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***Heat Source Capsule
Fabrication Technology
Program: Final Report
January 1971 - March 1972***

D.E. Wendeln, D.L. Coffey, H.B. Kreider,

P.A. Tucker, W.C. Wyder, and J.R. Wysong

AEC Research and Development Report

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P. A. Tucker, W. C. Wyder, and J. R. Wysong

July 31, 1972

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FOREWORD

The Heat Source Capsule Technology Program was started in April, 1970. An interim report, Heat Source Capsule Fabrication Technology Program: September 1970 - January 1971, MLM-1796, was published in March, 1971. The interim report covered the initial development phase of the program. This report covers the final development work and the production of capsules for the Pioneer and Transit Programs through March 1972.

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TEAM RESPONSIBILITY

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Manufacturing Engineering	J. R. Wysong
Hydroform Tooling Design and Procurement	J. E. Newland
Hydroform Parameter Development Annealing and Metallurgy	W. C. Wyder
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Machining Fixtures and Tools	R. G. Cooper H. A. Huber
Machine-Tool Evaluation and Setup	J. N. Griffith N. D. Hignite R. W. Saylor
Quality Control Program	H. B. Kreider
Mathematical Analysis	J. S. Madachy
Coordination	D. E. Wendeln

SUMMARY

The development phase of the Heat Source Capsule Technology Program started in April of 1970 was continued to August 1971. In the period January 1971 to August 1971 the major goal was to reduce the amount of out-of-roundness of the body capsules after forming and before machining and to optimize the previously established forming and machining techniques. Dimensional and metallurgical inspections were performed on all development parts to insure conformance to drawings and specifications.

The production phase of the Heat Source Capsule Technology Program was started in September of 1971 and is nearing completion for the Pioneer and Transit Programs.

A Brew Model #902 High-Temperature Vacuum Annealing Furnace with a hot zone 12 by 12 by 24 in. was installed, calibrated, and placed in operation in January 1972.

Nine hydroformed liner assemblies were fabricated, inspected, welded, and used in the Pioneer Backup Test Capsules. Seven complete hydroformed Pioneer capsule assemblies were used to fabricate the Pioneer-Transit test capsules. Three complete hydroformed Transit assemblies were used to produce Pioneer PF-15. Three complete hydroformed Transit assemblies were used to produce Transit TF-2.

A quality summary by parts is shown below.

Liner caps Twenty-one dimensions are checked for conformance to the drawings. Out of a total of 795 measurements there were 24 deviations noted and only eight of these were greater than 0.001 in. There was no predominate problem area except in machining of radii where 11 of these deviations were found. To date, 28 liner caps have been accepted, four of which were assigned a restricted end use. Two liner caps were rejected.

Liner bodies Fifteen dimensions are checked for conformance to drawings. Out of a total of 570 measurements there were 19 deviations noted and only one of them was greater than 0.001 in. The predominate problem area was the inside spherical radius which had 14 of the 19 reported deviations. To date, 35 liner bodies have been accepted, one of which was assigned a restricted end use. One liner body was rejected.

Strength Member Caps Twenty-eight dimensions are checked for conformance to drawings. Out of a total of 644 measurements there were 42 deviations reported and only five of these deviations were greater than 0.001 in. Nineteen of these deviations were machined intentionally to provide a better fit in the weld step to the strength member bodies. Seventeen other deviations were found in the inside diameter and in the concentricity of the inside diameter. To date, 22 strength member caps have been accepted, 11 of which were assigned to restricted end use because of an annealing temperature change and three more due to dimensional variations. One strength member cap was rejected.

Strength Member Bodies Twenty-five dimensions are checked for conformance to drawings. Out of a total of 533 measurements there were 57 deviations. Forty of these deviations were greater than 0.001 in. The major problem with the strength member bodies was one of ovality. Forty-eight of the deviations were in the inside and weld step diameters and are considered a hydroforming problem. To date 21 strength member bodies have been accepted, nine of which were assigned to restricted end use because a change was made in the annealing temperatures after the first nine strength member bodies were manufactured. There were no strength member bodies rejected.

Clad Caps Sixteen dimensions are checked for conformance to the drawings. Out of a total of 373 measurements there were 15 deviations and only one of these was greater than 0.001 in. Seven of the 15 deviations were in the wall thickness in the weld area. To date, 17 clad caps have been accepted and two have been rejected. There were no clad caps assigned to a restricted end use.

Clad Bodies Nineteen dimensions are checked for conformance to the drawings. Out of a total of 594 measurements there were 19 deviations with 10 greater than 0.001 in. Eight of these deviations were found in the dome wall thickness. To date, 31 clad bodies have been accepted and nine of these have been assigned to a restricted end use. There were no clad bodies rejected.

In summary there have been 156 items inspected and six of these have been rejected which is a rejection rate of 3.8%. There have been 3,509 individual measurements made of which 145 were determined to be deviant which is 4.1%. Strength member bodies and caps appear to present the biggest challenge, and the problems in these cases originate in the hydroforming process. The strength member caps have the highest percentage of deviations (6.5%) only because they have been machined out of specification to provide a better weld joint with the strength member bodies.

INTRODUCTION

The specific goals and objectives of the Technology Program were:

To form a higher quality capsule by replacing the mechanical deep drawing process with the Hydroforming Process.

To eliminate dimensional deviations and to reduce the number of MRB (Material Review Board) actions experienced in the Test Capsule phase by applying manufacturing engineering principles to the entire capsule fabrication process.

The quality summary on pages 5-6 and Table 1 below indicate the degree of achievement of these goals.

Table 1

QUALITY SUMMARY				
<u>Part</u>	<u>Total Fabricated</u>	<u>Accepted Without MRB</u>	<u>Restricted End Use</u>	<u>Rejected</u>
Liner Cap	30	24	4	2
Liner Body	36	34	1	1
Strength Member Cap	23	8	14	1
Strength Member Body	21	12	9	0
Clad Cap	19	17	0	2
Clad Body	<u>31</u>	<u>22</u>	<u>9</u>	<u>0</u>
Total	160	117	37	6

The Technology Program Goals were most difficult to achieve in the area of the weld joint. A matching technique of surface geometry and size of the mating weld diameters was used to maintain the critical 0.003 in. weld gap. The drawings allow for a maximum difference of 0.0045 in.

between mating weld diameters. Experience in capsule fabrication indicates it is more economical to select by matching than to fabricate to closer tolerances on a 100% interchangeability basis.

A total of 346 MRB actions were processed for 168 capsule components fabricated in the deep drawing test phase as compared to 41 MRB actions for 50 capsule components produced with the Hydroforming Process. On a percentage of component basis this is a 50.5% reduction.

The Hydroforming-Annealing Development and the Manufacturing Engineering sections of this report illustrate the methods used to achieve these goals.

HYDROFORMING

GENERAL

Hydroforming is a relatively new technique for deep drawing and has its disadvantages as well as its advantages. It has proved to be a benefit in the fabrication of hardware for large radioisotopic heat sources, but it is certainly not the final solution.

Because the hydroform process uses a confined hydraulic fluid as the female die, many more complex shapes can be formed. Also, the reduced friction resulting from the elimination of a pressure pad permits greater blank reductions, giving deeper draws. However, the hydroform has a limited hydraulic pressure which can be applied to a blank being formed, and as materials become thicker and stronger, by work hardening, the machine's ability to move them becomes a limiting factor. Also the basic design of the machine requires that some type of flange be left on all parts. This flange is usually trimmed off and discarded, thus creating wasted material. The hardware for the Transit/Pioneer capsules was not formed by pure hydroforming because of these disadvantages.

After a considerable development effort, a production program was started. Tooling, blank sizes, and the forming, cleaning, and annealing procedures were finalized, based on a best effort guess from the development work.¹ Because of the nature of this program, changes were slow to be made or not made at all.

The basic forming operations were not changed with the exception of an added flange sizing operation here and there. This operation was added to minimize the waste of material, improve dimensional quality, and provide an archive ring for metallographic study.

Figure 1 shows the forming sequence for caps, with the exception of the sized cap. Such a cap would be placed in the middle of the four items shown. Likewise, Figure 2 shows the forming sequence for bodies, again with the exception of the sized predraw can. Such a can would follow the flanged predraw can on the left and would appear the same as the can the second from the left, except the bottom would not be square, but would be irregular, caused by the earring of the material.

FIGURE 1 - Forming sequence for caps.

FIGURE 2 - Forming sequence for bodies.

A typical set of tooling for the forming of a cap is shown in Figure 3. Figure 4 shows the predraw tooling and Figure 5 shows a part of the redraw tooling for the body. A sizing ring is illustrated in Figure 6.

All punches, sleeves, draw ring inserts, and flange sizing ring inserts were made of Ampco DiBronze 25 to eliminate galling between these alloys and steel tooling. The tooling used with the Pt-20 wt % Rh alloy was fabricated of hardened, 60-65 Rc, tool steel. The same lubricant, Cimflo-10, was used as was used in the development work. All punches were grit blasted to provide a rough surface in order to reduce slipping between part and punch, and thereby to reduce stretching and thinning.

FIGURE 3 - Typical set of tooling for the forming of the cap.

FIGURE 4 - Predraw tooling for the body.

FIGURE 5 - Part of the redraw tooling for the body.

LINER CAP (Ta-10 wt % W)

Hydroform Tool Design The hydroform tooling used for the fabrication of the liner cap is shown in Figure 7. As noted above, the punch, draw ring insert, and flange sizing ring insert were fabricated of Ampco DiBronze 25 to eliminate galling. The punch was ground to a spherical radius of 1.0723 in. and a diameter of 2.1445 in. It was also grit blasted to reduce slippage and stretching of the cap.

Dimensional quality of the as-formed caps was quite good. Figure 8 is a typical trace of the inside spherical radius of a later formed cap. It shows an inside spherical radius deviation from the nominal 1.072 in. of 0.0015 to 0.002 in. The allowable deviation was 0.001 in., thus causing this particular cap to be out of specification by 0.001 in. This deviation and some from other caps on the order of 0.0025 in. were not cause for rejection of the parts. Although the caps were not as desired they were useable.

The product drawing for the cap did not specify an inside spherical radius but only an outside spherical radius and a wall thickness. This left the inside dimension to be derived from the outside dimension and the wall thickness. The outside spherical radius was given as 1.102 ± 0.003 in. and the wall thickness as 0.031 ± 0.001 in. These two dimensions permit, at the extremes, an inside spherical radius of 1.071 ± 0.004 in. Thus the caps were useable although out of specification.

FIGURE 6 - Flange sizing operation.

FIGURE 7 - Forming operation.

FIGURE 8 - Inside spherical radius of typical liner cap.

By not holding the inside spherical radius to some reasonable tolerance, no room for error was left for the machining operation, which was not a tolerable situation. All of this leads to the realization that the out of specification hydroformed caps were salvageable if care was taken during machining, which was in fact the case.

Figure 9 is a typical trace of the roundness of a cap at the equator and shows an out-of-roundness of 0.0007 in. The majority of caps had an out-of-roundness of 0.001 in. or less, but some were as great as 0.005 in. The worst cases were caused by wrinkles created during the initial stages of forming. It should be noted that, even though the caps were out-of-round, the average of the maximum and minimum diameters was always within the 2.144 ± 0.001 in. diameter specified. The fact that the machining fixture did force the caps into a round condition allowed for their being machined to a uniform wall thickness.

Wall thinning occurred in the dome area, varying in position, and amounting to a reduction from 0.045 in. down to a range of 0.036 to 0.039 in.

Hydroform Parameters The blank sizes used for the production parts were slightly larger and thicker than those used in the development effort. The liner cap blanks were increased from 4 to 4-1/4 in. and the thickness increased from 0.035 to 0.045 in. As was done in the development work, a 0.056 in. thick mild steel waster sheet was used with the initial blanks formed, but they were discontinued after a short time as a time saver. It was felt that the increased thickness of the blank and the larger radiused draw ring, plus the time saved in not having to strip the waster sheets, was sufficient reason to eliminate their use. The unwanted shock line, which the waster sheet was to prevent, was not present to any great degree when the waster sheets were not used.

The hydroform machine parameters used for the forming operation were as follows:

Punch start height	1/4 in.
Final punch height	1-5/8 in.
Starting potential	4000 $\pm$ 200 psi
Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 4 notches

FIGURE 9 - Roundness of a typical liner cap at equator.

After cleaning and annealing, the caps were then sized to straighten the flange and thereby form an added cylindrical section on the cap. This sizing operation also improved the roundness of the cap to some extent. However, the real necessity for it was to provide an archive ring for metallurgical study. As it turned out, the cylindrical section was most useful in holding the cap on an expandable arbor for machining of the outside contour.

Figure 6 illustrates the setup used for the flange sizing operations on the liner cap. The cover shell was used, both to hold the sizing ring down and to prevent the diaphragm from being extruded down into the sizing ring once the cap cleared it. The diaphragm pressure on the cover shell was set at 3000 ± 500 psi during the sizing operation. The punch was raised just enough for the cap to clear the ring. With the punch and cap above the ring the pressure was released and the cover shell removed. A split stripping ring was then placed around the punch on the top of the ring, and the punch was then stripped out of the cap.

During the hydroforming operation for the cap, it was discovered that a worn or torn wear pad, the flat sheet of rubber which covers and protects the diaphragm, would sometimes cause wrinkling in the edge of the blanks. This was due to small scraps of the torn pad being forced under the raised blank during the initial stages of the hydroforming operation. The scrap of torn pad would cause a bend or deformation in the blank which in turn would nucleate a wrinkle. Wrinkles were undesirable in that they cause out-of-roundness.

After the sizing operation the caps were then cleaned and annealed prior to being inspected.

LINER BODY (Ta-10 wt % W)

Hydroform Tool Design The hydroform tooling used to form the liner body is illustrated in Figures 10-12. Little was changed in the forming process over that used in the development work, with the exception of the flange sizing operation. As can be seen from the illustrations, the liner body was formed in two drawing operations and one sizing operation.

The dimensional quality of the predraw can was of importance only in that the wall thickness was not reduced too greatly, and that the roundness was not too distorted to fit the redraw tooling. All three body components were predrawn on the same tooling, and all three predraw cans were sized on the predraw punch but with different sizing rings.

The redraw punch for the liner body was ground to a spherical radius of 1.0799 in. and a diameter of 2.1614 in. These values were within the dimensions shown in Figure 12.

All of the first bodies formed exhibited a spherical radius well within the 1.080 ± 0.002 in. specification. But for some unexplained reason

FIGURE 10 - Predraw forming operation.

FIGURE 11 - Predraw sizing operation.

FIGURE 12 - Redrawing operation.

the latest bodies formed have exhibited a slight deviation of a few tenths over the maximum. Figure 13 shows a typical trace of the inside spherical radius of one of the later liner bodies. The roundness of the bodies has been fairly consistent throughout the production run. Figure 14 illustrates a typical trace of a liner body at three different positions along the cylindrical sections. The out-of-roundness runs from 0.001 to 0.0015 in. at the equator, from 0.003 to 0.004 in. at the center, and from 0.005 to 0.009 in. at the open end. This large deviation was tolerated because the body is flexible enough to be made round on the machining fixture and thus a uniform wall can be machined.

Wall thinning occurred over the major portion of the body with the maximum not occurring consistently in any particular location. The minimum thickness was usually of the order of 0.040 to 0.044 in.

Hydroform Parameters The blank diameter for the liner body was increased from a development blank size of 7-3/8 to 8 in., and the thickness from 0.045 to 0.060 in. Like the liner cap, a waster sheet was used but it was discontinued after a short time.

Predraw cans were hydroformed using the following machine parameters:

Punch start height	1/4 in.
Final punch height	4 in.
Starting potential	4000 $\pm$ 400 psi
Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 4 notches

The predraw can was then sized to increase the length and produce a uniform wall thickness. Figure 11 illustrates the flange sizing operation for the predraw can. The same hydroform machine pressure of 3000 $\pm$ 500 psi was used during the operation. Because of the great amount of work induced in the blanks, especially in the flange area, cracks were generated. They were not many in number nor were they very long in length.

After the flange had been sized the cans were trimmed to give a squared end can. They were then cleaned, annealed, and redrawn to the final shape and length of the liner body. Figure 12 illustrates the redrawing operation. It should be noted that the predraw can was not and could not be drawn completely out of the draw ring. If such had been done, the diaphragm would have been extruded down into the space between the draw ring and sleeve causing it to tear and possibly rupture.

FIGURE 13 - Inside spherical radius of typical liner body.

FIGURE 14 - Roundness of typical liner body at three places.

The hydroform machine parameters for the redrawing operation are as follows:

Punch start height	to move can
Punch finish height	5-1/2 in.
Starting potential	5000 $\pm$ 250 psi
Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 4 notches

STRENGTH MEMBER CAP (T-111)

Hydroform Tool Design Like the liner cap, the strength member cap was formed in two operations. The hydroform tooling used to form the cap and the flange sizing tooling are similar to those used for the liner (Figures 6 and 7). The Ampco 25 punch was ground to a spherical radius of 1.1123 in. and to a diameter of 2.2226 in.

It should be noted that the spherical radius was not exactly one-half of the diameter but was actually 0.001 in. larger. This small difference made it difficult to gage the inside spherical radius with consistency since the exact center of rotation could not be found. Thus some reference point had to be chosen, namely the pole position of the inside spherical surface. However, this was not done consistently and a generalization concerning the dimensional quality of all the caps formed thus far cannot be made.

Figure 15 is a typical trace of the inside spherical radius of one of the later caps formed. The pole area was arbitrarily set at a spherical radius of 1.111 in., even though the punch radius was 1.112 in. The point to be noted is the positive deviation of the spherical radius in the area 0 to 45° from the equator. However, even with this deviation, the caps were still useable because of the unspecified inside spherical radius of the finished cap.

The roundness of the caps was quite good, with the majority being within the 2.222 ± 0.002 in. dimension set in the specification. Figure 16 is a trace of one of the later caps formed.

Wall thinning occurred in the spherical portion of the cap in an area approximately 20° from the equator. The range of thickness of material in this area was from 0.100 to 0.109 in.

FIGURE 15 - Inside spherical radius of typical strength member cap.

FIGURE 16 - Roundness of typical strength member cap at equator.

Hydroform Parameters The blank size for the strength member cap was increased from the development size of 4-1/4 in. diameter and 0.100 in. thick, to 4-1/2 in. diameter and 0.120 in. thick. The hydroform machine parameters for the forming operation are as follows:

Punch start height	1/4 in.
Final punch height	1-7/8 in.
Starting potential	4000 $\pm$ 200 psi
Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 4 notches

The hydroformed caps were then cleaned and annealed, and the flange was sized at a pressure of 3000 $\pm$ 500 psi. After sizing, the caps were again cleaned and annealed before final inspection.

STRENGTH MEMBER BODY (T-111)

Hydroform Tool Design Like the liner body, this component was formed in two drawing operations and one intermediate flange sizing operation. The tooling was similar to that used for the liner body (Figures 10-12).

The redraw punch for this component was made to the same nominal dimension as the strength member cap. The actual dimensions were 1.1124 in. for the spherical radius and 2.2218 in. for the diameter. These components, like all others, exhibited a positive deviation from the nominal in the inside spherical radius and, of course, an out-of-roundness in the cylindrical section. Figure 17 is a typical tracing of the inside spherical radius of a strength member body, and Figure 18 is a tracing of the cylindrical section at three different positions. For the same reasons as stated about the strength member cap, no generalization can be made about the inside spherical radius of the strength member body.

The roundness of this component was not too bad. It was of the order of 0.001 in. T.I.R. (total indicator reading) in the area of the equator of the domed end, and 0.003 in. to 0.004 in. T.I.R. at the open end.

Wall thinning was quite severe in this component due mainly to the stretching that occurred. The stretching was the result of slippage between the component and the punch as it was being redrawn. This was alleviated to some degree by grit blasting the punch. Thinning occurred in the cylindrical section near the domed end with the thickness being

FIGURE 17 - Inside spherical radius of typical strength member body.

FIGURE 18 - Roundness of typical strength member body at three places.

reduced from the original 0.115 in. to a range of 0.092 to 0.097 in.

Hydroform Parameters The blanks used for this component were 8 in. in diameter and 0.115 in. thick. The hydroforming parameters for forming the predraw can are as follows:

Punch start height	1/4 in.
Final punch height	4-1/8 in.
Starting potential	4000 $\pm$ 400 psi
Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 4 notches

The predraw can was then sized to straighten the flange. This operation was done with a pressure of 3000 $\pm$ 500 psi.

After the flange sizing operation, the predraw can was trimmed to square the open end, and the outside diameter was turned to 3.630 in. to 3.635 in. A cleaning and an annealing operation were performed on the can, whereupon it was redrawn to final size. The redraw parameters are as follows:

Punch start height	to move can
Final punch height	5-1/2 in.
Starting potential	5000 $\pm$ 250 psi
Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 4 notches

The redrawn strength member body was trimmed to length, cleaned, and annealed before gaging.

CLAD CAP (Pt-20 wt % Rh)

Hydroform Tool Design Unlike the tooling used for the liner and the strength member components, the tooling for the clad components was made

of hardened tool steel. As a matter of fact, some experimental ironing operations done on the Pt-20 wt % Rh alloy using Ampco 25 ironing rings proved to be a disaster. The Ampco 25 seems to gall severely when used on this alloy. This experience necessitated the use of hardened steel tooling for the clad components.

The hydroform tooling for the clad cap and the tooling for flange sizing operations are similar to those used for the liner cap (Figures 6 and 7). Although the flange sizing operation was later eliminated from the fabrication schedule because of hardness variations, it was useful in improving dimensional quality of the cap. This lack of dimensional quality was tolerated because the tooling used to machine these components compensated for this deficiency.

The punch used for hydroforming the clad cap was ground to a spherical radius of 1.2104 in. and a diameter of 2.4203 in.

Figure 19 is a typical trace of the inside spherical radius of a clad cap. The nominal for this dimension was 1.210 ± 0.001 in. It can be seen from this figure that the inside spherical radius, like all other components, exhibited a positive deviation from the nominal. In general the inside spherical radius was out of specification from 0.0005 to 0.0015 in. Again this type of deviation was not critical because of the unspecified inside spherical radius.

Roundness of the clad cap at the equator of the spherical end is illustrated in a representative tracing shown in Figure 20. The allowed out-of-roundness was 0.001 in. T.I.R. with the caps generally out-of-round in the range 0.0015 to 0.002 in. T.I.R.

Thinning occurred at or near the pole of the spherical end and was on the order of 0.023 to 0.024 in. down from the original thickness of 0.025 in.

Hydroform Parameters The blanks for the clad cap were 4-3/8 in. in diameter and 0.025 in. thick. Because of the thinness of the blank, a 0.056 in. thick mild steel waster sheet was used during the forming operation. Initially, the cap was formed with the waster sheet, the latter was removed chemically, and the cap was then cleaned for heat treatment. Both the clad cap and clad body were annealed together after which the cap was sized to straighten out the small flange, nothing being done to the annealed body. This flange sizing operation after annealing evidently caused a slight increase in hardness of the cap which was detrimental to the welding process. The flange sizing operation was therefore discontinued even though eliminating it might be detrimental to the dimensional quality of the cap. However, the machining fixture compensated for the extreme out-of-roundness of the unsized cap.

FIGURE 19 - Inside spherical radius of a typical clad cap.

FIGURE 20 - Roundness of typical clad cap at equator.

The hydroform parameters for the forming of the clad cap are as follows:

Punch start height	1/4 in.
Final punch height	1-3/4 in.
Starting potential	4000 $\pm$ 200 psi
Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 7 notches

CLAD BODY (Pt-20 wt % Rh)

Hydroform Tool Design The clad body, like the other body components, was formed in two drawing operations and one flange sizing operation (Figures 10-12), and like the clad cap was formed with a waster sheet. The galling problem between the Pt-20 wt % Rh alloy and Ampco 25 did not manifest itself when Ampco 25 tooling was used to draw the platinum alloy but only during ironing operations, which were not a part of this procedure. The clad body predraw can was formed on the same tooling as the other two body components, namely an Ampco 25 punch and a draw ring with an insert of the same material.

The flange sizing operation on the predraw can was done with the waster sheet attached. Because of this an Ampco 25 insert sizing ring was used, the Ampco 25 being in contact with the mild steel waster sheet and not the platinum alloy.

The punch used to redraw the body was of hardened steel and had a spherical radius of 1.2105 in. and a diameter of 2.4204 in. The nominal dimensions were 1.2098 to 1.2100 in. for the spherical radius and 2.4196 to 2.4200 in. for the diameter.

The dimensional quality of the clad body was no better nor worse than the clad cap. Figure 21 is a tracing of the inside spherical radius of a body. In general the inside spherical radius of the formed bodies averaged from 0.0005 to 0.003 in. oversize; some of course were within the required specification. The roundness, a typical trace illustrated in Figure 22, ran out as much as 0.007 in. T.I.R. at the open end of the body.

Wall thinning occurred mostly at the equator of the spherical end or in the cylindrical side wall just below the equator. At these points the wall thickness averaged between 0.018 to 0.024 in.

FIGURE 21 - Inside spherical radius of typical clad body.

FIGURE 22 - Roundness of typical clad body at three places.

Hydroform Parameters The blank size for the clad body was 8 in. in diameter and 0.025 in. thick. The waster sheet used was 0.056 in. thick mild steel and remained on the Pt-20 wt % Rh alloy blank through the entire operation. It had beneficial effects as noted below and was removed chemically after the redrawn can was trimmed to size. The hydroform machine parameters for the forming of the clad predraw can are as follows:

Punch start height	1/4 in.
Final punch height	4 in.
Starting potential	3500 $\pm$ 350 psi
First potential change	10000 $\pm$ 500 psi
Final potential	13000 $\pm$ 500 psi
Gain on	1.0 in.
Gain off	6.5 in.
Punch speed	valve open 7 notches

The flange sizing operation was done on the predraw can using a continuous pressure of 3000 $\pm$ 500 psi. After the predraw flange sizing, the can was trimmed to a length of 4-1/2 in. This definitive cutoff length was necessitated by the poor quality of the blanks. The alloy had such severe preferred grain orientation that the resulting earring made the can almost useless. By sheer coincidence the use of a mild steel waster sheet lying against the platinum alloy blank helped greatly to reduce this earring. In fact when the direction of rolling of the Pt-20 wt % Rh blank happened to be aligned at exactly 45° to the direction of rolling of the mild steel blank, the earring was completely eliminated and a predraw can with a perfectly round flange would result. However, the alignment was one of pure chance and only a very few predraw cans were formed with no ears. In order to make the process consistent, all the predraw cans had to be trimmed to the shortest length obtained.

With the predraw can trimmed to length, and the waster sheet still attached, the predraw can was redrawn to the clad body size. But because of the earring problem, the predraw can was trimmed to a length insufficient to give a redrawn body long enough to yield both an archive ring and a Transit length body. The hydroform machine redraw parameters are as follows:

Punch start height	to move can
Final punch height	4-1/2 in.
Starting potential	5000 $\pm$ 500 psi

Final potential	15000 $\pm$ 500 psi
Gain on	0 in.
Gain off	6.5 in.
Punch speed	valve open 7 notches

The redrawn can was trimmed and the waster sheet removed before the bodies were sent to gaging. This component was the most difficult to form of all six. For some reason there was a tendency to form wrinkles in the cylindrical section during the redrawing operation.

CLEANING AND ANNEALING

CLEANING

Ta-10 wt % W and T-111 Alloys Both tantalum base alloys were cleaned by the same method. The procedure was performed on each component at least three times, once before each of the two heat treatments and once after final inspection of the fully machined components. Before they were cleaned, with this procedure, they were cleaned in Stoddard solvent to remove the hydroform lubricant for ease of handling.

The original procedure required that the components first be ultrasonically cleaned with trichloroethylene for 2 to 5 min , followed by an acetone and then tap water rinse. If the parts showed no signs of surface contamination, they were then placed in an acid bath of 30% hydrofluoric acid and 70% nitric acid, by volume measure, for 2 to 3 min , followed by a flowing tap water rinse for at least 1 min or until all visible acid activity stopped. If a continuous film of water was present after the rinse, then the parts were rinsed with ethyl alcohol and blown dry in clean dry air or inert gas.

A porosity problem during the welding of the Ta-10 wt % W liner components caused the insertion of a NaOH rinse in the procedure. After the parts were cleaned with the trichloroethylene they were placed in a hot, 180°F, solution of 10 wt % NaOH in water. To date no evidence has been presented to show that the change in procedure has eliminated the porosity problem.

Pt-20 wt % Rh Alloy Because the clad components were heat treated only once, they were cleaned twice. However, because a mild steel waster sheet was used in forming, a chemical bath had to be used to remove this sheet.

To remove the mild steel waster sheets, the components were cleaned in Stoddard solvent and wiped dry. They were then immersed in a 50% nitric acid - 50% water solution, by volume measure, until the waster sheet had been completely removed. The solution was renewed or replaced as needed. With the waster sheet removed, the parts were rinsed in tap water and wiped dry.

The cleaning procedure started with a 2 to 5 min immersion in an ultrasonic bath of trichloroethylene followed by an acetone and a tap water rinse. They were then immersed in a room temperature solution of 75% hydrochloric acid - 25% nitric acid, by volume measure, for 1 to 5 min. After the acid immersion, they were rinsed in flowing tap water, rinsed in ethyl alcohol and blown dry with clean air or inert gas.

ANNEALING

Ta-10 wt % W and T-111 Alloys Because of the nature of these tantalum base alloys they were of course heat treated in a vacuum furnace. Figure 1 is a picture of the high temperature vacuum furnace used for these parts. After some study as to heat treating temperatures that produced the best metallurgical properties, it was determined that the Ta-10 wt % W liner components should be annealed for 1 hr at $2600 \pm 25^\circ\text{F}$ in a vacuum of 10^{-5} torr or better; and the T-111 strength member components should be annealed for 1 hr at $2700 \pm 25^\circ\text{F}$ in a vacuum of 10^{-5} torr or better. As noted earlier these components were given two such annealing treatments.

Pt-20 wt % Rh Alloy The procedure for the single annealing treatment for these components specified a temperature of $1600 \pm 25^\circ\text{F}$ for 1 hr in either air, inert atmosphere, or a vacuum. The great majority of these components were annealed in air, but a discoloration on the surface, supposedly

FIGURE 1 - High temperature vacuum furnace used for annealing.

an oxide of rhodium, caused the process to be changed to vacuum annealing. Whether or not the discoloration was detrimental has not been shown. The parts are now annealed in the same vacuum furnace as the tantalum base components.

MANUFACTURING ENGINEERING

The manufacturing engineering of the forming, machining, and inspection was based on a process engineering analysis with primary emphasis on in-process inspection where feasible and control of manufacturing errors.

The process engineering analysis provided a process flow sequence which minimized manufacturing errors and prevented subsequent processing of parts not meeting component specification and tolerances. The process flow diagrams (Appendix I) were distributed to the manufacturing areas and the critical steps outlined on Operation Sheets, which were used for both data collection and process verification. The process had a natural two-phase structure; hydroforming and inspection, and machining and subsequent inspections. Thus, operation sheets were prepared for both of these major areas. Appendix II contains the flow sheets, process flow diagrams, and operation sheets for the manufacturing of the strength member body. Similar manufacturing plans were used for the other component hardware.

BLANK MATERIAL

The conformance of the blanks to thickness, metallurgical, and chemical specifications was assured through receipt of a Certificate of Inspection from the vendor. The blanks were then inspected for pores, cracks, and laminations by visual, ultrasonic, and dye penetrant techniques. The blanks were given serial numbers using the following system:

<u>Serial Number</u>	<u>Blanks</u>
LC-300 series	Liner Caps
LB-300 series	Liner Bodies
SC-300 series	Strength Member Caps
SB-300 series	Strength Member Bodies
CC-300 series	Clad Caps
CB-300 series	Clad Bodies

An archive ring was machined from each component after completion of the hydroforming and annealing steps. Random samples of these rings were sent to metallography for grain structure and micro-hardness analysis. The remaining rings were sent to material control for historical samples. The archive rings were identified with the serial number of the component from which it was removed, thus providing complete traceability of the archive rings.

A tool control program was maintained throughout production. Cutting tools were made to a drawing by an outside vendor, inspected at receiving, and issued for use. After a prescribed use, the tool was sent for regrinding and inspection.

DIMENSIONAL INSPECTION

After completion of the hydroforming, cleaning, and annealing operations, the capsules were sent to the Tooling Laboratory for inspection of the internal contour for surface geometry and of the size and wall thickness for machining stock per manufacturing drawings 3-8591 and 3-8592.

A manufacturing engineering and quality review is made at this time to prevent capsules that will not ultimately meet drawings and specifications, from entering the machining operations.

In the machining operations the majority of the dimensions are checked on the machine or in process. Those dimensions which are not feasibly checked in the machining operations such as a) wall thickness in some areas, b) the matching of weld diameters, and c) surface finish are checked in the Tooling Laboratory.

The matching of the weld diameters ensures that the 0.003 in. maximum weld gap is maintained even though drawing dimensions and tolerance allow a slightly larger gap.

The welding engineer and the quality control engineer review the final inspection weld area inspection data and segregate and assign capsules by serial number to be assembled. These selected assemblies are inspected with functional fixed gages that simulate the live fuel and are compensated for differential expansion and weld shrinkage.

The liner assembly-to-strength member clearance and the strength member-to-clad assembly clearance are also functionally checked and recorded.

MACHINING

The inside contour was formed to size, so all machining was to the outside contour and the weld step areas. The outside contour was machined on a tracer lathe using mechanical expanding arbors with ball locators.

The ball locators permit the in-process inspection without removing the part from the arbor.

The weld step area machining was done on an engine lathe using hydraulic contracting chucks. In-process gaging was designed so that critical dimensions could be verified before removing the part from the chuck. Mechanical expanding plugs were used in conjunction with the chucks to minimize the effects of part out-of-roundness.

An inspector was assigned to the machining production area full time to perform the in-process inspections.

QUALITY ASSURANCE PROGRAM

The Quality Control program for the production of hydroformed hardware at Mound Laboratory for the Transit and Pioneer programs is designed to assure compliance of the raw material to the specifications; provide traceability of each final product item to the raw material supplier; provide rapid feedback information concerning the evaluation of die blanks, hydroformed blanks, "in process" dimensions, and final dimensions; assure that all accepted parts meet all drawing and specification requirements, and that those conditions which do not conform are documented and the deviations are either accepted by the appropriate Material Review Board or are rejected and removed from the system.

Operation Sheets designed by the joint efforts of the manufacturing engineers and the quality control engineer are used to provide a complete history of the fabrication of each item and to assure that all work is completed on an item before it is presented for use in a heat source.

Quality Control provides continuous auditing of the manufacturing process and maintains quality records for each dimension required by the drawings and specifications. These records are reviewed with the manufacturing engineers.

COMPARISON OF DEEP DRAWN WITH HYDROFORMED HARDWARE

Twenty-eight Transit test capsules were built with deep drawn hardware which used 168 components. Of these 168 components, 154 had a total of 346 deviations. Six capsules and seven liner assemblies (TZM test capsules) were built with hydroformed hardware using a total of 50 hydroformed components. Of these 50 components, 23 had a total of 41 deviations. A comparison of deep drawn and hydroformed hardware deviations is given in Table 1.

Table 1

COMPARISON OF DEVIATIONS IN DEEP DRAWN AND HYDROFORMED HARDWARE

	<u>No. of Capsules</u>	<u>No. of Components</u>	<u>No. of Deviant Components</u>	<u>% Devient Components</u>	<u>No. of Deviations</u>	<u>Average Deviation per Component</u>
Deep Drawn	28	168	154	91	346	2.06
Hydro- formed	13	50	23	46	41	0.82

METALLOGRAPHIC ANALYSIS

The Heat Source Capsule Fabrication Program was supported by metallographic analyses at all appropriate stages to ensure the metallurgical soundness of the formed products. Representative samples of all starting materials were examined, components produced in the hydroforming development work were analyzed metallographically, the results of experimental annealing were evaluated, and the microstructures of representative components from all production processes were analyzed thoroughly. Finally, tests were performed to determine the mechanical properties of the materials in the formed components.

The microstructures and properties of all starting materials for hydroforming were controlled by the MRC Material Specifications for Ta-10 wt % W, T-111, and Pt-20 wt % Rh and the MRC Hydroform Heat Source Component Specification. For tantalum base alloys, one additional manufacturing process control not included in the specifications was exercised to assure the desired quality of sheet material for hydroforming. Cross-rolling was found to be necessary to provide a suitable texture in the material. Sheet completely long-rolled in the forging direction has a preferred orientation in the microstructure and responds anisotropically and nonreproducibly during forming. A reduction in thickness of 60-75% by cross-rolling destroys the preferred orientation and allows the material to respond uniformly and reproducibly. The materials can be cross-rolled at any stage of reduction following forging.

Compliance of the starting materials with metallurgical specifications was physically verified for each lot of material received. Representative samples were examined metallographically to ensure that the material was fully recrystallized without secondary recrystallization, to ensure that it was free from cracks, pores, and inclusions, and to determine grain size and microhardness. In some cases tests were performed to confirm the tensile properties of the material.

Figure 1 is an illustration of the Ta-10 wt % W sheet material from which the hydroform blanks were cut for producing the liner components. The structure is uniformly recrystallized showing equiaxed, equisized grains and freedom from defects. The grain size is ASTM 6 and the average microhardness is DPH 209.

FIGURE 1 - Ta-10W hydroform blank, heat 620054A. 100X. Grain size: ASTM 6. Microhardness: DPH 209.

Figure 2 is an illustration of the T-111 sheet material from which hydroform blanks were cut for producing the strength member components. The structure is uniformly recrystallized showing equiaxed, equisized grains and freedom from defects. The grain size is ASTM 6 and the average microhardness is DPH 222.

Figure 3 is an illustration of the Pt-20 wt % Rh sheet material from which hydroform blanks were cut for producing the clad components. The structure is uniformly recrystallized showing equiaxed, equisized grains and freedom from defects. The grain size is ASTM 5 and the average microhardness is DPH 127.

The microstructures illustrated in Figures 1-3 are typical for the three starting materials. They were not, however, identical in all lots of material employed. Some variations in grain size and microhardness existed between lots for all three materials.

FIGURE 2 - T-111 hydroform blank, sheet No. 2. 100X (reduced to 75%). Grain size: ASTM 6. Microhardness: DPH 222 (average).

FIGURE 3 - Pt-20Rh hydroform blank, heat 87178A. 100X. Grain size: ASTM 5. Microhardness: DPH 127.

Complete evaluation of the microstructure of the formed components was made by metallographic analysis of strips cut longitudinally from the entire length of the components. These were cut into shorter lengths to facilitate mounting in standard metallographic mounts, and the structure of the specimens was examined between inner and outer surfaces in a direction parallel to the forming direction.

Prior to annealing, the hydroformed components exhibited a gradient of cold work from the forming process. Figures 4-8 illustrate the microstructure of an unannealed T-111 strength member body at five points of interest. The entire width of the sidewall is shown at the weld preparation area (near the open end of the capsule), the center of the cylindrical section, the start of the hemispherical radius, the 45° position of the hemisphere, and the polar area of the hemisphere. The highly deformed condition of the microstructure in Figures 4 and 5 illustrates the amount of cold work present throughout the cylindrical section. The cold work is also reasonably uniform across the sidewall as shown additionally by the microhardness data. The amount of cold work in the microstructure

inside edge

FIGURE 4 - Unannealed T-111 strength member body, MD-401, at the weld preparation area. 100X (reduced to 75%). Microhardness: inside - DPH 291, center - DPH 267, outside - DPH 310.

FIGURE 5 - Unannealed T-111 strength member body, MD-401, in the cylindrical section. 100X (reduced to 75%). Microhardness: inside - DPH 297, center - DPH 267, outside - 272.

inside edge

in Figures 6, 7, and 8 appears sharply reduced showing that the material in the hemispherical area experienced much less deformation during forming.

As a result of the gradient of cold work along the length of each component, uniform recrystallization during annealing was not possible. As observed in early experience, the cylindrical sidewalls of all hydroformed bodies were highly worked and recrystallized completely. The polar regions of the hemispheres of both caps and bodies were not worked significantly and did not recrystallize during annealing. In the case of the thicker-walled strength member components, a zone of critically strained material between the two regions exhibited rapid grain growth producing an undesirable duplex microstructure.

The optimum microstructure for the hydroformed components to enable the heat source capsule to survive its most severe requirement (high temperature impact) without rupturing is a uniform fine grained microstructure. In experimental annealing tests annealing temperatures were found which produced uniform fine-grained microstructures in all components. This was achieved by annealing at temperatures a little lower than the temperatures normally employed for the materials. The components were stress relieved over a portion of the hemispherical area, recrystallized over the remaining length, and contained no separating zone of duplex microstructure. Microhardness tests showed the materials to be uniform in both the stress-relieved and recrystallized areas and typical of the hardness of recrystallized materials.

Following establishment of the final production and annealing procedures, one of each hydroformed component was analyzed metallographically in the annealed condition for complete evaluation of the microstructure.

Figures 9-12 illustrate the microstructure of a Ta-10 wt % W liner cap at the weld preparation area, the start of the hemispherical radius, the 45° position of the hemisphere, and the polar area of the hemisphere, respectively. The cap was annealed twice for one hour at 2600°F. Some recrystallization and growth occurred at the first two positions resulting in a slight coarsening of the grain size (ASTM 6). The grain size at the final two positions (ASTM 6-7) and the microhardness over the entire length are typical of the starting condition of the hydroform blank.

Figures 13-17 illustrate the microstructure of a Ta-10 wt % W liner body at the weld preparation area, the center of the cylindrical section, the start of the hemispherical radius, the 45° position of the hemisphere, and the polar area of the hemisphere respectively. The body was given a one-hour intermediate anneal at 2600°F and a one-hour final anneal at 2600°F. The material is completely recrystallized from the weld preparation area through the start of the hemispherical radius. In the hemispherical area the transition from recrystallized to stress-relieved

(Text continues on page 62)

FIGURE 6 - Unannealed T-111 strength member body, MD-401, at start of hemisphere. 100X (reduced to 75%). Grain size: ASTM 6. Microhardness: inside - DPH 276, center - DPH 280, outside - DPH 267.

inside edge

FIGURE 7 - Unannealed T-111 strength member body, MD-401, at 45° position of hemisphere. 100X (reduced to 75%). Grain size: ASTM 6. Microhardness: inside - DPH 264, center - DPH 276, outside - DPH 279.

inside edge

FIGURE 8 - Unannealed T-111 strength member body, MD-401, at polar area of hemisphere. 100X (reduced to 75%). Grain size: ASTM 6. Microhardness: inside - DPH 238, center - DPH 297, outside - DPH 272.

inside edge

FIGURE 9 - Annealed Ta-10W liner cap, 315, at weld preparation area. 100X. Grain size: ASTM 6. Microhardness: inside - DPH 221, center - DPH 227, outside - DPH 235.

inside edge

FIGURE 10 - Annealed Ta-10W liner cap, 315, at start of hemisphere. 100X. Grain size: ASTM 6. Microhardness: inside - DPH 224, center - DPH 210, outside - DPH 232.

inside edge

FIGURE 11 - Annealed Ta-10W liner cap, 315, at 45° position of hemisphere. 100X. Grain size: ASTM 6-7. Microhardness: inside - DPH 215, center - DPH 219, outside - DPH 216.

inside edge

FIGURE 12 - Annealed Ta-10W liner cap, 315, at polar area of hemisphere. 100X. Grain size: ASTM 6-7. Microhardness: inside - DPH 231, center - DPH 216, outside - DPH 227.

inside edge

FIGURE 13 - Annealed Ta-10W liner body, 305, at the weld preparation area. 100X. Grain size: ASTM 6-7. Microhardness: inside - DPH 203, center - DPH 194, outside - DPH 208.

inside edge

FIGURE 14 - Annealed Ta-10W liner body, 305, in the cylindrical section. 100X. Grain size: ASTM 6-7. Microhardness: inside - DPH 204, center - DPH 199, outside - DPH 209.

inside edge

inside edge

FIGURE 15 - Annealed Ta-10W liner body, 305, at start of hemisphere. 100X. Grain size: ASTM 6-7. Microhardness: inside - DPH 203, center - DPH 194, outside - DPH 216.

FIGURE 16 - Annealed Ta-10W liner body, 305, at 45° position of hemisphere. 100X. Grain size: ASTM 6-7. Microhardness: inside - DPH 212, center - DPH 206, outside - DPH 207.

inside edge

inside edge

FIGURE 17 - Annealed Ta-10W liner body, 305, at polar area of hemisphere. 100X. Grain size: ASTM 6-7. Microhardness: inside - DPH 212, center - DPH 212, outside - DPH 212.

material is gradual with no obvious demarcation. The grain size (ASTM 6-7) and the microhardness are uniform over the entire length. This component was sectioned and examined after machining of the outer surface.

Figures 18-21 illustrate the microstructure of a T-111 strength member cap at the same positions illustrated for the liner cap. This component was annealed twice for one hour at 2700°F. The material is partially recrystallized at the weld preparation area and the start of the hemispherical radius. Throughout most of the hemispherical area the material is in the stress-relieved condition and appears typical of the starting condition of the hydroform blank. The uniform microhardness data attest to the fully annealed condition of the cap. This component was sectioned and examined prior to machining. In the final machined condition the sidewall would consist of the material extending 6 3/8 in. from the inside edge of the photomicrographs in Figures 18-21.

(Text continues on page 67)

FIGURE 18 - Annealed T-111 strength member cap, 334, at the weld preparation area. 100X (reduced to 70%). Grain size: ASTM 6. Microhardness: inside - DPH 216, center - DPH 199, outside - DPH 212.

inside edge

FIGURE 19 - Annealed T-111 strength member cap, 334, at start of hemisphere. 100X (reduced to 70%). Grain size: ASTM 6. Microhardness: inside - DPH 190, center - DPH 209, outside - DPH 198.

inside edge

FIGURE 20 - Annealed T-111 strength member cap, 334, at 45° position of hemisphere. 100X (reduced to 70%). Grain size: ASTM 5-6. Microhardness: inside - DPH 216, center - DPH 198, outside - DPH 219.

inside edge

inside edge

FIGURE 21 - Annealed T-111 strength member cap, 334, at polar area of hemisphere. 100X (reduced to 70%). Grain size: ASTM 5-6. Microhardness: inside - DPH 207, center - DPH 209, outside - DPH 215.

Figures 22-24 illustrate the undesirable microstructural features observed throughout the midportions of the hemispherical areas of T-111 strength member bodies whose annealing temperatures were not satisfactory. Figure 22 shows the 45° position of the hemisphere of a component given a one-hour intermediate anneal at 2700°F and a one-hour final anneal at 3000°F. Figure 23 shows the same position of a component given a one-hour intermediate anneal at 3000°F and a one-hour final anneal at 2700°F. Figure 24 shows the same position of a component given a one-hour intermediate anneal at 3000°F and a one-hour final anneal at 3000°F.

All the components illustrated in the above figures contained insufficient cold work in the hemispherical region to cause complete recrystallization during annealing. The presence of critical strain in this region produced accelerated grain growth resulting in duplex microstructure (bands or colonies of coarse and fine grained material) or gradients of sharply increasing grain size. The position and length of areas containing this type microstructure varied with the annealing temperatures employed.

Figures 25-29 illustrate the microstructure of a T-111 strength member body at the same positions illustrated for the liner body. This component was annealed in the manner chosen for production. It was given a one-hour intermediate anneal at 2700°F and a one-hour final anneal at 2700°F. The material is fully recrystallized and exhibits a fine uniform grain size (ASTM 6-7) from the weld preparation area through the start of the hemispherical radius. The grain structure is slightly coarser, although still fine and uniform, throughout the hemispherical region reflecting the starting condition of the hydroform blank. The transition from recrystallized material to stress-relieved material is gradual with no obvious demarcation. The microhardness data show the fully annealed condition of the component. Like the strength member cap in Figures 18-21, it was sectioned and examined metallographically prior to machining.

Figures 30-33 illustrate the microstructure of a Pt-20 wt % Rh clad cap at the same positions illustrated for the liner and strength member caps. This component was annealed for one hour at 1600°F. The material is partially recrystallized at the weld preparation area and the start of the hemispherical radius. From this position the microstructure changes gradually to the stress-relieved condition illustrated for the final two positions. The grain size at these positions (ASTM 5) and the microhardness over the entire length are typical of the starting condition of the hydroform blank.

Figures 34-38 illustrate the microstructure of a Pt-20 wt % Rh clad body at the same positions illustrated for the liner and strength member bodies. This component was annealed for one-hour at 1600°F. The entire cylindrical section is completely recrystallized showing a fine uniform grain size (ASTM 7). The material is only partially recrystallized at the start of the hemispherical radius where the grain size is ASTM 6. Throughout

(Text continues on page 80)

FIGURE 22 - Annealed T-111 strength member body, 313, at 45° position of hemisphere. 100X (reduced to 75%). Grain size: range from ASTM 2-6. Microhardness: inside - DPH 224, center - DPH 225, outside - DPH 232.

inside edge

FIGURE 23 - Annealed T-111 strength member body, 312, at 45° position of hemisphere. 100X (reduced to 75%). Grain size: range from ASTM 2-6. Microhardness: inside - DPH 221, center - DPH 222, outside - DPH 227.

inside edge

FIGURE 24 - Annealed T-111 strength member body, 305, at 45° position of hemisphere. 100X (reduced to 75%). Grain size: range from ASTM 3-6. Microhardness: inside - DPH 221, center - DPH 209, outside - DPH 225.

inside edge

FIGURE 25 - Annealed T-111 strength member body, 314, at weld preparation area. 100X (reduced to 75%). Grain size: ASTM 6-7. Microhardness: inside - DPH 216, center - DPH 212, outside - DPH 215.

inside edge

FIGURE 26 - Annealed T-111 strength member body, 314, in cylindrical section. 100X (reduced to 75%). Grain size: ASTM 6-7. Microhardness: inside - DPH 202, center - DPH 211, outside - DPH 215.

inside edge

inside edge

FIGURE 27 - Annealed T-111 strength member body, 314, at start of hemisphere. 100X (reduced to 75%). Grain size: ASTM 6. Microhardness: inside - DPH 192, center - DPH 224, outside - DPH 195.

inside edge

FIGURE 28 - Annealed T-111 strength member body, 314, at 45° position of hemisphere. 100X (reduced to 75%). Grain size: ASTM 5-6. Microhardness: inside - DPH 217, center - DPH 219, outside - DPH 224.

inside edge

FIGURE 29 - Annealed T-111 strength member body, 314, at polar area of hemisphere. 100X (reduced to 75%). Grain size: ASTM 5-6. Microhardness: inside - DPH 212, center - DPH 215, outside - DPH 224.

inside edge

FIGURE 30 - Annealed Pt-20Rh clad cap, 340, at weld preparation area. 100X. Grain size: ASTM 6. Microhardness: inside - DPH 146, center - DPH 143, outside - DPH 137.

inside edge

FIGURE 31 - Annealed Pt-20Rh clad cap, 340, at start of hemisphere. 100X. Grain size: ASTM 6. Microhardness: inside - DPH 147, center - DPH 128, outside - DPH 148.

inside edge

FIGURE 32 - Annealed Pt-20Rh clad cap, 340, at 45° position of hemisphere. 100X. Grain size: ASTM 5. Microhardness: inside - DPH 135, center - DPH 135, outside - DPH 143.

inside edge

FIGURE 33 - Annealed Pt-20Rh clad cap, 340, at polar area of hemisphere. 100X. Grain size: ASTM 5. Microhardness: inside - DPH 139, center - DPH 130, outside - DPH 130.

FIGURE 34 - Annealed Pt-20Rh clad body, 318, at weld preparation area. 100X. Grain size: ASTM 7. Microhardness: inside - DPH 137, center - DPH 147, outside - DPH 149.

inside edge

FIGURE 35 - Annealed Pt-20Rh clad body, 318, in cylindrical section. 100X. Grain size: ASTM 7. Microhardness: inside - DPH 123, center - DPH 120, outside - DPH 117.

inside edge

inside edge

FIGURE 36 - Annealed Pt-20Rh clad body, 318, at start of hemisphere. 100X. Grain size: ASTM 6. Microhardness: inside - DPH 137, center - DPH 138, outside - DPH 140.

FIGURE 37 - Annealed Pt-20Rh clad body, 318, at 45° position of hemisphere. 100X. Grain size: ASTM 6. Microhardness: inside - DPH 127, center - DPH 143, outside - 142.

inside edge

inside edge

FIGURE 38 - Annealed Pt-20Rh clad body, 318, at polar area of hemisphere. 100X. Grain size: ASTM 6. Microhardness: inside - DPH 145, center - DPH 147, outside - DPH 149.

most of the hemispherical region the material is in the stress-relieved condition and the grain size (ASTM 6) and microhardness are typical of the starting condition of the hydroform blank. The transition from recrystallized to stress-relieved material is gradual with no obvious demarcation.

Specimens for mechanical properties tests were taken from the cylindrical sidewalls of the liner, strength member, and clad bodies representative of the final production and annealing procedures. Following are the results of room temperature tensile tests on these specimens:

<u>Component</u>	<u>Yield Strength (psi)</u>	<u>Ultimate Tensile Strength (psi)</u>	<u>Elongation (%)</u>
Liner Body 305	65,600	91,000	21
Strength Member Body 314	74,300	93,300	36
Clad Body 318	25,100	61,700	38

All of the above tensile properties exceed specification requirements.

The mechanical properties of heat source container materials were determined in cooperation with a commercial metallurgical testing facility. All other materials studies and component analyses are conducted "in house".

FIGURE 39 - Bench metallograph.

The Metallurgy-Metallography Laboratory is a well equipped facility containing a variety of types of sectioning, specimen mounting, and grinding equipment. Specimens are polished manually or by automatic polishers, vibratory polishers, or electropolishing equipment. The specimens are etched by chemical, electrolytic, or ion bombardment techniques. A variety of bench metallographs (Figure 39) and metallurgical microscopes are employed for analysis of specimens in brightfield illumination or polarized light. Three research metallographs (Figure 40) are also employed providing the additional capabilities of phase contrast and vacuum hot stage studies. Several types of equipment are used for hardness testing and microhardness testing (Figure 41).

Additional supporting facilities are available which can be utilized in the study of materials problems. An electron microscope (Figure 42) equipped with a hot, cold, and tilting stage is used for high magnification structural analyses. An electron microprobe x-ray analyzer (Figure 43) is used for applications such as identification of phases, inclusions, and impurities segregated in grain boundaries. A scanning electron microscope (Figure 44) is employed for analysis of fracture surfaces of materials.

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FIGURE 40 - Research metallograph.

FIGURE 41 - Microhardness testing equipment.

FIGURE 42 - Electron microscope.

FIGURE 43 - The electron microprobe.

FIGURE 44 - Scanning electron microscope.

EVALUATION OF THE WELDABILITY OF HYDROFORMED HARDWARE

A series of studies was performed to evaluate the weldability of each of the hydroformed components. The welding parameters, welding environments, and weld inspection criteria used during these studies are those which were developed for the Pioneer program and are defined in the Pioneer Operation Sheets MD-70130 and the Pioneer Heat Source Assembly Specification MD1-14447. Additional tests and inspections such as room temperature bend tests and microhardness measurements were also performed.

The facility, fixturing, and associated equipment used during these studies are the ones used to produce test capsules for the Pioneer and Transit programs. Figure 1 shows a typical TIG weld setup in an inert gas welding box with the hydroformed assembly in the water-cooled fixturing and the weld torch in position for welding. Figure 2 is an overall view of the inert gas weld box and its associated oxygen, nitrogen, and H₂O analyzers. The programmed Miller Model SR-200 TIG Welder and the associated control

FIGURE 1 - Typical TIG weld setup.

FIGURE 2 - Weld box and analyzers.

and measuring equipment are shown in Figure 3. A portion of the inert gas purifier system is shown to the left of the welder in this photograph.

Figures 4, 5, 6, and 7 are photomicrographs of the electron beam PRD (pressure relief device) weld, the liner TIG closure weld, the strength member TIG closure weld, and the clad TIG closure weld, respectively. The condition of the parent material in the weld joint area is critical if the effects of the weld on the physical properties of the capsule are to be minimized. For instance, the area needs to be essentially strain free, the alloy must have a suitable chemical composition, and the grain size needs to be small in order to preclude undesirable grain growth and precipitation in the grain boundaries during welding. Hardware cleanliness and dimensional attributes in the weld joint area are also quite critical. Examination of the photomicrographs and other data gathered during these studies indicate that all of these critical requirements have been satisfactorily met for the various alloys studied.

A comparison of the weldability of the hydroformed hardware with that of deep drawn hardware previously used on the Pioneer and Transit programs indicates that they have comparable welding characteristics.

FIGURE 3 - Programmed TIG welder with measuring and control equipment.

It was concluded from these studies that all of the hydroformed components display good weldability.

REFERENCES

1. D. E. Wendeln, W. C. Wyder, P. A. Tucker, and J. E. Newland, Heat Source Capsule Fabrication Technology Program: September 1970 - January 1971, MLM-1796 (March 5, 1971), 104 pp.

FIGURE 4 - Pressure relief device EB weld (40X, as etched).

FIGURE 5 - Liner TIG closure weld (40X, as etched).

FIGURE 6 - Strength member TIG closure weld (40X, as etched).

FIGURE 7 - Clad TIG closure weld (40X, as etched).

APPENDIX I

FLOW DIAGRAMS

MONSANTO RESEARCH CORPORATION
MOUND LABORATORY

TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 7	MANUAL NUMBER MD-70151	OPERATION 1
AUTHORIZATION <i>D E Wall</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED	
OPERATION TITLE Forming of Liner Caps

Suboperation
Number → 00 = OPERATION

□ = INSPECTION

➡ = TRANSFER

MONSANTO RESEARCH CORPORATION
MOUND LABORATORY

TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 11	MANUAL NUMBER MD-70151	OPERATION 2
AUTHORIZATION <i>DE W. L. L.</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED	
OPERATION TITLE Liner Cap - Machining

MRC ML 128

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PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION	SHEET 1 of 9	MANUAL NUMBER MD-70151	OPERATION 3
AUTHORIZATION <i>D E C 11/11</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED

OPERATION TITLE
Forming of Liner Bodies

1 INSPECT
8 INCH
DIAMETER
X 0.060
INCH
Ta-10W
BLANKS

3 FORM
PREDRAW
CANS

7 SIZE
FLANGE
ON PRE-
DRAW CANS

9 TRIM
PREDRAW
CAN

10 CLEAN
PREDRAW
CANS PER
SPECIFICATION
1-14682

11 ANNEAL
PREDRAW
CANS PER
SPECIFICATION
1-14680

13 REDRAW
CAN

15 TRIM
BODIES

↓
A

↑
A

16 CLEAN
BODIES
PER
SPECIFICATION
1-14682

17 ANNEAL
BODIES
PER
SPECIFICATION
1-14680

18 INSPECT
INTERNAL
CONTOUR

Suboperation Number **00** = OPERATION = INSPECTION = TRANSFER

MONSANTO RESEARCH CORPORATION
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TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 10	MANUAL NUMBER MD-70151	OPERATION 4
AUTHORIZATION <i>DEW</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED	

OPERATION TITLE
Liner Body - Machining

Suboperation Number → 00 = OPERATION

□ = INSPECTION

◁ = TRANSFER

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TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 7	MANUAL NUMBER MD-70151	OPERATION 5
AUTHORIZATION <i>DE L... ..</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED	
OPERATION TITLE Forming of Strength Member Caps

Suboperation
Number = OPERATION

= INSPECTION

= TRANSFER

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TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 11	MANUAL NUMBER MD-70151	OPERATION 6
AUTHORIZATION <i>[Signature]</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN/ST INCORPORATED	

OPERATION TITLE
Strength Member Cap - Machining

MRC ML 128

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TRANSIT / PIONEER
OPERATION SHEET

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TRANSIT AND PIONEER HARDWARE FABRICATION	1 of 10	MD-70151	7
AUTHORIZATION <i>DEW</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED

OPERATION TITLE

Forming of Strength Member Bodies

Suboperation
Number → 00 = OPERATION

□ = INSPECTION

➡ = TRANSFER

MONSANTO RESEARCH CORPORATION
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TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 12	MANUAL NUMBER MD-70151	OPERATION 8
AUTHORIZATION <i>[Signature]</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED	
OPERATION TITLE Strength Member Body - Machining

PROGRAM	SHEET	MANUAL NUMBER	OPERATION
TRANSIT AND PIONEER HARDWARE FABRICATION	1 of 6	MD-70151	9
AUTHORIZATION <i>[Signature]</i>	CLASSIFICATION	EFFECTIVITY	ECN(S) INCORPORATED
	Unclassified	9-1-71	
OPERATION TITLE			
Forming of Clad Caps

Suboperation
Number → 00 = OPERATION

□ = INSPECTION

◡ = TRANSFER

MONSANTO RESEARCH CORPORATION
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TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 9	MANUAL NUMBER MD-70151	OPERATION 10
AUTHORIZATION <i>[Signature]</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED	

OPERATION TITLE
Clad Cap - Machining

Suboperation Number **00** = OPERATION

[Square] = INSPECTION

[Arrow] = TRANSFER

PROGRAM	SHEET	MANUAL NUMBER	OPERATION
TRANSIT AND PIONEER HARDWARE FABRICATION	1 of 9	MD-70151	11
AUTHORIZATION <i>J. E. M. L.</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED
OPERATION TITLE Forming of Clad Bodies

Suboperation Number

= OPERATION

= INSPECTION

= TRANSFER

MONSANTO RESEARCH CORPORATION
MOUND LABORATORY

TRANSIT / PIONEER
OPERATION SHEET

PROGRAM	SHEET	MANUAL NUMBER	OPERATION
TRANSIT AND PIONEER HARDWARE FABRICATION	1 of 11	MD-70151	12
AUTHORIZATION <i>[Signature]</i>	CLASSIFICATION	EFFECTIVITY	ECN(S) INCORPORATED
	Unclassified	9-1-71	
OPERATION TITLE			
Clad Body - Macnining

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APPENDIX II

COMPLETE MANUFACTURING PLANS FOR
STRENGTH MEMBER BODY

By: D. E. Wendeln
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N. D. Hignite

Prepared by:
W. C. Wyder
J. R. Wysong
March 20, 1972

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PROCESS ENGINEERING SHEETS - HYDROFORMING

FLOW SHEET AND OPERATION SHEETS - MACHINING

PROCESS ENGINEERING SHEETS - MACHINING

MONSANTO RESEARCH CORPORATION
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TRANSIT / PIONEER
OPERATION SHEET

PROGRAM TRANSIT AND PIONEER HARDWARE FABRICATION		SHEET 1 of 10	MANUAL NUMBER MD-70151	OPERATION 7
AUTHORIZATION <i>[Signature]</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED	
OPERATION TITLE Forming of Strength Member Bodies

Suboperation Number → 00 = OPERATION

□ = INSPECTION

➡ = TRANSFER

OPERATION SHEET

OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Forming of Strength Member Bodies		2 of 10	MD-70151	7	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
	<div style="background-color: black; color: white; text-align: center; padding: 5px; margin-bottom: 10px;">IMPORTANT</div> <p>Area Supervisors are responsible to assure that the latest applicable operation sheet is in use in the area of his responsibility. Operation sheets are obtained from Drawing Control and the latest revision verified from the Product Index.</p> <p>Verify that the serial numbers on the blanks correspond to the serial numbers on the Material Transfer Sheet. Record the serial numbers on the Operation sheet.</p> <ol style="list-style-type: none"> 1. Set up hydroform machine as per "Machine Setting 9," Hydroforming-Predraw Can Strength Member Body and run mild steel blank. 2. Examine mild steel part for any anomalies, if none are found then continue with program material. Blank size: 8 inches diameter by 0.120 inch thick, T-111. <p style="text-align: center;">NOTE: Keep draw ring and punch free of all foreign material.</p> <ol style="list-style-type: none"> 3. Inspect and select that side of blank with fewest marks, scratches, and defects, apply lubricant, Cimflo-10, to that side and place lubricated side down in machine. Center blank in machine by balancing on raised punch. Form blank into predraw can. 4. Remove predraw can from machine and vibro-etch serial number on inside of flange, in two places, as near the end as possible. 				

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OPERATION SHEET

OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Forming of Strength Member Bodies		3 of 10	MD-70151	7	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
4.	Continued NOTE: Keep draw ring and punch free of all foreign mate- rial.				
5.	Inspect predraw can for any anomalies, if none appear then continue forming the remaining blanks in the lot.				
6.	Set up hydroform machine as per "Machine Setting 10," Flange Sizing-Predraw Can Strength Member Body. NOTE: Keep draw ring and punch free of all foreign mate- rial.				
7.	Inspect and clean inside of predraw can, where necessary, apply lubricant, Cimflo- 10, and size flange.				
8.	Inspect sized predraw can for any ano- malies, if none appear then continue sizing the remaining cans in the lot.				
9.	Clean sized can in solvent and trim to length removing only enough material to make the open end of the can square. Turn o.d. of can to 3.630/3.635 inch. NOTE: Use chlorothene Nu cutting oil only.				
10.	Clean predraw cans as per Mound Speci- fication No. 1-14682.				
11.	Anneal the cleaned predraw cans as per Mound Specification No. 1-14680.				
12.	Set up hydroform machine as per "Machine Setting 11," Hydroforming-Redrawing- Strength Member Body.				

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OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Forming of Strength Member Bodies		4 of 10	MD-70151	7	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
12.	Continued NOTE: Keep draw ring and punch free of all foreign mate- rial.				
13.	Inspect and clean inside of predraw can, where necessary, apply lubricant, Cimflo- 10 and redraw can.				
14.	Inspect the redrawn body for any anoma- lies if none appear then continue forming the remaining predraw cans in the lot.				
15.	Clean the sized bodies in solvent and cut to a length of 4.950 inches. NOTE: Use chlorothene Nu cutting oil only.				
16.	Clean the trimmed bodies as per Mound Specification No. 1-14682.				
17.	Anneal the cleaned bodies of per Mound Specification No. 1-14680.				
18.	<u>Inspect Internal Contour</u> 1. Inspect 1.112 inch ± 0.001 inch spher- ical radius using air sweep gage Drawing #SK-1467 at 0° and 90°. Plot data on polar chart record dimensions on data sheet. 2. Inspect 2.222 inch ± 0.002 inch inside diameter unrestrained using two point bore gage. Inspect minimum and maxi- mum diameter at equator, center and open end. Record dimensions on data sheet.				

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OPERATION SHEET

OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Forming of Strength Member Bodies		5 of 10	MD-70151	7	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	QC INITIALS	OPERATORS INITIALS
18.	Continued				
	3. Inspect roundness of 2.222 inch diameter unrestrained at equator, center and open end using proficorder. Record dimensions on data sheet.				
	4. Inspect internal contour using fixed go gage, Drawing #3-8654. Record go or no-go on data sheet.				
	5. Inspect wall thickness. Search for minimum and maximum conditions. Record minimum and maximum conditions and their positions on data sheets.				
	6. Visually inspect parts and note any anomalies.				
	7. Manufacturing Engineering to review data for conformance to process and release parts listed for machining.				

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OPERATION SHEET

OPERATION TITLE	SHEET	MANUAL NUMBER	OPERATION								
Hydroforming - Predraw Can - Strength Member Body	6 of 10	MD-70151	7								
<p>Cincinnati Hydroform Machine Model 12-15-7 Forming Step <u>Machine Setting 9</u></p> <ol style="list-style-type: none"> Draw ring No. <u>SK-D-1330-A</u> Punch No. <u>SK-D-1330</u> Punch rise rate valve <u>Open four notches</u> Edging valve <u>Closed</u> Punch start height <u>1/4 inch</u> Final punch height <u>4-1/8 inches</u> Charge sync. range <u>1000-max</u> Starting potential <u>4000 ±400 psi</u> Potential change one <u>15,000 ±500 psi</u> (Potential change two, three, and four not used.) Gain On switch <u>0</u> Off switch <u>6.5</u> Scan and start switch <u>0</u> Potential change switches <table> <tr> <td>No. One</td> <td><u>0</u></td> </tr> <tr> <td>No. Two</td> <td><u>Off</u></td> </tr> <tr> <td>No. Three</td> <td><u>Off</u></td> </tr> <tr> <td>No. Four</td> <td><u>Off</u></td> </tr> </table> Cycle auto switch <u>Auto single</u> Forming condition <u>Hydro</u> Punch reset <u>Auto</u> Diaphragm shape <u>0.4</u> Recap cycle switch <u>Form with strip</u> 				No. One	<u>0</u>	No. Two	<u>Off</u>	No. Three	<u>Off</u>	No. Four	<u>Off</u>
No. One	<u>0</u>										
No. Two	<u>Off</u>										
No. Three	<u>Off</u>										
No. Four	<u>Off</u>										

OPERATION SHEET

OPERATION TITLE	SHEET	MANUAL NUMBER	OPERATION
Flange Sizing - Predraw Can - Strength Member Body	7 of 10	MD-70151	7

Cincinnati Hydroform Machine Model 12-15-7
Forming Step Machine Setting 10

1. Draw ring No. LB-1A
2. Punch No. SK-D-1330
3. Sizing ring No. SK-C-1355
4. Cover shell No. SK-C-1981
5. Punch rise rate valve Open four notches
6. Edging valve Closed
7. Punch start height Bottom of stroke
8. Final punch height 6 inches
9. Charge sync. range 1000-max
10. Starting potential 3000 ±500 psi
11. Potential change one 3000 ±500 psi
(Potential change two, three, and four not used.)
12. Gain On switch 0
Off switch 6.5
13. Scan and start switch 0
14. Potential change switches

No. One	<u>0</u>
No. Two	<u>Off</u>
No. Three	<u>Off</u>
No. Four	<u>Off</u>
15. Cycle auto switch Auto single
16. Forming condition Hydro
17. Punch reset Manual
18. Diaphragm shape 0.6
19. Recap cycle switch Form without strip
20. Stripping ring No. SK-C-1976

OPERATION SHEET

OPERATION TITLE	SHEET	MANUAL NUMBER	OPERATION
Hydroforming - Redrawing - Strength Member Body	8 of 10	MD-70151	7

Cincinnati Hydroform Machine Model 12-15-7
Forming Step Machine Setting 11

1. Draw ring No. SK-D-1335
2. Punch No. SK-D-1335-C
3. Sleeve No. SK-D-1335
4. Sleeve support No. SK-D-1335
5. Punch rise rate valve Open four notches
6. Edging valve Closed
7. Punch start height To move can
8. Final punch height 5-1/2 inches
9. Charge sync. range 1000-max
10. Starting potential 5000 ±250 psi
11. Potential change one 15,000 ±500 psi
(Potential change two, three, and four not used.)
12. Gain On switch 0
Off switch 6.5
13. Scan and start switch 0
14. Potential change switches No. One 0
No. Two Off
No. Three Off
No. Four Off
15. Cycle auto switch Auto single
16. Forming condition Hydro
17. Punch reset Auto
18. Diaphragm shape 0.6
19. Recap cycle switch Form without strip
20. Stripping Ring No. SK-C-1976

HYDROFORM BLANK INSPECTION

PAGE 1 OF 2

DATE _____

PART SERIAL NUMBER

[illegible]

REMARKS:

*DENOTES OUT OF TOLERANCE

Forming of Strength Member Bodies

SHEET

MANUAL NUMBER
MD-70151

OPERATION	7
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OPERATION SHEET

HYDROFORM BLANK INSPECTION

ITEM Strength Member Body

PROGRAM TRANSIT AND PIONEER

PAGE 2 OF 2

DRAWING NO 3-8592

REV Orig.

INSPECTOR

DATE _____

PART SERIAL NUMBER

[illegible]

REMARKS:

*DENOTES OUT OF TOLERANCE

Forming of Strength Member Bodies

SHEET
10 of 10

MANUAL NUMBER
MD-70151

OPERATION
7

OPERATION SHEET

③

FORM PREDRAW CANS (MACHINE SETTING 9)

DRAW RING SKD-1330A

PUNCH SKD-1330

BLANK SIZE 0.120 x 8" DIA T-111

⑦

SIZE FLANGE ON PREDRAW CAN (MACHINE SETTING 10)

DRAW RING	LB-1A
PUNCH	SKC-1330
SIZING RING	SKC-1325
COVER SHELL	SKC-1981
STRIPPING RING	SKC-1976

9

TRIM FREDRAU CAN
ENGINE LATHE

(13)

REDRAW BODIES (MACHINE SETTING 11)

DRAW RING SKD-133E

PUNCH SKD-1335C

SLEEVE SKD-1335

SLEEVE SUPPORT SKD-1335

STRIPPING RING SKC-1976

15

TRIM BODIES
ENGINE LATHE

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TRANSIT / PIONEER

OPERATION SHEET

PROGRAM	SHEET	MANUAL NUMBER	OPERATION
TRANSIT AND PIONEER HARDWARE FABRICATION	1 of 12	MD-70151	8
AUTHORIZATION <i>[Signature]</i>	CLASSIFICATION Unclassified	EFFECTIVITY 9-1-71	ECN(S) INCORPORATED

OPERATION TITLE
Strength Member Body - Machining

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OPERATION SHEET

OPERATION TITLE Strength Member Body - Machining		SHEET 2 of 12	MANUAL NUMBER MD-70151	OPERATION NO 8	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
	<div style="text-align: center; border: 1px solid black; padding: 5px; background-color: black; color: white; margin-bottom: 10px;"> IMPORTANT </div> <p>Area Supervisors are responsible to assure that the latest applicable operation sheet is in use in the area of his responsibility. Operation sheets are obtained from Drawing Control and the latest revision verified from the Product Index.</p> <p>In all machining operations, only chloro-thene Nu is to be used.</p> <p>If finishing paper is required, only garnet paper is to be used.</p> <p>Identity of parts must be maintained during machining operations.</p> <ol style="list-style-type: none"> 1. Place mechanical expanding arbor drawing number 4-9779, on tracer lathe. Align scribe marks. 2. Place part on arbor. 3. Machine 3/8 inch minimum archive ring and rough machine final overall length Pioneer (3.494 inch) Transit (4.342 inch) (about 0.040 inch oversize) using 1/16 inch Tang Tung (144-G) parting tool. <p style="text-align: center;">NOTE: This operation may be done on the engine lathe.</p> <p>Spindle Speed _____ rpm Feed Rate _____ in/rev.</p>				

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OPERATION SHEET

OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Strength Member Body - Machining		3 of 12	MD-70151	8	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	QC INITIALS	OPERATORS INITIALS
4.	Machine 2.402 inch outside diameter using L.H. profile tool Drawing #3-8652. NOTE: Review inspection data for i.d. to machine optimum outside diameter. Spindle Speed _____ rpm Feed Rate _____ in/rev.				
5.	Inspect 2.402 inch diameter using air gage Drawing #3-8078. Record dimension on data sheet. NOTE: Do not remove part for arbor.				
6.	Machine 1.202 inch spherical radius and blend to diameter using L.H. profile tool Drawing #3-8652 and tracer template Drawing #2-13864. NOTE: Do not remove part for arbor. Spindle Speed _____ rpm Feed Rate _____ in/rev.				
7.	Inspect 1.202 inch spherical radius using air gage Drawing #3-8078. Record dimension on data sheet.				
8.	Electrochemical etch serial number on the part as per specification 1-14684, paragraph 3.3 in the location shown on the print.				
9.	Remove part and archive ring from arbor.				
10.	Move archive ring to material control.				
11.	Place hydraulic contracting chuck Drawing #3-8049 on engine lathe using spacer for either Transit or Pioneer, which ever is being machined.				

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OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Strength Member Body - Machining		4 of 12	MD-70151	8	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
12.	Place expanding plug Drawing 3-8787 into part and place part in chuck.				
13.	Tram in part.				
14.	Machine overall length to 4.304 inch for Transit and 3.456 inch for Pioneer (0.005 inch oversize), using L.H. profile tool Drawing #3-8752. Spindle Speed _____ rpm Feed Rate _____ in/rev.				
15.	Check overall length, using dial depth gage.				
16.	Machine 2.322 inch step diameter (0.014 inch deep), 0.003 inch corner radius, and 4.290 (Transit) or 3.442 inch (Pioneer) length using R.H. turning tool Drawing #2-14616. Spindle Speed _____ rpm Feed Rate _____ in/rev.				
	NOTE: Tool must be sharp to machine corner radius.				
17.	Inspect 2.322 inch step diameter using a Mueller Gage Drawing #4-9780-3 or #3-8659-3. Record dimension on data sheet.				
18.	Machine 0.009 inch step length off the face using L.H. profile tool Drawing #3-8652. Spindle Speed _____ rpm Feed Rate _____ in/rev.				
19.	Inspect 3.451 inch (Pioneer) or 4.299 inch (Transit) length using gage 3-8093.				
20.	Record on data sheet. Inspect 0.009 inch step length using air gage Drawing #3-7975. Record dimension on data sheet.				

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OPERATION SHEET

OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Strength Member Body - Machining		5 of 12	MD-70151	8	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
21.	Set compound to 45° angle.				
22.	Machine 2.242 inch diameter, 0.060/0.040 inch length, 0.007 inch minimum step and 45° internal chamfer using nose boring and facing tool Drawing #2-14615. Spindle Speed _____ rpm Feed Rate _____ in/rev. NOTE: Tool must be sharp to machine radii and 45° angle.				
23.	Inspect 2.242 inch diameter using Mueller indicator Gage Drawing #4-9780-4 or #3-8659-2. Record dimension on data sheet.				
24.	Deburr and machine radii: sharp corner 0.002 inch R maximum, 0.003/0.007 inch R, 0.005 inch R.				
25.	Inspect radii: perpendicularity, sharp corner, 0.040/0.060 inch length, 0.002 inch R maximum, 0.003/0.007 inch R, 0.005 inch R, 45° angle 0.003 inch R maximum, 0.006/0.002 inch R using one-to-one profile trace Drawing #5-1933 or optical comparator. Record dimensions on data sheet.				
26.	Remove part from chuck.				
27.	Bag and tag part.				
28.	Move parts to final inspection.				
29.	Examine all cutting tools for edge conditions and conformance to drawings. Send worn tools to regrinding and inspection.				

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OPERATION SHEET

OPERATION TITLE Strength Member Body - Machining		SHEET 6 of 12	MANUAL NUMBER MD-70151	OPERATION NO 8											
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS										
30.	<u>Final Inspection</u> <u>General</u> All components shall be inspected by qualified tool and gage inspectors using calibrated equipment and the procedures outlined herein. The equipment listed is intended as a guide only. Alternate equipment may be used with the approval of the Source Development and/or Encapsulation Group and the Quality Control Engineer. <u>Instructions</u> Measure the following attributes with the indicated equipment and visually inspect each component for gross defects which preclude its use. Record the inspection results on data sheet. Identify out of tolerance attributes with an asterisk. <table border="0"> <tr> <td><u>ATTRIBUTES</u></td> <td><u>INSPECTION EQUIPMENT</u></td> </tr> <tr> <td>0.090 inch ±0.003 inch wall thickness (straight section)</td> <td>Electrojet caliper</td> </tr> <tr> <td>0.090 inch ±0.004 inch wall thickness (dome area)</td> <td>Special 1 inch ball and electrojet</td> </tr> <tr> <td>0.080 inch ±0.003 inch wall thickness (weld area)</td> <td>Open setup with feathertouch and accutron</td> </tr> <tr> <td>2.220 inch minimum inside diameter and spherical contour</td> <td>Functional plug gage</td> </tr> </table>	<u>ATTRIBUTES</u>	<u>INSPECTION EQUIPMENT</u>	0.090 inch ±0.003 inch wall thickness (straight section)	Electrojet caliper	0.090 inch ±0.004 inch wall thickness (dome area)	Special 1 inch ball and electrojet	0.080 inch ±0.003 inch wall thickness (weld area)	Open setup with feathertouch and accutron	2.220 inch minimum inside diameter and spherical contour	Functional plug gage				
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OPERATION SHEET

OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Strength Member Body - Machining		7 of 12	MD-70151	8	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
30.	<p>Continued</p> <p><u>ATTRIBUTES</u></p> <p>2.404 inch maximum out-side diameter</p> <p>Match strength member cap to body and determine functional clearance of matched liner and cap</p> <p>On one chart check: 2.322 inch diameter roundness</p> <p> A 0.002</p> <p> A 0.001</p> <p> A 0.002</p> <p>2.222 inch i.d. to 2.242 inch i.d. step (0.007 inch minimum condition)</p> <p>2.322 inch ± 0.001 inch diameter</p> <p> 0.001</p> <p>1.201 inch o.s. Spherical Radius</p> <p>Check surface finish</p> <p>Weigh part and record weight</p>				

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OPERATION SHEET

OPERATION TITLE		SHEET	MANUAL NUMBER	OPERATION NO	
Strength Member Body - Machining		8 of 12	MD-70151	8	
SUB OP NO	SUB OPERATIONS	PART SERIAL NO	DATE	Q C INITIALS	OPERATORS INITIALS
31.	Inspect dye penetrant, as per ASTM E-165 procedure A-2, with tracer tech penetrant P-150 or equivalent.				
32.	Clean parts per Specification 1-14682.				
33.	Re-etch serial number on parts as per Specification 1-14684, paragraph 3.3, if necessary.				
34.	Return parts to material control in plastic bags for storage.				

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IN-PROCESS INSPECTION

ITEM Strength Member Body

PROGRAM TRANSIT AND PIONEER

PAGE 1 OF 2

DRAWING NO. 3-8006

- REV. Orig.

Orig. INSPECTOR

PART SERIAL NUMBER

DATE _____

[illegible]

REMARKS:

*DENOTES OUT OF TOLERANCE

OPERATION TITLE	DATE	TIME	LOCATION	STATUS	REMARKS
1. Initial Setup	10/26/2023	08:00	Lab A	Completed	Equipment calibrated.
2. Data Collection	10/26/2023	09:30	Lab A	In Progress	Sample 1 analyzed.
3. Analysis	10/26/2023	11:00	Lab A	Pending	Results pending review.
4. Cleanup	10/26/2023	15:00	Lab A	Completed	Area sanitized.
5. Reporting	10/26/2023	16:30	Lab A	Pending	Report draft in progress.

Strength Member Body - Machining

SHEET

9 of 12

MANUAL NUMBER

MD-70151

OPERATION

8

OPERATION SHEET

IN-PROCESS INSPECTION

PAGE 2 OF 2

DATE _____

PART SERIAL NUMBER

[illegible]

REMARKS:

*DENOTES OUT OF TOLERANCE

OPERATION TITLE	DATE	TIME	LOCATION	STATUS	REMARKS
1. Initial Setup	10/26/2023	08:00	Lab A	Completed	Equipment calibrated.
2. Data Collection	10/26/2023	09:30	Lab A	In Progress	Sample 1 analyzed.
3. Analysis	10/26/2023	11:00	Lab A	Pending	Results pending review.
4. Cleanup	10/26/2023	12:30	Lab A	Completed	Area sanitized.
5. Report Generation	10/26/2023	14:00	Lab A	Pending	Report draft in progress.
6. Review Meeting	10/26/2023	15:30	Lab A	Completed	Findings discussed.
7. Final Report	10/26/2023	17:00	Lab A	Pending	Final report to be submitted.
8. Archiving	10/26/2023	18:30	Lab A	Completed	Data stored in archive.
9. Equipment Maintenance	10/26/2023	19:00	Lab A	Pending	Scheduled for next week.
10. Project Summary	10/26/2023	20:00	Lab A	Completed	Summary report completed.

Strength Member Body - Machining

SHEET

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MANUAL NUMBER

MD-70151

OPERATION

8

OPERATION SHEET

MRC-ML-2513

FINAL INSPECTION

ITEM Strength Member Body

PROGRAM TRANSIT AND PIONEER

PAGE 1 OF 2

DRAWING NO. 3-8006

-REV Orig.

INSPECTOR

DATE _____

PART SERIAL NUMBER

[illegible]

REMARKS:

*DENOTES OUT OF TOLERANCE

Strength Member Body - Machining

SHEET
11 of 12

MANUAL NUMBER
MD-70151

18

OPERATION SHEET

FINAL INSPECTION

PROGRAM TRANSIT AND PIONEER

PAGE 2 OF 2

-REV Orig.

INSPECTOR

DATE _____

PART SERIAL NUMBER

[illegible]

REMARKS

*DENOTES OUT OF TOLERANCE

Strength Member Body - Machining

SHEET
12 of 12

MANUAL NUMBER
MD-70151

OPERATION
8

OPERATION TITLE	DATE	TIME	LOCATION	STATUS	REMARKS
1. Initial Setup	10/26/2023	08:00	Lab A	Completed	Equipment calibrated.
2. Data Collection	10/26/2023	09:30	Lab A	In Progress	Sample 1 analyzed.
3. Analysis	10/26/2023	11:00	Lab A	Pending	Results pending review.
4. Cleanup	10/26/2023	12:30	Lab A	Completed	Area sanitized.
5. Reporting	10/26/2023	14:00	Lab A	Pending	Report draft in progress.
6. Review	10/26/2023	15:30	Lab A	Pending	Final review scheduled.
7. Archiving	10/26/2023	17:00	Lab A	Pending	Data backup initiated.
8. Shutdown	10/26/2023	18:30	Lab A	Completed	Lab closed.

OPERATION SHEET

3

MACHINE TO APPROXIMATE LENGTH
TRACER LATHE
EXPANDING ARBOR 4-9779
1/16" TANG TUNG 144 G PARTING TOOL

④

MACHINE 2.402 OUTSIDE DIAMETER

TRACER LATHE

EXPANDING ARBOR 4-9779

L.H. PROFILE TOOL 3-8652

5

INSPECT 2.402 OUTSIDE DIAMETER
TRACER LATHE
EXPANDING ARBOR 4-9179
AIR GAGE 3-8078

⑥

MACHINE 1.202 SPHERICAL RADIUS

TRACER LATHE

EXPANDING ARBOR 4-9779

TRACER TEMPLATE 2-13864

L.H. PROFILE TOOL 3-8652

7

INSPECT 1.202 SPHERICAL RADIUS
TRACER LATHE
EXPANDING ARBOR 4-9779
AIR GAGE 3-8078

14

MACHINE OVERALL LENGTH TO FINAL SIZE

ENGINE LATHE

HYDRAULIC CHUCK 3-8049

EXPANDING PLUG 3-8787

L.H. PROFILE TOOL 3-8652

16

MACHINE 2.322 STEP DIAMETER
ENGINE LATHE
HYDRAULIC CHUCK 3-8049
EXPANDING PLUG 3-8787
R. H. TURNING TOOL 2-14616

17

INSPECT 2.322 STEP DIAMETER

ENGINE LATHE

HYDRAULIC CHUCK 3-8049

EXPANDING PLUG 3-8787

GAGE 4-9780

(18)

MACHINE 0.009 STEP LENGTH

ENGINE LATHE

HYDRAULIC CHUCK 3-8049

EXPANDING PLUG 3-8787

L. H. PROFILE TOOL 3-8652

19

INSPECT 3.451 (PIONEER) OR 4.229 (TRANSIT) LENGTH
ENGINE LATHE
HYDRAULIC CHUCK 3-8049
EXPANDING PLUG 3-8787
GAGE 3-8093

20

INSPECT 0.009 STEP LENGTH
ENGINE LATHE
HYDRAULIC CHUCK 3-8049
EXPANDING PLUG 3-8787
GAGE 3-7975

22

MACHINE 2.242 DIAMETER
ENGINE LATHE
HYDRAULIC CHUCK 3-8049
EXPANDING PLUG 3-8787
NOSE BORING & FACING TOOL 2-14615

23

INSPECT 2.242 DIAMETER
ENGINE LATHE
HYDRAULIC CHUCK 3-8049
EXPANDING PLUG 3-8787
GAGE 4-9780

(24)

DEBURR AND MACHINE RADII

ENGINE LATHE

HYDRAULIC CHUCK

EXPANDING PLUG 3-8787

SMALL SWISSFILES AND WHITE ARKANSAS STONES

25

INSPECT SHARP CORNERS AND RADII

ENGINE LATHE

HYDRAULIC CHUCK 3-8049

EXPANDING PLUG 3-8787

ONE TO ONE PROFILE TRACE 5-1933