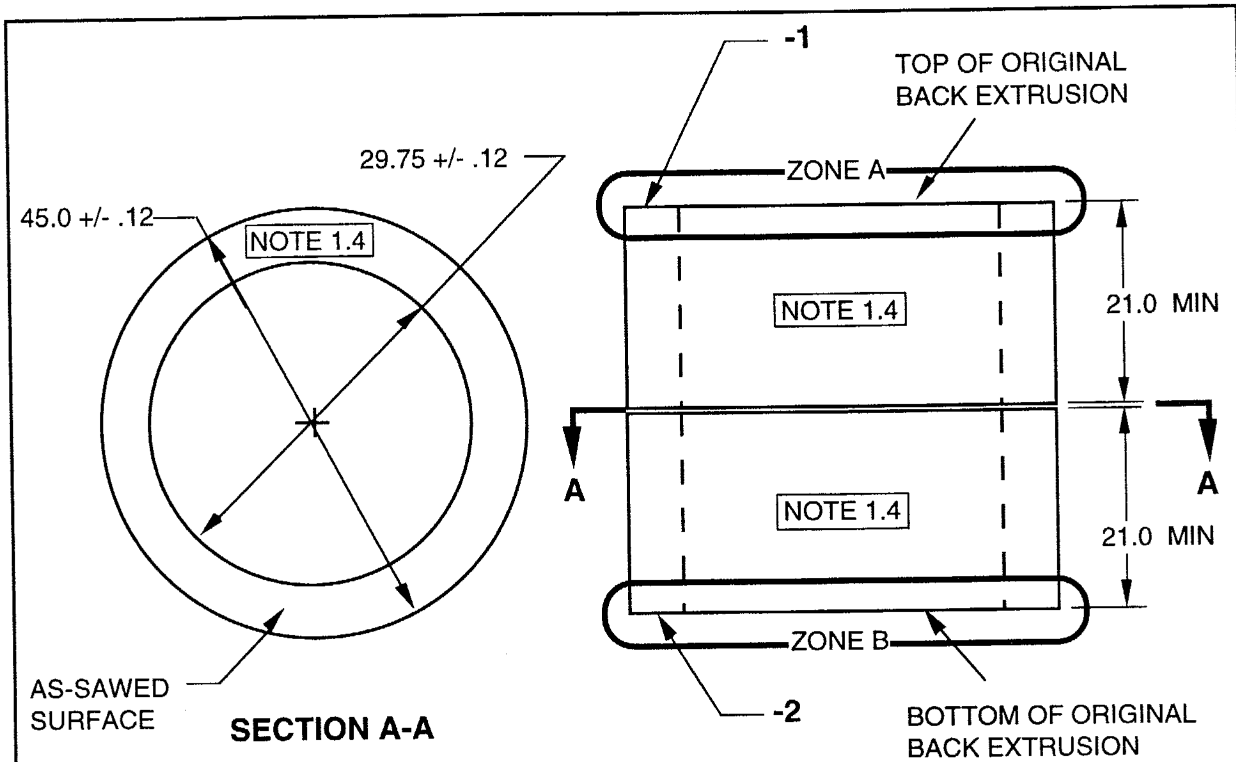


Figure 2-15. Upset conversion of Al-Li 2195 ingot.



NOTES:

1.1 INSIDE DIAMETER, OUTSIDE DIAMETER, AND ONE END OF EACH RING TO BE LEFT IN THE AS-EXTRUDED CONDITION. THE OPPOSITE END OF EACH RING CAN BE LEFT IN THE AS-SAWED CONDITION.

1.2 CONDITION ALL SURFACES TO REMOVE SHARP CORNERS, CRACKS AND SURFACE DEFECTS.

1.3 END EFFECTS ARE ANTICIPATED AND PERMISSIBLE IN ZONES A AND B

1.4 MARK EACH RING USING A STENCIL AND PERMANENT INK WITH THE PART NUMBER NNF-D-007, DASH NUMBER, INGOT DROP OR HEAT NUMBER, AND SELLER'S PART NUMBER. MARK ON THE OUTSIDE DIAMETER AND ON ONE END OF EACH RING AS SHOWN. MARKING METHODS THAT SCRATCH OR LEAVE AN IMPRESSION ARE PROHIBITED.

1.5 APPLY PROTECTIVE COATING TO ALL SURFACES TO PREVENT OXIDATION COATING MATERIAL TO BE APPROVED BY LMA PRIOR TO USE. WRAP PARTS IN HEAVY PLASTIC AND PACKAGE IN SUCH A MANNER THAT ALL SURFACES WILL BE PROTECTED FROM SHIPPING DAMAGE AND THE PART IDENTIFICATION IS VISIBLE.

DRAWING - NNF-D-007
8 November 1995

Figure 2-16. Back extruded cylindrical blocker preform drawing.

Figure 2-17. 45 .0 inch outside diameter X 31.3 inch inside diameter X 43 inch tall Al-Li 2195 back extruded cylinder.

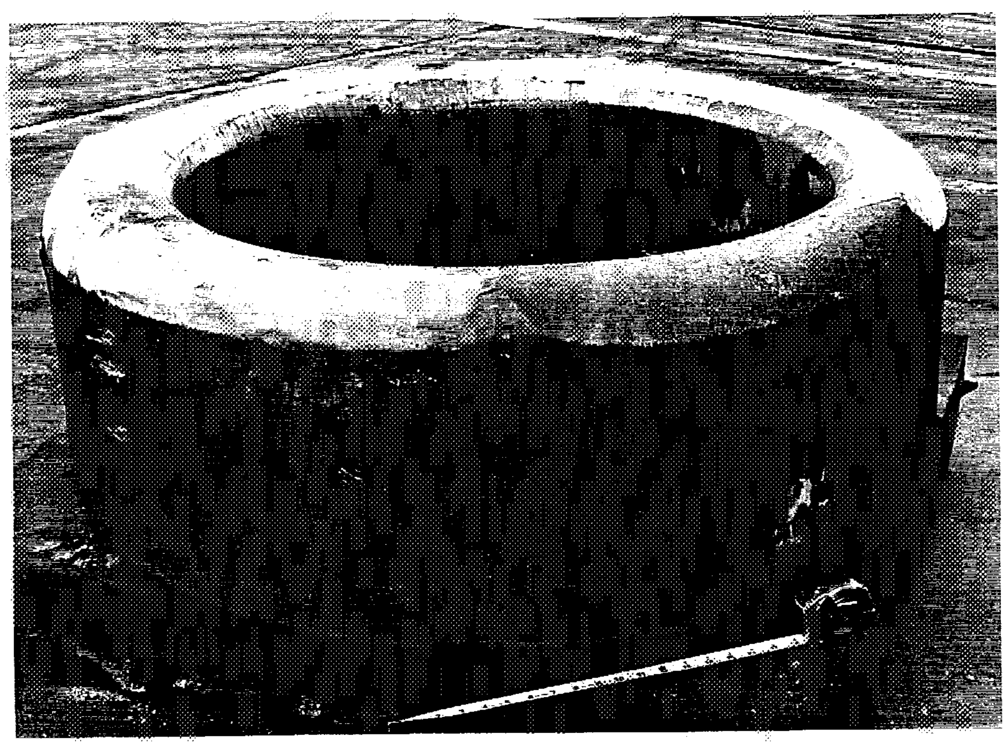


Figure 2-18. Blocker preform.

2.4 CONTOUR PREFORM RING ROLLING

2.4.1 Contour Preform SN #1

Since the first blocker preform, SN #1, was essentially a contour preform process proofing article, it was determined that it should under go all contour preform fabrication operations before any processing was performed on the remaining three blockers. In this manner, minor changes to the tooling or processing parameters could be made before the remaining three contour preforms were fabricated.

The pre-heat temperature was 825°F for all contour preform fabrication operations. The minimum rolling (or local sizing) temperature was 650°F. Whenever the preform temperature fell below 650°F, a wash heat was required. All tooling (mandrels and drive roller) was heated to 300°F minimum.

Prior to rolling, Ladish performed a flattening operation to establish the height of the preform. The flattening operation was followed by a conventional ring rolling or "pre-pass" rolling operation to increase the diameter of the rectangular cross section preform. This was followed by the first pass contour rolling operation.

Ladish reported that the first pass rolling and local sizing operations did not go completely as expected. The "gentle" hoop bulges did not completely fill before the targeted intermediate ring diameter was achieved. Nevertheless, Ladish anticipated that the hoop bulges would eventually fill during the second pass contour rolling operation. Also, the local sizing operation, intended to push the test ring/flange bulge from the internal to the external surface was only partially successful. The local sizing operation caused the cylindrical ring to become tapered (resembling a truncated conic section).

Although the tapered ring did straighten back out, complete filling of the circumferential contour features did not occur during second pass contour rolling. In fact, several times during both the first and second pass contour rolling operations the preform tended to climb in the ring mill causing portions of the circumference features that had formed to be flattened back out (when the preform climbs in the ring mill, the mandrel contour no longer matches the developing contour of the preform). Additionally, due to the requirement for material to be allocated into the large internal y-ring bulge hoop area while the ring is being rolled larger in circumference, some "suck-back" was observed on the outside surface of the preform directly opposite the y-ring bulge. Both the suck-back on the external surface and the incomplete filled and partially flattened contours on the internal surfaces are evident in the photographs included in Figures 2-19 and 2-20.

Figure 2-19. Contour preform, SN #1, contour not completely formed / partially flattened during contour rolling.

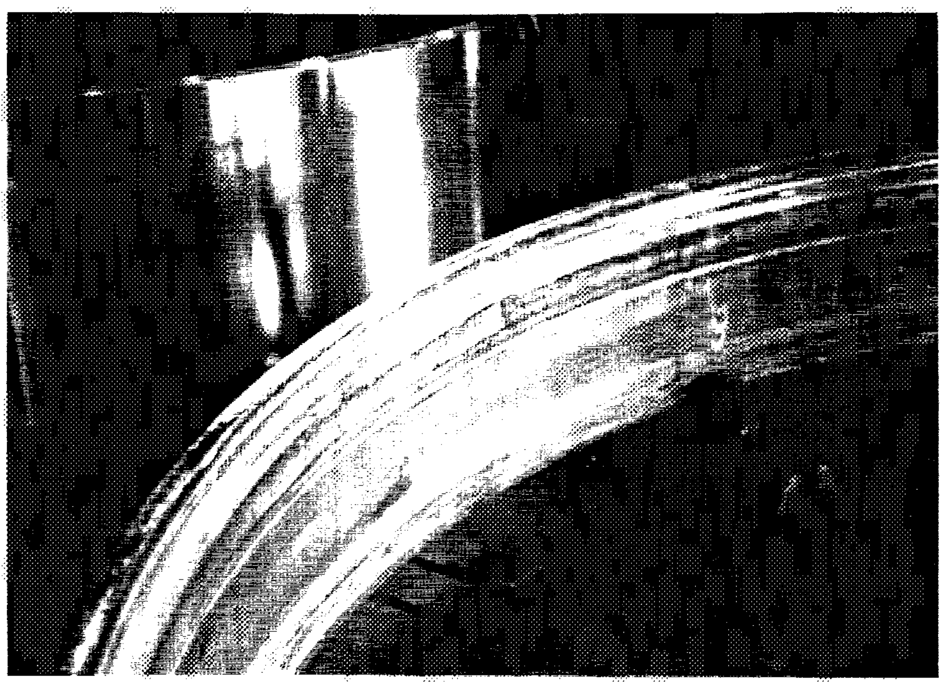


Figure 2-20. Contour preform, SN #1, contour not completely formed / partially flattened during contour rolling.

2.4.2 Contour Preforms SN's #2-4

Due to the under-fill experienced during contour rolling of the first preform, the remaining three blockers, SN's #2, 3, and 4, were pre-pass rolled to a smaller intermediate diameter than SN #1 The smaller intermediate diameter permits more contour rolling - more revolutions or passes - to fill the cross section before the target diameter is achieved. Still, during first pass contour rolling of the remaining preforms some areas of non-fill occurred in the contour at the membrane to test ring/flange and y-ring areas. The same problem with the preform being pushed out into a taper also occurred during the local sizing operation.

Although more contour rolling was performed during the first and second pass contour rolling operations, the same non-filled and partially flattened contour problems also resulted to differing degrees on the remaining three preforms. These rings also climbed in the ring mill. This was due to the mandrel initially only contacting the bottom of the preform (due to the taper) and the test ring/flange bulge which was still for the most part located on the internal surface. Gradually, the rings did once again become cylindrical and the test ring/flange bulge was translated to the outside surface.

Height control lips or rings were installed on the ring mill guide rollers to keep preforms SN's #3 and #4 from climbing. However, since these were off-the-rack items, they were not exactly the same height as the preforms. As a result, the preforms still could climb a few inches, wiping out or partially flattening the contour over large portions of the circumference.

In an attempt to promote complete filling of the cross section on contour preform SN #3 a higher temperature of 875°F was used. It was felt that a lower material flow stress, as a result of the higher temperature, would facilitate material movement during the contour rolling operation. The effect of the higher temperature on forging quality, however, proved negative. The higher temperature, hence lower flow stress for the 2195 Al-Li material, made the ring less stable and harder to control in the ring mill. Photos of contour preform SN #3, after first-pass contour rolling are shown in Figures 2-21 and 2-22. The suck-back on the outside diameter surface is clearly visible. Photos of contour preform SN #4 are included in Figures 2-23 and 2-24.

All of the preforms resulted in under-filled areas and or areas of flattened contour. Although not perfect, it was still felt that the preforms could be used to complete the program. They could either be used as is, or be fully machined on all surfaces to produce the desired contour. The decision was made, therefore, to proceed and near-net forge one of the preforms as a pathfinder.

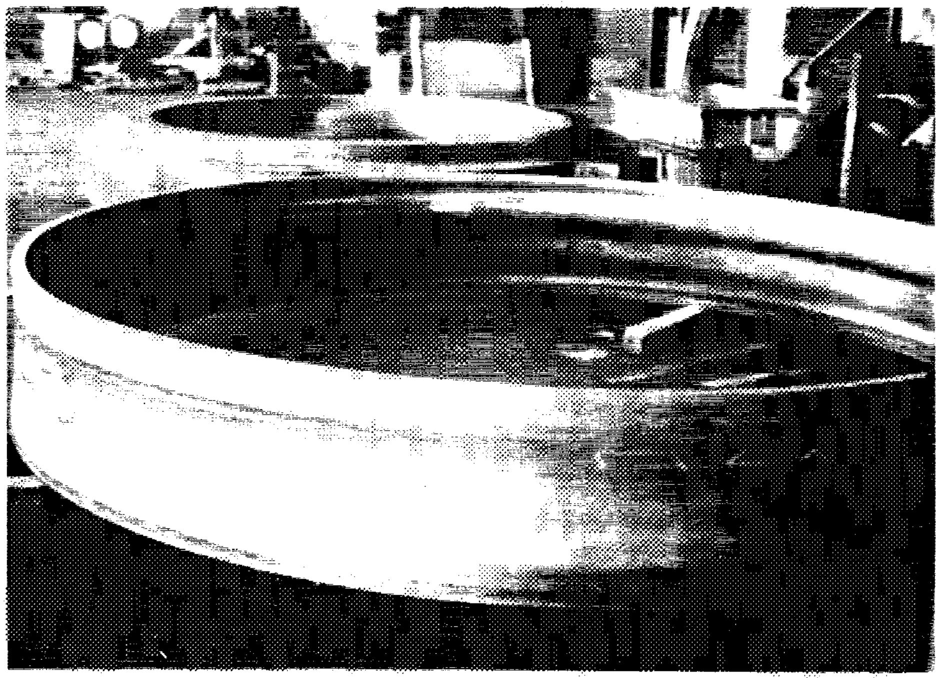


Figure 2-21. Contour preform, SN #3, contour not completely formed / partially flattened during contour rolling.

Figure 2-22. Contour preform, SN #3, contour not completely formed / partially flattened during contour rolling.

Figure 2-23. Contour preform, SN #4, contour not completely formed / partially flattened during contour rolling.

Figure 2-24. Contour preform, SN #4, contour not completely formed / partially flattened during contour rolling.

2.5 NEAR-NET FORGING PRODUCIBILITY ENHANCEMENT TASKS

2.5.1 2-D Finite Element Near-Net Forging Computer Model

On the complementary NASA LaRC contract, Ladish prepared a 2-D finite element near-net forging computer model to analyze forging temperature (material flow stress), force, and preform thickness using the full scale near-net forged adapter geometry. The purpose of the model was to aid in understanding and resolving the non-uniform fill rate issue which apparently had been the cause of lap defects observed in the blade stiffeners on the sub-scale cylinders in areas directly over the circumferential hoop bulges.

Two runs of the model compared alloys 2195 and 2219 to determine the effect of material flow stress on forging parameters. Although the 2-D model did not truly represent the 3-D near-net forging process, it served to establish upper forging parameter boundary conditions and provided significant insight into the near-net forging process. Additionally, Ladish ran several proprietary ring rolling parameter calculations which served to establish lower drum rolling parameter boundary conditions. This work is documented in the NASA LaRC, NAS1-19242, Task 7, final program report (NNSF-DOC-96-002).

In summary, it was determined that at a given strain rate and temperature, alloy 2195 exhibits a much higher flow stress than alloy 2219. Hence, the near-net forging temperature for alloy 2195 must be higher to achieve the same flow stress as 2219. For this contract we selected a 2195 forging temperature that was approximately 100°F higher than the most successful forging trial using 2219. Also, from the model it was determined that a higher forging tonnage was required to get complete stiffener fill (with less passes or revolutions).

2.5.2 Clay Modeling Simulations

Concurrent with the Ladish computer simulations, Lockheed Martin performed several clay modeling simulations using the full scale y-ring adapter stiffener spacing and geometry. This work was also performed on the NASA LaRC program. The purpose of these simulations was to develop and proof forging procedures to improve the non-uniform stiffener fill rate problem.

Tooling for this task included a full scale segment of the drum tool machined from a thick acrylic plastic plate and a full size 120° arc segment of the full scale rolling mandrel. The Plexiglas drum tool segment included two blade stiffener cavities. Different colored layers of clay, prepared to duplicate a section of the contour preform, were placed on the see-through acrylic tool. The mandrel tool was used to simulate the drum rolling process and forge the clay down into the acrylic drum tool.

As a result of the clay simulation work, a forging procedure was developed and demonstrated to address the non-uniform fill rate problem. In these simulations, a clay preform, with additional thickness in the circumferential hoop bulge was used to demonstrate that a more uniformly filled blade stiffener could be produced. Forging into the drum tool is slower opposite the thickened areas of the preform. It is assumed that fill rate is a function of forging pressure at the preform-to-drum-tool interface. This pressure is inversely related to the preform thickness. To compensate the clay studies indicated that if we allowed the mandrel to contact and deflect the thicker hoop area first, the thicker areas were given a head start. By finding the proper amount of head start the stiffener cavities over both the thick and thin regions can be made to fill at the same time.

2.6 NEAR-NET FORGING OF "PATHFINDER" Y-RING

2.6.1 Drum Rolling

Based on the quality of the contour preforms SN #4 was chosen to be the pathfinder y-ring adapter near-net forging. Contour preform SN #4 was cold stretched (rounded) prior to machining. The outside surface of the preform was then machined to fit into the drum tool and to provide a clean surface for forging into the drum tool stiffener cavities.

Based on the clay modeling simulations, and on the subscale near-net forging trials, the internal membrane surface on the contour preform was machined so that the thickness of the y-ring hoop bulge was increased by 0.200 of an inch (membrane wall became thinner). Another ring of "extra" 0.200 inch material thickness was also left on the internal membrane at the same axial location where the external stiffeners intersect into the test ring/flange. As with the added material thickness at the y-ring hoop, the intent of adding extra material at the stiffener to flange location was to provide material for filling under-filled areas on the contour preform and to provide a local forging head start at the stiffener-to-test ring/flange intersection to possibly aid in avoiding the formation of a lap. The SN #4 contour preform machining drawings are included in Figures 2-25 and 2-26.

The machined contour preform was loaded into the drum tool and both were heated together in a furnace to the targeted forging temperature of 925°F. The thermal expansion mismatch between the Al-Li preform and the steel drum tool caused an interference fit which effectively locked the preform into the drum. Locking the preform into the drum is critical to prevent rotational slip during the initial drum rolling passes. The heated contour preform / drum assembly was loaded onto Ladish's large ring mill and rolled ten (10) revolutions at the predetermined tonnage, as shown in Figure 2-27 and 2-28.

The flash was chiseled and ground-off the end faces of the drum tool and the fill sensor holes were drilled out. The near-net forged y-ring adapter / drum assembly was then allowed to slow cool in open air. As the two parts cooled the aluminum forging pulled away from the steel drum tool due to the lower coefficient of thermal expansion of the steel. Throughout the cooling process centering wedges were tapped into the emerging gap to keep the forging centered in the drum. This kept the near-net forging from binding in the stiffener cavities in the drum tool. As the forging circumference contracts so does the spacing between the stiffeners. If the part is not centered within the drum the narrowing distance between stiffeners will lock onto the wider stiffener cavity spacing of the drum tool. On the NASA LaRC contract considerable problems were encountered as a result of the forging cocking in the drum tool during extraction. On this program jack screw blocks were used to keep the part level during extraction to prevent binding. Figures 2-29 through 2-33 show the adapter during the various extraction procedures.

2.6.2 Results

A photograph of this adapter during near-net forging, is included in Figure 2-34. This "process pathfinder" verified tool designs, forging process parameters, and for the first time demonstrated the near-net forging process on a large scale. A slight under-fill of the stiffeners directly opposite the lower portion of the internal y-ring hoop bulge did exist. Even though one of the best preforms was used for this process pathfinder, the internal hoop on the preform was not completely filled and thus did not perfectly match the contour of the ring mill mandrel. As a result, during near-net forging, the internal bulge had to fill before the radial component of the rolling force could cause material to flow into the drum stiffener cavities.

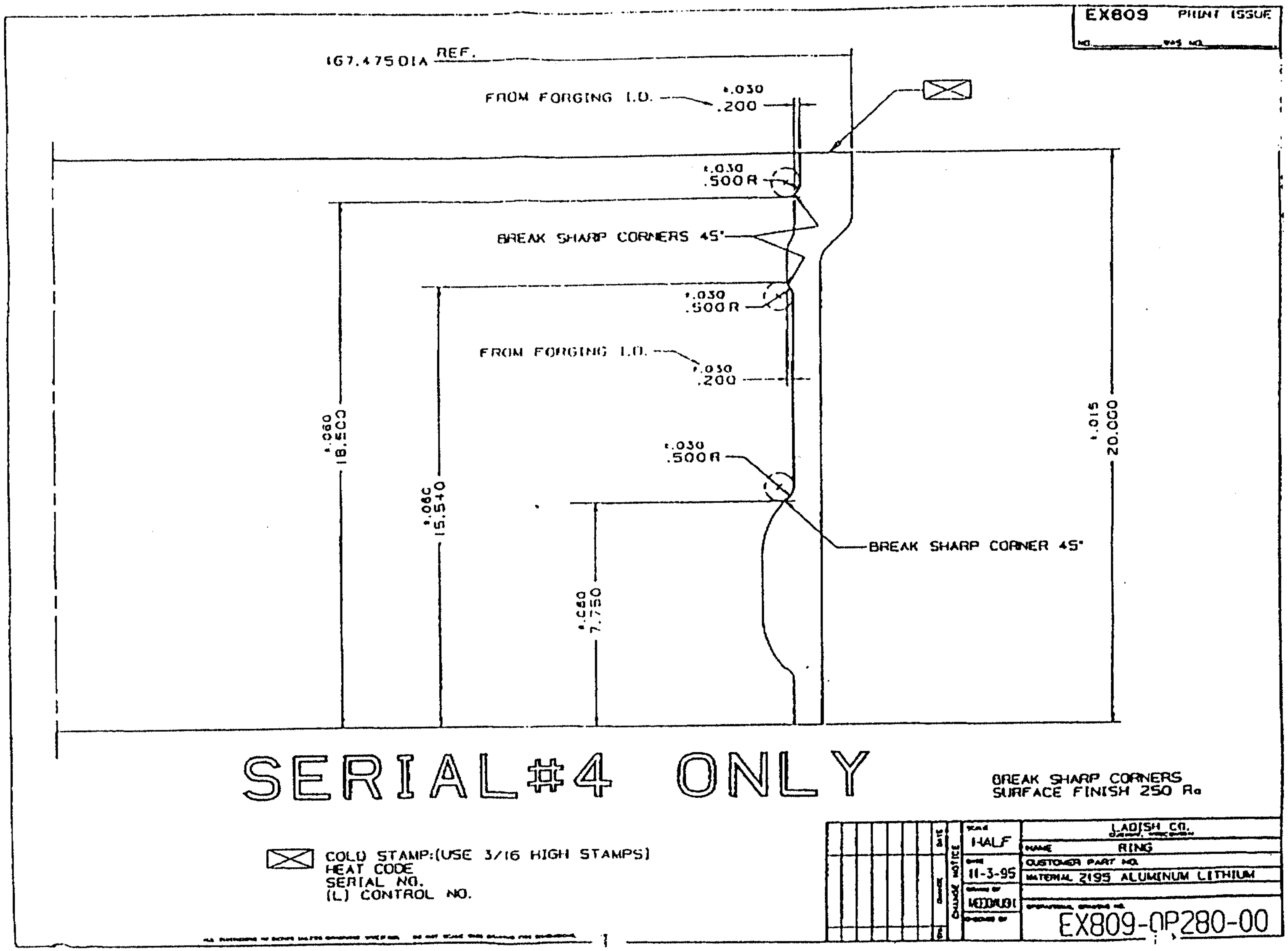


Figure 2-25. Contour preform SN #4 machining drawing provides 0.200 inch extra thickness at key locations to improve stiffener fill rate uniformity.

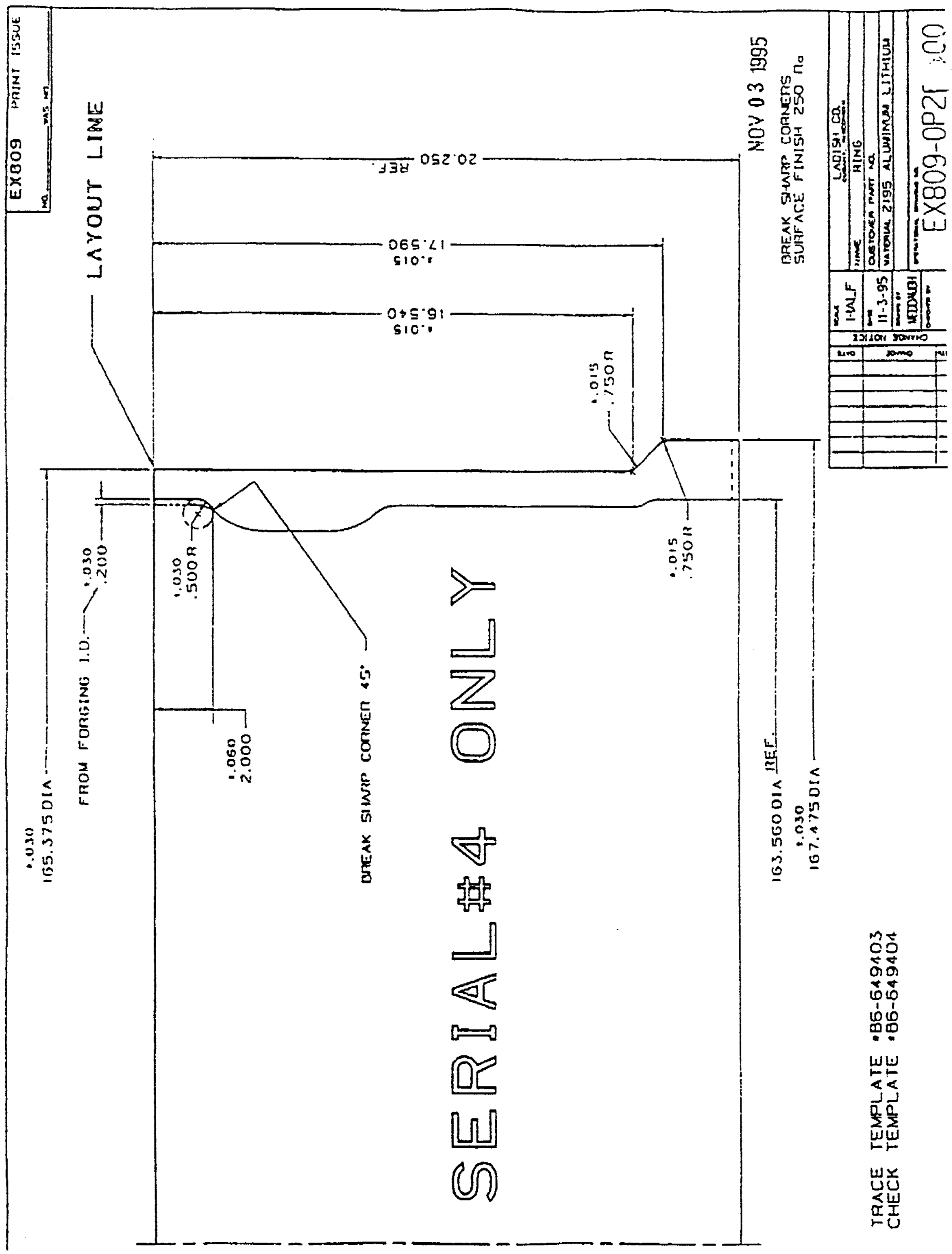


Figure 2-26. Contour preform SN #4 machining drawing provides 0.200 inch extra thickness at key locations to improve stiffener fill rate uniformity.

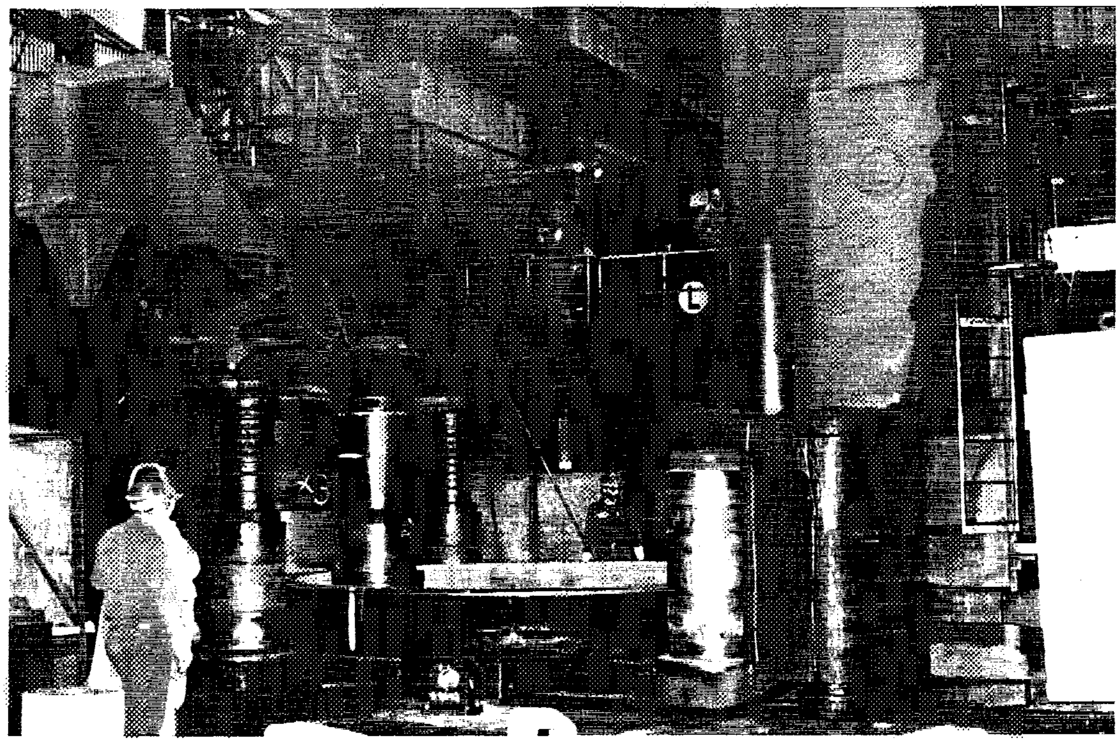


Figure 2-27. Near-net forging of y-ring adapter on Ladish's large ring mill.

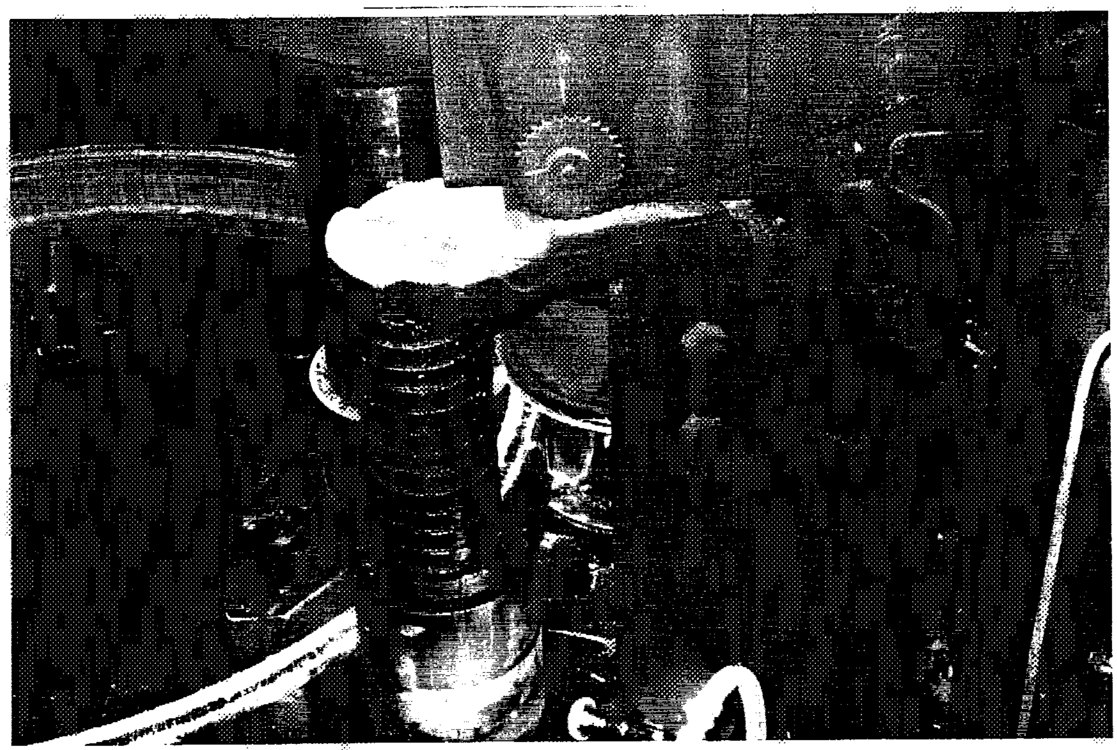


Figure 2-28. Close-up of y-ring adapter being near-net forged.

Figure 2-29. Fill sensor probe being used to verify stiffener fill (demonstrated after near-net forging in this photo).

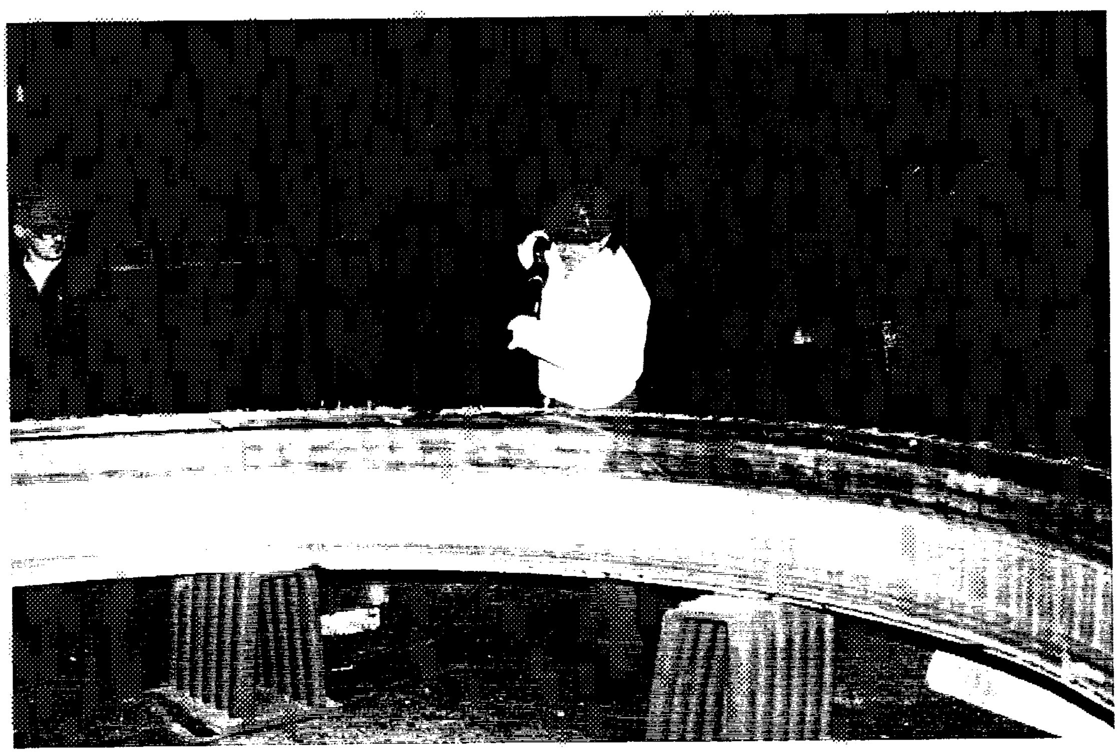


Figure 2-30. Flash is chiseled-off from both ends of the drum tool / near-net forged y-ring adapter as it cools.

Figure 2-31. Flash is ground-off from both ends of the drum / near-net forged y-ring adapter assembly as it cools.

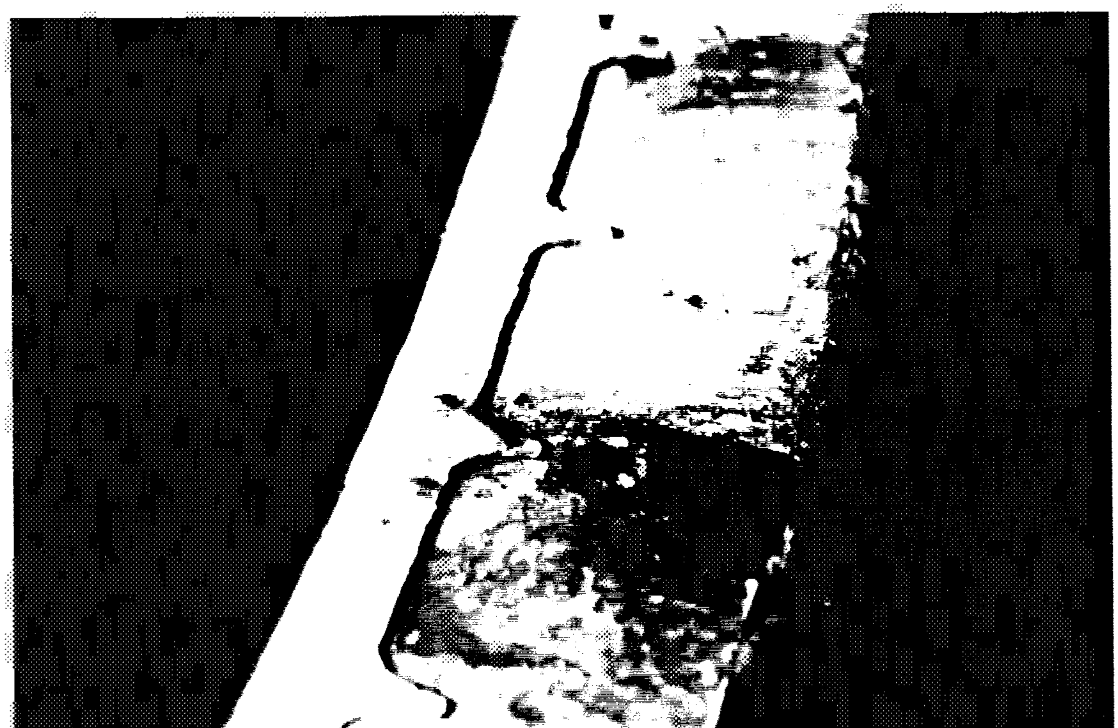


Figure 2-32. A gap emerges between Al-Li near-net forging and steel drum tool as they cool.

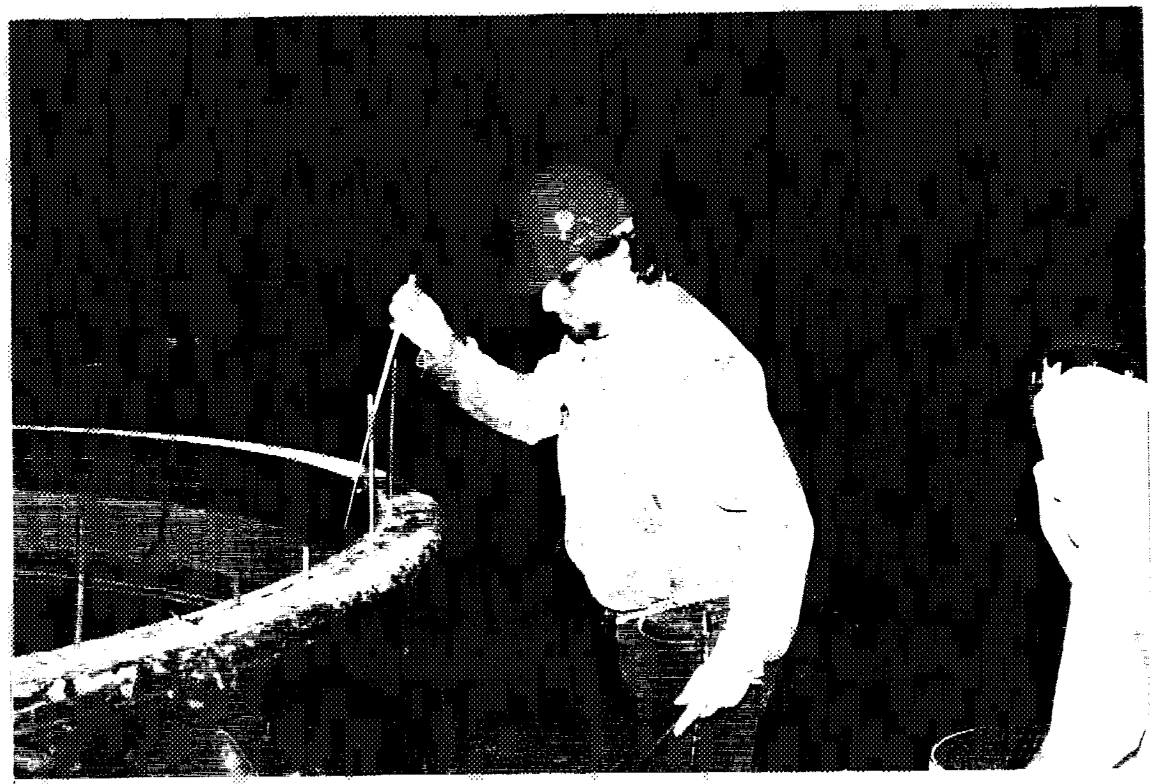


Figure 2-33. Centering wedges are tapped into gap between Al-Li near-net forging and steel drum tool.

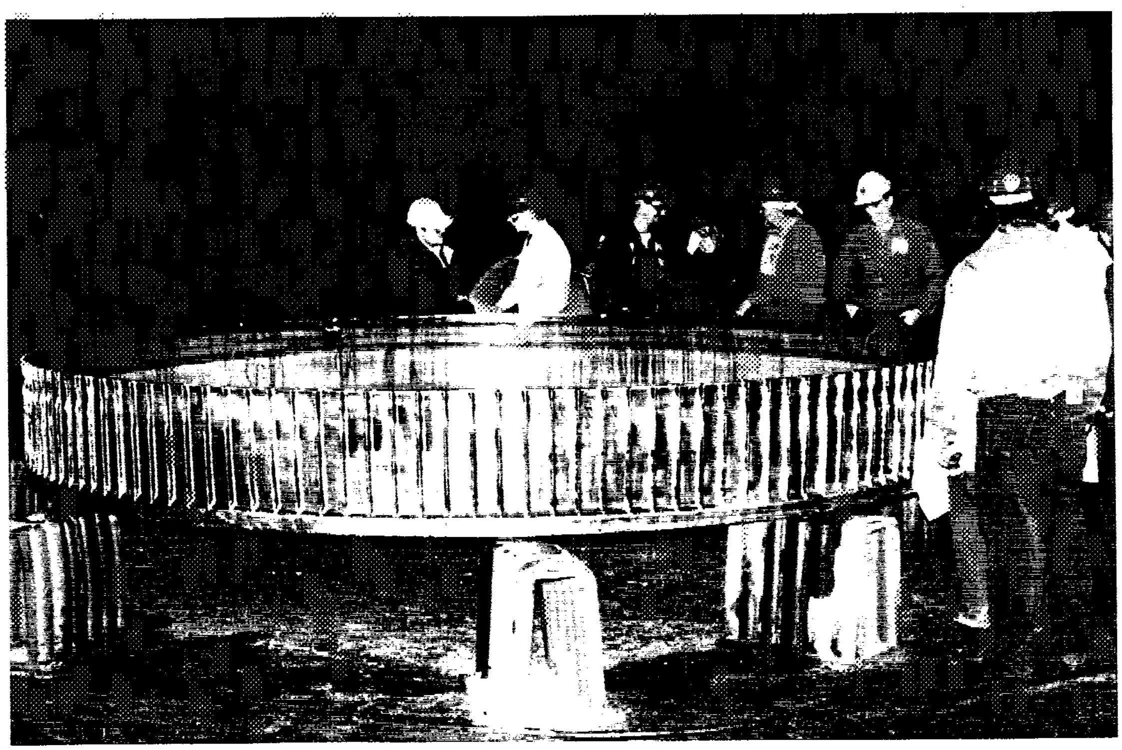


Figure 2-34. Photograph of 170-inch diameter, Al-Li near-net forged, "process pathfinder" y-ring adapter, SN #4.

2.7 NEAR-NET FORGING OF "MECHANICAL PROPERTIES" Y-RING ADAPTER

2.7.1 Drum Rolling

Concurrent with the performance of this contract the Reynolds Metals Company (RMC) was refining their casting processes to improve the quality and consistency of 2195 aluminum-lithium. These refinements were dictated by the Super Light Weight Tank program. The ingot that was used to produce SN's #3 and 4 was procured prior to the refinement of the RMC processes. Mid-way through this program we became concerned about using this older vintage material for either mechanical properties evaluations or to produce flight quality adapters for use in the CTTP tank.

Since contour preform SN #1 had been fabricated from recent vintage ingot, it was decided that it would be near-net forged and used for tool proofing, weld evaluation, and for mechanical properties testing. It was determined that there would be sufficient material for the test programs even if the resulting near-net forging did not turn out any better than the first near-net forged adapter (SN #4 made from the questionable old vintage ingot).

During machining of contour preform SN #1 a machining error was made and material on the outside diameter surface was inadvertently removed at the membrane to test ring/flange location. Since the contour of the preform was already imperfect, it was determined that this imperfection would not impact the intent of the near-net forging trial. The machined contour preform was loaded into the drum tool. The preform and drum tool assembly were heated to 925°F.

The heated "mechanical properties pathfinder" contour preform / drum assembly was loaded onto the Ladish large ring mill and rolled for five revolutions at the Ladish predetermined tonnage. The fill level was checked and the drum assembly was rolled for five more revolutions. After a second fill level check the perform was once again rolled for five additional revolutions (total of 15 plus ramp-ups and ramp-downs).

The y-ring adapter / drum assembly was allowed to cool, the flash was removed and the part was extracted.

2.7.2 Results

Due to the imperfect starting condition of the SN #1 preform we were not surprised to find a degree of under-filling of the stiffeners after near-net forging. Differential fill rates were expected along the length of the stiffeners due to the under-filled areas on the contour preform which did not initially contact the mandrel during the near-net forging operation. The portion of the stiffeners away from the y-ring bulge area filled before the portion of the stiffeners located over the y-ring bulge. Moreover, the fill rate varied around the circumference due to the non-uniformity of the circumferential y-ring bulge.

There were, however, sufficient areas that were properly forged from which weld evaluation panels and mechanical properties test panels were machined. The mechanical properties testing and an artificial aging studies are being performed on a related contract. Photos of the second near-net forged y-ring adapter, SN #1, are included in Figures 2-35 through 2-37.

Figure 2-35. *Photograph of 170-inch diameter, Al-Li near-net forged "mechanical properties", y-ring adapter, SN #1.*

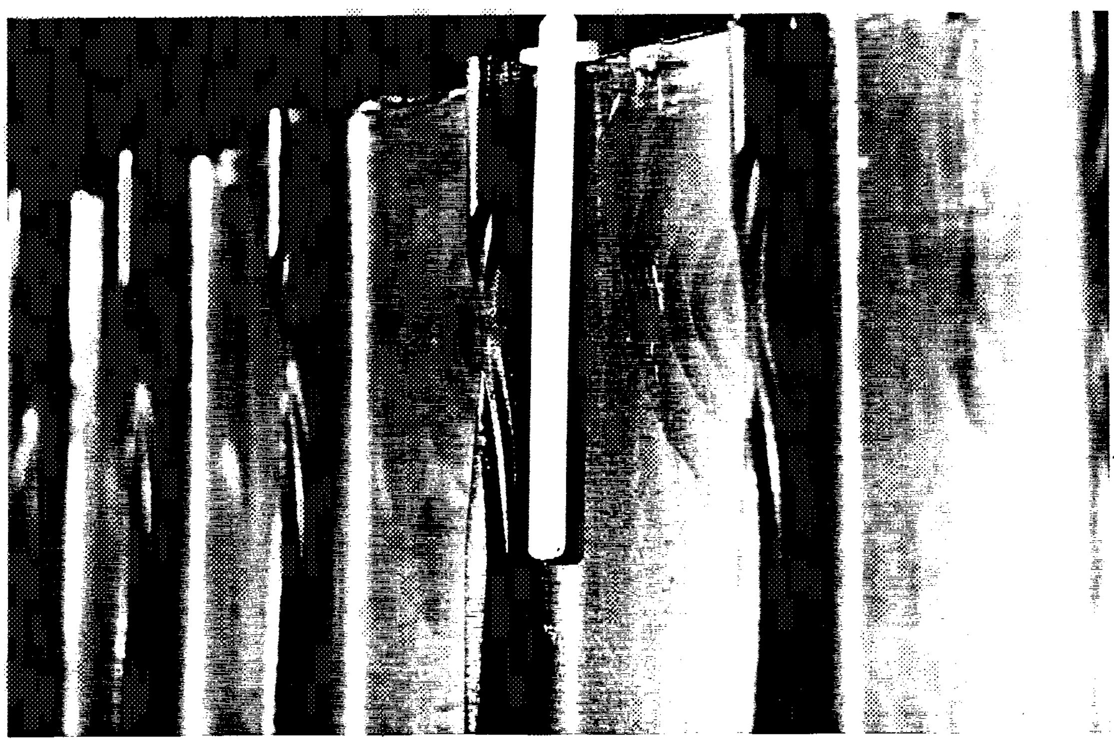


Figure 2-36. *Close-up photograph of near-net forged, "mechanical properties" y-ring adapter, SN #1 near bottom of adapter (oriented up in this photo).*

Figure 2-37. Close-up photograph of near-net forged, "mechanical properties" y-ring adapter at the stiffener-to-test ring/flange intersection.

2.8 MANUFACTURE OF TWO "REPLACEMENT" CONTOUR PREFORMS

Prior to near-net forging the two "flight quality" adapters, LMA choose to procure an additional 2195 aluminum-lithium ingot of the latest vintage, produce two additional preforms, and substitute them for older vintage material non-perfectly filled preforms already produced on this contract. These two additional preforms were designated #5 and #6. Of the two remaining contour preforms, SN #3 was of the older vintage ingot. SN #2, although of recent vintage ingot, had a large section of flattened internal y-ring bulge.

The existing preforms could have been used to fulfill the requirements of the contract. However, LMA desired to produce the best near-net forged adapters possible to ensure the success of the subsequent cryogenic tank test program. The two additional contour preforms were provided to the program at the sole discretion of LMA.

The 3,950 pound 2195 ingot (Reynolds Metals Mill Heat No. RYC1144A-249B) provided to the program was slightly larger than either of the first two ingots. The certification for this ingot is also included in Appendix B.

Ingot conversion and back extrusion of the cylindrical blocker preform were again performed by Wyman Gordon, in accordance with established practices and procedures. The tall cylindrical blocker produced was parted in half to make the two additional blocker preforms.

Ladish performed the "pre-pass" rolling operation on both blockers using the same parameters used to fabricate the three previous preforms.

2.8.1 Tooling Modifications

Before proceeding to contour roll the remaining two preforms, the entire ring mill tooling setup was modified. The rollers were inverted so that the flange end on the preforms would be oriented downwards during contour rolling. This effectively locked the preform in place, preventing it from climbing in the ring mill as encountered on SN's #1 - #4.

Additionally, lips were installed on the guide rollers at the preform height level. The drive roller was machined slightly to provide a relief area to limit "suck-back" on the outside diameter directly opposite the internal y-ring bulge area.

Ladish also modified the preform fabrication process prior to producing preforms S/N's #5 & 6. Previously, during the first pass contour rolling operation, a circumferential bulge or allocation of material was gathered for the flange/test ring on the inside of the top end of the preform. This bulge was then pushed radially toward the outside diameter of the preform during an intermediate sizing operation. This operation proved only partially successful during fabrication of the first four preforms. Before preforms S/N #5 & 6 were rolled, Lockheed Martin elected to fabricate an additional drive roll mandrel for the first pass contour rolling operation and to re-machine the contour of the inner mandrel. Instead of the conventional cylindrical drive roll mandrel previously used, the new drive roll mandrel was recessed (smaller diameter) at the flange/test ring location. Furthermore, the inner mandrel was machined to remove the flange/test ring recess, leaving only the Y-ring bulge recess.

The gentle contour produced by the modified first pass contour rolling operation results in the flange/test ring bulge now being formed on the outside of the preform. No other changes were made to the second pass contour rolling operation or tooling, which imparts the desired final contour geometry to the preform cross-section.

Due to these ring mill tooling improvements, the remaining two preforms were successfully rolled. Near complete fill of the contour features was achieved.

2.8.2 Machining Of The Two Additional Contour Preforms

It was decided that since both the outside and most of the inside surfaces of the contour preform were already slated to be machined to provide the 0.200 inch thick "head start" areas, 100 percent machining of the contour preform would not result in a significant added cost. Thus, any slightly under-filled or non-regular areas on any of the contour features would be machined to produce a perfect perform.

2.9 NEAR-NET FORGING OF "FLIGHT QUALITY" Y-RING ADAPTERS

Contour preforms SN #5 and #6 were near-net forged to produce the "flight quality" Y-ring adapters to be incorporated into the NASA MSFC / Lockheed Martin, Cryogenic Tank Technology Program (CTTP) test tank. Near-net forging of these preforms was performed on this contract in lieu of SN's #2 and #3.

2.9.1 Near-Net Forging The SN #5 Y-Ring Adapter

Prior to loading the SN #5 preform into the drum tool the tool was heated to approximately 900°F, causing it to expand. Heating was necessary in order for this particular preform to fit into the drum tool. Due to the cold sized (rounding) diameter of this particular preform (S/N #5), in order to get near 100% clean-up of the cross-section it was determined that the outside diameter would be machined slightly larger than that of the other preforms on the program. This resulted in an interference fit condition between the preform and the drum tool at room temperature.

The preform/drum tool assembly was then loaded back into the furnace and heated to 925°F, removed from the furnace and immediately near-net forged. One revolution was required to achieve the target forging pressure. After reaching the target pressure S/N #5 was then rolled eleven complete revolutions. After near-net forging the piece was allowed to cool, the flash was chiseled and ground away, and the Y-ring adapter was extracted using the same techniques discussed previously.

2.9.1.1 Results

Since they were completely machined, the last two contour preforms to be near-net forged were very near perfect in cross section. In addition, the added 0.200 inch thickness material allocations at key locations on the inside diameter of the preforms caused fill of the stiffeners to begin in advance of those portions of the stiffeners located over membrane areas. In fact, since the contour preforms had no under-filled contour features, the 0.200 inch extra material may have been more than necessary. On the first two near-net forgings the fill rate of the stiffeners areas located over the y-ring hoop bulge lagged in comparison with the portion of the stiffener located over the membrane. Due to the extra 0.200 inch material allocations, on SN #5 the fill rate trend was reversed.

The overall observed forging quality of y-ring adapter SN #5 was good. As shown in Figure 2-38, there was a slight under fill (approximately 1/16" to 1/8") of the stiffeners in the area over the membrane (not over the hoop as on the first two adapters produced).

Also on SN #5, an arc section of approximately eight stiffeners around the circumference only filled to about half height. This can be seen in Figure 2-38. It is not understood exactly what caused this unexpected occurrence. It is possible that flash (produced in excess on S/N #5 & 6), got between the outside diameter surface of the drum tool and drive roll mandrel. Since the ring mill is very large and slow reacting, there may have been a pressure increase in the areas where flash had accumulated, causing the fill rate to increase. Likewise, there may have been an adjacent pressure decrease when areas without flash passed through the now wider gap between the rollers. Due to mass of the machine the rollers sluggishly move closer together to maintain the desire forging pressure resulting in an area with reduced forging pressure and thus slower fill rates.

As for the eight half-filled stiffeners, after solution heat treat and quench, we should be able to stretch the adapter to a slightly larger diameter than was initially targeted. This will cause the machined part to be biased toward the inside diameter of the near-net forging (instead of the center). In this manner the Y-ring adapter to be machined should be able to be enveloped within this preform. The near-net forging will be inspected and exact dimensions will be taken both before and after cold stretching; prior to machining. Another option would be to simply change the design of the stiffeners in this location of the adapter making them short and thick instead of tall and thin.

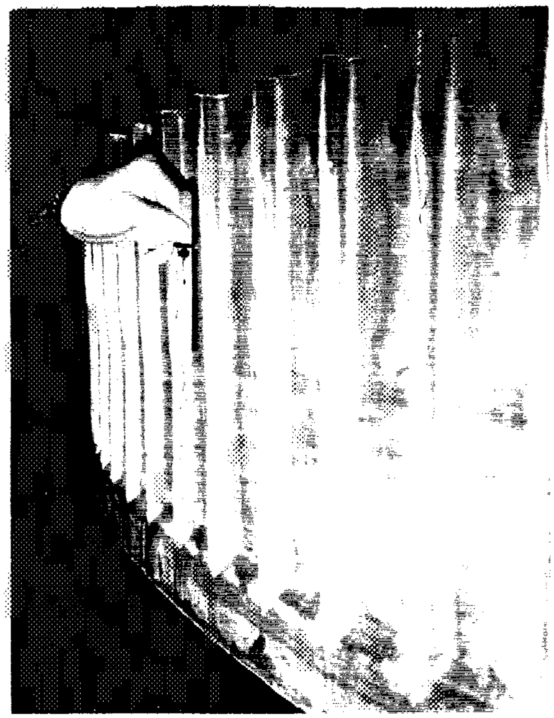


Figure 2-38. A slight under-fill of the stiffeners on near-net forged y-ring adapter, SN #5, can be observed.

Figure 2-39. An arc section of approximately 8 stiffeners only filled to about half height on near-net forged y-ring adapter SN #5.

2.9.2 Near-Net Forging Of SN #6 Y-Ring Adapter

Unlike SN #5, which required that the drum tool be preheated to expand before the preform could be loaded, the nominal diameter preform S/N #6 was loaded into the drum tool with both the preform and drum tool being at room temperature.

The preform/drum tool assembly was heated to 925°F, removed from the furnace and immediately near-net forged. As with SN #5 one revolution was required to achieve the target forging pressure. After reaching the target pressure S/N #6 was then rolled twelve complete revolutions. After near-net forging the piece was allowed to cool, the flash was chiseled and ground away, and the Y-ring adapter was extracted.

2.9.2.1 Results

As shown in Figure 2-40, the stiffener fill on Y-ring adapter SN #6 was very good. The only obvious defects on both near-net forged y-ring adapters were at the stiffener to flange/test ring intersection. This was expected, and was observed on all the previous near-net forged y-ring adapters. On SN #6, the lap in this area, as shown in Figure 2-41, was observed about one half inch down the stiffener instead of directly at the stiffener to flange/test ring area, as was the case on the first two near-net forged adapters. The lap was more severe at some locations than others. The lap was also more obvious on S/N #6 in that it appeared that the lap had been pulled open during the extraction operation.

It is believed that the movement of the lap slightly down the length of the stiffener is due to the use of near perfect preforms for these last two forging trials. Originally the outside diameter of the near-net preform was designed to be one tenth of an inch smaller in radius than the inside diameter of the drum tool at the flange/test ring area only. During drum rolling the mandrel would push the preform over against the drum as the stiffeners below were filling. Since there is no drum forging going on in this area (the stiffeners do not extend up the full length of the adapter, rather they merge into the flange/test ring) it was felt that there was no need for the preform in this area to experience any forging force. However, since the flange/test ring (and other areas) on preforms #'s 1-2 had under-fill areas across this section, the process plan was modified and the preform was machined in this area so that it could contact the drum tool during rolling. In this manner the forging force would cause the material to flow axially and circumferentially to fill the under-filled flange/test ring while the stiffeners were filling below. This proved successful on the under-filled pathfinder adapters. However, on the well filled and fully machined preforms, SN's #5 and #6, the force of the mandrel against the preform, reacting against the drum tool, caused the material to flow axially, up and out the top of the drum as excess flash. Material was also pushed axially downward into the top of the stiffener cavities just below their point of intersection into the flange/test ring, causing the lap to move a slight distance down the stiffener. Since the preform cross-section was filled, the material could not flow significantly in the circumferential direction.

The location of the lap, however, will not matter. Engineering design has determined that the lap can be eliminated during the subsequent machining operation. The machining drawing will be revised so that the stiffeners will no longer be integral to the "L-flange". Instead they will be scarfed-off to transition into the cylinder membrane just below the flange.

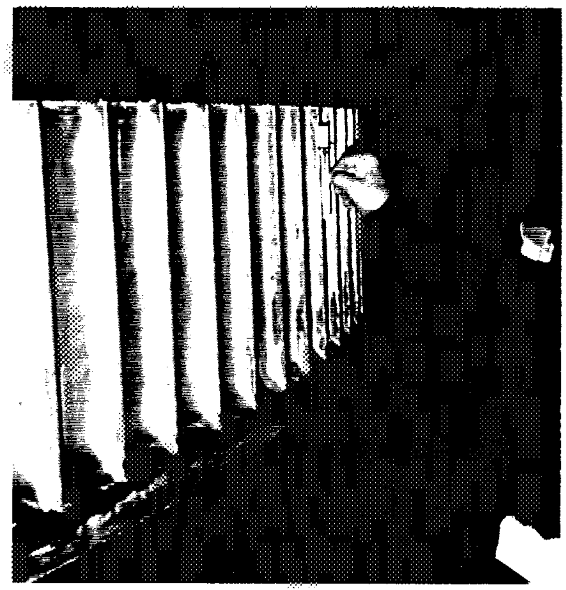


Figure 2-40. Photograph of 170-inch diameter, Al-Li 2195 near-net forged adapter, SN #6.

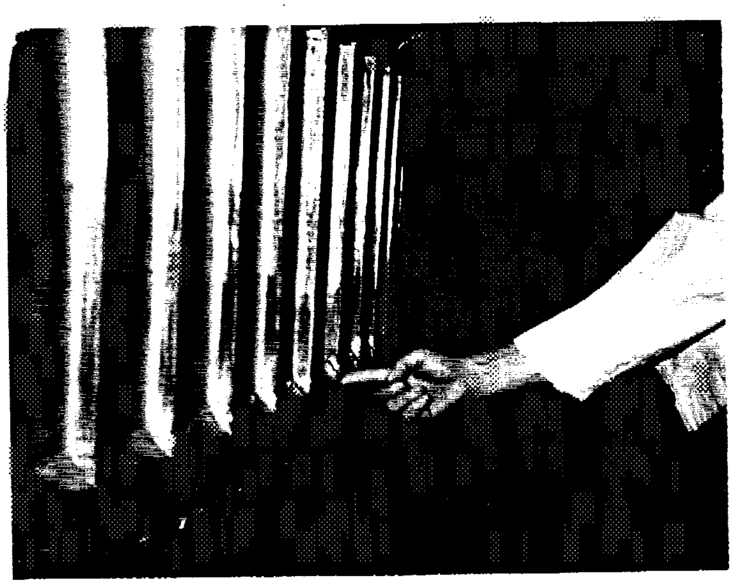


Figure 2-41. Lap defect at stiffener-to-test ring/flange location is severe on SN #5 and #6.

SECTION 3

RECURRING COST SUMMARY

A detailed recurring cost study, including the development of a recurring cost model which compares full scale near-net forged structures with those conventionally machined from plate, was performed on the NASA LaRC near-net forging development contract (reference: *Near-Net Shape Roll Forging Of Al-Li Integrally Stiffened Dry Bay structures And Cryogenic Propellant Tanks -* NAS1-19242, Task 7, *Final Report, July 1996*, NNSF-DOC-002).

3.1 RECURRING COST MODEL SUMMARY OUTPUT

The recurring cost model outputs to near-net forge or machine a Titan oxidizer barrel section from either aluminum 2014 or aluminum-lithium 2195 are summarized in Table 3-1. The Titan oxidizer barrel structure was used as an example in the model since historical cost data for the machining process was readily available. From the outputs listed, it is obvious that the current process to machine Titan oxidizer barrel panels from aluminum plate is the least expensive. However, for space launch applications, where performance, in terms of weight savings, can be valued at up to $10,000 per pound, Al-Li alloys become very attractive. Where performance does not necessitate the use of Al-Li there may be no cost justification to use the near-net forging process.

When using Al-Li, given the relatively adolescent state of the near-net forging process, the decision to produce a structure using the conventional machining approach or via near-net forging must be carefully traded. As shown in Table 3-1, the current estimated cost to near-net forge the Titan oxidizer barrel section from Al-Li 2195 is only about $1500 less than the estimated cost to conventionally machine it. However, as discussed below, significant near term near-net forging cost reductions are felt achievable.

Table 3-1. Recurring cost model calculated values to produce the Titan oxidizer barrel section using conventional machining versus near-net forging for aluminum and Al-Li alloys.

PROCESS	MATERIAL	RAW MATERIAL COSTS	TOTAL COST
MACHINED	ALUMINUM	$59,848	$345,420
NEAR-NET FORGED	ALUMINUM	$25,268	$512,703
NEAR-NET FORGED	ALUMINUM-LITHIUM	$159,301	$643,713
MACHINED	ALUMINUM-LITHIUM	$350,527	$645,161

3.2 ACHIEVABLE NEAR TERM NEAR-NET FORGING COST REDUCTIONS

As discussed in the introduction to this report, the ultimate cost reduction goal, once the near-net forging process has matured, is to reduce the cost to produce Al-Li launch vehicle structures 50% below industry standards. As illustrated in Figure 3-1, and as described below, this goal was not achieved on this first-of-a-kind, full scale, research and development program. Significant near term cost reductions are, nevertheless, deemed achievable. Near term near-net forging cost reduction projections on the order of 20% are expected. The 50% cost reduction value, discussed in Section 1, is still the goal for the near-net forging process once it has matured.

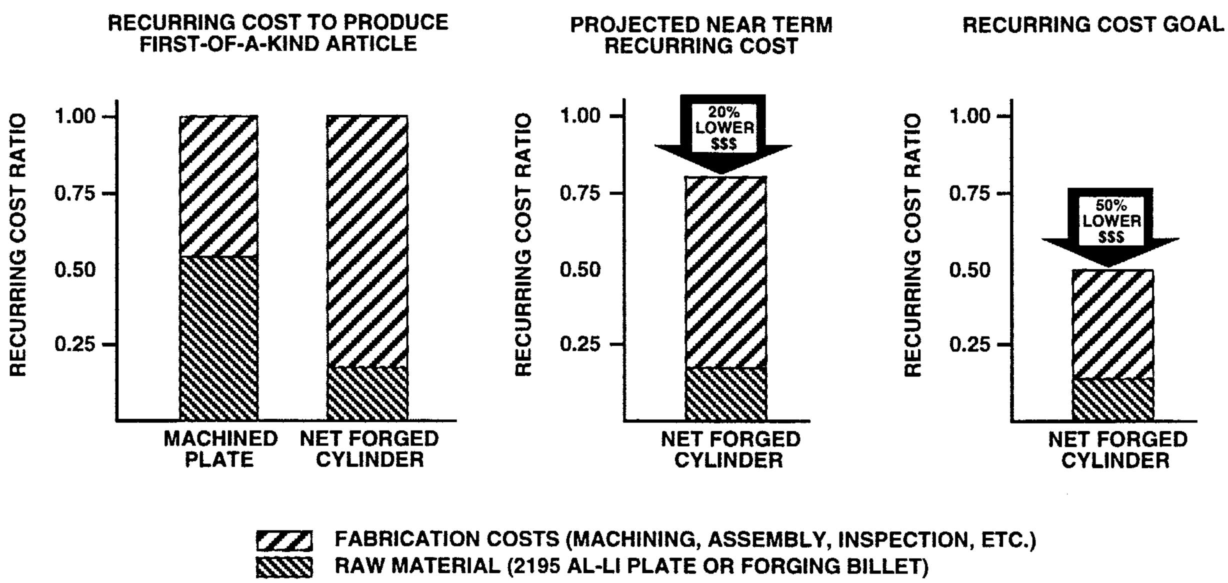


Figure 3-1. Al-Li near-net forging recurring cost reduction potential.

The costs used in the model were actual research and development costs incurred on this NASA MSFC full scale 2195 y-ring adapter program. These costs were based on tooling and processing approaches used on this first-of-a-kind effort. As with a typical learning curve for any process, it is believed that there have been sufficient lessons learned to date, such that were we to proceed now to near-net forge a Titan oxidizer barrel section, the cost could be significantly decreased over that currently calculated in the model. It is reasonable to assume that for this particular structure, the shop floor near-net forging operations, labor and associated costs could be reduced by as much as 50%. Precursory operations such as ingot conversion and back extrusion are mature and are only expected to decrease in cost as a function of volume increase.

For the near-net forging process, using Al-Li 2195, the estimated 50% percent decreased near-net forging labor hour value was input into the model. The model projected overall cost to near-net forge a Titan oxidizer barrel section was $503,091; down from the current cost of $643,713. Thus a 50% near-net forging labor savings would potentially produce an overall cost savings of 21.8%. Additional savings will also be realized as the process matures and as the material utilization percentage increases for given designs.

3.3 MATERIAL UTILIZATION

As shown in Figure 3-2, the initial raw material requirements to near-net forge a Y-ring adapter were reduced by 63% over machining a similar adapter from a rolled ring forging.

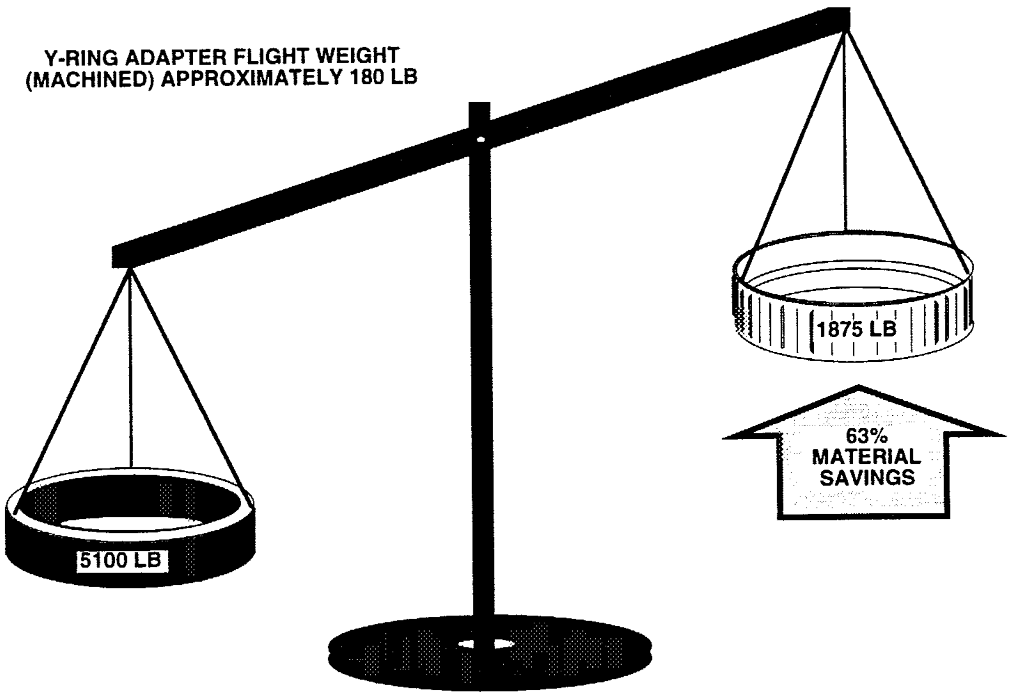


Figure 3-2. Near-net forging a y-ring adapter uses 63% less raw material than machining one from a seamless rolled ring forging.

As mentioned previously, material utilization percentage is highly dependent upon the geometry and complexity of the design of the structure being fabricated. For example a near-net forged part with simple blade stiffeners requires less machining than a part with a "T" stiffener.

Material utilization also has to be balanced against the non-recurring costs of tools and their complexities, and associated recurring labor costs, based on the complexity of the design of the structure to be near-net forged. It may or may not be less expensive to near-net forge "close-to-finished" geometry. For structures requiring both inside circumferential features (e.g. hoop stiffeners and external stiffener features) the tooling is more complex and the associated labor costs are higher than for a near-net forged structure requiring only external stiffeners.

Near-net forging tooling and labor costs must also be compared with the material scrap (chips) costs, and against the tooling and labor costs of subsequent assembly operations, should they be required, i.e. fabrication and installation of mid-frames if circumferential hoop stiffeners are not near-net forged in-place.

It should also be pointed out that for small diameter near-net forged structures the material utilization percentage is much higher due to tighter post forging processing tolerance controls. For large structures the diameter or circumferential tolerance for cold stretching is very wide in comparison to small diameter rings; hence the near-net forging envelope has to be increased for large diameter parts.

Notwithstanding such complexities, as more experience is gained with the near-net forging process, the near-net envelope surrounding the finished part will be tightened and higher material utilization percentages are expected.

SECTION 4

WELDING EVALUATION

4.1 WELD EVALUATION OBJECTIVE

Weldability of 2195 near-net forged material is an important concern, especially in applications where subsequent assemblies cannot be joined by other means (e.g. cryogenic propellant tank components). A limited scope variable polarity plasma arc (VPPA) weld development evaluation was therefore performed on 2195-T8 near-net forged material.

4.2 APPROACH

Two 7.5-inch x 9.75-inch panels, designated panel A and B for this discussion, were cut from the "mechanical properties pathfinder" near-net forged y-ring adapter (SN #1). Panel A was cut from the adapter-to-cylinder weld area and included portions of stiffeners 72-74. Panel B was taken from the membrane area between the test ring/flange and the y-ring bulge and included portions of stiffeners 110-113.

The 2195-T8 near-net forged panels ranged in thickness from 0.875 to 1.625 inches. They were both "dry" machined down to 0.320-inches at a through thickness location of approximately t/4 relative to the outer membrane surface. This through thickness designation indicates that the center of the 0.320 panel was located below the outer surface of the panel a distance approximately equal to 1/4 of the starting membrane thickness. Four, 0.320-inch-thick panels panel were also "dry" machined from 0.400-inch-thick 2195-RT70 plate material (lot # 934U651A-2B2).

Each near-net forged panel was VPPA welded to a plate panel. All welds were made parallel to the circumferential orientation of the near-net forged panels. A weld panel was also produced by welding two 2195-RT70 plates panels together. This panel was to act as a control in the experiment. All welds were produced using 4043 filler wire.

Visual, radiographic, dye penetrant, and metallographic inspection methods were used to inspect the integrity of the welds. Room temperature tensile specimens were also machined from the welded panels and tested. Tensile specimens were all perpendicular to the weld seam with the weld reinforcement left intact.

An internal LMA report documenting the weld evaluation task is included in Appendix C. Appendix C contains the weld panel layouts defining the locations where tensile and metallographic specimens were taken, raw tensile data, etc..

4.3 WELD SET-UP

Prior to welding, each weld joint was wiped with isopropyl alcohol. Tack welding of the weld test panels was performed using DCEN GTA welding with helium shield gas. Two autogenous tack welds were made on the panels, with start and stop tabs welded to the panel ends. The following equipment was used for tack welding.

1. Square Wave TIG-350, Three Phase 460 Volt Lincoln Power Supply.

2. WNI 250 Amp Manual GTA Weld Torch.

Mechanized VPPA welding of the panels was performed at NASA MSFC in building #4711 of the Productivity Enhancement Complex using Weld Station #2. The VPPA weld schedule used in the evaluation is also included in the report in Appendix C.

The following is a list of equipment used to perform the VPPA welding.

1. VP-300-S Hobart Ciber Tig II Variable Polarity Power Supply.

2. MSFC (B&B) Plasma Weld Torch.

3. Hobart Digial Taper Weld Programmer, V6B.

4. General Digital Industries (GDI) Weld Computer.

5. Cyclomatic AVC unit.

6. Hobart "Hot Block" and Plasma Console.

7. Standard NASA MSFC aluminum weld fixture

8. "Opened Faced" backside weld shield.

4.4 RESULTS

All three welded test panels passed visual, radiographic, dye penetrant, and metallographic inspection. Average room temperature tensile results for Panels A, B and the control are summarized in Table 4-1. Photomicrographs from the welded test panels are included as Figures 4-1 through 4-3. Peaking and mismatch data, tensile data sheets, and load vs. strain curves are contained in the report in Appendix C

Table 4-1. Averaged room temperature tensile data for 2195-T8 VPPA welds with 4043 filler wire.

WELD ID	QTY	FTY (KSI)	FTU (KSI)	E (%) *	E (%) **
PANEL A	5	28.4	37.30	3.63	1.84
PANEL B	5	33.70	48.60	5.48	2.65
CONTROL	5	35.00	48.30	5.18	2.32

* 1.0-INCH GAUGE LENGTH
** 2.0-INCH GAUGE LENGTH

The Panel B weld, made with near-net forged material from the membrane area, produced an averaged room temperature tensile value equal to welded plate; approximately 48 ksi for ultimate weld strength. However, the Panel A weld, made with near-net forged material from the cylinder weld joint area, produced an averaged room temperature tensile value 11 ksi less than welded plate. A review of the tensile data also revealed a lot of scatter in the ultimate weld strength of the specimens tested from Panel A. The standard deviation for this panel was 3.99.

A post-test inspection of the fractured Panel A tensile specimens revealed that all the specimens broke on the near-net forged material side of the weld. In contrast, the Panel B welds broke in the weld, plate fusion line, or the near-net forging fusion line. The fracture surfaces of the Panel A weld displayed a very jagged texture. The Panel A macro, in Figure 4-3, revealed that the near-net forged material grains were oriented approximately 68° offset from the weld joint, which coincided with the orientation of the jagged fractures. Grain orientation is typically normal to the weld joint. Therefore, at this time it is presumed that the cause of the low and highly scattered tensile properties is related to the near-net forging material grain orientation at the location of the weld. A-R (and C-R) plane macro sections of the near-net forging are currently being prepared on another contract. The macros will aid in making a determination of how the flow lines relate to the near-net forged part geometry and tooling set-up, and hence, how they affect weld properties.

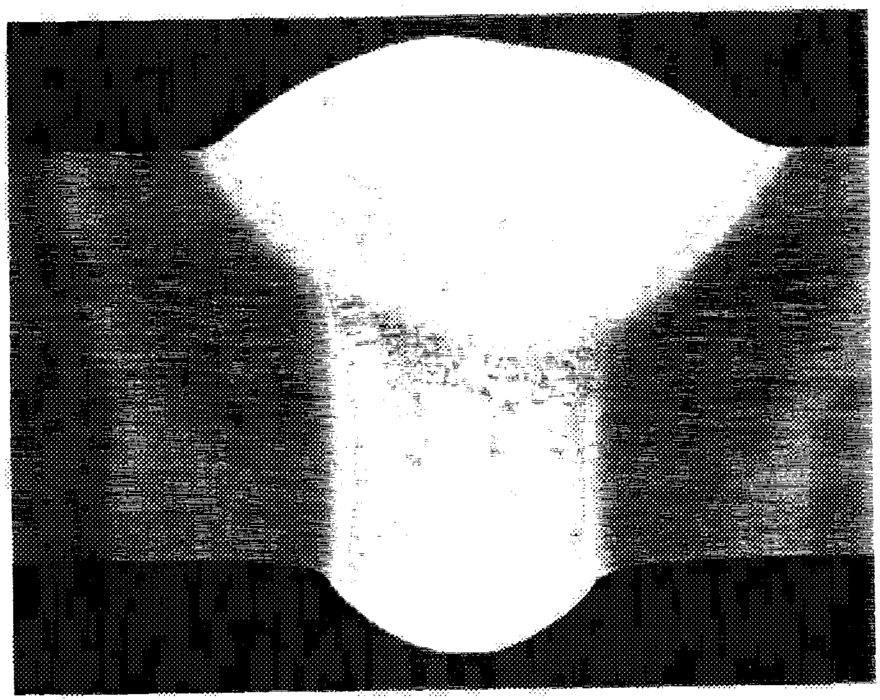


Figure 4-1. 0.320 inch thick, 2195-RT70 plate-to-plate VPPA weld baseline (PLT-M01) 12.5 X magnification.

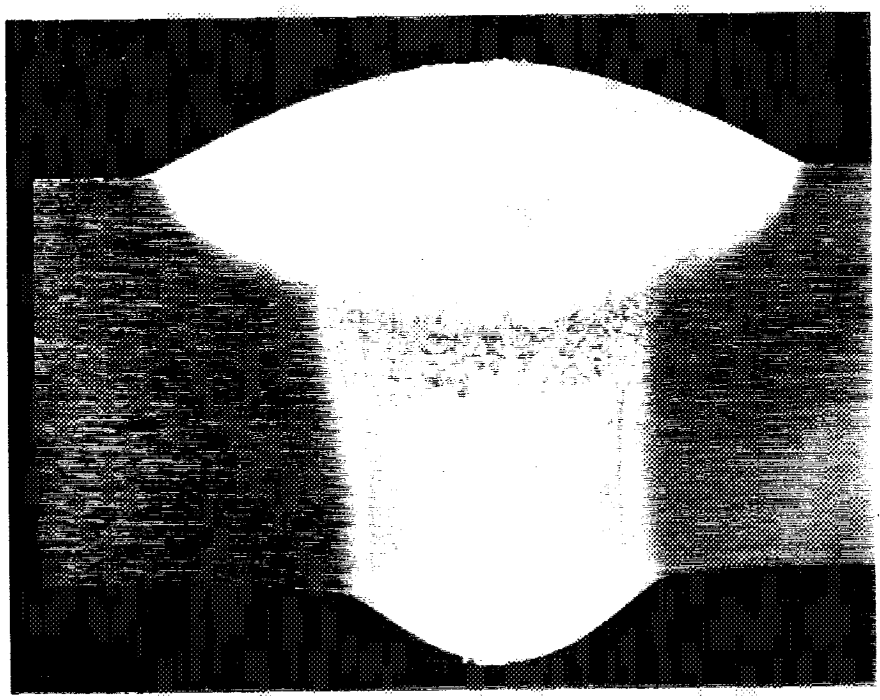


Figure 4-2. 0.320 inch thick, 2195-T8 near-net forged "membrane" panel VPPA welded to 2195-RT70 plate (Panel B-M01) 12.5 X magnification.

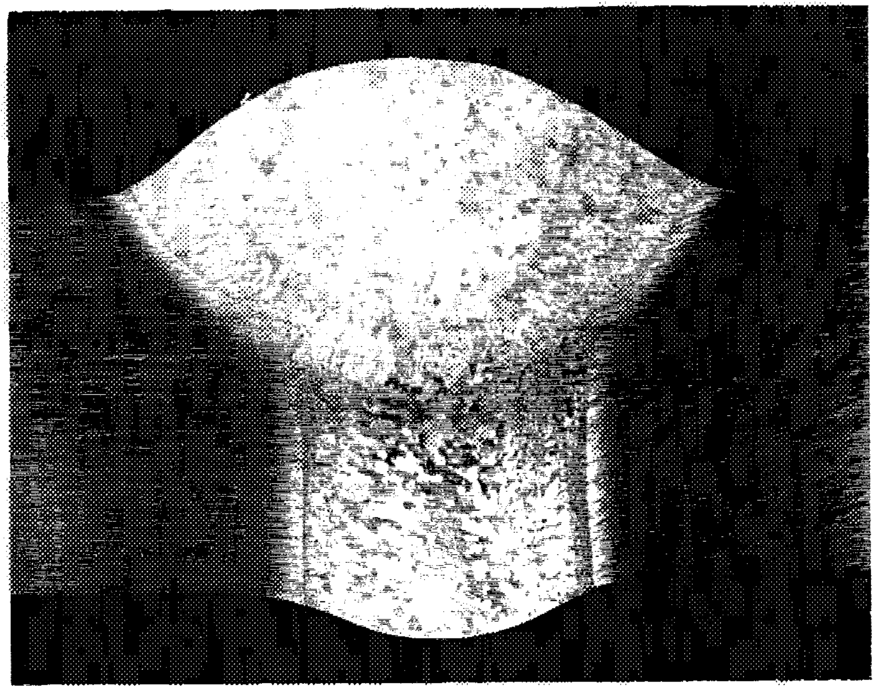


Figure 4-3. 0.320 inch thick, 2195-T8 near-net forged "membrane" panel VPPA welded to 2195-RT70 plate (Panel A-M01) 12.5 X magnification.

4.5 WELD EVALUATION CONCLUSIONS AND RECOMMENDATIONS

Despite the lower room temperature tensile results of the Panel A weld (adapter-to-cylinder weld location on the adapter), the weldability of 2195 near-net forged material appears promising. There was no porosity observed in the welds originating from the near-net forged material, and the grain size, which was five times larger than observed in the plate, did not seem to be detrimental to tensile properties.

Further weld development should involve repair welding and welding in the dome-to-Y-ring area. Additional work should be performed to fully understand the affects of grain orientation on weld properties.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

PROGRAM OBJECTIVES

- Scale-up of the near-net forging process, using Al-Li alloy 2195, was successfully demonstrated.
- Four, 170-inch diameter, near-net forged Y-ring adapters were produced; one "process pathfinder" adapter, one "mechanical properties" adapter, and two "flight quality" adapters.
- Although minimizing the amount of raw material used was not an objective of this first-of-a-kind production of a full scale part, a 63% material saving was achieved when compared to conventionally machining an identical y-ring adapter from a seamless rolled ring forging.
- Scale-up issues addressed on the NASA LaRC program proved key to the successful fabrication of the Y-ring adapters produced on this NASA MSFC sponsored contract.

LESSONS LEARNED

- A "well formed" contour preform is key to obtaining complete and uniform fill during near-net forging.
- The 0.200 inch increased wall thickness at selected locations on the contour preforms proved to be a useful technique to promote uniform and complete filling of the stiffener cavities during drum rolling of the first two (imperfect contour preforms) Y-ring adapters. The 0.200 inch increased thickness may, however, have provided too much of a "head start" on the near perfect (fully machined) contour preforms used to produce the last two, or flight quality Y-ring adapters. A head start of 0.050 to 0.100-inch should be considered in the future.

GOVERNMENT / INDUSTRY PARTNERSHIP

- This NASA MSFC sponsored program played a vital role in the overall integrated near-net forging development and demonstration effort. The government / industry partnership worked very effectively to develop and demonstrate this advanced technology.

FURTHER DEVELOPMENT

- The area of further development with the greatest potential for cost reduction and quality improvement is contour preform fabrication.

- Additional work should also be performed to understand the effects of material flow lines on final properties so that this issue can be incorporated into the preform, tooling, and final part design.

APPENDIX A
LADISH FINAL PROGRAM REPORT

EX809
FINAL REPORT

NEAR-NET FORGED ALUMINUM LITHIUM RING

LOCKHEED MARTIN P.O. 011-13308

SUMMARY

Ladish produced for Lockheed Martin four (4) near-net 14' diameter forged Y-ring adaptors for a prototype liquid oxygen tank. These rings were produced from 2195 Aluminum Lithium for reduced weight and increased strength as compared to 2219-type Aluminum structures. The goal of the project was to transform extruded straight walled donuts into a near net forged ring with a contoured ID circumferential Y-flange, integral axial OD ribs, and a circumferential attachment flange using near-net processing technology.

The use of the near-net technology was aimed at minimizing the required amount of metal needed, and subsequent machining. In producing this as a near-net forging, an approximate 3,000 lbs. of Aluminum Lithium material was saved per ring versus straight walled ring rolled counterparts. The manufacture of the near-net Y-ring adaptor was accomplished through numerous separate operations, including contour ring rolling and Ladish patented drum roll technology.

After contour rolling, it was determined that two of the four initial rings were from an early chemistry pedigree which were determined later in the program to be no longer acceptable to Lockheed Martin, and were replaced with an ingot with the correct chemistry requirements. The two new preforms were processed through all operations to replace the previous "off-chemistry" components.

Ladish was able to drum roll axial ribs into the OD of the Y-ring adaptor, although the first two rings had uneven and incomplete rib fill. All the rings had varying numbers of ribs with an entrance side rib abnormality along with laps in the OD rib-to-flange transition. Lockheed Martin noted that it will be possible to design around these problems and use these prototype rings.

Overall the program was successful in producing four complex, near-net seamless launch vehicle adaptor rings. Further research to fully understand the metal flow will be required to produce fully defect free drum rolled rings having the ID contour and the OD rib-to-flange transition of this design.

BACKGROUND

In efforts to reduce costs and increase payloads on space launch vehicles, Aerospace companies are looking for light weight stronger alloys to replace the current 2219 type material for space vehicle components. One promising alternate material is Aluminum Lithium which has lower density and is able to achieve higher strength and stiffness levels. The disadvantages of this alloy are the 10,000 lb. maximum ingot size, along with being 10 to 15 times more expensive than 2219 type Aluminum alloys. In order to economically utilize this new alloy for large diameter rings with integral stiffeners, an alternate near-net forging process needed to be developed. Ladish developed and patented a new drum roll process which accomplishes this goal.

General Dynamics worked with Ladish to produce subscale Aluminum cylinders with an integral isogrid rib pattern drum rolled on the OD (EX683). This program was a success but the difficulty of the tooling manufacture and extraction led to a 40" cylinder with axial OD stiffeners and circumferential ID contoured rolled hoop stiffeners (EX817). This design would allow for part removal by sliding the axial stiffened ring out of the tool by utilizing the differential shrink factor between the steel tool and the aluminum ring. With this program progression, Lockheed Martin decided to put the technology into a prototype production 14' diameter Y-ring adaptor for a Liquid Oxygen tank (EX809).

The goal of the EX809 program was to produce four (4) near-net Y-ring adaptors for use in a 14' Liquid Oxygen tank using Ladish drum roll technology. The use of the near-net technology would minimize the required amount of input metal, resulting in machining, and material cost saving. The calculation for overall weight savings is 3,000 lbs. (4,700 lbs. for a conventional rectangular ring versus 1,700 lbs. for the near-net ring).

The program started as a cost plus fixed fee program but due to the complexity of the technology and the requirement by Lockheed Martin of Ladish not to incorporate contingency money, Ladish/Lockheed Martin determined three-quarters of the way through the process that there was not enough available funding to complete the program. The program was then switched to a firm fixed price program requiring Ladish to use their own IRAD money to support the completion of the program.

After the first four rings of the program were through the contour roll stage of processing, it was determined that two of the rings (S/N's 3 and 4) were from an early chemistry pedigree no longer acceptable to Lockheed Martin, and would need to be replaced. An ingot with the correct chemistry requirements was procured by Lockheed-Martin and two new preforms (S/N's 5 and 6) were processed through all operations under an add-on contract to replace the previous "off-chemistry" components.

PROCESS SUMMARY

Material: 2195 Aluminum Lithium

All material was supplied by Reynolds Metals Co. Mill reports in Attachment 1

Serial No.	Mill Heat No.	Ladish Heat Code	Ladish Lot No.	Lockheed Martin P.O. No.
1	RYC940Z423A-1	EXP323	E51448	PO4-082027
2	RYC940Z423A-2	EXP324	E51449	PO4-082027
3	RYC114027A-1	EXP325	E51450	PO4-082027
4	RYC114027A-2	EXP326	E51451	PO4-082027
5	RYC1144A-249B	EXP361	E51449	RS5-082077
6	RYC1144A-249B	EXP361	E51450	RS5-082077

GENERAL PROCESSING STEPS

The goal of the project was to transform extruded straight walled donuts into a near net forged ring with a contoured ID circumferential Y-flange, integral axial OD ribs, and a circumferential attachment flange. The manufacture of the Y-ring adaptor was accomplished through numerous separate operations, which are listed below.

1. **Condition Incoming Extruded Blanks** - 54" OD x 31" ID x 21" high extruded ring blanks were received at Ladish as the starting stock. Conditioning was required on the ID (remnants from the extrude and shearing operations) and corners. Refer to "Starting Donut" photo, Figure 1.

2. **Flatten Operation** - Incoming extrusions had to be flattened because they were not uniform in height.

3. **Roll Rectangular Ring** - Roll to intermediate diameter ring prior to contour rolling.

4. **Condition Ring** - Grind and examine ring in preparation for first contour roll.

5. **First Contour Roll** - Ring roll to intermediate contour shape allocating metal to the correct areas of the ring, in preparation of final contour roll. Due to Lockheed Martin's instructions to eliminate a drive roll tool, the first four (4) rings only had contour on the ID. The OD flange was designed to be developed by locally sizing the ID contour rolled flange to the OD in the following operation. Refer to "First Contour Pass Rolled Preform Ring", Figure 2.

Ladish Co., Inc.

2195 Al-Li Y-ring Adapter
Starting Donut

EX809-01, S/N 1

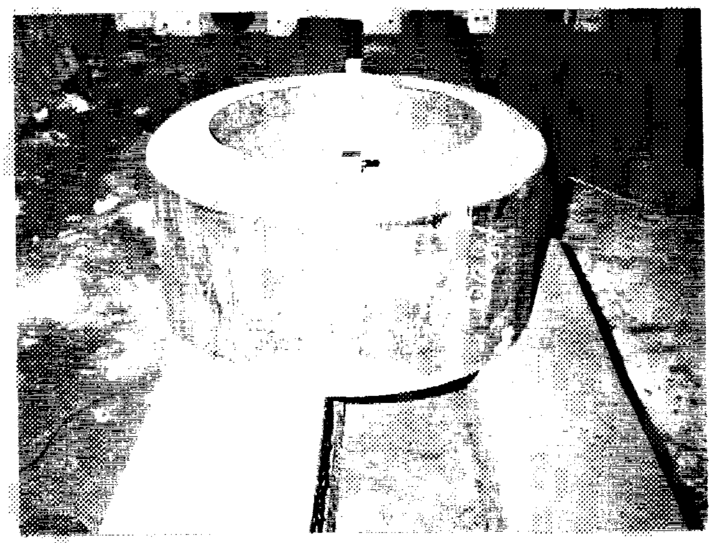
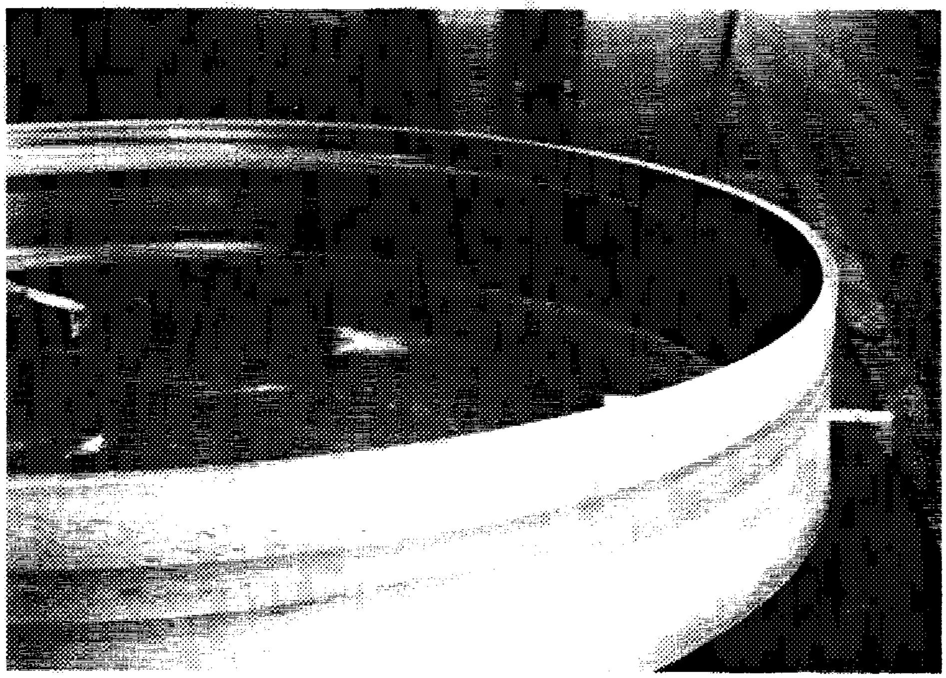


FIGURE 1

Ladish Co., Inc.

2195 Al-Li Y-ring Adapter
First Contour-Pass Rolled Preform Ring

EX809-01, S/N 3



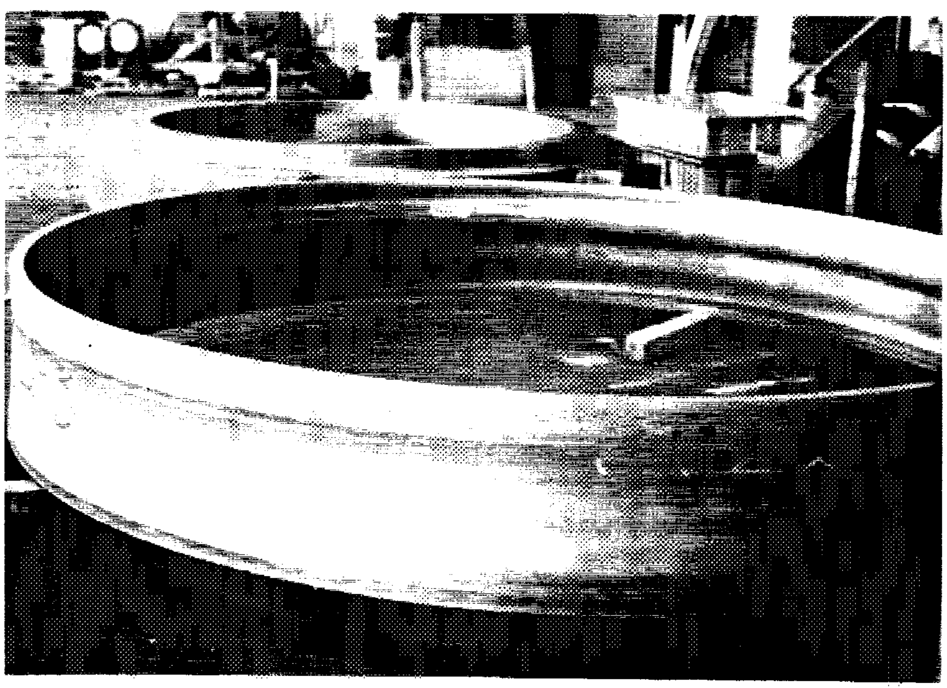


FIGURE 2

6. **Locally Size ID Flange Contour to OD** - Move contour rolled flange from the ID to the OD by locally sizing. (This operation was discontinued after the fourth ring when the Ladish requested OD contour tool was added to the process.)

7. **Condition** - Grind and examine ring in preparation for second contour roll.

8. **Second Contour Roll** - Finish forge contour ring to final configuration for further processing in drum tool. Refer to "Preform Ring", Figure 3.

9. **Cold Size** - Contour ring is inspected and final sized to best fit ring in drum tool.

10. **Machine and Condition** - Machine OD and end faces of contour ring. A machined OD surface was required to allow a clean, near-net surface to be formed when extruding ribs during the drum roll operation. (It was determined that 100% machining of ring was needed on the OD for near-net surface finish and on the ID for the required tool fit and alignment. The last two rings were 100% machined to optimize the drum roll operation.)

11. **Drum Roll Contour Ring** - Place machined preform ring into drum tool (Figures 4 and 5) and drum roll axial ribs on OD of ring.

12. **Extract Ring** - Remove ring from drum tool using differential shrink and supplemental wedges and jacks. See Figure 6 for finished drum rolled ring.

RESULTS OF FORGE STEPS

The six rings were run with varying degrees of success through all the ring forge operations and four through the drum roll operation. The following is a description of the forging steps and results. Changes which were incorporated as the development program proceeded are also recorded and explained.

S/N 1 was run by itself through all contour ring rolling operations prior to rolling the remaining three serials of the original program. This was to establish the optimal processing parameters and geometries (diameters) for the three rolling operations. S/N's 2 through 4 (group #2) and S/N's 5 - 6 (group #3) were run together as groups following S/N 1.

Flatten / Roll / Flatten - All rings went through these operations with no difficulty. The incoming stock should be more consistent with respect to donut height, which would result in eliminating the first flatten operation.

First Contour Roll - All rings were rolled through this operation with some areas of non-fill in the contour at the transition from the membrane to the flange and the Y-ring. To help in guiding the rolled ring through the rolling mill, an in-process change of adding flanged guide rolls was used when rolling the 3rd group of forgings.

Locally Size ID Flange Contour to OD - This operation was used to eliminate a drive roll tool by placing all the ring contour (Y-ring and flange) on the ID of the ring and locally transferring the flange contour to the OD with the size operation. This technique did not work in practice for this short ring and resulted in forming conical rings. The ring became tapered when locally sizing, with the flange contour remaining on the ID. This was thought to be due to the short height of the cylinder. The last two forgings (S/N's 5 and 6) used a contoured drive roll tool in the first contour roll operation, which eliminated this procedure. This process was the initial Ladish design at the onset of the program.

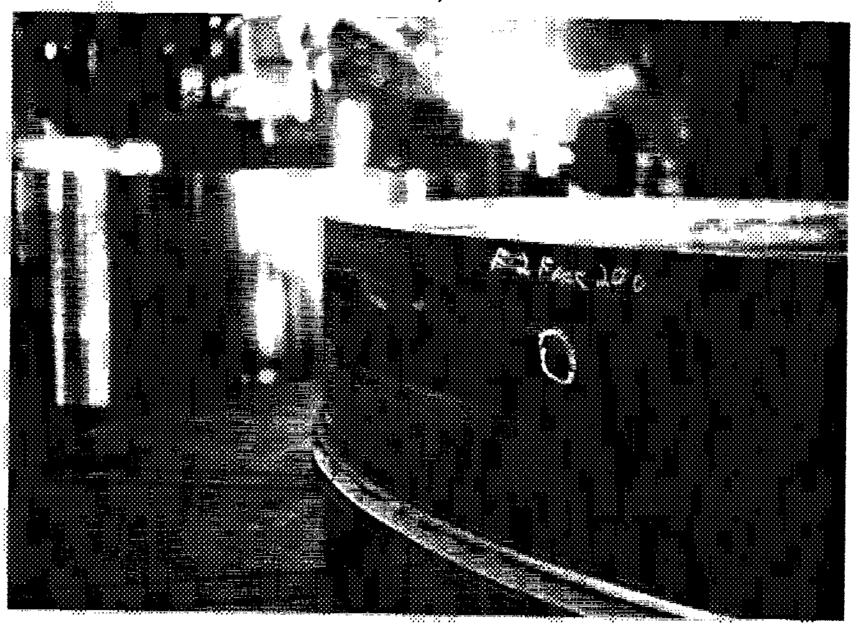
Second Contour Roll - This operation resulted in problems for the first four forgings due to non-uniform tool contact at the start of this operation. This was due to not having the flange contour transferred to the OD of the ring during the flange size operation, and the fact that the rings became tapered. The tapered rings did not contact the second contour roll tools correctly which caused the rings to climb up the mandrel when rolling. The climbing resulted in rolling over the Y-ring adaptor contour, leaving a not completely formed ring for the drum roll operation. Guide roll flanges were used with some success to hold down S/N's 3 through 6. Higher temperature (875°F) (with negative effect) was tried, to help correct the problem on S/N 3. The ring became less stable with the higher temperature and was able to slip past the guide roll and climb the mandrel, rolling over one-half of the Y-ring contour. A first contour roll drive roll tool was added for S/N's 5 and 6 which eliminated the problem completely. Following this operation, pantographs were produced on S/N's 1, 4, 5 and 6 to determine fill.

Drum Roll and Extract - Ladish developed and patented the drum roll process required to forge the OD axial ribs produced in this part. The drum roll forge parameters for this part were calculated by Ladish using a two dimensional finite element analysis model along with a Ladish proprietary ring roll program. Additionally, data from a subscale drum rolling program (L-M/NASA-LaRC; EX817) were used to scale the

Ladish Co., Inc.

2195 Al-Li Y-ring Adapter
Preform Ring

EX809-01, S/N 1



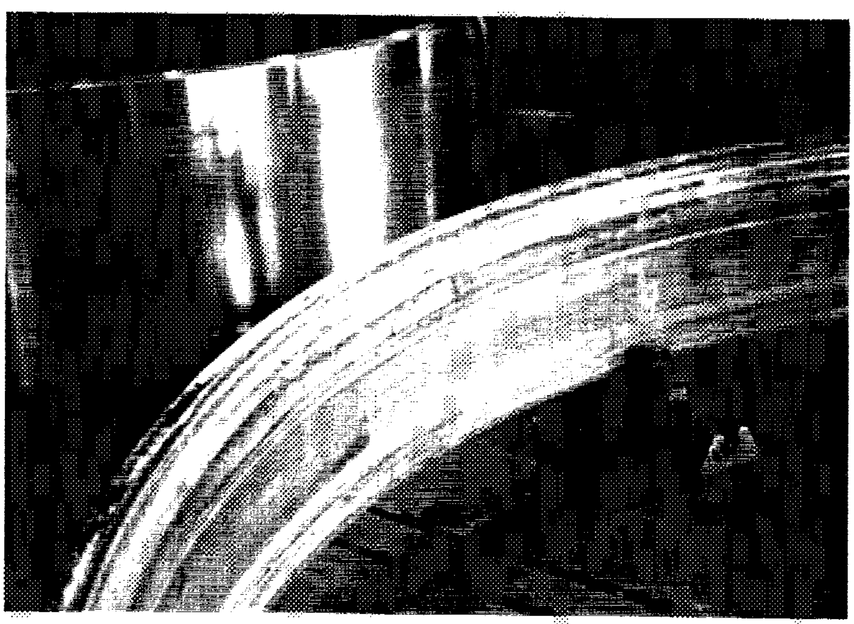
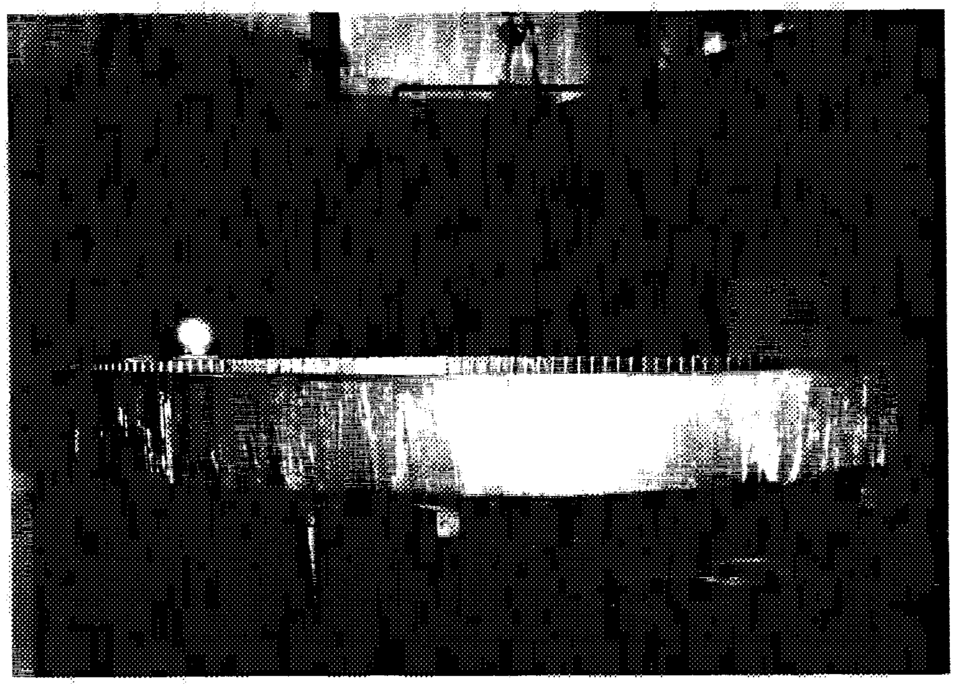


FIGURE 3

Ladish Co., Inc.

2195 Al-Li Y-ring Adapter Program
Drum Tool

EX809-01



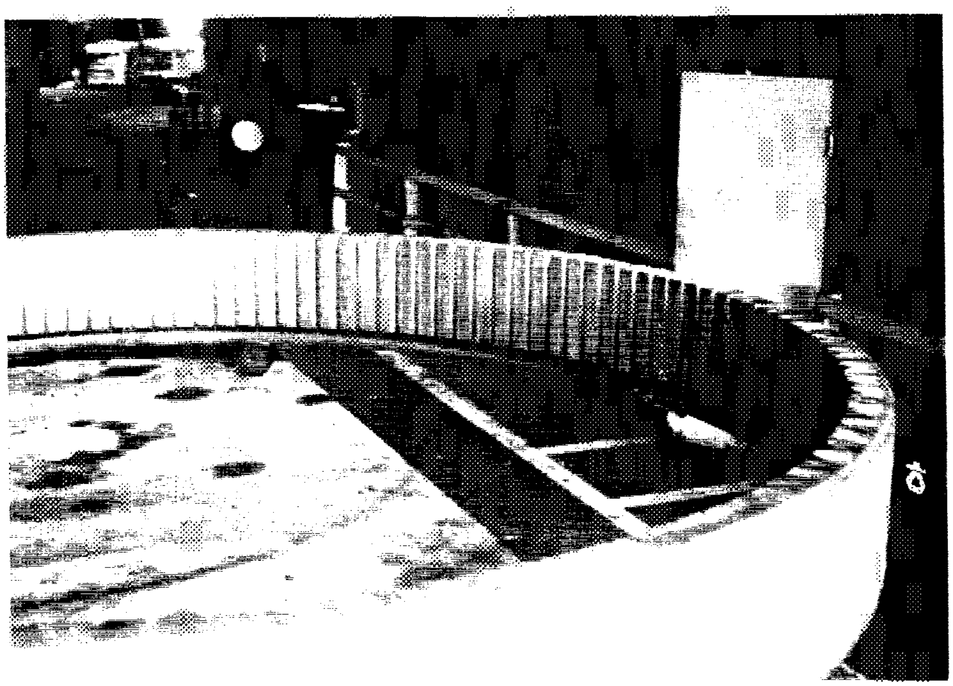
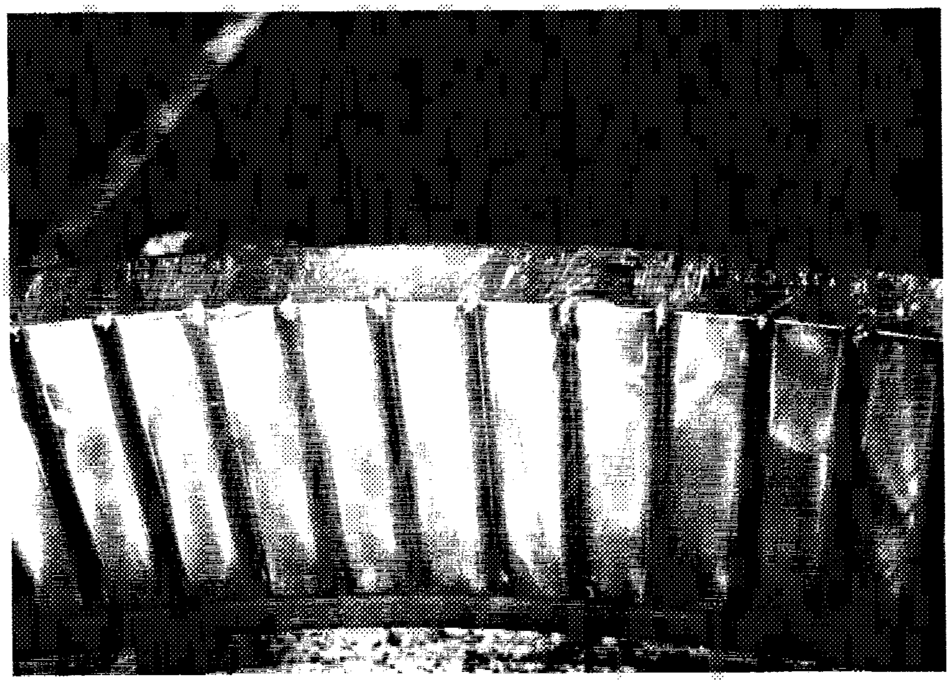


FIGURE 4

Ladish Co., Inc.

2195 Al-Li Y-ring Adapter Program
Drum Tool

EX809-01



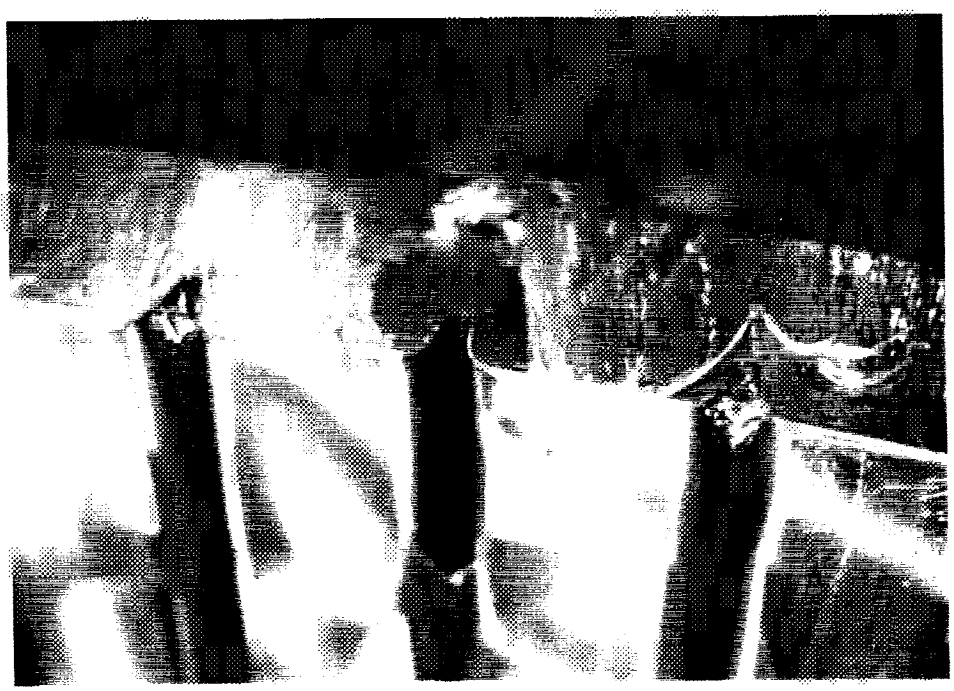
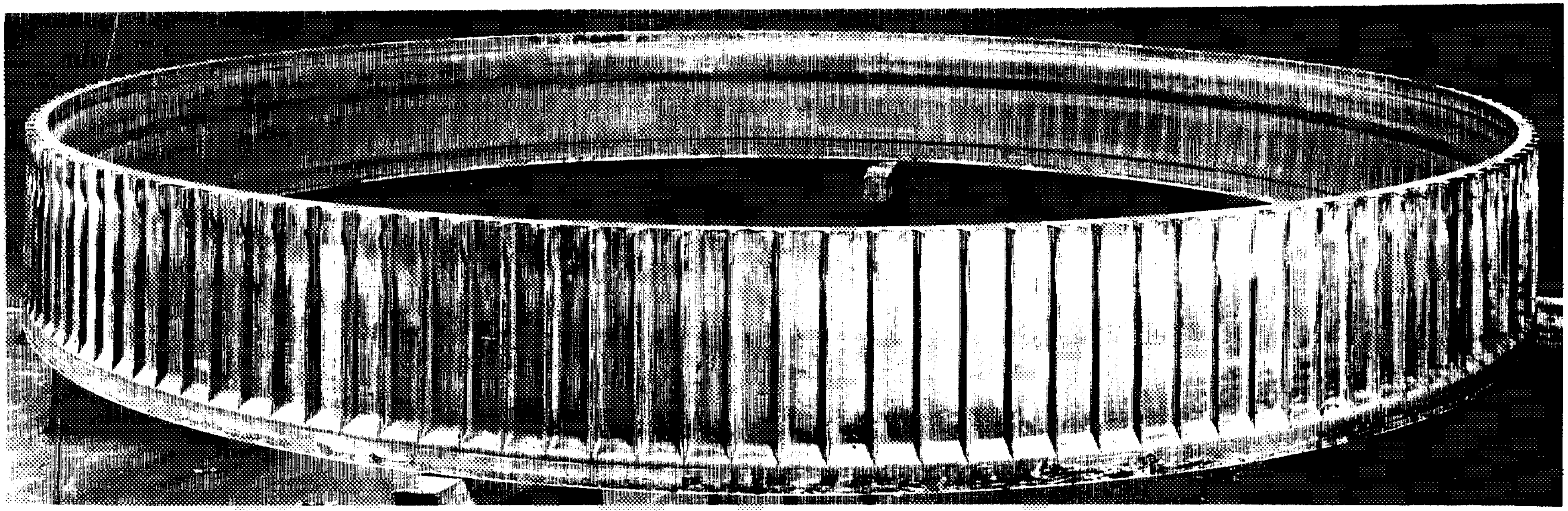


FIGURE 5



Near-Net Forged 14 ft. Diameter Aluminum-Lithium Ring Structure

Ladish Co., Inc.

LOCKHEED MARTIN

FIGURE 6

forging parameters for the full-scale components produced in this program. These developed parameters were used for all four rings.

All rings were machined and sonic tested prior to drum rolling. The sonic test on all four rings showed good sonic penetration and no reportable or rejectable indications. Reports are attached in Appendix A.

Lockheed Martin requested that Ladish produce a radial forging "Head Start" for the axial ribs in the thicker walled areas by machining away an additional 0.200" on the ID wall in all areas except in the flange transition and the entire Y-flange bulge area. The purpose of this machining was to allow the initial drum rolling contact to be in the heavy walled areas which in theory should start the radial forging of the axial ribs in these areas prior to the start of the rest of the areas. The selective "Head Start" ID machining was done on all four drum rolled rings. Ladish has past experience showing that this type of corrective action does not work and stated that the machining was not recommended.

The machining had no known adverse effect on the first two drum rolled forgings (S/N's 4 and 1), but appears to have caused increased radial movement and lapping in the "Head Start" area on the last two rings (S/N's 5 and 6).

Four (4) rings were drum rolled in the following order: S/N 4, 1, 5, and 6. The rings were aligned inside the drum tool and heated to 925°F which caused an interference fit in the drum at the forging temperature. The drum and ring are then transferred to the ring mill for drum rolling.

All four rings were removed from the drum with little difficulty. Grinding was required on all rings to remove flash on the end faces. Wedges and jacks were used to loosen the ring from the drum tool when required. Individual results follow below.

S/N 4 - S/N 4 was machined on the OD and both end faces. After machining, there were two under filled areas on the ring. One area was located on the OD in the transitions from the end flange to the wall membrane and one area on the ID in the circumferential Y-flange bulge were the bulge transitions to the membrane.

See Table 1 for the visual inspection report of S/N 4.

The drum rolled rings were liquid penetrant inspected and reviewed. (Report attached in Appendix B.)

S/N 1 - S/N 1 was machined on the OD, both end faces, and the selective 0.200" removal on the ID wall for the "Head Start". After machining, there were two under filled areas on the ring. One area of non-fill was located on the OD in the transitions from the flange to the wall membrane. The other area was the ID Y-flange bulge. The Y-flange bulge was flattened off for 90° with 60° on either end having partial bulge flattening.

See Table 1 for the visual inspection report of S/N 1.

The ring was liquid penetrant inspected and reviewed. (Report attached in Appendix B.)

S/N 5 - A change was made in the machining instructions of S/N 5. In addition to the "Head Start" ID machining, a machine operation was added on the ID Y-flange bulge to assure a complete fit between the mandrel and the ID of the ring. Figure 7 shows the ring dimensions prior to and following drum rolling.

See Table 1 for the visual inspection report of S/N 5.

The ring was liquid penetrant inspected and reviewed. (Report attached in Appendix B.)

S/N 6 - S/N 6 was 100% machined the same as S/N 5. Figure 8 shows the ring dimensions prior to and following drum rolling. The drum and ring were heated to 925°F and equalized. The furnace was then increased to 935°F for three hours prior to drum roll to raise the temperature slightly to help with rib fill.

Due to the "Head Start" machining, the ribs across from the Y-flange bulge and end flange filled first and moved axially up and down the ribs.

See Table 1 for the visual inspection report of S/N 6.

The ring was liquid penetrant inspected and reviewed. (Report attached in Appendix B.)

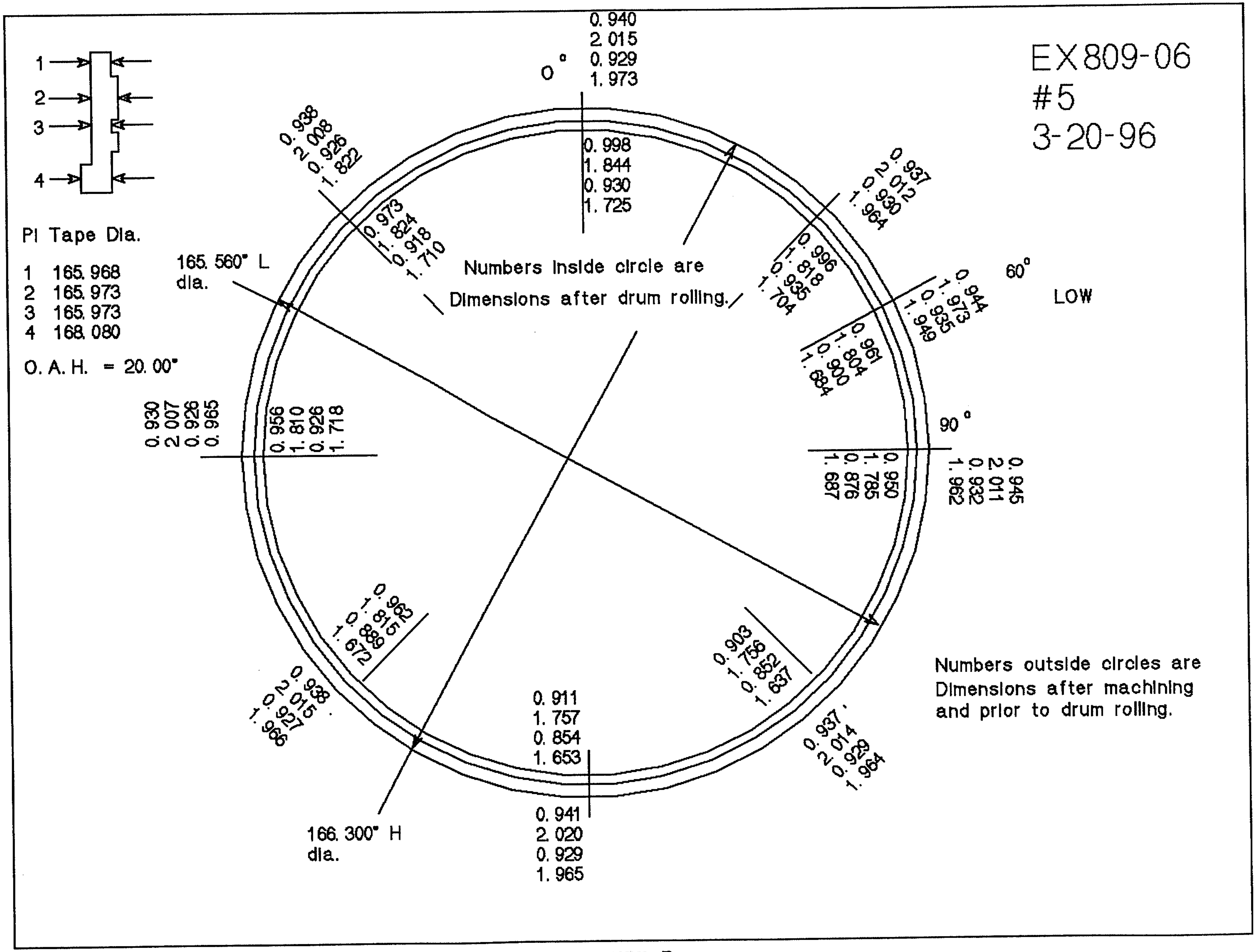
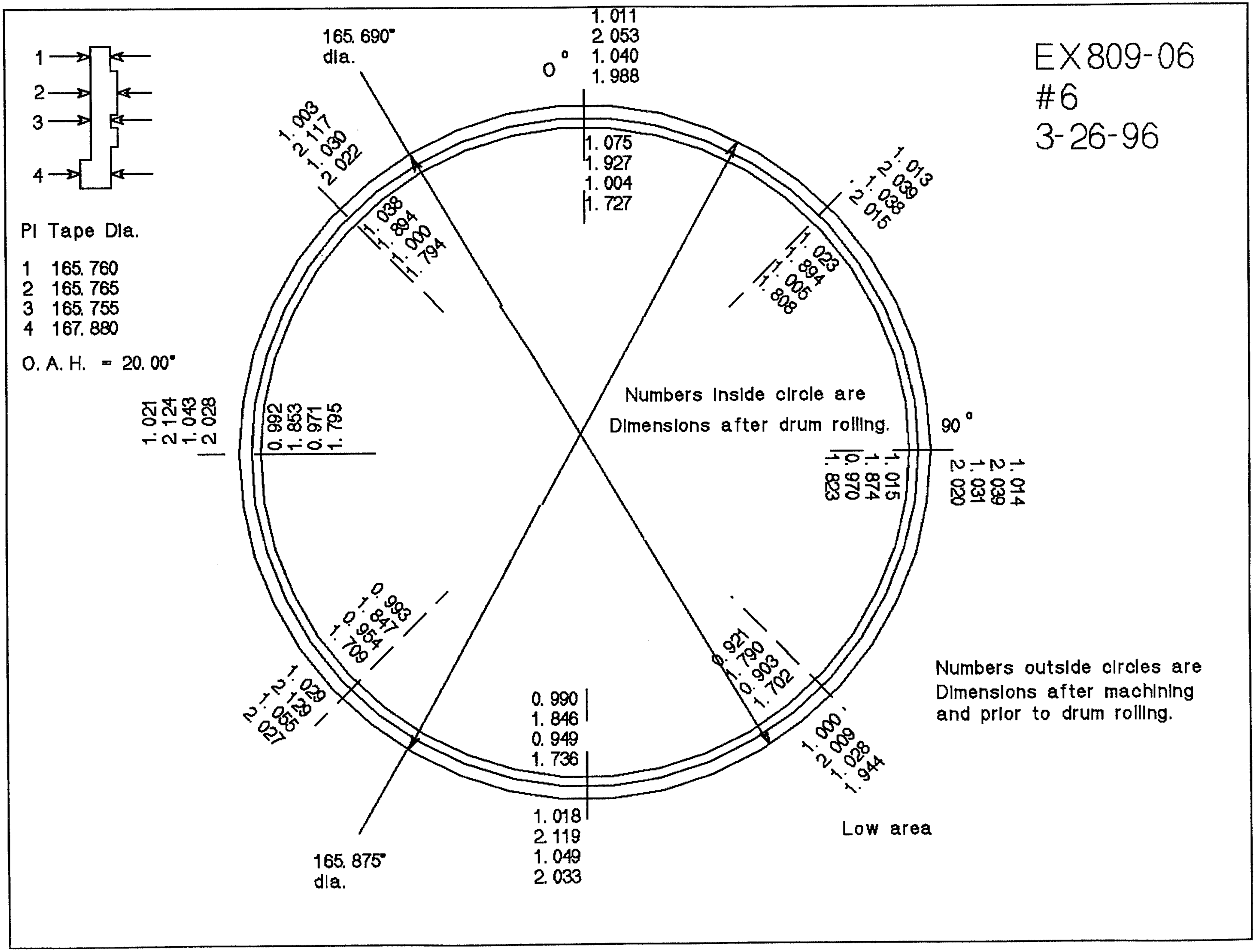

EX809-06
#5
3-20-96
1
2
3
4
Pi Tape Dia.
1 165.968
2 165.973
3 165.973
4 168.080
O. A. H. = 20.00"
165.560" L dia.
166.300" H dia.
0°
60°
LOW
90°
Numbers inside circle are Dimensions after drum rolling.
Numbers outside circles are Dimensions after machining and prior to drum rolling.
0.940
2.015
0.929
1.973
0.998
1.844
0.930
1.725
0.937
2.012
0.930
1.964
0.996
1.818
0.935
1.704
0.944
1.973
0.935
1.949
0.961
1.804
0.900
1.684
0.945
2.011
0.932
1.962
0.950
1.785
0.876
1.687
0.937
2.014
0.929
1.964
0.903
1.756
0.852
1.637
0.941
2.020
0.929
1.965
0.911
1.757
0.854
1.653
0.938
2.015
0.927
1.966
0.963
1.815
0.889
1.672
0.930
2.007
0.926
0.965
0.956
1.810
0.926
1.718
0.938
2.008
0.926
1.822
0.973
1.824
0.918
1.710

FIGURE 7



EX809-06
#6
3-26-96
1
2
3
4
PI Tape Dia.
1 165.760
2 165.765
3 165.755
4 167.880
O. A. H. = 20.00"
165.690" dia.
165.875" dia.
0°
90°
1.011
2.053
1.040
1.988
1.075
1.927
1.004
1.727
1.003
2.117
1.030
2.022
1.038
1.894
1.000
1.794
1.013
2.039
1.038
2.015
1.023
1.894
1.005
1.808
1.021
2.124
1.043
2.028
0.992
1.853
0.971
1.795
1.015
1.874
0.970
1.823
1.014
2.039
1.031
2.020
0.993
1.847
0.954
1.709
1.029
2.129
1.055
2.027
0.990
1.846
0.949
1.736
1.018
2.119
1.049
2.033
0.921
1.790
0.903
1.702
1.000
2.009
1.028
1.944
Numbers inside circle are
Dimensions after drum rolling.
Numbers outside circles are
Dimensions after machining
and prior to drum rolling.
Low area

FIGURE 8

TABLE 1

VISUAL INSPECTION REPORT OF NEAR-NET FORGED RINGS

A. *Visual inspection of S/N 4 showed the following results.*

Ribs at the end-flange/rib interface - Some evidence of a lap in this area.

Ribs at the membrane wall - Nearly filled ribs with no visible defects.

Ribs opposite the circumferential Y-flange bulge - There was non-fill and the start of some folds at the rib peaks. The base of the ribs show some entrance side abnormalities.

B. *Visual inspection of S/N 1 showed the following results.*

Ribs at the end-flange/rib interface - Some evidence of a lap in this area.

Ribs at the membrane wall - Nearly filled ribs with no visible defects.

Ribs opposite the circumferential Y-flange bulge - There was severe under fill of the ribs in areas of the ring were the Y-flange bulge was flattened going into this operation. Other areas had minor non-fill and the start of some folds at the rib peaks. The base of the nearly filled ribs show some entrance side abnormalities.

C. *Visual inspection of S/N 5 showed the following results.*

Ribs at the end-flange/rib interface - A more pronounced lap was seen in the end flange rib interface with some rib separation seen.

Ribs at the membrane wall - The ribs in the membrane area were under filled with a developing fold.

TABLE 1 (Continued)

VISUAL INSPECTION REPORT OF NEAR-NET FORGED RINGS

Ribs opposite the circumferential Y-flange bulge - The rib at the Y-flange bulge area showed signs of early fill that developed into a lap. There is an entrance side abnormality (at the base of the ribs 360°) more pronounced than the first two (#4 & #1) drum rolled rings.

D. Visual inspection of S/N 6 showed the following results.

Ribs at the end-flange/rib interface - A most pronounced lap was seen in the end-flange/rib interface with rib and end-flange separation up to 2" long. Pieces from the end of several ribs were missing, which is believed to be the result of the lap folding on itself and breaking off during extraction.

Ribs at the membrane wall - The ribs in the membrane area were filled with a lap at the peak.

Ribs opposite the circumferential Y-flange bulge - The rib at the Y-flange bulge area showed signs of early fill that developed into a lap. The lap has separated from the rib in one area. There is an entrance side abnormality at the base of the ribs 360°, more pronounced then the first three (#'s 4, 1 and 5) drum rolled rings.

EX809
FINAL REPORT

NEAR-NET FORGED ALUMINUM LITHIUM RING

CONCLUSIONS

1. Ladish was able to drum roll axial ribs into a 2195 Al-Li Y-ring flange adaptor.

2. Rib-to-flange transitions develop a lap during drum rolling, which will require further process development to correct.

3. Complete ID/mandrel contact is believed to be best for uniform radial forging.

4. Wider ribs with larger radii would help eliminate entrance side rib defects and would promote filling.

5. Entrance side rib defects develop to a greater extent in thicker wall sections, where metal appeared to translate circumferentially with respect to the drum.

6. Minimization of rolling passes is believed to help minimize circumferential metal movement within the drum and help eliminate entrance side defects.

7. "Head Start" machining of thicker wall sections to develop early rib filling did not produce uniform rib heights during drum rolling.

Rick R. Hoffman

RICK HOFFMAN

ATTACHMENT 1

MILL CERTIFICATIONS

SHIPPING TALLY

REYNOLDS ORDER: S4F7B44M

8-4-5 (REV. 9-71)

REYNOLDS METALS COMPANY
SHEET & PLATE PLANT
McCOOK, ILLINOIS

Any shortage or damage in connection with this shipment must be immediately reported to the carrier with request that the carrier make an inspection and furnish appropriate inspection report or notation on the freight bill, and the shipment should not be unloaded until the carrier has done so. Whenever damage or shortage is noted please contact Reynolds Metals Company.

SHIP TO
COOPER INDUSTRIES
CAMERON FORGE PRODUCTS DIV
10825 TELGE ROAD
HOUSTON TX 77095

CUSTOMER ORDER	SALES OFFICE	SALES AREA	SALESMAN	MKT	CUSTOMER CODE	
18-00151	MCCK	HAYN	3450 HANE	21	4817405113	A

INVOICE	ROUTE	TALLY	BILL OF LADING	DATE
	BURLINGTON NORTHERN AIR FREIGHT INC	C226607	294766	12/22/94

ITEM	DESCRIPTION	LOT	CONT. CODE	PARTIAL COMPLETE	CASES	NET WEIGHT	GROSS WEIGHT	NUMBER OF PIECES	SEQUENCE	MULTI CODE	CASE TICKET
01	10153577 2195 ALUMINUM-LITHIUM INGOT 14.375" X 47.750" X 54.250" PACKING: MILL OPTION 145010	9402423A		C	1	3787	3790	1			040944
					1*	3787*	3790*	1*			
					1	3787	3790	1			

HFNO
P-23560

REYNOLDS METALS COMPANY

EXECUTIVE OFFICES, Richmond, Virginia 23261

Certificate of Inspection and Test Results

YOUR ORDER NUMBER		SHIPPING POINT	DATE	
REYNOLDS NUMBER S4F7844	18-00151	MCCOOK SHEET AND PLATE PLANT	12/22/94	PAGE 3 OF
		REYNOLDS CODES M 4817405113 21 F 9 003 202	TALLY NO. AND/OR BILL OF LADING NO. 0294766	CERTIFICATE NO. C226607

SOLD TO: MARTIN MARIETTA ASTRONAUTICS
SPACE SYSTEMS
PO BOX 9004 GD-FSC ACCT
TEMECULA CA
92589-9004

SHIP TO (SAME AS SOLD TO UNLESS OTHERWISE INDICATED): COOPER INDUSTRIES
CAMERON FORGE PRODUCTS DIV.
10825 TELGE ROAD
HOUSTON TX
77095
ATTN: CHARLES ECKHART

CASES	GR. WEIGHT	NET WEIGHT	QUANTITY
1	3790	3787	1

ITEM NO. | PRODUCT NO. | DESCRIPTION
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

ALLOY: 2195 TEMPER: GAUGE: 14.3750 WIDTH: 47.7500 LENGTH: 54.250

CHEMICAL ANALYSIS

LOT NUMBER	CU	FE	LI	MG	SI	TI	ZN	ZR	AG
940Z423A									
	3.9	.04	1.0	.34	.02	.02	.02	.14	.30

VALUES FROM ADDITIONAL ANALYSES OR TESTS MAY DIFFER, DEPENDING ON METHODS, EQUIPMENT, AND SAMPLING.

obtained by 2nd analysis
alex Cho will ck on silver.
hand written cert was .44

12/16/93

CAMERON FORGE, Houston, TX (GENERAL DYNAMICS)

P.O.	LOT	Cast / Drop	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Li	Ag	Zr		Size	UTS	YS
S3S0073-1	----------------	1140-27	0.02	0.05	4.05	0	0.46	0.01	0.01	0.07	1.05	n/a	0.14	1 pc	14.38" x 53.25" x 47.75"		

1140-27A

NOTE: OTHER ELEMENTS NOT TO EXCEED .05% MINIMUM EACH, AND LESS THAN .15% TOTAL.

REYNOLDS METALS COMPANY

COPY OF INVOICE

INCLUDE INVOICE NUMBER WITH REMITTANCE FOR PROPER IDENTIFICATION PAGE 1
****

CODE	
YOUR ORDER NUMBER	
SHIPPING POINT	MCCOOK 003
DATE OF INVOICE	11-16-95
INVOICE NUMBER	03110193
REYNOLDS NUMBER	S5F4234- RS5-082044
REYNOLDS CODES	4817402037 21F88 003 204 A
BILL OF LADING NO.	299528
TALLY NO.	236878
ITEMS SHIPPED COMPLETE	
ROUTE	EW WYLIE CORP
VIA REYNOLDS OPTION	
DEL. TERMS	F.O.B. DESTINATION
FREIGHT	PPD

SOLD TO:
MARTIN MARIETTA CORP
DENVER DIV
P.O. BOX 31
DENVER CO
80201

SHIP TO:
MARTIN MARIETTA ASTRONA
C/O WYMAN GORDON
10825 TELGE ROAD
HOUSTON TX
77095
ATTN: CHARLES ECKHARDT
(SAME AS SOLD TO UNLESS OTHERWISE INDICATED)

PAYMENT TERMS (FROM INVOICE DATE) NET 30 DAYS UNLESS OTHERWISE INDICATED
NET 30 DAYS

D-U-N-S
03

REMITTANCES WILL BE RECEIVED BY A BANK SIMPLY AS A CLEARING AGENCY. THE RECEIVING BANK HAS NO AUTHORITY TO DETERMINE WHETHER OR NOT THE AMOUNT REMITTED CONSTITUTES PAYMENT IN FULL. REMITTANCES MARKED TO INDICATE PAYMENT IN FULL WILL BE DEPOSITED BY THE BANK NOTWITHSTANDING SUCH MARKINGS AND SUCH DEPOSIT SHALL NOT INDICATE OUR ACCEPTANCE OF THE REMITTANCE AS PAYMENT IN FULL UNLESS THE REMITTANCE ACTUALLY CONSTITUTES PAYMENT OF ALL SUMS OWED.

SALESMAN
4550 KJELSTROM K L PCKK
PAUL FIELDING LS65

P.O. BOX
500619 ST LOUIS MO 63150-0619

PLEASE MAIL REMITTANCE TO THE INDICATED ADDRESS

CODE	ITEM	PRODUCT NO.	DESCRIPTION	PRICE	GR/WEIGHT	NET/WEIGHT	QUANTITY	AMOUNT
C	01	10157019	CUST ITEM# 01	13.0000 LBS	4,011	3,950	3,950	51,350.00
		2195 ALUMINUM-LITHIUM INGOT 14.500" X 55.000" X 50.000" 112045 3G1006 2195 0039			LOT 950P032A		PCS 1	

"THE REMAINDER OF THE ITEM DESCRIPTION(S) ARE AS STATED ON ORDER ACKNOWLEDGEMENT"

INVOICE TOTAL 51,350.00

SELLER REPRESENTS THAT WITH RESPECT TO THE PRODUCTION OF THE MATERIAL AND/OR THE PERFORMANCE OF THE SERVICES COVERED BY THIS INVOICE, IT HAS FULLY COMPLIED WITH THE REQUIREMENTS OF THE FAIR LABOR STANDARDS ACT OF 1938 AS AMENDED.

EXECUTIVE OFFICES, RICHMOND, VIRGINIA 23261
CABLE ADDRESS: "REYMETCO"

REYNOLDS METALS COMPANY

EXECUTIVE OFFICES, Richmond, Virginia 23261

Certificate of Inspection and Test Results

CODE	YOUR ORDER NUMBER	SHIPPING POINT	DATE	PAGE OF
		MCCOOK SHEET AND PLATE PLANT	11/10/95	1

REYNOLDS NUMBER		REYNOLDS CODES	TALLY NO. AND/OR BILL OF LADING NO.	CERTIFICATE NO.
S5F4234	RS5-082044	M 4817402037 21 F 8 003 20	0000000	C236878

SOLD TO:
MARTIN MARIETTA CORP
DENVER DIV
P.O. BOX 31
DENVER CO
80201

SHIP TO: (SAME AS SOLD TO UNLESS OTHERWISE INDICATED)
MARTIN MARIETTA ASTRONA
C/O WYMAN GORDON
10825 TELGE ROAD
HOUSTON TX
77095
ATTN: CHARLES ECKHARDT

CASES	GR. WEIGHT	NET WEIGHT	QUANTITY
1	4011	3950	1

ITEM NO.	PRODUCT NO.	DESCRIPTION
1	10157019	95/11/11 950F032A

2195 ALUMINUM-LITHIUM INGOT
14.500" X 55.000" X 50.000"
PACKING: MILL OPTION
112045
ITEM NOTES: MATERIAL PRODUCED IN ACCORDANCE
WITH STM11A1

This document certifies that the material described above has been inspected and tested in accordance with (i) Seller's standard sampling and testing procedures or (ii) the requirements of any specifications of the material described above. The chemical composition limits and the applicable mechanical property test results of samples representative of the material are set forth above or in any attachments hereto. Samples of the material have been found to meet the specifications described above. Inspection and test records are maintained on file.

This certificate shall be subject to the general terms and conditions on the reverse side of Seller's Acknowledgment and Sales Order.

QUALITY CONTROL AND INSPECTION MANAGER B. T. KIPFER SIGNED FOR REYNOLDS METALS COMPANY

REYNOLDS METALS COMPANY

EXECUTIVE OFFICES, Richmond, Virginia 23261

Certificate of Inspection and Test Results

CODE	YOUR ORDER NUMBER	SHIPPING POINT	DATE	PAGE	OF
		MCCOOK SHEET AND PLATE PLANT	11/10/95	3	

REYNOLDS NUMBER		REYNOLDS CODES	TALLY NO. AND/OR BILL OF LADING NO.	CERTIFICATE NO.
95F4234	RS5-082044	M 4817402037 21 F 8 003 20	0000000	C236878

SOLD TO:
MARTIN MARIETTA CORP
DENVER DIV
P. O. BOX 31
DENVER CO
80201

SHIP TO:
MARTIN MARIETTA ASTRONA
C/O WYMAN GORDON
10825 TELGE ROAD
HOUSTON TX
77095
ATTN: CHARLES ECKHARDT
(SAME AS SOLD TO UNLESS OTHERWISE INDICATED)

CASES	GR. WEIGHT	NET WEIGHT	QUANTITY
1	4011	3950	1

ITEM NO.	PRODUCT NO.	DESCRIPTION

ALLOY: 2195 TEMPER: GAUGE: 14.5000 WIDTH: 55.0000 LENGTH: 50.000

CHEMICAL ANALYSIS

LOT NUMBER	CU	FE	LI	MG	MN	SI	TI	ZN	ZR	AG
950P032A										
1144A-249B	4.2	.03	.9	.32	<.01	.02	.03	.02	.14	.30

VALUES FROM ADDITIONAL ANALYSES OR TESTS MAY DIFFER, DEPENDING ON METHODS, EQUIPMENT, AND SAMPLING.

This document certifies that the material described above has been inspected and tested in accordance with (i) Seller's standard sampling and testing procedures or (ii) the requirements of any specifications of the material described above. The chemical composition limits and the applicable mechanical property test results of samples representative of the material are set forth above or in any attachments hereto. Samples of the material have been found to meet the specifications described above. Inspection and test records are maintained on file.

This certificate shall be subject to the general terms and conditions on the reverse side of Seller's Acknowledgment and Sales Order.

MANAGER ... SIGNED FOR REYNOLDS METALS COMPANY

APPENDIX A

SONIC INSPECTION REPORTS

LADISH CO., INC.

QUALITY DEPARTMENT
ULTRASONIC INSPECTION REPORT

DATE: 12-4-95

CUSTOMER: MARTIN MARIETTA

PART NO.: 165.375 x 163.560 x 20 1/4

P.O.:

MATERIAL SPEC.: ALUM. LITHIUM

ULTRASONIC SPEC.: (L) INFO.

LJO: EX-809-05

EQUIPMENT LADISH NO. 2430 TYPE K.K. USIP 11 UNIT DUE DATE 3-15-96

LADISH NO. ______ TYPE ______ UNIT DUE DATE ______

COUPLANT: OIL

WATER PATH DISTANCE:

WAVE FORM: ☒ LONGITUDINAL ☐ SHEAR

METHOD: ☒ CONTACT ☐ IMMERSION

TRANSDUCER FREQUENCY (MHZ): ☐ 0.5 ☐ 1.0 ☐ 2.25 ☒ 5.0 ☐ 10.0 ☐ 15.0

TRANSDUCER LADISH NO. 1060 SIZE 1" ϕ TYPE PANAMETRICS SCAN INCREMENT OVERLAPPING

LADISH NO. ______ SIZE ______ TYPE ______ SCAN INCREMENT ______

SENSITIVITY: SET TO RECEIVE A FULL BR + 6DBs FOR SEARCH

ALARM LEVEL ______

ALARM LEVEL ______

TEST PROCEDURE: TEST 7/8" WIDE BAND 360° ADJACENT TO WIDE FACE, ALSO " WIDE BAND 360° OF OD.

INSPECTOR: GONZALEZ GRAVELLE

MATERIAL INSPECTED

SERIAL	CODE	PART NAME	DISPOSITION	EST. RMS
1	—	RING	SONIC ACCEP.	PARTIAL MACH.

GOOD PENETRATION, NO REPORTABLE OR REJECTABLE INDS. NOTED.

NOTE: A 3" WIDE BAND OF O.D. NOT TESTED DUE TO CONFIGURATION AND POOR MACH. SURFACE

LCO 2096 R6

LADISH CO., INC.

QUALITY DEPARTMENT
ULTRASONIC INSPECTION REPORT

DATE: 11-15-95

CUSTOMER: Martin Marietta

PART NO.: 165.375 X 163.560" X 20 1/4"

P.O.:

MATERIAL SPEC.: Aluminum Lithium

ULTRASONIC SPEC.: (L) Info.

LJO: EX-809-0P281-

EQUIPMENT
LADISH NO. 2430 TYPE K.K UNIT DUE DATE 3-15-96
LADISH NO. ______ TYPE ______ UNIT DUE DATE ______

COUPLANT: Oil

WATER PATH DISTANCE:

WAVE FORM: ☒ LONGITUDINAL ☐ SHEAR

METHOD: ☒ CONTACT ☐ IMMERSION

TRANSDUCER FREQUENCY (MHZ): ☐ 0.5 ☐ 1.0 ☐ 2.25 ☒ 5.0 ☐ 10.0 ☐ 15.0

TRANSDUCER
LADISH NO. 1060 SIZE 1" Ø TYPE Panametrics SCAN INCREMENT Overlapping
LADISH NO. ______ SIZE ______ TYPE ______ SCAN INCREMENT ______

SENSITIVITY: Set to receive a full screen back reflection + 6 DBS for search.

ALARM LEVEL ______

ALARM LEVEL ______

TEST PROCEDURE: Test 7/8" wide band 360° adjacent to wide face also 16 1/2" wide band 360° of O.D.

INSPECTOR: Hugo

MATERIAL INSPECTED

SERIAL	CODE	PART NAME	DISPOSITION	EST. RMS
4		Ring	Sonic Acceptable	Mach.

Very good penetration.
No reportable or rejectable indications noted.
Note: A 2 1/2" wide band of O.D not tested due to configuration and poor mach surface.

LCO 2096 R6

LADISH CO., INC.

QUALITY DEPARTMENT
ULTRASONIC INSPECTION REPORT

DATE: 3-21-96

CUSTOMER: MARTIN MARIETTA
PART NO.: 165" x 163" x 20" RING
P.O.:

MATERIAL SPEC.: 2195 AL-LI
ULTRASONIC SPEC.: L INFO
LJO: EX-809-06

EQUIPMENT
LADISH NO. 2430 TYPE USIP-11 UNIT DUE DATE 8-28-96
LADISH NO. ______ TYPE ______ UNIT DUE DATE ______
COUPLANT: OIL
WATER PATH DISTANCE:

WAVE FORM: ☒ LONGITUDINAL ☐ SHEAR
METHOD: ☒ CONTACT ☐ IMMERSION
TRANSDUCER FREQUENCY (MHZ): ☐ 0.5 ☐ 1.0 ☐ 2.25 ☒ 5.0 ☐ 10.0 ☐ 15.0

TRANSDUCER
LADISH NO. 1136 SIZE 1" RD. TYPE PANAMETRICS SCAN INCREMENT ______
LADISH NO. ______ SIZE ______ TYPE ______ SCAN INCREMENT ______

SENSITIVITY
SET TO RECEIVE 100% BACK REFLECTION PLUS 6 db FOR SCANNING

ALARM LEVEL ______
ALARM LEVEL ______

TEST PROCEDURE
TEST 1½" BAND 360° ADJACENT TO WIDE FACE & 16" BAND 360° ADJACENT TO OPPOSITE FACE

INSPECTOR: GRAVELLE, POPODI

MATERIAL INSPECTED

SERIAL	CODE	PART NAME	DISPOSITION	EST. RMS
5		NEAR NET RING	SONIC ACCEPTABLE	180

GOOD PENETRATION NO REPORTABLE OR REJECTABLE INDICATIONS NOTED

NOTE: A 2¾" WIDE BAND OF THE O.D. WAS NOT TESTED DUE TO MACHINED CONFIGURATION.

LADISH CO., INC.

QUALITY DEPARTMENT
ULTRASONIC INSPECTION REPORT

DATE: 3-25-96

CUSTOMER: MARTIN MARIETTA

PART NO.:

P.O.:

MATERIAL SPEC.: 2195 AL-LI

ULTRASONIC SPEC.: ⓛ INFO

LJO: EX-809-06

EQUIPMENT
LADISH NO. 2430 TYPE USIP-11 UNIT DUE DATE 8-28-96
LADISH NO. ______ TYPE ______ UNIT DUE DATE ______

COUPLANT: OIL

WATER PATH DISTANCE:

WAVE FORM: ☒ LONGITUDINAL ☐ SHEAR

METHOD: ☒ CONTACT ☐ IMMERSION

TRANSDUCER FREQUENCY (MHZ): ☐ 0.5 ☐ 1.0 ☐ 2.25 ☒ 5.0 ☐ 10.0 ☐ 15.0

TRANSDUCER
LADISH NO. 1136 SIZE 1" RD TYPE PANAMETRICS SCAN INCREMENT ______
LADISH NO. ______ SIZE ______ TYPE ______ SCAN INCREMENT ______

SENSITIVITY
SET TO RECEIVE 100% BACK REFLECTION PLUS 6db FOR SCANNING

ALARM LEVEL ______

ALARM LEVEL ______

TEST PROCEDURE
TEST 2" BAND 360° ADJACENT TO WIDE FACE & 16" BAND 360° ADJACENT TO OPPOSITE FACE

INSPECTOR: POPODI

MATERIAL INSPECTED

SERIAL	CODE	PART NAME	DISPOSITION	EST. RMS
6		NEAR NET RING	SONIC ACCEPTABLE	180

GOOD PENETRATION, NO REPORTABLE OR REJECTABLE INDICATIONS NOTED.

NOTE: A 2" WIDE BAND OF THE O.D. WAS NOT TESTED DUE TO MACHINED CONFIGURATION

APPENDIX B

LIQUID PENETRANT INSPECTION REPORTS

LADISH CO., INC.
QUALITY & TECHNOLOGY
LIQUID PENETRANT INSPECTION REPORT

ISTOMER	MARTIN MARRIETTA	(L) PROCEDURE .	9Q107	REV	12	DATE	4/14/94
(L) MFG.ORDER NO.	EX-809-01	INSTRUCTION SHEET NO.		REV		CODE	
CUSTOMER PART		SUPPLEMENT.		REV		DATE	
PART NAME	RING	APPLICABLE SPECIFICATION	MIL-STD-6866	REV	I-A	DATE	11/29/85

PCS.ACCEPTED	CODES SERIAL NOS.
	SER #1

SURFACES EXAMINED ☒ ALL ☐ PARTIAL (DESCRIBE)

MEETS THE APPLICABLE ACCEPTANCE STANDARD

REMARKS ALL INDICATIONS MARKED SEE ATTACHED SKETCH

THE RECORDING OF FALSE, FICTICIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELON UNDER FEDERAL STATUTES, INCLUDING FEDERAL LAW TITLE 18, CHAPTER 47.

OPERATORS/INSPECTORS SIGNATURE	LEVEL	STAMP NO.	DATE
DAVE DZIUK JEFF MAHNKE	II II	P16 P27	12/18/95 12/18/95

ABOVE EXAMINATION AND EVALUATION HAS BEEN PERFORMED TO MY SATISFACTION

SIGNED Thomas Sorce THOMAS SORCE LEVEL III DATE 12/20/95

THE ABOVE NDT PERSONNEL ARE CERTIFIED TO THE REQUIREMENTS OF THE PURCHASE ORDER. RECORDS OF THEIR QUALIFICATIONS ARE ON FILE IN THE EXAMINERS OFFICE.

LADISH CO., INC.
QUALITY & TECHNOLOGY
LIQUID PENETRANT INSPECTION REPORT

CUSTOMER	MARTIN MARIETTA	(L) PROCEDURE .	9Q107	REV	12	DATE	4/14/94
MFG.ORDER NO.	EX-809-01	INSTRUCTION SHEET NO.		REV		CODE	
CUSTOMER PART		SUPPLEMENT.		REV		DATE	
PART NAME	RING	APPLICABLE SPECIFICATION	MIL-STD-6866	REV	I-A	DATE	11/29/85

PCS.ACCEPTED	CODES SERIAL NOS.
	SER #4

SURFACES EXAMINED [X] ALL [ ] PARTIAL (DESCRIBE)

MEETS THE APPLICABLE ACCEPTANCE STANDARD

REMARKS ALL INDICATIONS MARKED SEE ATTACHED SKETCH (FIG 1)

THE RECORDING OF FALSE, FICTICIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELON UNDER FEDERAL STATUTES, INCLUDING FEDERAL LAW TITLE 18, CHAPTER 47.

OPERATORS/INSPECTORS SIGNATURE	LEVEL	STAMP NO.	DATE
DAVE DZIUK	II	P16	11/21/95

ABOVE EXAMINATION AND EVALUATION HAS BEEN PERFORMED TO MY SATISFACTION

Thomas Sorce

SIGNED THOMAS SORCE LEVEL III DATE 11/22/95

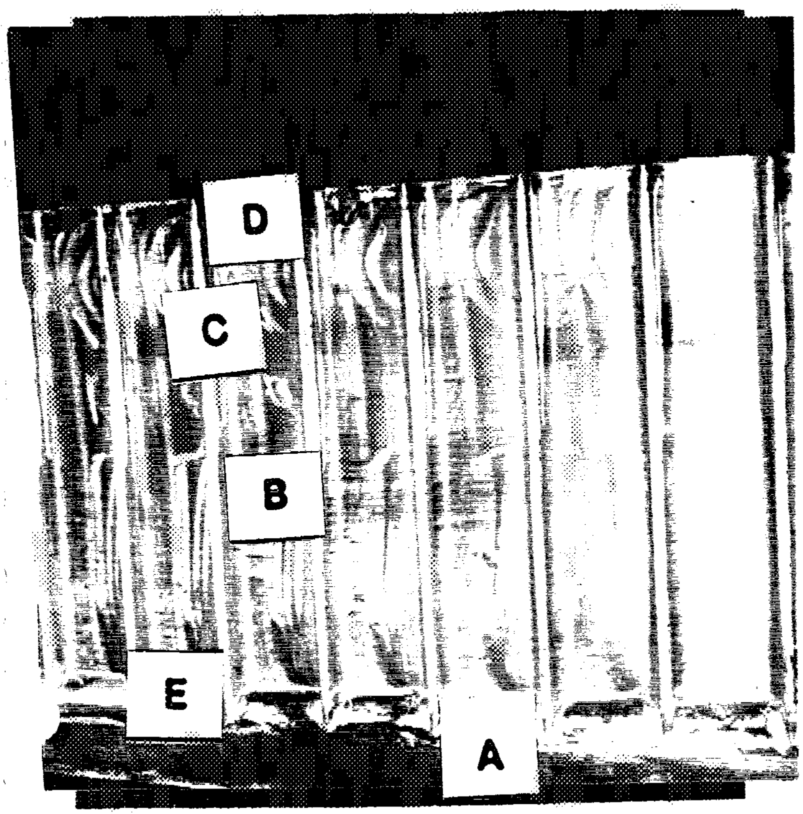
THE ABOVE NDT PERSONNEL ARE CERTIFIED TO THE REQUIREMENTS OF THE PURCHASE ORDER. RECORDS OF THEIR QUALIFICATIONS ARE ON FILE IN THE EXAMINERS OFFICE.

LCO 3092 R12

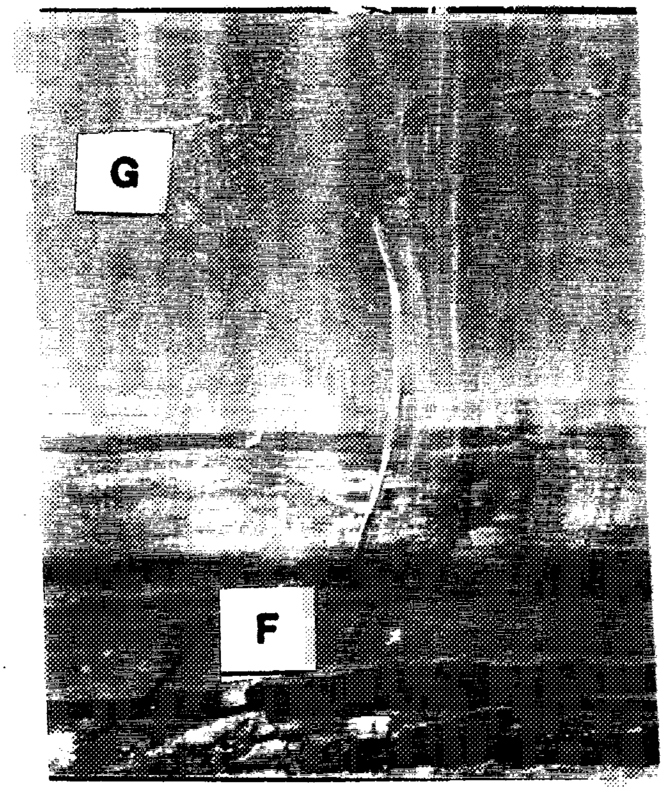
LADISH CO., INC.
QUALITY & TECHNOLOGY DEPT.

FIGURE 1

FPI INSPECTION SKETCH, EX890 AL-LI CYLINDER



OD SECTION



ID SECTION

SER #1

Location A - OD Flange, intermittent metal foldovers(scabs) (when the scab is removed a pit-like crevice exists).

Location B - OD Web, small intermittent metal scabs.

Location C - OD Stiffener Peak, laps and NFO condition, 360°.

Location D - OD Stiffener Base, crack-like indication, 360°.

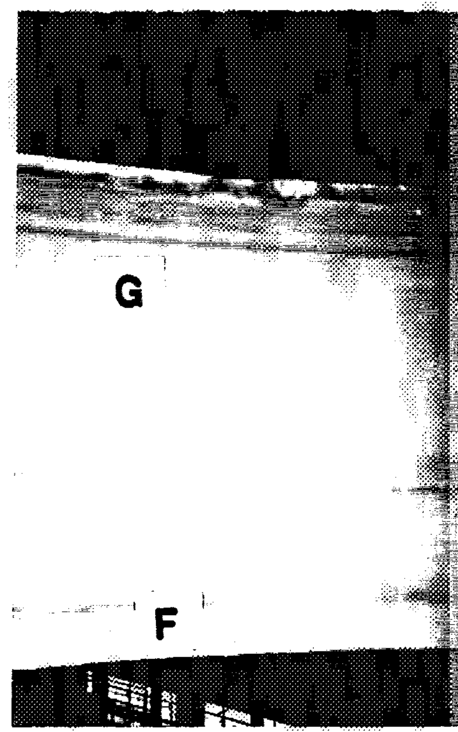
Location E - OD Stiffner-Flange Junction, metal fold at radius, 360°.

Location F - ID Base, metal foldover, 1" width, 360°.

Location G - ID, varied locations, small intermittent blemishes.

LADISH CO., INC.
QUALITY & TECHNOLOGY DEPT.

FIGURE 1 (SERIAL #4)
FPI INSPECTION SKETCH,EX809 AL-LI CYLINDER



OD SECTION ID SECTION

Location A - OD Flange, intermittent metal foldovers (scabs)
(when the scab is removed a pit-like crevice exists)

Location B - OD Web, small intermittent metal scabs.

Location C - OD Stiffener Peak, Laps anf NFO condition, 360°.

Location D - OD Stiffener Base, crack-like indication, 360°.

Location E - OD Stiffener-flange junction metal fold at radius, 360°.

Location F - ID Base, metal foldover, 1" width, 360°.

Location G - ID, varied locations, small intermittent blemishes.

LADISH CO., INC.
QUALITY & TECHNOLOGY
LIQUID PENETRANT INSPECTION REPORT

'TOMER	MARTIN MARRIETTA	(L) PROCEDURE .	9Q107	REV	12	DATE	4/14/94
L) MFG.ORDER NO.	EX-809-06	INSTRUCTION SHEET NO.		REV		CODE	
CUSTOMER PART		SUPPLEMENT.		REV		DATE	
?ART NAME	RING	APPLICABLE SPECIFICATIO	MIL-STD-6866	REV	1-A	DATE	11/29/85

PCS.ACCEPTED	CODES SERIAL NOS.	CAS OPERATION NO.
	SER#5	

SURFACES EXAMINED ☒ ALL ☐ PARTIAL (DESCRIBE)

MEETS THE APPLICABLE ACCEPTANCE STANDARD

REMARKS

THE RECORDING OF FALSE, FICTICIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELON UNDER FEDERAL STATUTES, INCLUDING FEDERAL LAW TITLE 18, CHAPTER 47.

OPERATORS/INSPECTORS SIGNATURE	LEVEL	STAMP NO.	DATE
DAVE DZIUK	II	P16	4/1/96
JEFF MAHNKE	II	P27	4/1/96

ABOVE EXAMINATION AND EVALUATION HAS BEEN PERFORMED TO MY SATISFACTION

SIGNED Thomas Sorce THOMAS SORCE LEVEL III DATE 4/10/96

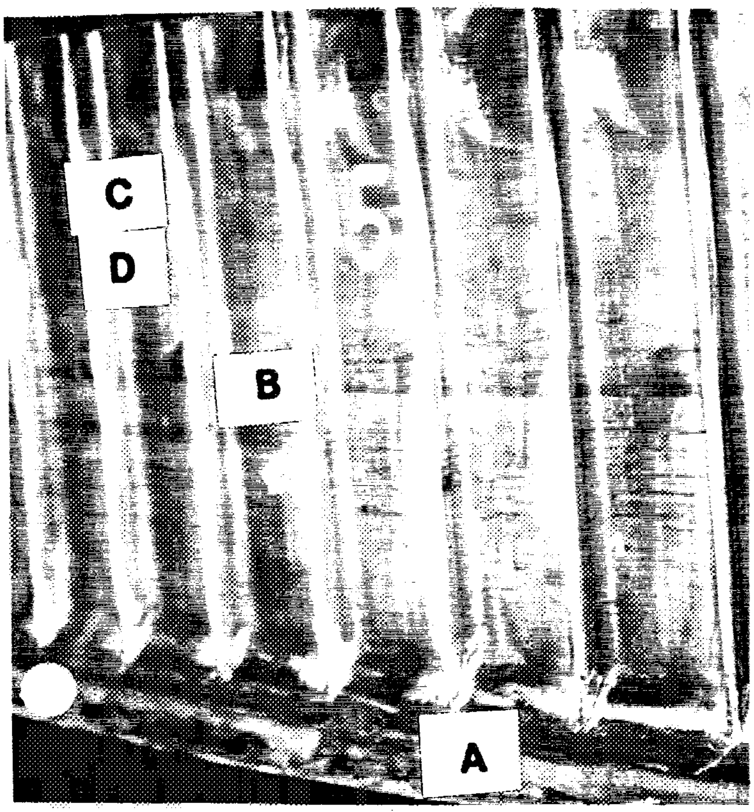
THE ABOVE NDT PERSONNEL ARE CERTIFIED TO THE REQUIREMENTS OF THE PURCHASE ORDER. RECORDS OF THEIR QUALIFICATIONS ARE ON FILE IN THE EXAMINERS OFFICE.

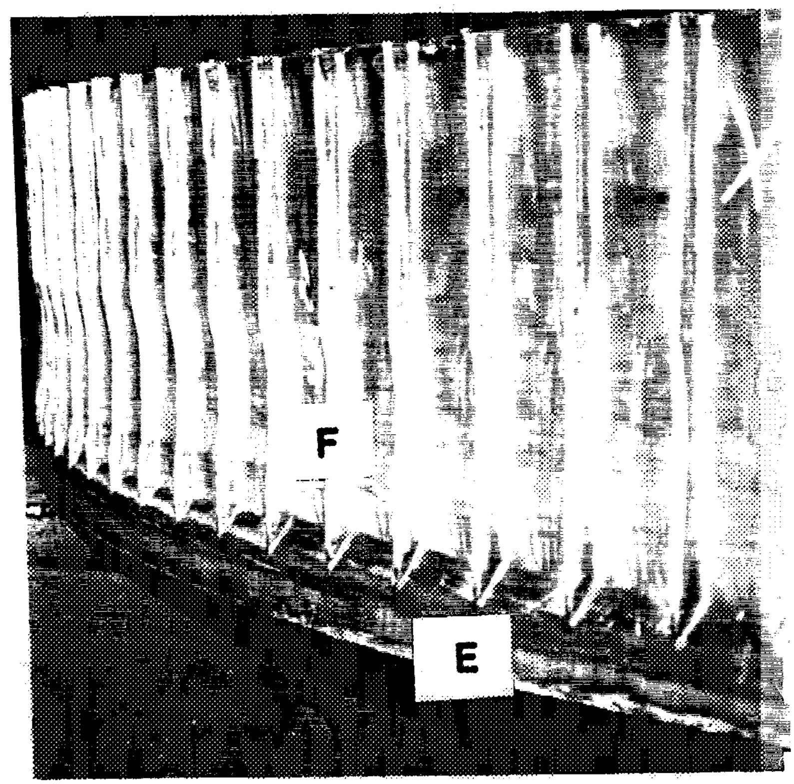
LCO 3092 R12

LADISH CO., INC.
QUALITY AND TECHNOLOGY DEPT.

FIGURE 1

FPI INSPECTION SKETCH, EX890 AL-LI CYLINDER (SER #5)





Location A - OD Flange, intermittent metal foldovers (scabs) (when the scab is removed pit like crevice exists)

Location B - OD Web, small intermittent metal scabs.

Location C - OD stiffener,opposite ID "Y" flange bulge, laps at peak.

Location D - OD entrance side stiffener,cracklike indications 360°.

Location E - OD stiffener-flange junction, metal fold at radius with separation.

Location F - NFO condition with developing fold.

ID: ID base, metal foldover, 1" width app 360°.
ID, varied locations, small intermittent blemishes.

LADISH CO., INC.
QUALITY & TECHNOLOGY
LIQUID PENETRANT INSPECTION REPORT

'STOMER	MARTIN MARRIETTA	(L) PROCEDURE .	9Q107	REV	12	DATE	4/14/94
(L MFG.ORDER NO.	EX-809-06	INSTRUCTION SHEET NO.		REV		CODE	
CUSTOMER PART		SUPPLEMENT.		REV		DATE	
PART NAME	RING	APPLICABLE SPECIFICATIO	MIL-STD-6866	REV	1-A	DATE	11/29/85

PCS.ACCEPTED	CODES SERIAL NOS.	CAS OPERATION NO.
	SER#6	

SURFACES EXAMINED [X] ALL [ ] PARTIAL (DESCRIBE)

MEETS THE APPLICABLE ACCEPTANCE STANDARD

REMARKS

THE RECORDING OF FALSE, FICTICIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELON UNDER FEDERAL STATUTES, INCLUDING FEDERAL LAW TITLE 18, CHAPTER 47.

OPERATORS/INSPECTORS SIGNATURE	LEVEL	STAMP NO.	DATE
DAVE DZIUK	II	P16	4/2/96
JEFF MAHNKE	II	P27	4/2/96

ABOVE EXAMINATION AND EVALUATION HAS BEEN PERFORMED TO MY SATISFACTION

Thomas Sorce

SIGNED THOMAS SORCE LEVEL III DATE 4/10/96

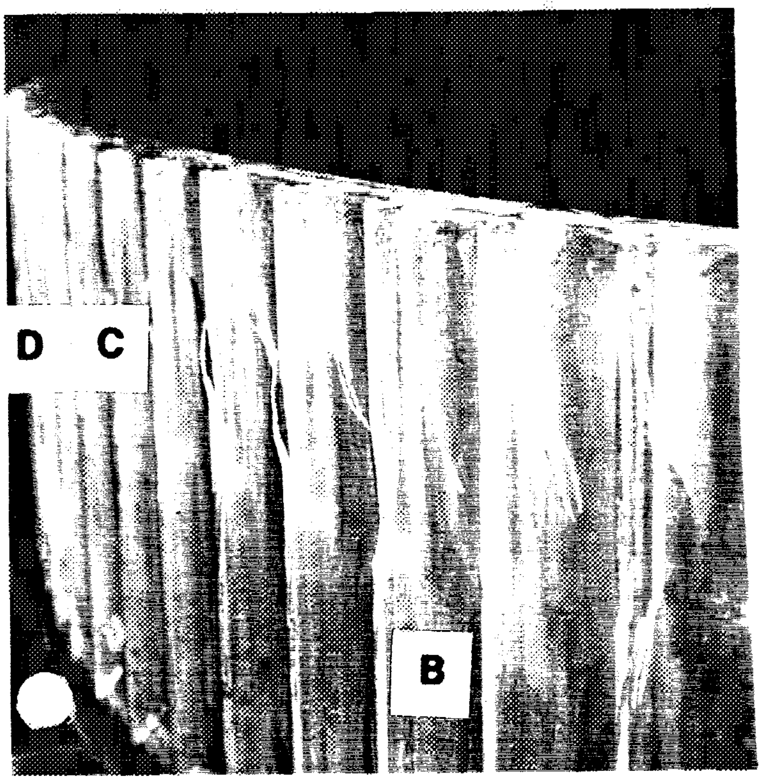
THE ABOVE NDT PERSONNEL ARE CERTIFIED TO THE REQUIREMENTS OF THE PURCHASE ORDER. RECORDS OF THEIR QUALIFICATIONS ARE ON FILE IN THE EXAMINERS OFFICE.

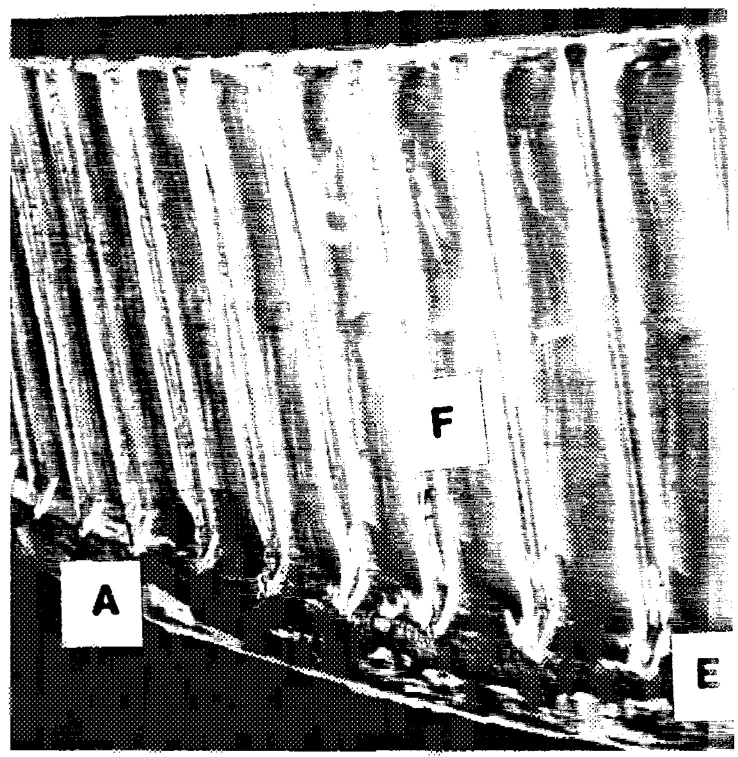
LCO 3092 R12

LADISH CO., INC.
QUALITY AND TECHNOLOGY DEPT.

FIGURE 1

FPI INSPECTION SKETCH, EX890 AL-LI CYLINDER (SER #6)





Location A -	OD Flange, intermittent metal foldovers (scabs) (when the scab is removed pit like crevice exists)
Location B -	OD Web, small intermittent metal scabs.
Location C -	OD stiffener,opposite ID "Y" flange bulge, laps at peak, with some separation.
Location D -	OD entrance side stiffener,cracklike indications 360°.
Location E -	OD stiffener-flange junction, metal fold at radius with separation up to 2" long.
Location F -	OD stiffener peak, with intermittent lap condition.
ID:	ID base, metal foldover, 1" width app 360°. ID, varied locations, small intermittent blemishes.

APPENDIX B
2195 INGOT CERTIFICATION

SHIPPING TALLY

B-4-5 (REV. 9-71)

REYNOLDS METALS COMPANY
SHEET & PLATE PLANT
McCOOK, ILLINOIS

Any shortage or damage in connection with this shipment must be immediately reported to the carrier with request that the carrier make an inspection and furnish appropriate inspection report or notation on the freight bill, and the shipment should not be unloaded until the carrier has done so. Whenever damage or shortage is noted please contact Reynolds Metals Company.

REYNOLDS ORDER: S4F7B44M

SHIP TO:
COOPER INDUSTRIES
CAMERON FORGE PRODUCTS DIV
10825 TELGE ROAD
HOUSTON TX 77095

CUSTOMER ORDER	SALES OFFICE	SALES AREA	SALESMAN	MKT	CUSTOMER CODE	
18-00151	MCCK	HAYN	3450 HANE	21.	4817405113	A

INVOICE	ROUTE	TALLY	BILL OF LADING	DATE
	BURLINGTON NORTHERN AIR FREIGHT INC	C226607	294766	12/22/94

ITEM	DESCRIPTION	LOT	CONT. CODE	PARTIAL COMPLETE	CASES	NET WEIGHT	GROSS WEIGHT	NUMBER OF PIECES	SEQUENCE	MULTI CODE	CASE TICKET
01	10153577 2195 ALUMINUM-LITHIUM INGOT 14.375" X 47.750" X 54.250" PACKING: MILL OPTION 145010	9402423A		C	1	3787	3790	1			040944
					1*	3787*	3790*	1*			
					1	3787	3790	1			

HTNo
P-23560

REYNOLDS METALS COMPANY

EXECUTIVE OFFICES, Richmond, Virginia 23261

Certificate of Inspection and Test Results

YOUR ORDER NUMBER

SHIPPING POINT: MCCOOK SHEET AND PLATE PLANT

DATE: 12/22/94

PAGE 3 OF

REYNOLDS NUMBER: S4F7844 18-00151

REYNOLDS CODES: M 4817405113 21 F 9 003 202

TALLY NO. AND/OR BILL OF LADING NO.: 0294766

CERTIFICATE NO.: C226607

SOLD TO:
MARTIN MARIETTA ASTRONAUTICS
SPACE SYSTEMS
PO BOX 9004 CD-FSC ACCT
TEMECULA CA
92589-9004

SHIP TO:
COOPER INDUSTRIES
CAMERON FORGE PRODUCTS DIV.
10825 TELGE ROAD
HOUSTON TX
77095
ATTN: CHARLES ECKHART
(SAME AS SOLD TO UNLESS OTHERWISE INDICATED)

CASES	GR. WEIGHT	NET WEIGHT	QUANTITY
1	3790	3787	1

ITEM NO. PRODUCT NO. DESCRIPTION

ALLOY: 2195 TEMPER: GAUGE: 14.3750 WIDTH: 47.7500 LENGTH: 54.250

CHEMICAL ANALYSIS

LOT NUMBER	CU	FE	LI	MG	SI	TI	ZN	ZR	AG
9402423A									
	3.9	.04	1.0	.34	.02	.02	.02	.14	.30

VALUES FROM ADDITIONAL ANALYSES OR TESTS MAY DIFFER, DEPENDING ON METHODS, EQUIPMENT, AND SAMPLING.

This document certifies that the material described above has been inspected and tested in accordance with (i) Seller's standard sampling and testing procedures or (ii) the requirements of any specifications of the material described above. The chemical composition limits and the applicable mechanical property test results of samples representative of the material are set forth above or in any attachments hereto. Samples of the material have been found to meet the specifications described above. Inspection and test records are maintained [illegible]

obtained by 2nd analysis
alex Cho will ck on silver.
hand written cert was .44

12/16/93

CAMERON FORGE, Houston, TX (GENERAL DYNAMICS)

P.O.	LOT	Cast / Drop	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Li	Ag	Zr		Size	UTS	YS
S3S0073-1	-----------------	1140-27	0.02	0.05	4.05	0	0.46	0.01	0.01	0.07	1.05	n/a	0.14	1 pc	14.38" x	53.25" x	47.75"

1140-27A

NOTE: OTHER ELEMENTS NOT TO EXCEED .05% MINIMUM EACH, AND LESS THAN .15% TOTAL.

REYNOLDS METALS COMPANY

COPY OF INVOICE

INCLUDE INVOICE NUMBER WITH REMITTANCE FOR PROPER IDENTIFICATION PAGE 1
****

INVOICE NUMBER: 03110193

CODE

YOUR ORDER NUMBER:

SHIPPING POINT: MCCOOK 003

DATE OF INVOICE: 11-16-95

REYNOLDS NUMBER: S5F4234- RS5-082044

REYNOLDS CODES: 4817402037 21F88 003 204 A

BILL OF LADING NO.: 299528

TALLY NO.: 236878

ITEMS SHIPPED COMPLETE:

SOLD TO:
MARTIN MARIETTA CORP
DENVER DIV
P.O. BOX 31
DENVER CO
80201

SHIP TO:
MARTIN MARIETTA ASTRONA
C/O WYMAN GORDON
10825 TELGE ROAD
HOUSTON TX
77095
ATTN: CHARLES ECKHARDT
(SAME AS SOLD TO UNLESS OTHERWISE INDICATED)

ROUTE: EW WYLIE CORP

VIA REYNOLDS OPTION

DEL. TERMS: F.O.B. DESTINATION

FREIGHT: PPD

PAYMENT TERMS (FROM INVOICE DATE) NET 30 DAYS UNLESS OTHERWISE INDICATED

NET 30 DAYS

D-U-N-S: 03

REMITTANCES WILL BE RECEIVED BY A BANK SIMPLY AS A CLEARING AGENCY. THE RECEIVING BANK HAS NO AUTHORITY TO DETERMINE WHETHER OR NOT THE AMOUNT REMITTED CONSTITUTES PAYMENT IN FULL. REMITTANCES MARKED TO INDICATE PAYMENT IN FULL WILL BE DEPOSITED BY THE BANK NOTWITHSTANDING SUCH MARKINGS AND SUCH DEPOSIT SHALL NOT INDICATE OUR ACCEPTANCE OF THE REMITTANCE AS PAYMENT IN FULL UNLESS THE REMITTANCE ACTUALLY CONSTITUTES PAYMENT OF ALL SUMS OWED.

SALESMAN: 4550 KJELSTROM K L PCKK
PAUL FIELDING LS65

P.O. BOX 500619 ST LOUIS MO 63150-0619

PLEASE MAIL REMITTANCE TO THE INDICATED ADDRESS

CODE	ITEM	PRODUCT NO.	DESCRIPTION	PRICE	GR/WEIGHT	NET/WEIGHT	QUANTITY	AMOUNT
C	01	10157019	CUST ITEM# 01	13.0000 LBS	4,011	3,950	3,950	51,350.00

2195 ALUMINUM-LITHIUM INGOT LOT 950P032A PCS 1
14.500" X 55.000" X 50.000"
112045 3G1006 2195 0039
"THE REMAINDER OF THE ITEM DESCRIPTION(S) ARE AS STATED ON ORDER ACKNOWLEDGEMENT"

INVOICE TOTAL 51,350.00

SELLER REPRESENTS THAT WITH RESPECT TO THE PRODUCTION OF THE MATERIAL AND/OR THE PERFORMANCE OF THE SERVICES COVERED BY THIS INVOICE, IT HAS FULLY COMPLIED WITH THE REQUIREMENTS OF THE FAIR LABOR STANDARDS ACT OF 1938 AS AMENDED.

EXECUTIVE OFFICES, RICHMOND, VIRGINIA 232
CABLE ADDRESS: "REYMETCO"

REYNOLDS METALS COMPANY

EXECUTIVE OFFICES, Richmond, Virginia 23261

Certificate of Inspection and Test Results

YOUR ORDER NUMBER		SHIPPING POINT	DATE		
		MCCOOK SHEET AND PLATE PLANT	11/10/95	PAGE 1 OF	
REYNOLDS NUMBER		REYNOLDS CODES	TALLY NO. AND/OR BILL OF LADING NO.	CERTIFICATE NO.	
S5F4234	RS5-082044	M 4817402037 21 F 8 003 20	0000000	C236878	

SOLD TO	SHIP TO	CASES	GR. WEIGHT	NET WEIGHT	QUANTITY
MARTIN MARIETTA CORP DENVER DIV P.O. BOX 31 DENVER CO 80201	MARTIN MARIETTA ASTRONA C/O WYMAN GORDON 10825 TELGE ROAD HOUSTON TX 77095 ATTN: CHARLES ECKHARDT (SAME AS SOLD TO UNLESS OTHERWISE INDICATED)	1	4011	3950	1

ITEM NO.	PRODUCT NO.	DESCRIPTION
1	10157019	95/11/11 95OF032A

2195 ALUMINUM-LITHIUM INGOT
14.500" X 55.000" X 50.000"
PACKING: MILL OPTION
112045
ITEM NOTES: MATERIAL PRODUCED IN ACCORDANCE
WITH STM11A1

This document certifies that the material described above has been inspected and tested in accordance with (I) Seller's standard sampling and testing procedures or (II) the requirements of any specifications of the material described above. The chemical composition limits and the applicable mechanical property test results of samples representative of the material are set forth above or in any attachments hereto. Samples of the material have been found to meet the specifications described above. Inspection and test records are maintained on file.

This certificate shall be subject to the general terms and conditions on the reverse side of Seller's Acknowledgment and Sales Order.

QUALITY ASSURANCE INSPECTION MANAGER S T KIPPER SIGNED FOR REYNOLDS METALS COMPANY

REYNOLDS METALS COMPANY

EXECUTIVE OFFICES, Richmond, Virginia 23261

Certificate of Inspection and Test Results

YOUR ORDER NUMBER	SHIPPING POINT	DATE	PAGE	OF
	MCCOOK SHEET AND PLATE PLANT	11/10/95	3	

REYNOLDS NUMBER		REYNOLDS CODES	TALLY NO. AND/OR BILL OF LADING NO.	CERTIFICATE NO.
85F4234	RS5-082044	M 4817402037 21 F 8 003 20	0000000	C236878

SOLD TO:
MARTIN MARIETTA CORP
DENVER DIV
P.O. BOX 31
DENVER CO
80201

SHIP TO:
MARTIN MARIETTA ASTRONA
C/O WYMAN GORDON
10825 TELGE ROAD
HOUSTON TX
77095
ATTN: CHARLES ECKHARDT
(SAME AS SOLD TO UNLESS OTHERWISE INDICATED)

CASES	GR. WEIGHT	NET WEIGHT	QUANTITY
1	4011	3950	1

ITEM NO. | PRODUCT NO. | DESCRIPTION

ALLOY. 2195 TEMPER. GAUGE. 14.5000 WIDTH. 55.6000 LENGTH. 56.000

CHEMICAL ANALYSIS

LOT NUMBER 950P032A	CU	FE	LI	MG	MN	SI	TI	ZN	ZR	AG
1144A-249B	4.2	.03	.9	.32	<.01	.02	.03	.02	.14	.30

VALUES FROM ADDITIONAL ANALYSES OR TESTS MAY DIFFER, DEPENDING ON METHODS, EQUIPMENT, AND SAMPLING.

APPENDIX C
REPORT OF PRELIMINARY 2195-T8 NEAR-NET FORGING WELD EVALUATION

Interoffice Memo

LOCKHEED MARTIN

NNF-MEM-023
August 8, 1996

To: Keith Hall, NNFTDP Principal Investigator

From: Gerry Björkman, Weld Engineer

Subject: Preliminary VPPA Weld Development of Near Net Forging Material

Enclosures:
1) Weld Panel Layout
2) Weld Schedules
3) Tensile Data
4) Metallography

Introduction:

This work was performed under the Near Net Forging Technology Demonstration Program (NNFTDP), contract No. NAS8-39935. Near Net Forging (NNF) of 2195 is a forming technique for producing large diameter single piece cylindrical components for launch vehicle structural applications. The process produces components that are near net to the desired configuration, reducing fabrication costs. The weldability of 2195 NNF material is a very important concern. This memo covers the preliminary weld development performed on 2195 NNF which incorporated variable polarity plasma arc (VPPA) welding.

Objective:

Perform preliminary VPPA weld development on 2195-T8 near net forged material using two specimens taken from a 14.0-foot-diameter near net forged adapter.

Approach:

Two 7.75-inch x 9.75-inch specimens, #72-74 and #110-113, were taken the 14-ft-diameter near net fogred mechanical properties pathfinder, which was produced from 2195 and processed to the T8 condition. # 72-74 was from the ring-to-cylinder weld area, and #110-113 was taken from the membrane area. The specimens, which ranged from 0.875 to 1.625 inches in thickness, were machined down to 0.320-inches in thickness to form weld test panels. Each panel was VPPA welded to 0.320-inch-thick 2195-RT70 plate material. For purposes in comparing plate and NNF weld properties, a third panel consisting of two 0.320-inch-thick 2195-T8 plate was VPPA welded. Visual, radiographic, dye penetrant, and metallographic inspection methods were used to inspect the integrity of the welds. Room temperature tensile test specimens were processed from the welded panels and tested. Enclosure 1 contains the weld panel layouts displaying the location where tensile and metallographic specimens were taken.

Weld Setup:

From original thickness ranging from 0.875 to 1.625-inches-thick, the 2195-T8 NNF specimens were "dry" machined to 0.320-inches-thick x 7.5-inches-wide x 9.75-inches-long weld panels. The specimens taken at approximately t/4 and machined so that welding was performed parallel to the circumferential orientation of the NNF ring. The 2195-RT70 plate material was "dry" machined from 0.400-inch-thick to 0.320-inch-thick, lot# 934U651A-2B2.

Prior to welding, the weld joint was wiped with isopropyl alcohol. Tack welding of the weld test panels was performed using DCEN GTA welding with helium shield gas. Two autogenous tack welds were made on the panels, with start and stop tabs welded to the panel ends. The following equipment was used for tack welding.

1. Square Wave TIG-350, Three Phase 460 Volt Lincoln Power Supply.
2. WNI 250 Amp Manual GTA Weld Torch.

Mechanized VPPA welding of the panels was performed at NASA/MSFC in building #4711 at the Productivity Enhancement Complex using Weld Station #2. Enclosure 2 contains the VPPA weld schedule used in the evaluation. The following is a list of equipment used to perform the VPPA welding.

1. VP-300-S Hobart Ciber Tig II Variable Polarity Power Supply.
2. MSFC (B&B) Plasma Weld Torch.
3. Hobart Digital Taper Weld Programmer, V6B.
4. General Digital Industries (GDI) Weld Computer.
5. Cyclomatic AVC unit.
6. Hobart "Hot Block" and Plasma Console.
7. Standard NASA MSFC aluminum weld fixture
8. "Opened Faced" backside weld shield.

Results:

Three welded test panels were successfully achieved through visual, radiographic, dye penetrant, and metallographic inspection methods. Five room temperature tensiles and two metallographic specimens were taken from the plate-to-plate weld, and five room temperature tensiles and three metallographic specimens were taken from the two NNF welds. Peaking and mismatch data, tensile data sheets, and load vs. strain curves are contained in Enclosure 3. Table 1.0 contains the averaged room temperature tensile results for the three welded panels. NNF specimen #110-113 is designated as RRF1, and NNF specimen #72-74 is designated as RRF2. Photomicrographs from the welded test panels are contained in Enclosure 4

Table 1. Averaged Room Temp. Tensile Data for 2195-T8 VPPA Welds with 4043 Filler Wire.

WELD ID	QTY	FTY (ksi)	FTU (ksi)	e (%) *	e (%) **
PLT(PLATE)	5	35.00	48.30	5.18	2.32
RRF#1	5	33.70	48.60	5.48	2.65
RRF#2	5	28.4	37.30	3.63	1.84

* 1.0-inch gauge length

** 2.0-inch gauge length

Discussion of Results:

The RRF1 weld, made with NNF material from the membrane area, produced an averaged room temperature tensile value equal to welded plate, approximately 48 ksi for ultimate weld strength. However, the RRF2 weld, made with NNF material from the cylinder weld joint area, produced an averaged room temperature tensile value 11 ksi less than welded plate. By reviewing the tensile data sheet, the RRF2 ultimate weld strength had a large amount of scatter, a standard deviation of 3.99. The standard deviation for plate-to-plate weld was 2.44 and 1.16 for RRF1 weld.

From inspecting the weld tensile fractures of the RRF2 weld, it was observed that all the tensile specimens broke on the NNF material side at the fusion line, which was not observed in the RRF1 weld. The RRF1 weld had various brakes in the weld, plate fusion line, and NNF fusion line. Different from the RRF1 weld, the fracture surfaces at the RRF2 weld fusion line displayed a very jagged texture. These jagged fractures are observed to be in line with the NNF grain orientation, as shown in the Enclosure 4 micrographs. The RRF2 micrographs reveal the NNF material grains are 68° offset from the weld joint. Typically, the grain orientation is normal to the weld joint for plate. Therefore, at this time it is presumed that the cause of the low and highly scattered tensile properties is related to the NNF material grain orientation.

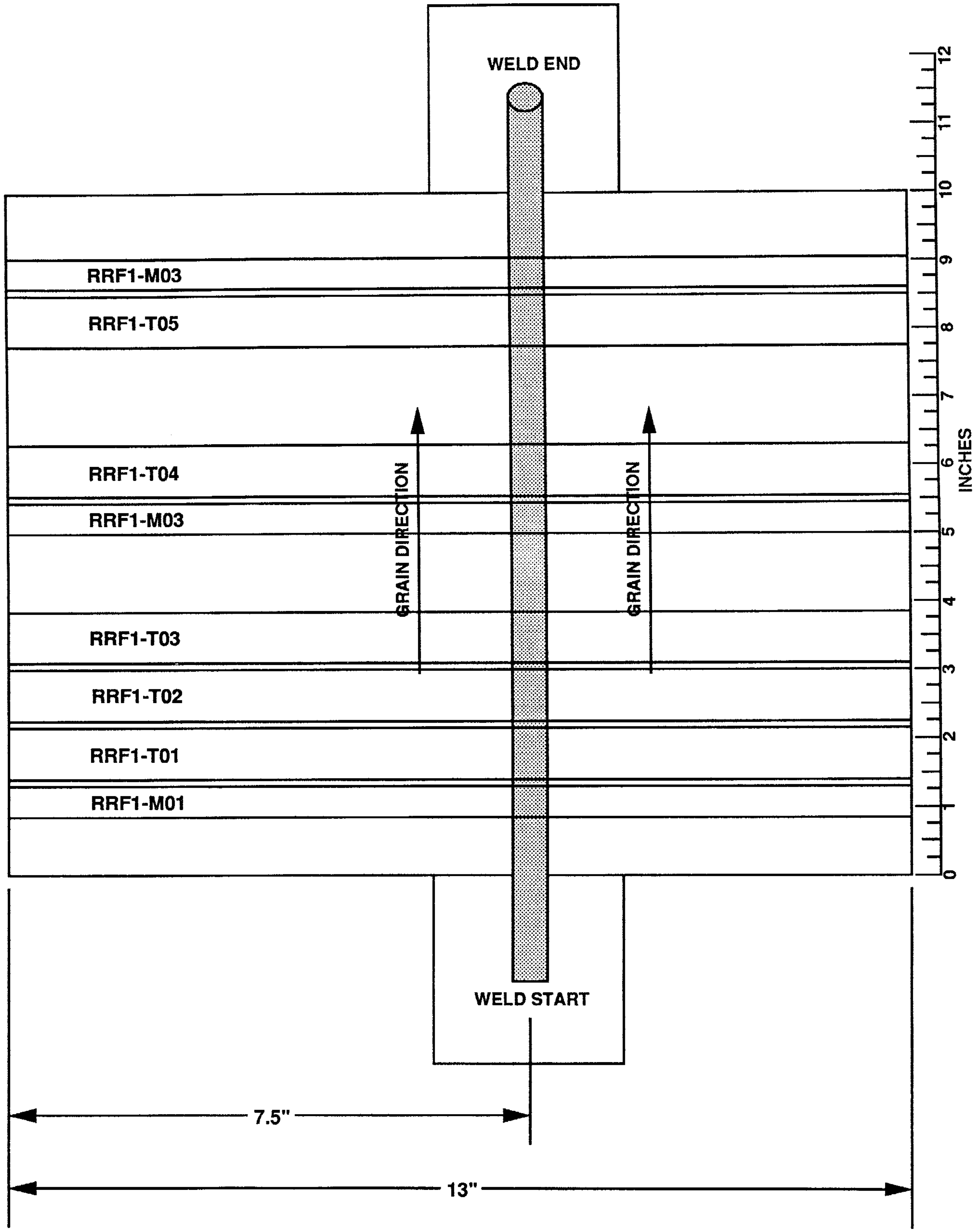
Conclusion and Recommendations:

Despite room temperature tensile results of the RRF2 weld, the weldability of NNF material is promising. There was no porosity observed in the welds originating from the NNF material, and the grain size, which was 5x larger than plate, did not seem to be detrimental to tensile properties.

Further weld development should involve repair welding and welding in the dome-to-Y-ring area of the near net forging. In Addition, future work should be performed to fully understand the affects of grain orientation on weld properties.

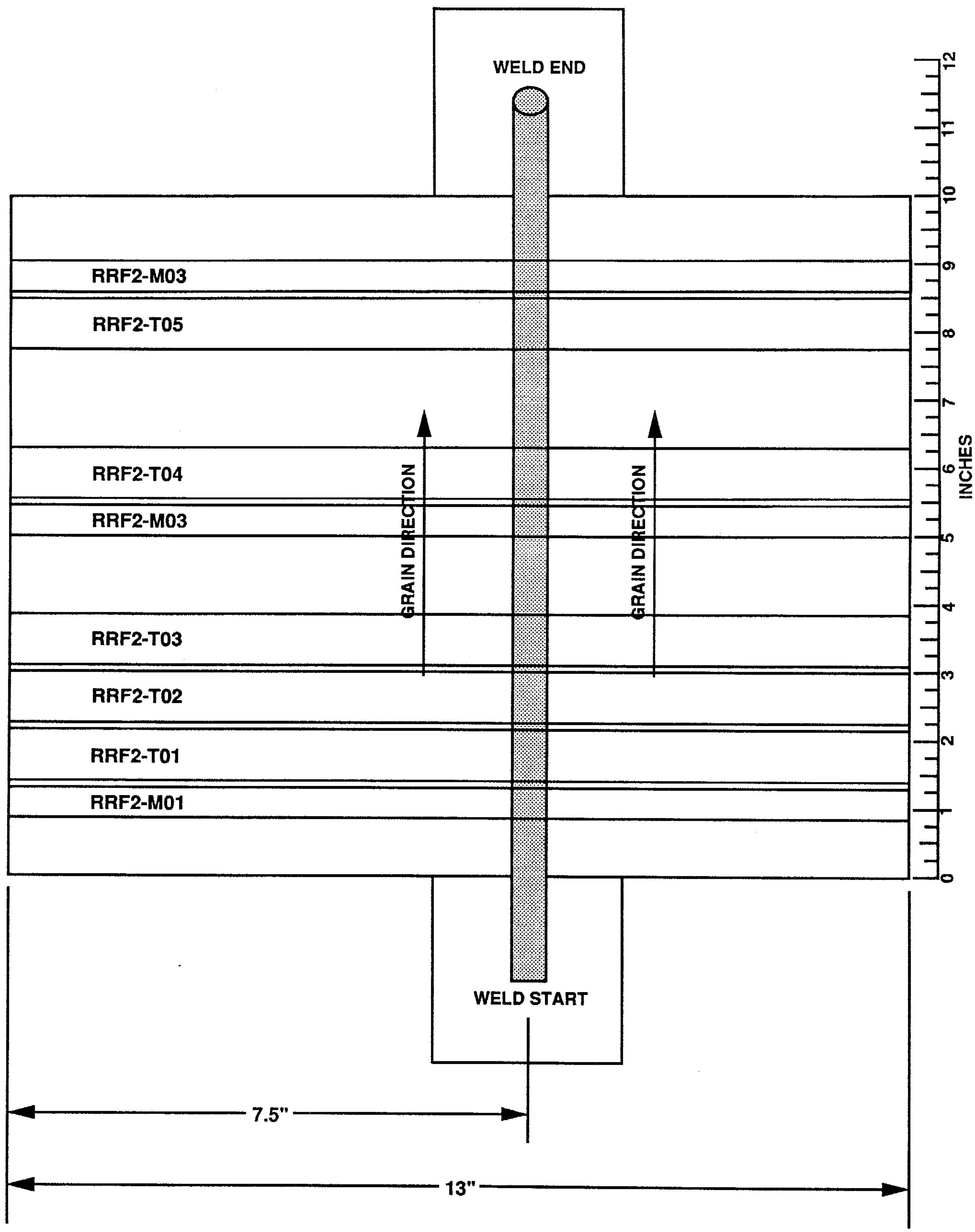
2195 NEAR NET ROLL RING FORGING
VPPA WELDED TEST PANEL

PANEL ID - RRF1



**2195 NEAR NET ROLL RING FORGING
VPPA WELDED TEST PANEL**

PANEL ID - RRF2



EH25 Weld Panel Traceability

Plasma Welding Data

Date Welded	7-10-96

Weld panel ID	Program Code	Matl. Type	Matl. Heat Lot #	Matl. Manufacturer	Matl. Thickness	Matl. Serial#	Welding Process (dc-,dc+,vppa)
RRF1	NNFTDP	2195-RT70	934U651U -2B2	RMC	0.320"	2B2-5	VPPA

Operator	Electrode Type	Welding Torch	Welding Torch Shield Cup	Torch Orientation	Welding Position	Back Purge Gas Type	Plasma Gas Type	Shield Gas Type	Trailing Shield Gas Type
BJORK.	2% THOR.	B&B	STD.	3° LEAD	VERT.	HELIUM	ARGON	HELIUM	n/a

Building#	Power Supply	Weld Fixture	Weld Station	Back Purge Type	Filler wire Type	Filler Wire Heat Lot#	Filler Wire Manufacturer	Trailing Shield Type
#4711	HOBART	STANDARD	#2	TRAVELLING SHOE	4043	156704	ALCOA	n/a

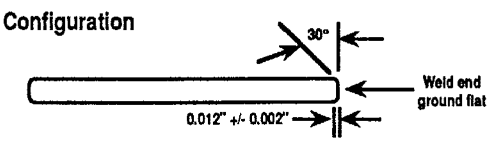
Electrode Configuration	Joint Configuration
*See Below	SQUARE BUTT

Weld Passes	Welding Current	Welding Voltage	Shield Gas Flow (SCFH)	Plasma Gas Flow Rate	Plasma Gas Pressure	Filler Wire Size Dia.	Filler Wire Rate (IPM)	Travel Rate (IPM)	Interpass Temperature	Orifice Size
Tack Pass										
First Pass	200	21.6	80	5.0	18.2	.063	25.0	11.0	RT	.156
2nd Pass	153	20.2	80	2.0	5.3	.063	50.0	7.0	RT	.156
3rd Pass										
4th Pass										
5th Pass										
6th Pass										
7th Pass										
8th Pass										

Weld Passes	Electrode Size	Electrode Set Back	Back Purge Gas Flow	Back Purge Gas Press.	Trail. Shld. Gas Flow	Strght. Pol. Time (ms)	Rev. Pol. Time (ms)	Add. Rev. Current	Arc Oscill. Dwell	Arc Oscill. Frequency	Arc Oscill. Position	Arc Oscill. Amplitude
Tack Pass												
First Pass	.156	.045	140	0	n/a	19	4	60	n/a	n/a	n/a	n/a
2nd Pass	.156	.045	140	0	n/a	19	4	60	n/a	n/a	n/a	n/a
3rd Pass												
4th Pass												
5th Pass												
6th Pass												
7th Pass												
8th Pass												

Comments:

Tungsten Configuration



Plasma Gas Bottle Number	Torch Shield Gas Bottle Number	Back Purge Gas Bottle Number	Room Temp	Humidity
BOC Lot# 60405	BOC Lot# 60712	BOC Lot# 60839 (He)	75F	67%
		BOC Lot# 60405 (Ar)		

NNF-MEM-023
Enclosure 2

EH25 Weld Panel Traceability

Plasma Welding Data

Date Welded	7-30-96

Weld panel ID	Program Code	Matl. Type	Matl. Heat Lot #	Matl. Manufacturer	Matl. Thickness	Matl. Serial#	Welding Process (dc-,dc+,vppa)
RRF2	NNFTDP	2195-RT70	934U651U -2B2	RMC	0.320"	2B2-5	VPPA

Operator	Electrode Type	Welding Torch	Welding Torch Shield Cup	Torch Orientation	Welding Position	Back Purge Gas Type	Plasma Gas Type	Shield Gas Type	Trailing Shield Gas Type
BJORK.	2% THOR.	B&B	STD.	3° LEAD	VERT.	HELIUM	ARGON	HELIUM	n/a

Building#	Power Supply	Weld Fixture	Weld Station	Back Purge Type	Filler wire Type	Filler Wire Heat Lot#	Filler Wire Manufacturer	Trailing Shield Type
#4711	HOBART	STANDARD	#2	TRAVELLING SHOE	4043	156704	ALCOA	n/a

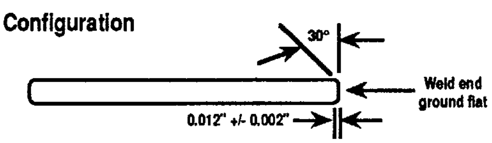
Electrode Configuration	Joint Configuration
*See Below	SQUARE BUTT

Weld Passes	Welding Current	Welding Voltage	Shield Gas Flow (SCFH)	Plasma Gas Flow Rate	Plasma Gas Pressure	Filler Wire Size Dia.	Filler Wire Rate (IPM)	Travel Rate (IPM)	Interpass Temperature	Orifice Size
Tack Pass										
First Pass	200	21.6	80	5.0	17.5	.063	25.0	11.0	RT	.156
2nd Pass	153	19.6	80	2.0	4.9	.063	50.0	7.0	RT	.156
3rd Pass										
4th Pass										
5th Pass										
6th Pass										
7th Pass										
8th Pass										

Weld Passes	Electrode Size	Electrode Set Back	Back Purge Gas Flow	Back Purge Gas Press.	Trail. Shld. Gas Flow	Strght. Pol. Time (ms)	Rev. Pol. Time (ms)	Add. Rev. Current	Arc Oscill. Dwell	Arc Oscill. Frequency	Arc Oscill. Position	Arc Oscill. Amplitude
Tack Pass												
First Pass	.156	.045	140	0	n/a	19	4	60	n/a	n/a	n/a	n/a
2nd Pass	.156	.045	140	0	n/a	19	4	60	n/a	n/a	n/a	n/a
3rd Pass												
4th Pass												
5th Pass												
6th Pass												
7th Pass												
8th Pass												

Comments:

Tungsten Configuration



Plasma Gas Bottle Number	Torch Shield Gas Bottle Number	Back Purge Gas Bottle Number	Room Temp	Humidity
BOC Lot# 60405	BOC Lot# 60712	BOC Lot# 60839 (He)	75F	67%
		BOC Lot# 60405 (Ar)		

NNF-MEM-023
Enclosure 2

EH25 Weld Panel Traceability

Plasma Welding Data

Date Welded	7-10-96

Weld panel ID	Program Code	Matl. Type	Matl. Heat Lot #	Matl. Manufacturer	Matl. Thickness	Matl. Serial#	Welding Process (dc-,dc+,vppa)
PLT	NNFTDP	2195-RT70	934U651A -2B2	RMC	0.320"	2B2-3	VPPA

Operator	Electrode Type	Welding Torch	Welding Torch Shield Cup	Torch Orientation	Welding Position	Back Purge Gas Type	Plasma Gas Type	Shield Gas Type	Trailing Shield Gas Type
BJORK.	2% THOR.	B&B	STD.	3° LEAD	VERT.	He/Ar	ARGON	HELIUM	n/a

Building#	Power Supply	Weld Fixture	Weld Station	Back Purge Type	Filler wire Type	Filler Wire Heat Lot#	Filler Wire Manufacturer	Trailing Shield Type
#4711	HOBART	STANDARD	#2	TRAVELLING SHOE	4043	156704	ALCOA	n/a

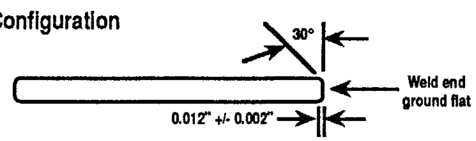
Electrode Configuration	Joint Configuration
*See Below	SQUARE BUTT

Weld Passes	Welding Current	Welding Voltage	Shield Gas Flow (SCFH)	Plasma Gas Flow Rate	Plasma Gas Pressure	Filler Wire Size Dia.	Filler Wire Rate (IPM)	Travel Rate (IPM)	Interpass Temperature	Orifice Size
Tack Pass										
First Pass	200	21.6	80	5.0	18.3	.063	25.0	11.0	RT	.156
2nd Pass	153	20.2	80	2.0	5.3	.063	50.0	7.0	RT	.156
3rd Pass										
4th Pass										
5th Pass										
6th Pass										
7th Pass										
8th Pass										

Weld Passes	Electrode Size	Electrode Set Back	Back Purge Gas Flow	Back Purge Gas Press.	Trail. Shld. Gas Flow	Strght. Pol. Time (ms)	Rev. Pol. Time (ms)	Add. Rev. Current	Arc Oscill. Dwell	Arc Oscill. Frequency	Arc Oscill. Position	Arc Oscill. Amplitude
Tack Pass												
First Pass	.156	.045	120/20	0	n/a	19	4	60	n/a	n/a	n/a	n/a
2nd Pass	.156	.045	120/20	0	n/a	19	4	60	n/a	n/a	n/a	n/a
3rd Pass												
4th Pass												
5th Pass												
6th Pass												
7th Pass												
8th Pass												

Comments:

Tungsten Configuration



Plasma Gas Bottle Number	Torch Shield Gas Bottle Number	Back Purge Gas Bottle Number	Room Temp	Humidity
BOC Lot# 60405	BOC Lot# 60712	BOC Lot# 60839 (He)	75F	67%
		BOC Lot# 60405 (Ar)		

MATERIALS AND PROCESS LAB
METALS PROCESS BRANCH
WELD EVALUATION LAB
PLATE-TO-FORGING 2195-T8

TENSILE TEST, 0.2 % OFFSET YIELD

LOAD RANGE, LBS	24000	FILENAME FOR DISK	JUL96
PRE / POST-YD STRAIN RNG, %	2 / 2	TEST PARAMETERS	TEST1
GAGE LENGTH, INCHES	1.985	PANEL I.D.	RRF-ROLL FORGED (RRF1)
SERVO CONTROL FILENAME	STANDARD	PROGRAM	[redacted] NNFDP
		WELD PROCESS	VPPA
		MATERIAL	2195

WORK #	SPEC ID	WD INCHES	THK INCHES	AREA SQ. IN	MODULUS MPSI	.2% YD LBS	.2% YD KSI	ULT LBS	ULT KSI	2" TE %	1" TE %
96813	T01	.842	.315	.265	12.46	9160	34.5	12950	48.8	2.77	6.09
96813	T02	.843	.316	.266	12.92	8690	32.6	12530	47.1	2.72	5.38
96813	T03	.836	.317	.265	12.07	8850	33.4	12980	49	2.62	5.69
96813	T04	.845	.316	.267	10.16	9100	34.1	12850	48.1	2.27	4.97
96813	T05	.84	.317	.266	11.25	8980	33.7	13370	50.2	2.87	5.28
AVERAGE		.841	.316	.266	11.77		33.7		48.6	2.65	5.48
SD. DEV		.00343	0	0	1.09		.723		1.16	.233	0.425

07-16-1996 15:55:45

TEST CONDUCTED BY GS

NNF-MEM-023
Enclosure 3

TENSILE TESTING DATA SHEET

TEST PANEL ID RRF1* DATE 7-15-96 PROGRAM NNFDP

SPECIMEN ID	WIDTH (inches)	THICKNESS (inches)	PEAKING ~~(inches)~~	MISMATCH (inches)
RRF -T01	SEE TENSILE DATA		17 min.	0.002
-T02	SHEET		17 min.	0.001
-T03			6 min.	0.001
-T04			13 min.	0.002
-T05			10 min.	0.001
		* ROLL RING FORGING, 2195-T8		

RRF1 T01 - T03

TASK: P-617 MATERIAL: 2195
SPECIMEN ID: MRFT- DATE: 7-16-96 TEST #: TESTER: GS
FULL SCALE LOAD: 12000
0.2%: 1"
LOAD RATE:
EXT. G.L.: 1"

o SMOOTH TENSILE o NOTCH TENSILE X SHEET TENSILE

GAGE$_I$: 1.985 GAGE$_F$: 2"
DIAMETER$_I$: DIAMETER$_F$:
WIDTH$_I$: WIDTH$_F$:
THICKNESS$_I$: THICKNESS$_F$:

X AIR o LN$_2$ o GHe o LH$_2$ o GH$_2$ o
X ATMOSPHERIC o 5,000 PSIG o
X AMBIENT o 1,600 °F o

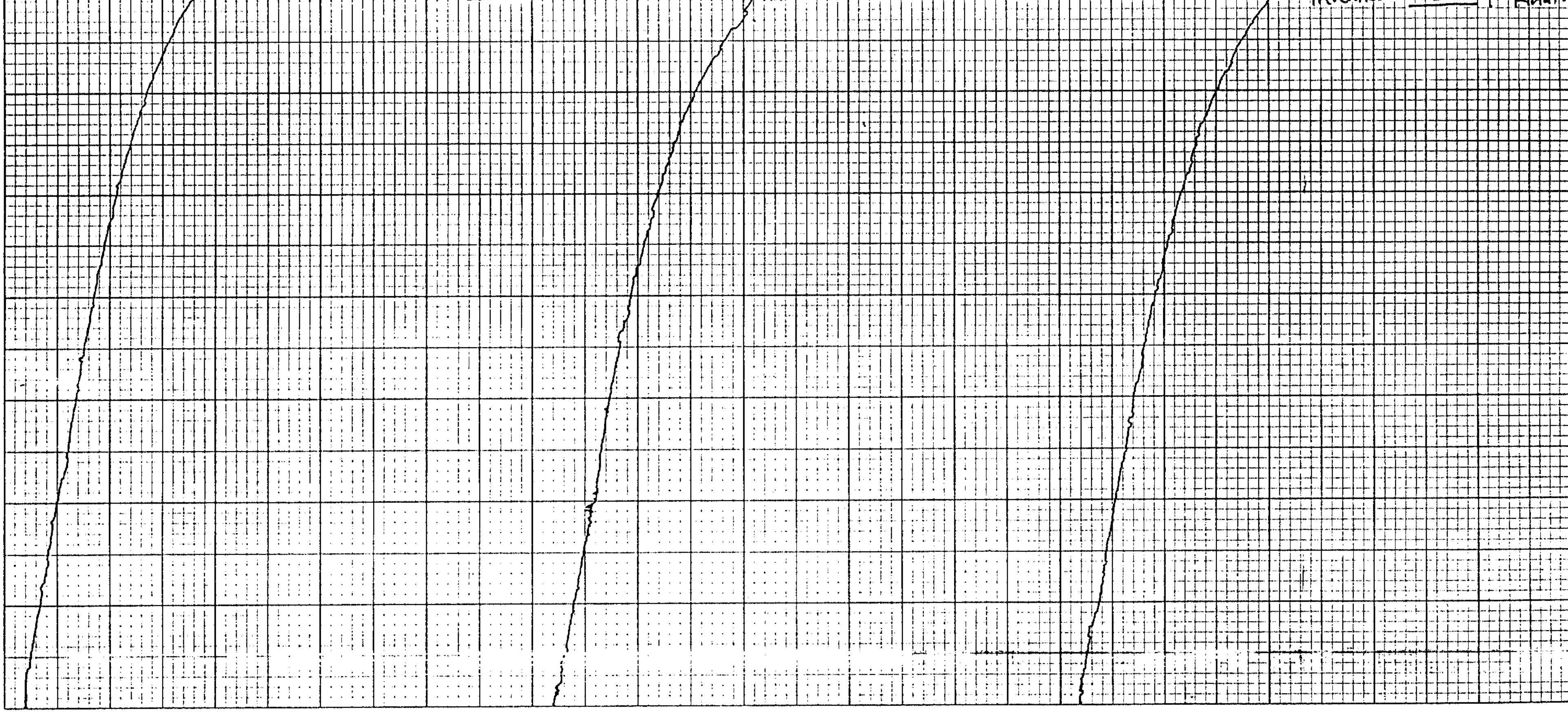
GAGE$_I$: .985 GAGE$_F$: 1"
GAGE$_I$: GAGE$_F$: 1/2" A
GAGE$_I$: GAGE$_F$: 1/2" B

GRAPH SLOPE: SPECIMEN AREA: in^2 .2% Y.S.: ksi 2" % ELONGATION: % 1" % ELONGATION 1/2" A % ELONGATION 1/2" B % ELONGATION
CONVERSION FACTOR: YOUNG'S MODULUS: Mpsi ULTIMATE: ksi % R.A.: %

TR 01 Width: .842 2" Final: 2.040
Thickness: .315 1" Final: 1.045

TR 02 Width: .843 2" Final: 2.039
Thickness: .316 1" Final: 1.038

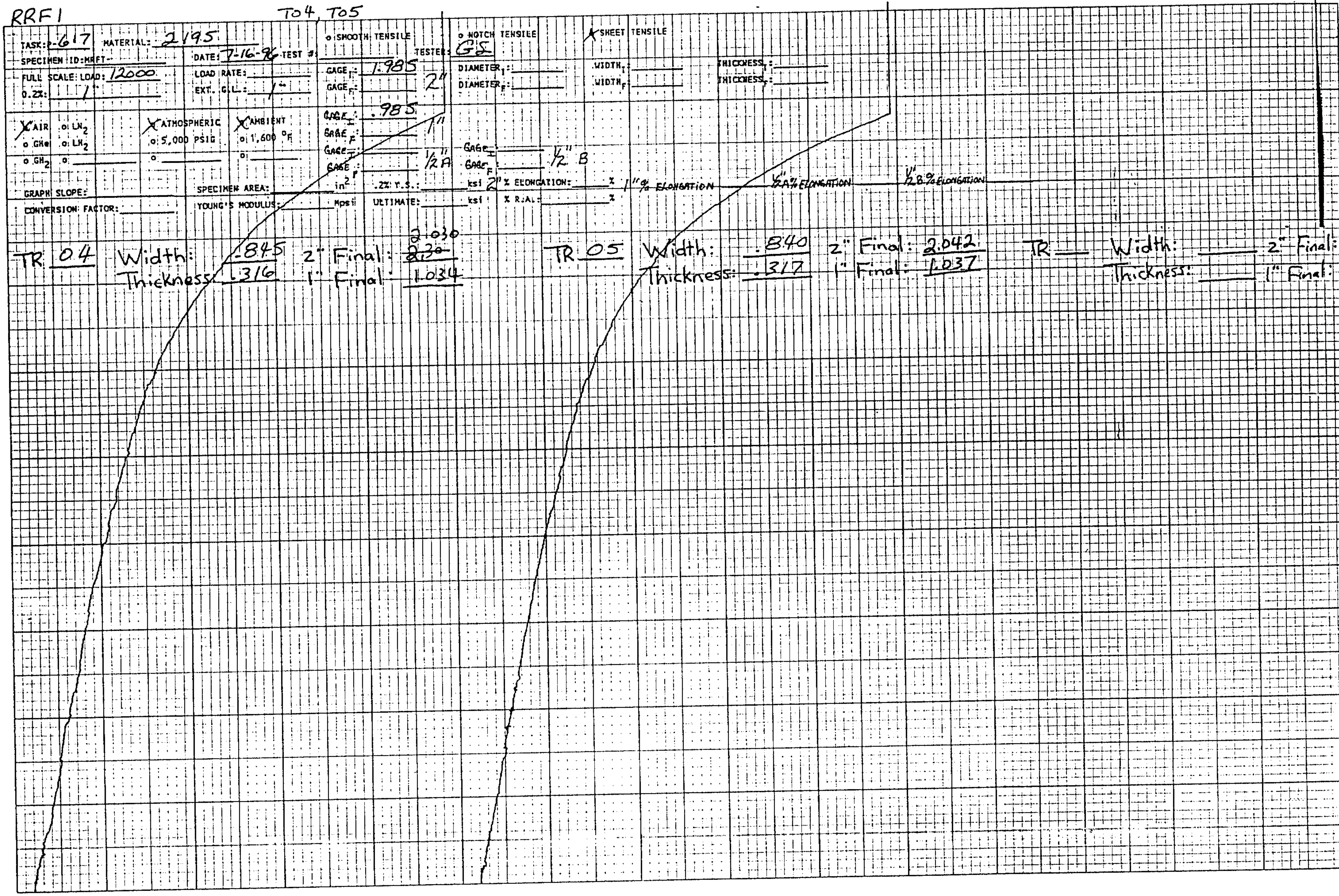
TR 03 Width: .836 2" Final:
Thickness: .317 1" Final:



No. XY 1101-SP5

GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK PRINTED IN U.S.A.

RRF1 T04, T05



TASK: P-617 MATERIAL: 2195
SPECIMEN ID: MRFT-
FULL SCALE LOAD: 12000
0.2%: 1

DATE: 7-16-96 TEST #:
LOAD RATE:
EXT. G.L.: 1"

X AIR o LN$_2$
o GHe o LH$_2$
o GH$_2$ o:

X ATMOSPHERIC
o 5,000 PSIG
o:

X AMBIENT
o 1,600 °F
o:

o SMOOTH TENSILE TESTER: GS
GAGE$_I$: 1.985 2"
GAGE$_F$:
GAGE$_I$: .985 1"
GAGE$_F$:
GAGE$_I$: 1/2" A
GAGE$_F$:

o NOTCH TENSILE
DIAMETER$_I$:
DIAMETER$_F$:
GAGE$_I$: 1/2" B
GAGE$_F$:

X SHEET TENSILE
WIDTH$_I$:
WIDTH$_F$:
THICKNESS$_I$:
THICKNESS$_F$:

GRAPH SLOPE:
CONVERSION FACTOR:
SPECIMEN AREA: in^2
YOUNG'S MODULUS: Mpsi
.2% Y.S.: ksi
ULTIMATE: ksi
2" % ELONGATION: %
% R.A.: %
1" % ELONGATION
1/2" A % ELONGATION
1/2" B % ELONGATION

TR 04 Width: .845 2" Final: ~~2.20~~ 2.030
Thickness: .316 1" Final: 1.034

TR 05 Width: .840 2" Final: 2.042
Thickness: .317 1" Final: 1.037

TR ___ Width: ___ 2" Final:
Thickness: ___ 1" Final:

NO. XY 1101-SP5
GC RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.

MATERIALS AND PROCESS LAB
METALS PROCESS BRANCH
WELD EVALUATION LAB

TENSILE TEST, 0.2 % OFFSET YIELD

LOAD RANGE, LBS	24000	FILENAME FOR DISK	JUL96
PRE / POST-YD STRAIN RNG. %	2 / 2	TEST PARAMETERS	TEST1
GAGE LENGTH, INCHES	1.965	PANEL I.D.	RRF2
SERVO CONTROL FILENAME	STANDARD	PROGRAM	[redacted] NNFDP
		WELD PROCESS	VPPA
		MATERIAL	2195

WORK #	SPEC ID	WD INCHES	THK INCHES	AREA SQ.IN	MODULUS MPSI	.2% YD LBS	.2% YD KSI	ULT LBS	ULT KSI	2" TE %	1" TE %
96857	T01	.73	.3	.219	10.22	6220	28.4	7800	35.6	1.511	2.64
96857	T02	.733	.303	.222	10.3	6140	27.6	6970	31.4	1.411	2.64
96857	T03	.733	.303	.222	10.66	6310	28.4	9320	41.9	2.47	4.57
96857	T04	.734	.303	.222	11.29	6290	28.3	8720	39.2	1.965	4.47
96857	T05	.736	.303	.223	11.23	6500	29.2	8510	38.2	1.854	3.86
AVERAGE		.733	.302	.222	10.98		28.4		37.3	1.844	3.63
SD. DEV		0	0	.001586	.595		.543		3.99	.419	0.948

07-31-1996 11:59:55

TEST CONDUCTED BY GS

TENSILE TESTING DATA SHEET

TEST PANEL ID RRF2 DATE 7/31/96 PROGRAM NNFDP

SPECIMEN ID	WIDTH (inches)	THICKNESS (inches)	PEAKING (inches)	MISMATCH (inches)
RRF2-T01	0.730	0.300	0°	0.002
RRF2-T02	0.733	0.303	0°	0.005
RRF2-T03	0.734	0.303	3 min	0.012
RRF2-T04	0.734	0.303	0°	0.012
RRF2-T05	0.736	0.303	0°	0.006

RRF2 To1 - To3

TASK: P-617 MATERIAL: 2195 ○ SMOOTH TENSILE ○ NOTCH TENSILE X SHEET TENSILE

SPECIMEN ID: MRFT- DATE: 7·31·96 TEST #: ______ TESTER: GS

FULL SCALE LOAD: 12000 LOAD RATE: ______ $GAGE_I$: 1.985 DIAMETER$_I$: ______ WIDTH$_I$: ______ THICKNESS$_I$: ______

0.2%: 1" EXT. G.L.: 1" $GAGE_F$: ______ 2" DIAMETER$_F$: ______ WIDTH$_F$: ______ THICKNESS$_F$: ______

X AIR ○ LN_2 X ATMOSPHERIC X AMBIENT $GAGE_I$: .985

○ GHe ○ LH_2 ○ 5,000 PSIG ○ 1,600 °F $GAGE_F$: ______ 1"

○ GH_2 ○ ______ ○ ______ ○ ______ $GAGE_I$: ______ 1/2" A $GAGE_I$: ______ 1/2" B

$GAGE_F$: ______ $GAGE_F$: ______

GRAPH SLOPE: ______ SPECIMEN AREA: ______ in^2 .2% Y.S.: ______ ksi 2" % ELONGATION: ______ % 1" % ELONGATION ______ 1/2" A % ELONGATION ______ 1/2" B % ELONGATION ______

CONVERSION FACTOR: ______ YOUNG'S MODULUS: ______ Mpsi ULTIMATE: ______ ksi % R.A.: ______ %

TO 1 Width: .730 2" Final: 2.015
Thickness: .300 1" Final: 1.011

TO 2 Width: .733 2" Final: 2.013
Thickness: .303 1" Final: 1.011

TO 3 Width: .734 2" Final: 2
Thickness: .303 1" Final: 1

RRF2 T04, T05

TASK: P-617 MATERIAL: 2195
SPECIMEN ID: MRFI-
FULL SCALE LOAD: 12000
0.2%: 1"

DATE: 7·31·96 TEST #:
LOAD RATE:
EXT. G.L.: 1"

o SMOOTH TENSILE TESTER: GS
o NOTCH TENSILE
X SHEET TENSILE

GAGE$_I$: 1.985 2"
GAGE$_F$:
GAGE$_I$: .985 1"
GAGE$_F$:
GAGE$_I$: 1/2" A
GAGE$_F$:
GAGE$_I$: 1/2" B
GAGE$_F$:

DIAMETER$_I$:
DIAMETER$_F$:
WIDTH$_I$:
WIDTH$_F$:
THICKNESS$_I$:
THICKNESS$_F$:

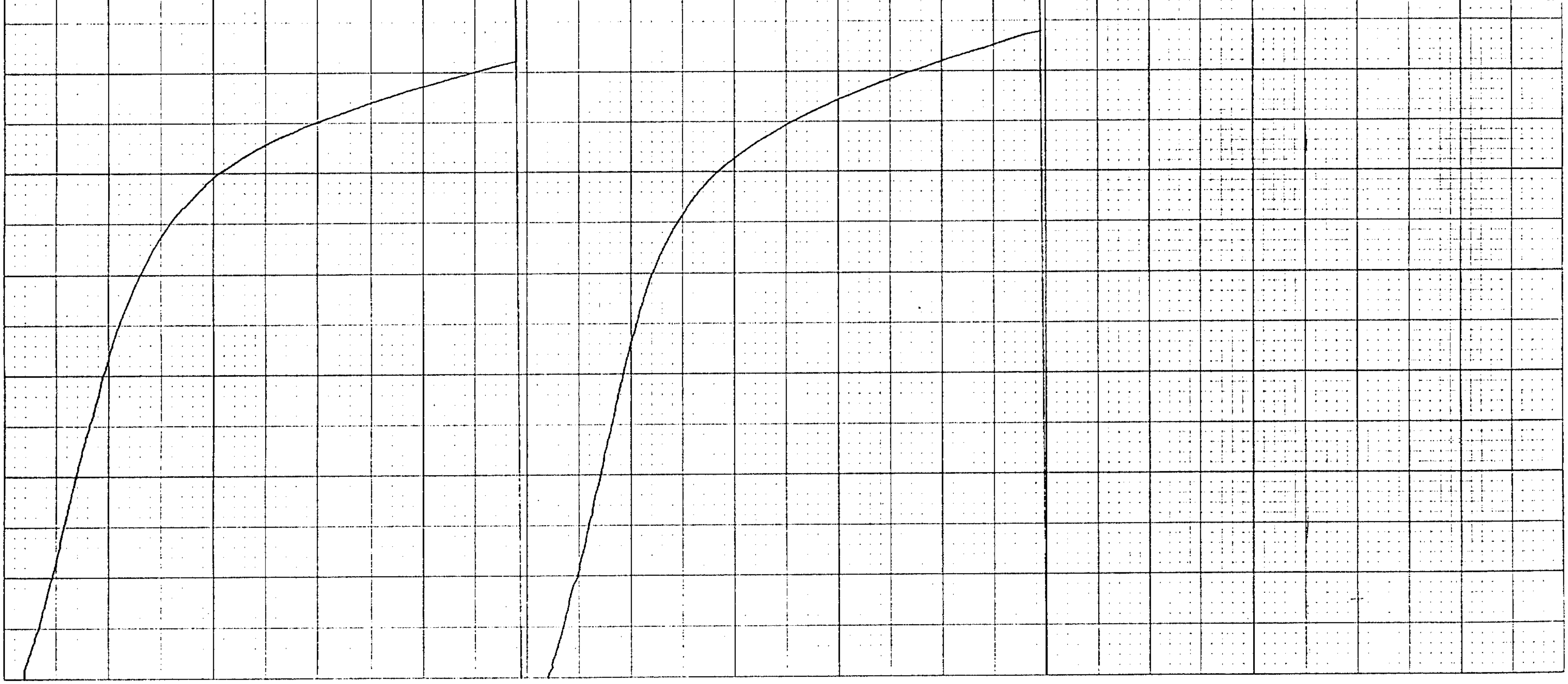
X AIR o LH_2 o GHe o LH_2 o GH_2 o
X ATMOSPHERIC o 5,000 PSIG o
X AMBIENT o 1,600 °F o

GRAPH SLOPE:
CONVERSION FACTOR:
SPECIMEN AREA: in^2
YOUNG'S MODULUS: Mpsi
.2% Y.S.: ksi
ULTIMATE: ksi
2" % ELONGATION: %
% R.A.: %
1"% ELONGATION
1/2" A% ELONGATION
1/2" B% ELONGATION

TØ 4 Width: .734 2" Final: 2.024
Thickness: .303 1" Final: 1.029

TØ 5 Width: .736 2" Final: 2.022
Thickness: .303 1" Final: 1.023

TR N/A Width: 2" Final:
Thickness: 1" Final:



NO. XY 1101-SP5

RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO NEW YORK
PRINTED IN U.S.A.

MATERIALS AND PROCESS LAB
METALS PROCESS BRANCH
WELD EVALUATION LAB
PLATE-TO-PLATE 2195-T8

TENSILE TEST, 0.2 % OFFSET YIELD

LOAD RANGE, LBS	24000	FILENAME FOR DISK	JUL96
PRE / POST-YD STRAIN RNG, %	2 / 2	TEST PARAMETERS	TEST1
GAGE LENGTH, INCHES	1.985	PANEL I.D.	PM-ROLL FORGED (PLT)
SERVO CONTROL FILENAME	STANDARD	PROGRAM	[redacted] NNFDP
		WELD PROCESS	VPPA
		MATERIAL	2195

WORK #	SPEC ID	WD INCHES	THK INCHES	AREA SQ. IN	MODULUS MPSI	.2% YD LBS	.2% YD KSI	ULT LBS	ULT KSI	2" TE %	1" TE %
96812	T01	.848	.317	.269	10.46	9630	35.8	13360	49.7	2.02	4.67
96812	T02	.846	.318	.269	12.45	9740	36.2	13410	49.8	2.37	4.97
96812	T03	.847	.318	.269	12.99	9720	36.1	13270	49.3	1.965	4.67
96812	T04	.845	.319	.27	12.3	9700	36	13110	48.6	2.77	5.79
96812	T05	.845	.318	.269	11.18	9390	34.9	11830	44	2.47	5.79
AVERAGE		.846	.318	.269	11.88		35.8		48.3	2.32	5.18
SD. DEV		0	0	0	1.027		.502		2.44	.334	0.570

07-16-1996
TEST CONDUCTED BY GS

TENSILE TESTING DATA SHEET

TEST PANEL ID PM* (PLT) DATE 7-15-96 PROGRAM NNFDP

SPECIMEN ID	WIDTH (inches)	THICKNESS (inches)	PEAKING ~~(inches)~~	MISMATCH (inches)
PM-T01	SEE TENSILE DATA SHEET		10 min.	0.002
-T02			6 min.	0.003
-T03			13 min.	0.001
-T04			6 min.	0.001
-T05			10 min.	0.001
		* PLATE MATERIAL, 2195-78		

PM (PLT) T01 - T03

TASK: P-617 MATERIAL: 2195 o SMOOTH TENSILE o NOTCH TENSILE X SHEET TENSILE

SPECIMEN ID: MRPT- DATE: 7-16-96 TEST #: TESTER: GS

FULL SCALE LOAD: 12000 LOAD RATE: GAGE$_I$: 1.985 2" DIAMETER$_I$: WIDTH$_I$: THICKNESS$_I$:

0.2%: 1" EXT. G.L.: 1" GAGE$_F$: DIAMETER$_F$: WIDTH$_F$: THICKNESS$_F$:

X AIR o LH$_2$ X ATMOSPHERIC X AMBIENT GAGE$_I$: .985 1"

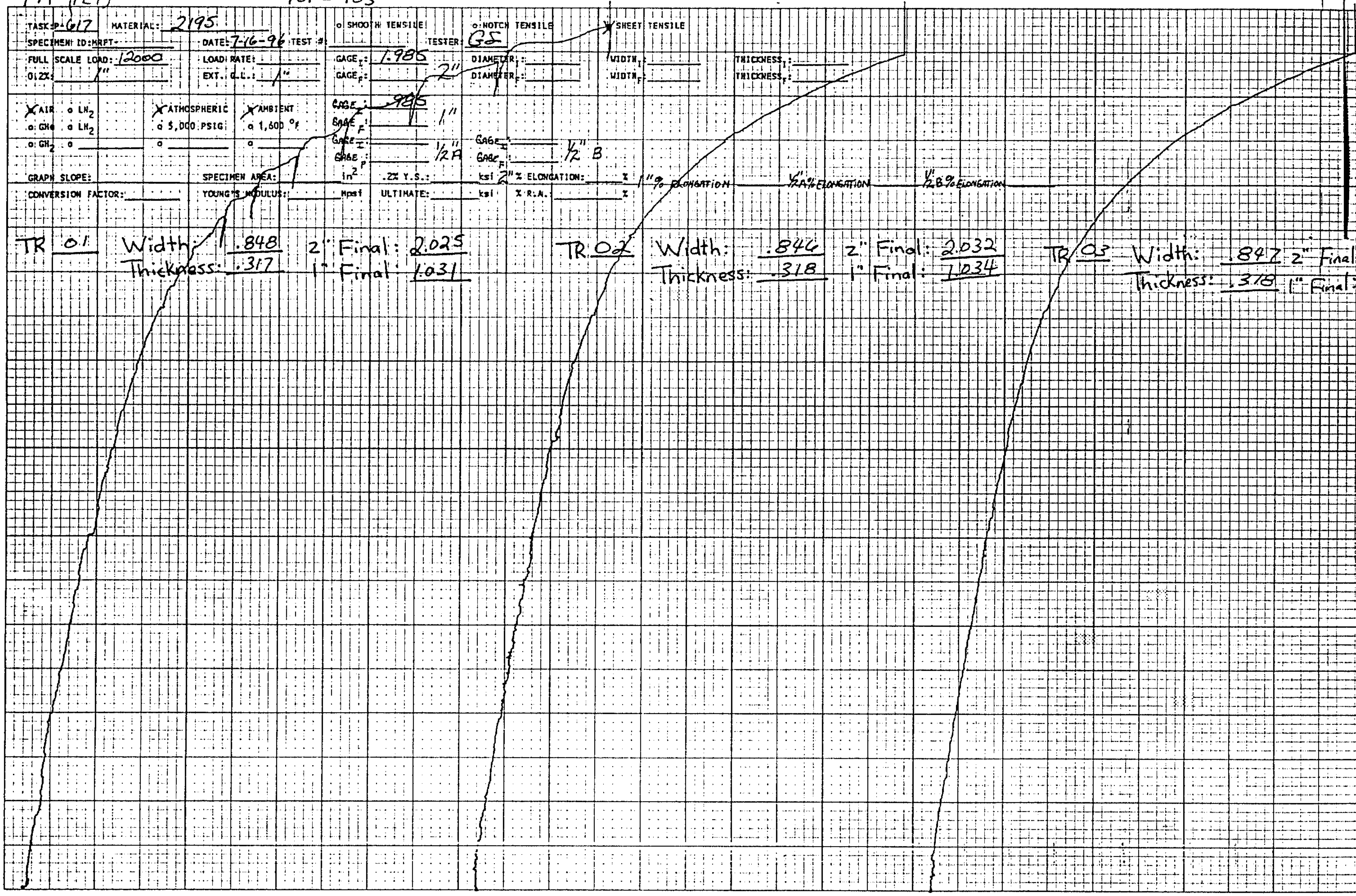
o GHe o LH$_2$ o 5,000 PSIG o 1,600 °F GAGE$_F$:

o GH$_2$ o o o GAGE$_I$: 1/2" A GAGE$_I$: 1/2" B

GAGE$_F$: GAGE$_F$:

GRAPH SLOPE: SPECIMEN AREA: in^2 .2% Y.S.: ksi 2" % ELONGATION: % 1" % ELONGATION 1/2" A % ELONGATION 1/2" B % ELONGATION

CONVERSION FACTOR: YOUNG'S MODULUS: Mpsi ULTIMATE: ksi % R.A.: %



NO. XY 1101-SP5

RECORDING CHARTS ® GRAPHIC CONTROLS CORPORATION BUFFALO NEW YORK PRINTED IN U.S.A.

PM (PLT) T04, T05

TASK: P-617 MATERIAL: 2195 o SMOOTH TENSILE o NOTCH TENSILE X SHEET TENSILE

SPECIMEN ID: MRFT- DATE: 7-16-96 TEST # ______ TESTER: GS

FULL SCALE LOAD: 12000 LOAD RATE: ______ $GAGE_I$: 1.985 $DIAMETER_I$: ______ $WIDTH_I$: ______ $THICKNESS_I$: ______

0.2%: 1" EXT. G.L.: 1" $GAGE_F$: 2" $DIAMETER_F$: ______ $WIDTH_F$: ______ $THICKNESS_F$: ______

X AIR o LH_2 X ATMOSPHERIC X AMBIENT $GAGE_I$: .985 $GAGE_F$: 1"

o GHe o LH_2 o 5,000 PSIG o 1,600 °F $GAGE_I$: ______ $GAGE_F$: 1/2" A $GAGE_I$: ______ $GAGE_F$: 1/2" B

o GH_2 o ______ o ______ o ______

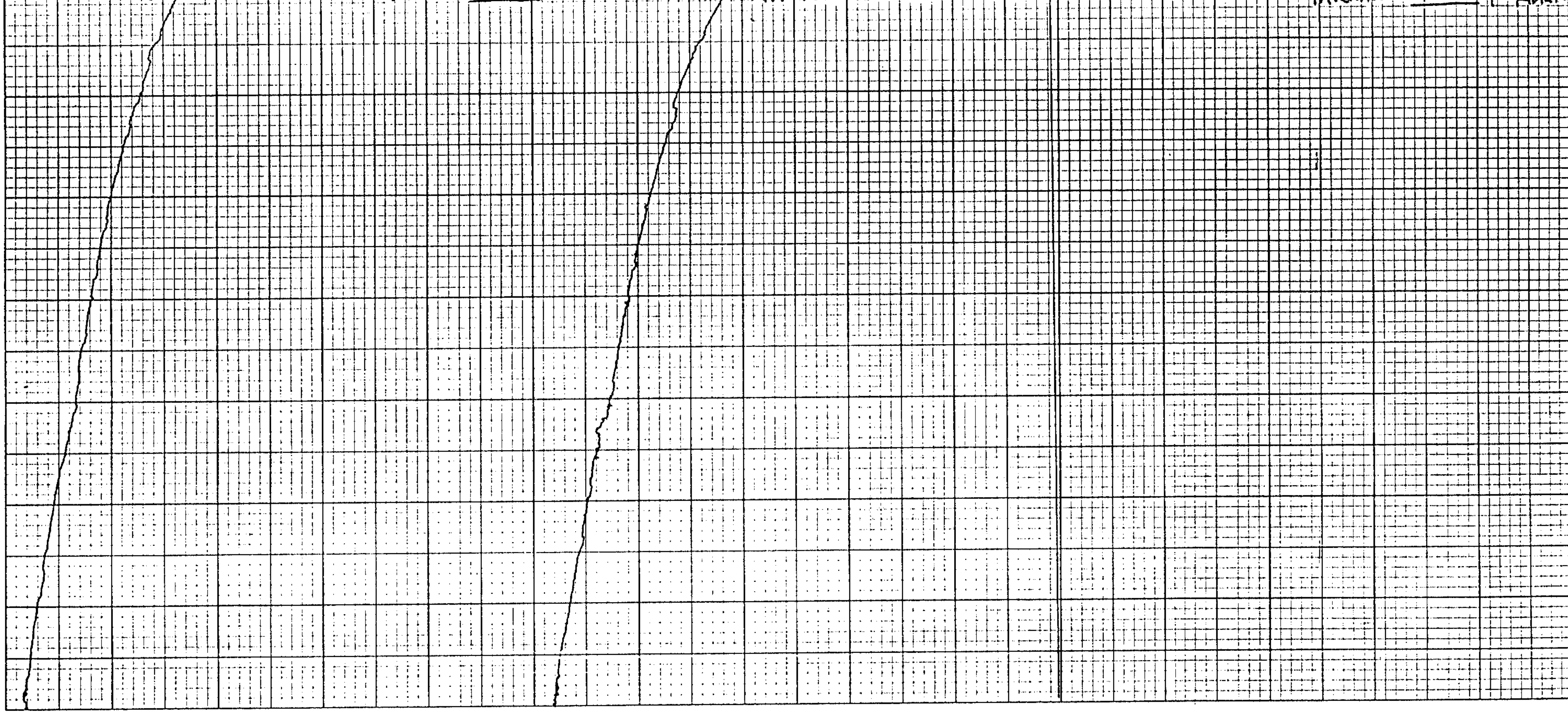
GRAPH SLOPE: ______ SPECIMEN AREA: ______ in^2 .2% Y.S.: ______ ksi 2" % ELONGATION: ______ % 1" % ELONGATION ______ 1/2" A % ELONGATION ______ 1/2" B % ELONGATION ______

CONVERSION FACTOR: ______ YOUNG'S MODULUS: ______ Mpsi ULTIMATE: ______ ksi % R.A.: ______ %

TR 04 Width: .845 2" Final: 2.040
Thickness: .319 1" Final: 1.042

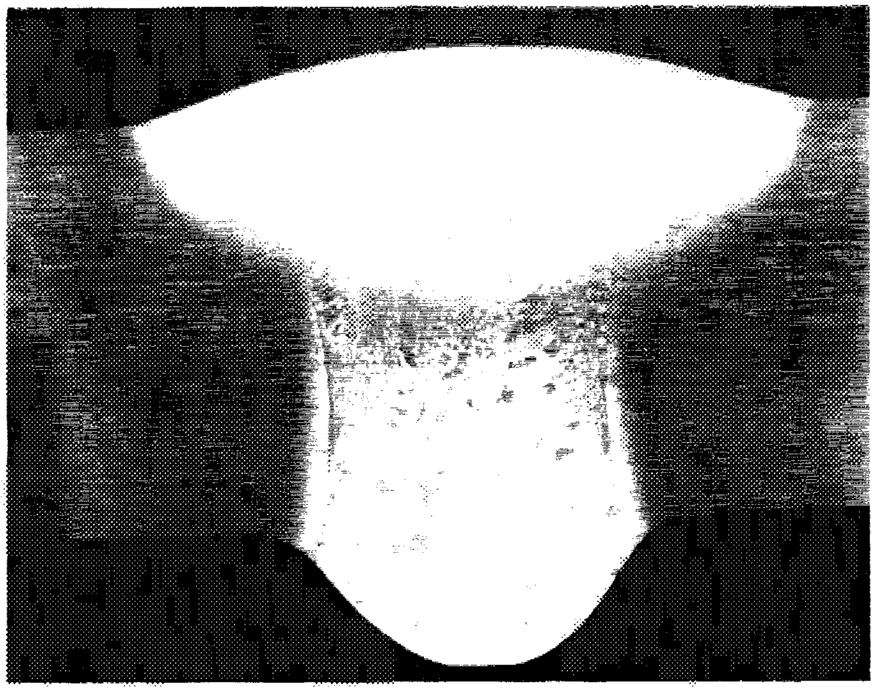
TR 05 Width: .845 2" Final: 2.034
Thickness: .318 1" Final: 1.042

TR ___ Width: ______ 2" Final:
Thickness: ______ 1" Final:

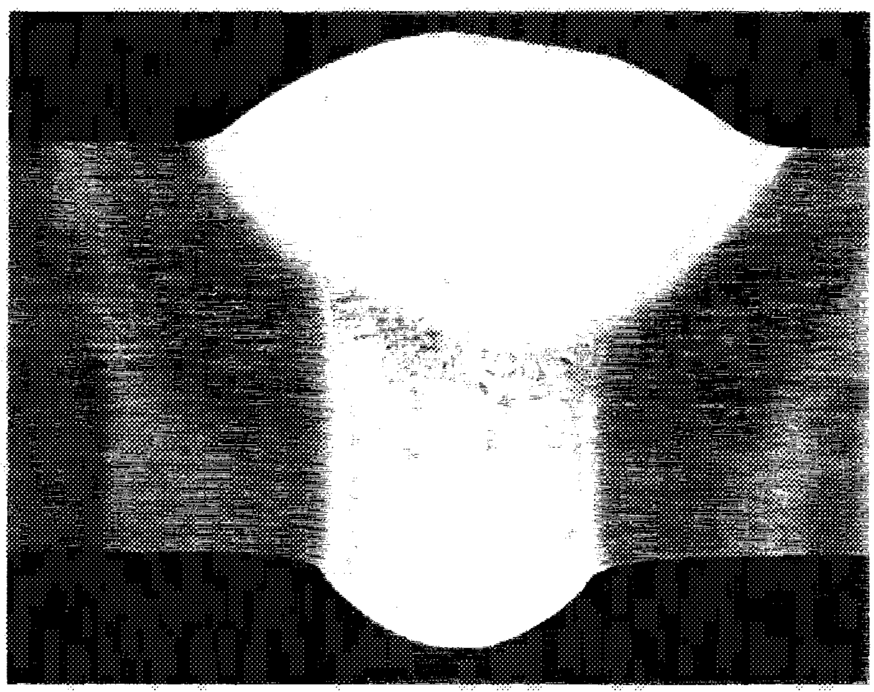


NO. XY 1101-SP5

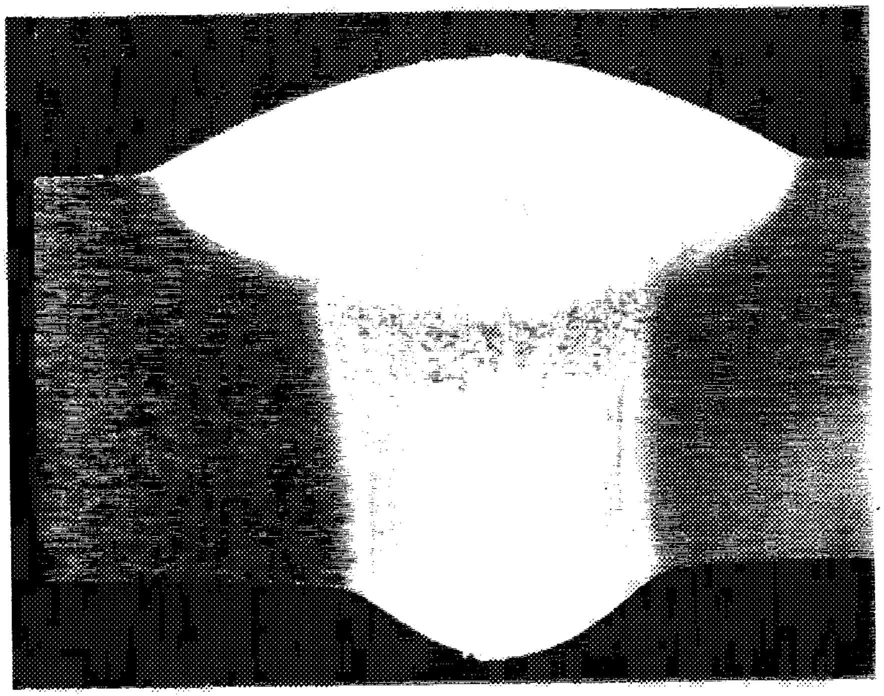
RECORDING CHARTS
GRAPHIC CONTROLS CORPORATION
BUFFALO, NEW YORK
PRINTED IN U.S.A.



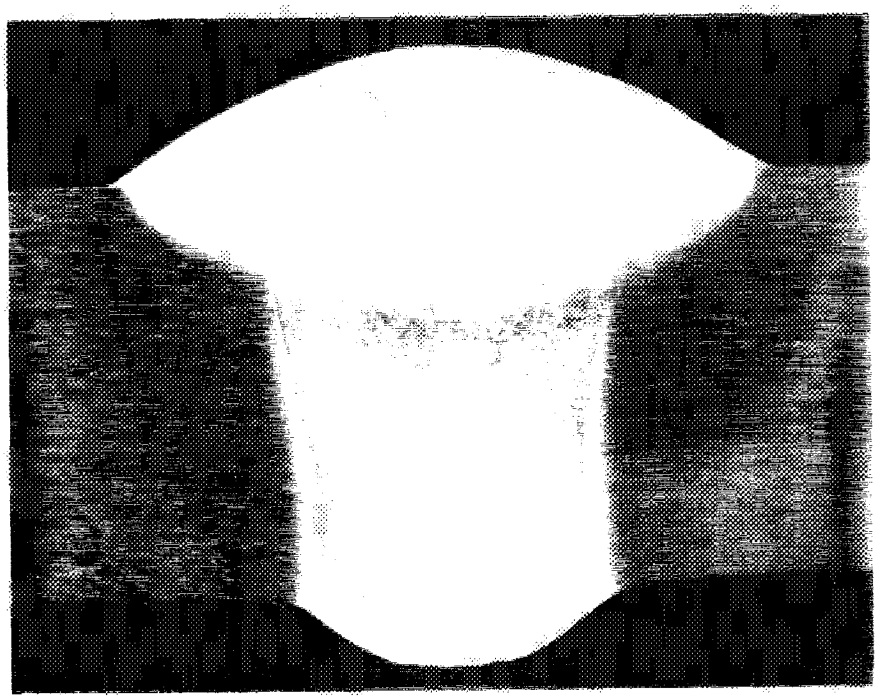
PLT-M01
0.320-Inch-Thick 2195-RT70 VPPA Weld
Plate-to-Plate
(12.5x Original Magnification).



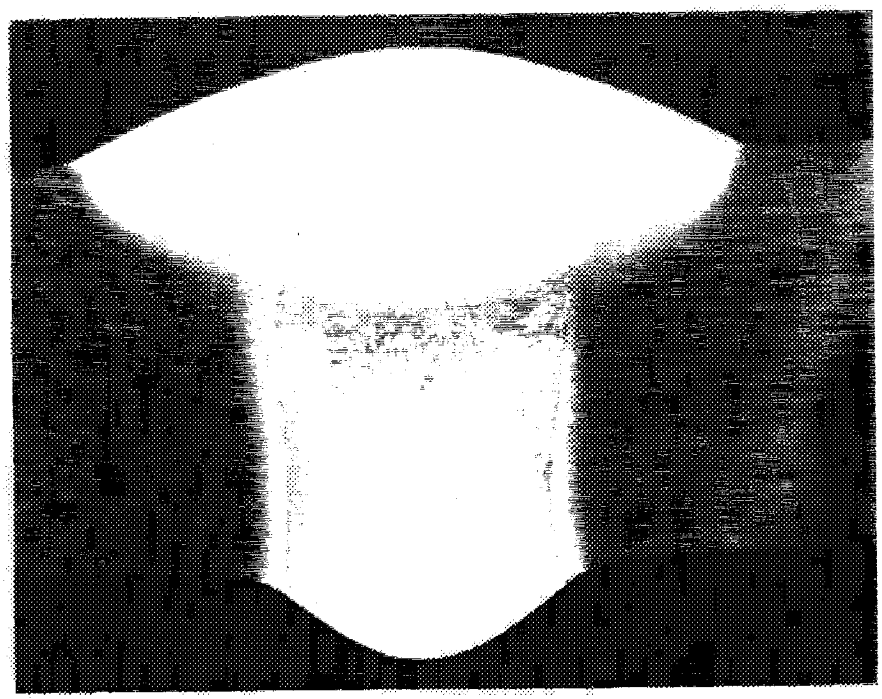
PLT-M02
0.320-Inch-Thick 2195-RT70 VPPA Weld
Plate-to-Plate
(12.5x Original Magnification).



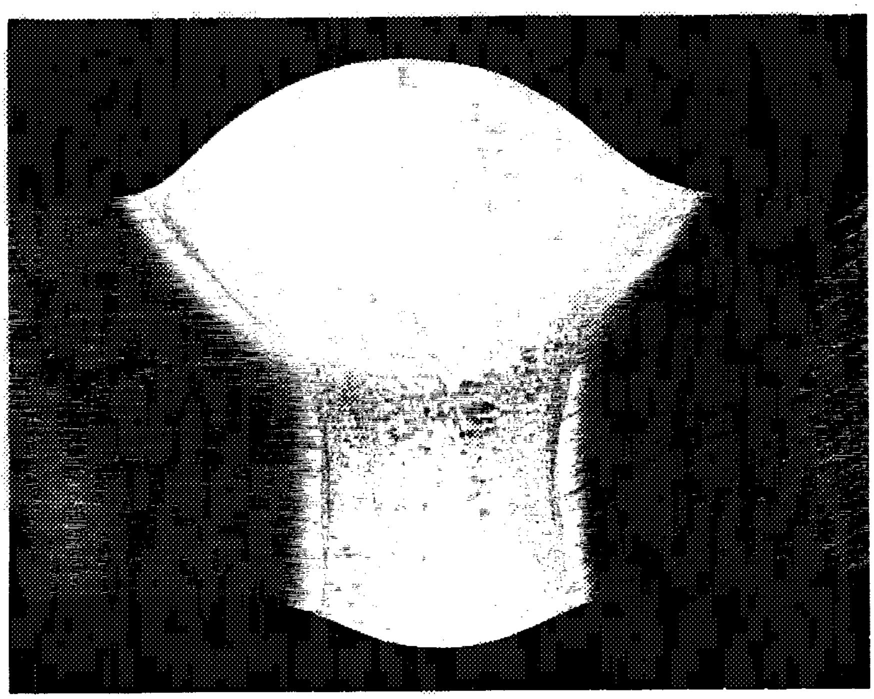
RRF1-M01
0.320-Inch-Thick 2195-T8 VPPA Weld
NFF-to-Plate
(12.5x Original Magnification).



RRF1-M02
0.320-Inch-Thick 2195-T8 VPPA Weld
NFF-to-Plate
(12.5x Original Magnification).



RRF1-M03
0.320-Inch-Thick 2195-T8 VPPA Weld
NFF-to-Plate
(12.5x Original Magnification).



RRF2-M01
0.320-Inch-Thick 2195-T8 VPPA Weld
NFF-to-Plate
(12.5x Original Magnification).

LOCKHEED MARTIN