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Development of End Fittings for Beryllium Structural Tubing

by

T. L. Stockham

[redacted]

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA/MSFC Contract Nas 8-20151

SOLAR

DIVISION OF INTERNATIONAL HARVESTER COMPANY

NOTICE

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FINAL REPORT

DEVELOPMENT OF END FITTINGS FOR BERYLLIUM STRUCTURAL TUBING

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July 1967

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GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

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ABSTRACT

This is the final report of a program to develop efficient methods of fabricating strut assemblies consisting of beryllium tubing and end fittings. The work consisted of the design and analysis of the strut assembly and components, laboratory evaluation of joining methods, procurement of beryllium forgings and tubing, testing of full-scale attachments on short tubes. and assembly of two 40.60-inch long struts. The joint configuration consists of a stainless steel lap strap. adhesive bonded to the butted beryllium tube and end fitting.

Processing variations produced premature adhesive failure on two parts, but the problems have been identified and corrected, and tests on other assemblies demonstrated the capability of the joint to exceed design requirements.

The end fittings. machined from beryllium forgings, and the extruded beryllium tubing exceeded design requirements. No failure of these beryllium components was experienced during the test program. The high quality evident in these procured materials represents the best current state of the art in beryllium production.

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INTRODUCTION

The work described in this report was performed for the National Aeronautics and Space Administration, Marshall Space Flight Center, by the Solar Division of International Harvester Company under Contract NAS 8-20151. The activities at Solar were performed under the direction of Aerospace Engineering with Mr. H. Jones as Program Manager until November 1966, since that time Mr. T. Stockham has been Program Manager. The NASA-MSFC technical managers have been Mr. Lawrence Dwyer, Mr. O. M. Tommie, and Mr. Carl M. Wood.

The program objective was to produce and deliver to NASA-MSFC two structural tube assemblies which meet the following requirements:

- Stiffness equivalent to a 5.0-inch OD, 0.625-inch wall 2219-T8511 aluminum alloy tube

- The assemblies to consist of a 5.0-inch OD beryllium tube with beryllium end fittings

- Pin-to-pin length of the assemblies to be 40.60 inches. One assembly having two fixed ends, and the other one fixed and one adjustable end

- The assemblies to be capable of carrying a load of 80,000 pounds in tension or compression.

The applicability of beryllium to this program was established by the high stiffness-to-weight ratio of the material. Thus, use of these struts to replace the current aluminum alloy design would result in a major weight reduction.

All of the program objectives have been accomplished. One assembly was tested to a 112,800-pound tensile load without failure. This load produces stress in the beryllium in excess of 58,000 psi, making very effective use of beryllium as a structural material. A 63 percent weight reduction of the comparable aluminum strut was indicated on the 40.60-inch long assembly.

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RECOMMENDATIONS

There are a number of areas in which further work could be done to enhance the results obtained in this program. The first of these is, of course. evaluation of the 40.60-inch long prototype strut assemblies. The results of this evaluation would be of significant value in establishing the nature and extent of any future work. The next area which warrants additional study is a thorough evaluation of the bonding process parameters to establish a working range which will consistently provide high-strength joints. A part of this investigation should include evaluation of nondestructive inspection techniques to ensure the quality of completed assemblies. Design refinements could be accomplished to reduce the end-fitting weight by removal of additional material from the forging in low stress areas. In addition, it might be possible to eliminate the lap straps through the use of mating tapered surfaces on the fitting and tube. The use of a shallow taper would provide a large joint area without extra material and would eliminate eccentricities in the load transfer from one beryllium element to the other. With this type of joint and current improvements in braze processes, it would be practical to reconsider brazing and thereby produce a more rigid assembly.

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DESIGN AND ANALYSIS

The tube assembly was designed to withstand an axial load of 80, 000 pounds in tension or compression, and to match the stiffness of a given aluminum tube. Analyses were therefore conducted on the tube, the end fitting, the end-fitting lug, and the tube-to-fitting joint.

3.1 TUBE ANALYSIS

The design criteria for the beryllium assembly specified a stiffness equal to an aluminum alloy strut 132 inches long with a 5.0-inch OD, and a 0.625-inch wall. Axial and transverse stiffness for tubular columns were calculated from:

$$K_A = P/\delta = AE/\ell$$

$$K_T = 48\ EI/\ell^3$$

where,

K_A	Axial spring constant (lb/in.)
K_T	Transverse spring constant (lb/in.)
P	Applied load (lb)
A	Cross section area (sq in.)
E	Modulus of elasticity (lb/sq in.)
ℓ	Length of section (in.)
δ	Deflection (in.)
I	Moment of inertia of section (in.^{4})

A 2219 aluminum alloy tube was assumed as a standard, and the wall thickness of a beryllium tube of equal OD and stiffness was calculated. Comparative data are:

	K_A	K_T
Al - 132.0 in. long by 5.0 in. OD by 0.625 in. wall	- 690,000 lb/in.	4630 lb/in.
Be - 132.0 in. long by 5.0 in. OD by 0.125 in. wall	- 647,000 lb/in.	5220 lb/in.

Axial and transverse stiffnesses could not be matched without changing the tube OD. Since column buckling behavior is proportional to K_T, this factor was considered most important. The 0.125-inch wall was therefore selected, yielding an increase in K_T of 12 percent.

3.2 END FITTING

The tube-end fittings (dwg. 46763, Appendix A) have been designed for failure loads of 80,000 pounds or greater. Early in the program it was established that a forging would be the only practical means of obtaining satisfactory material properties in the end-fitting blank. Machining the part from beryllium block is undesirable because of the low ductility and low strength of hot pressed block material. Two configurations for the assembly were given prime consideration. These were a brazed joint design and a bonded joint design. The major portion of the analysis concerned the stress discontinuities of the end fittings and the tube in the vicinity of the joint.

The analysis was conducted using a computer program which has been written for a 7094 computer system. The method employed is discussed in "Beams on Elastic Foundations" by M. Hetenyi. It consists of writing deflection and continuity equations for many short cylinders, and then solving the system of equations by matrix techniques.

The end fitting and the joint were assumed to be a homogenous surface of revolution. The surface of revolution was broken into many very short elements. The assumed boundary conditions provide for the first element near the lug to be completely fixed (all deflections equal to zero). For the lap ring joint design the last element at the joint was also assumed to be fixed against rotational or radial deflections. The purpose of fixing the last element was to ascertain the worst condition which may exist and to provide a basis for design.

The analysis shows that this particular configuration will have bending stresses of significant magnitude developed both at the joint and at the transition of the end fitting from cylindrical to tapered shape. The nature of beryllium makes this a very critical structural problem. Bending stresses in the vicinity of discontinuities must be held to a minimum because of the sensitivity of beryllium to high localized stresses. The analysis leads to the conclusion that the fitting design has a reasonable probability of performing reliably at high joint efficiency.

3.3 END-FITTING LUG

A particularly critical design area on the forged beryllium end fitting is the pin-joined lug, by which the tube assembly is attached to the adjacent structure. Stress distribution in the lug, especially around the pin, would normally be established from past experience with similar configurations. In the case of a beryllium forging, this experience is too sparse to be of any real value in design. Consequently, after making the best estimate possible from the available data, it was decided to build a one-third scale model of the lug to increase confidence in the design prior to forging the first full-scale end fitting.

Figure 1 shows the test specimens fabricated for this purpose. The tapered end simulates the machined forging. The material used was cross-rolled beryllium plate, chosen for the similarity of its mechanical properties to those of the forging. After machining, the test specimen was chemically etched to remove surface stresses (the full-scale part was also finished this way). The final dimensions and fits obtained were, therefore, a close simulation of those expected on the full-scale parts.

One of the specimens was tested. The load was applied in tension through a steel clevis fitting and a close fitting drill rod pin. At a load of 11, 000 pounds the pin failed in bending due to excessive clearance between the clevis and the beryllium lug. As a result of the pin failure, the end of the beryllium lug also failed. The load at which failure took place is equivalent to a scale load of 99, 000 pounds on the full-size forging, 124 percent of the 80, 000-pound design load.

3.4 JOINT

Various factors affect the design of the joint between the tubing and the end fitting. The results of the joining investigation, Section 4, have shown that a lap-strap joint is necessary for high efficiency. The design must transmit loads from one beryllium element to the other without imposing severe stress concentrations, it

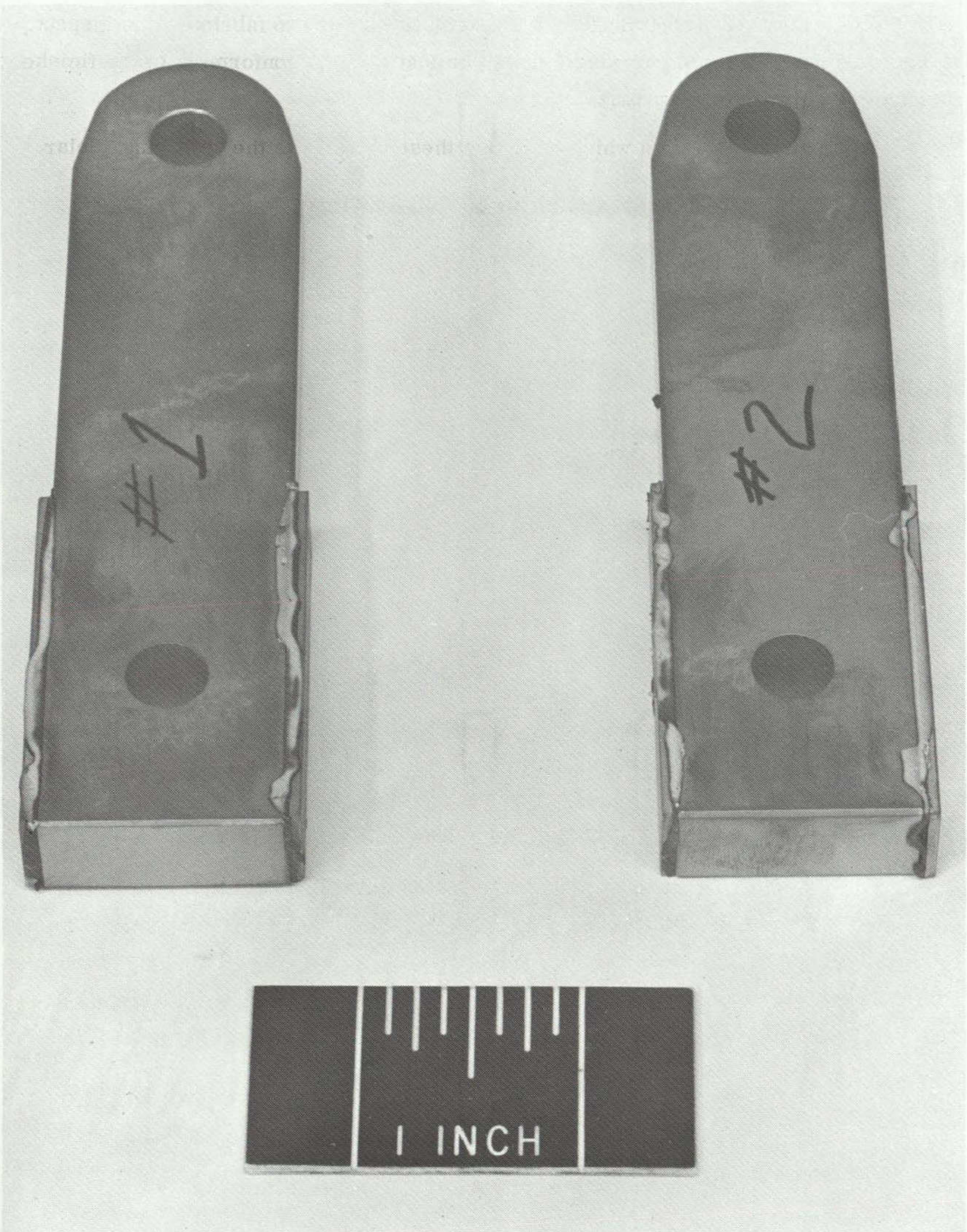

FIGURE 1. LUG TEST SPECIMENS

should minimize load eccentricities, and be relatively easy to fabricate and inspect. It must also be capable of carrying the applied loads and of conforming to the finished dimensions of the beryllium parts.

The simplest design which can meet these criteria is the split ring, Solar P/N 44858-11, (App. A). The split in the ring provides for assembly fitup without imposing excessive stress concentrations. The bonding area is sufficient to maintain adhesive shear stress below 3000 psi and the tensile stress in the strap is below 67,000 psi at the design load of 80,000 pounds.

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JOINING INVESTIGATION

To provide confidence in the assembly design, it was necessary to develop and evaluate methods of attaching beryllium end fittings to beryllium structural tubing. The joining techniques investigated were brazing and chemical bonding.

Mechanical fastening was not investigated on the basis of a comparison of the results published in NASA technical memorandum X-53453 and the results obtained on adhesive bonded specimens at Solar. The findings of the NASA investigation produced a maximum of 36,000 psi ultimate stress in the parent beryllium material by using huckbolts, while the initial bonding investigation at Solar yielded nearly twice that strength.

The joint configurations represent a conservative approach made necessary by the difficulty of reliably joining an anisotropic brittle material. The configurations selected for study were fabricated from sheet beryllium of gages and material properties similar to the tubing used in the full-scale hardware.

Type 19-9DL stainless steel was selected for the lap straps because it closely matches the expansion coefficient of beryllium and has fairly high strength properties (F_{tu} = 118,000; F_{ty} = 69,000). Lap straps of 0.043-inch Type 19-9DL stainless steel were used in both the bonded and brazed joint sample configurations.

In the bonded configuration both simple lap and double lap strap joints were tested. In the brazed samples, configurations with interlocking fingers but no lap straps, and with a double lap strap and no fingers were fabricated and tested. Specimen blanks for all these tests were machined and then chemically etched 0.002 inch minimum.

Specimens were also fabricated to investigate process parameters. A series of 0.75-inch wide strips were cut from 0.125-inch sheet, then the edges were ground and the surfaces etched. These strips were used in the laboratory to evaluate the effectiveness of various cleaning, bonding, and brazing methods prior to evaluating the joint configuration samples. Process specifications generated from this investigation are shown in Appendix B.

4.1 ADHESIVE BONDING

The requirements in this area are considered to be within the current state of the art; therefore, the effort was restricted to confirmation of various vendor recommendations and other sources of reliable information for the cleaning and bonding processes.

Four epoxy type materials were evaluated:

- BR 92 - Bloomingdale Rubber two component liquid resin
- BR 92B - Similar to (a) but more viscous
- FM-1000 - Bloomingdale Rubber unsupported solid epoxy-nylon film
- Narmco 332 - One component epoxy resin

The test specimens for the first series of tests consisted of strips of cross-rolled beryllium sheet (0.75 in. by 2.5 in. by 0.10 in.) joined to similar strips of Type 19-9DL stainless steel in a single shear configuration. The lap area was deliberately made small (0.30 to 0.50 in.^{2}) since these tests were intended to produce bond shear strength data rather than optimum joint designs.

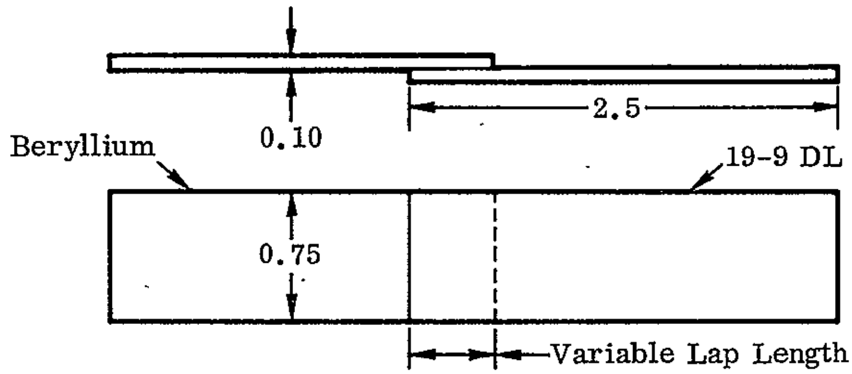
These tests were to evaluate the effects of bond line thickness and sensitivity to pressure for each adhesive system. Bonding times, temperatures, and pressures were in accordance with the manufacturer's recommendations for each adhesive system tested.

The results of this test series, summarized in Table I, were:

- Highest strength values were attained with the FM-1000 film when bonded under pressure, and with a minimum bond line thickness.
- Within the limitations of the small number of tests, FM-1000 appeared to be completely reliable with respect to a design level of 3000 psi shear stress.
- The BR 92 and BR 92B liquids seemed rather unreliable. Shims to control the bond line thickness between 0.002 and 0.010 inch would be required.

Following the above tests, a similar series of simple lap joints were tested using two Type 19-9DL stainless steel straps for symmetrical double shear on a

TABLE I - SINGLE LAP SHEAR SPECIMENS



Serial Number	Adhesive	Bond Cycle	Pressure	Joint Shim (in.)	Area (in.^{2})	Load (lb)	Shear Stress (psi)	Comments
A1	BR 92		Yes	0	.455	112	246	
2		90 Min	Yes	0	.533	345	647	19-9/19-9
3		at	No	0	.529	600	1134	19-9/19-9
4			Yes	.002	.370	1500	4054	
5		180 F	Yes	.010	.380	1400	3684	
6			Yes	.020	.388	--	--	Failed before test
B1	BR 92B		Yes	0	.408	980	2402	
2		90 Min	Yes	0	.482	493	1023	19-9/19-9
3		at	No	0	.560	802	1432	19-9/19-9
4		180 F	Yes	.002	--	--	--	Failed before test
5			Yes	.010	.378	1620	4286	
6			Yes	.020	--	--	--	Failed before test
C1	FM-1000		Yes	0	.384	2940	7656	19-9/19-9
2		60 Min	Yes	0	.319	2270	7116	19-9/19-9
3		at	No	0	.473	1540	3256	
4			Yes	.002	.360	1515	4208	
5		350 F	Yes	.010	.373	1500	4021	
6			Yes	.020	.414	2600	6280	
D1	Narmco 332		Yes	0	.510	68	133	19-9/19-9
2		60 Min	No	0	.505	154	305	
3			Yes	.002	.350	774	2211	
4			Yes	.010	.350	540	1543	
5		350 F	Yes	.020	.335	226	675	

central beryllium strip. The Narmco 332 was not tested because of poor results in the preceding tests. The liquid resin systems were assembled using 0.010-inch shims to control bond line thickness. No shims were used with the FM-1000 adhesive. One BR 92 specimen (A9) was deliberately cured at 350 F in addition to the recommended 180 F. All specimens were bonded under approximately 25 psi pressure. Results of these tests are shown in Table II.

Specimens A8 and B8 failed first on one side then shortly afterwards on the other side, with visible evidence of asymmetric loading. Self-aligning load fixtures were not available for these tests. With the exception of these two premature failures, all other results were considerably in excess of requirements, including the sample which was overheated.

Based on these results, the investigation proceeded to specimens which simulated the full-scale joint. Two of the more promising systems, one liquid epoxy (BR 92) and one solid film epoxy (FM-1000), were evaluated on specimens simulating a one-inch wide section of the full-scale tube/fitting joint. Surface preparation and bonding procedures were identical to those for the single- and double-lap shear specimens.

Lap straps varied from one to four inches in length. A specimen using one-inch straps (BL7) is shown in Figure 2, while one with longer straps (BL6) is shown in Figure 3. Some specimens failed in the parent metal using the FM-1000 adhesive system, while those with lap lengths of 0.75 to 1.0 inches failed in the bond joint.

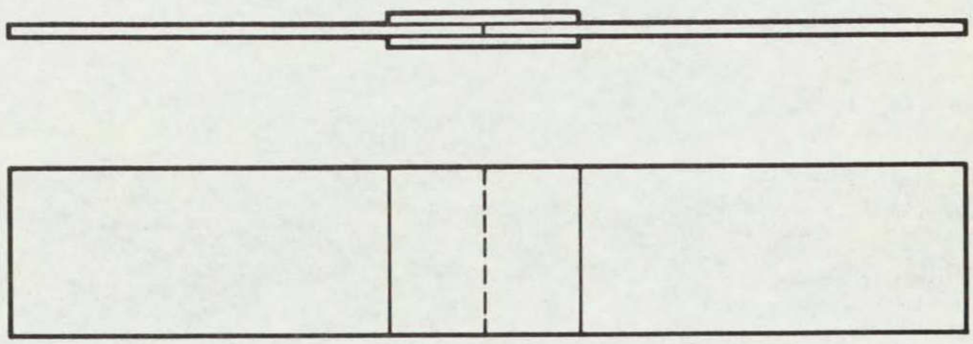
The results of these tests are shown in Table III and are summarized as follows:

- BR 92 liquid again proved to be unreliable. Even with a 4.0-inch long lap strap, failures were all in the bond at a low stress level. Difficulty was experienced with wetting the beryllium with this adhesive resulting in excessive scatter of results.

- FM-1000 film adhesive was able to carry the applied loads up to a level producing failure of the parent beryllium sheet with 4.0- and 2.0-inch lap straps.

- When the lap-strap length was reduced to 1.0 inch, one specimen failed in the bond and one in the parent material. A further reduction to 0.75 inch also resulted in bond failure (at 6000 psi shear stress). As the lap-strap length was reduced, the stress at which tensile failure of the parent beryllium sheet took place was observed to decrease, i.e., joint

TABLE II - DOUBLE SHEAR SPECIMENS



Specimen Serial Number	Adhesive	Bond Cycle	Area (in.^{2})	Load (lb)	Shear Stress (psi)	Comments
A7	BR 92	90 Min at 180 F	.710	3670	5169	Beryllium failed F_{tu} = 65ksi
8		90 Min at 180 F	.508	1270	2500	Asymmetric Failure
9		90 Min at 180 F and 60 Min at 350 F	.532	2060	3872	
B7	BR 92B	90 Min at 180 F	.624	2390	3830	
8		90 Min at 180 F	.76	1690	2224	Asymmetric Failure
C7	FM-1000	60 Min at 350 F	.532	3100	5827	Beryllium failed F_{tu} = 55 ksi
8		60 Min at 350 F	.488	3030	6209	Beryllium failed F_{tu} = 53 ksi

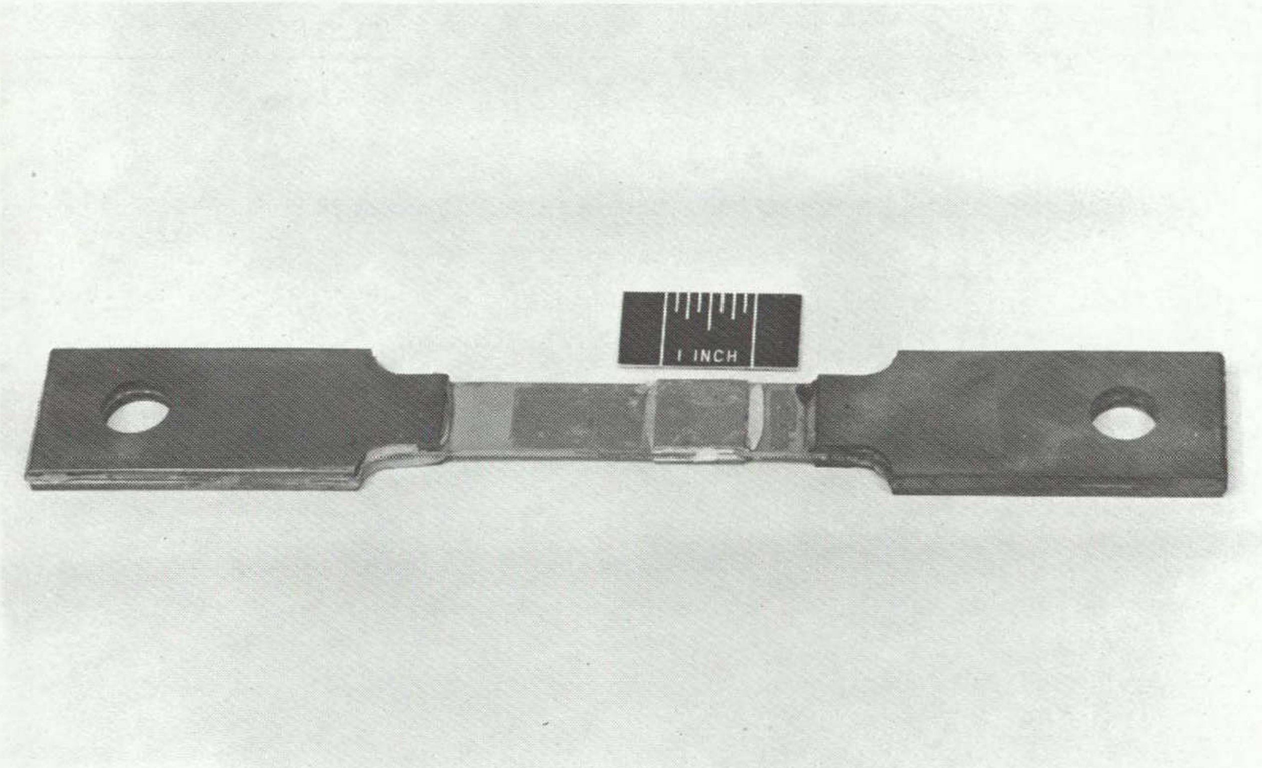


FIGURE 2. LAP JOINT TEST SPECIMEN (BL7)

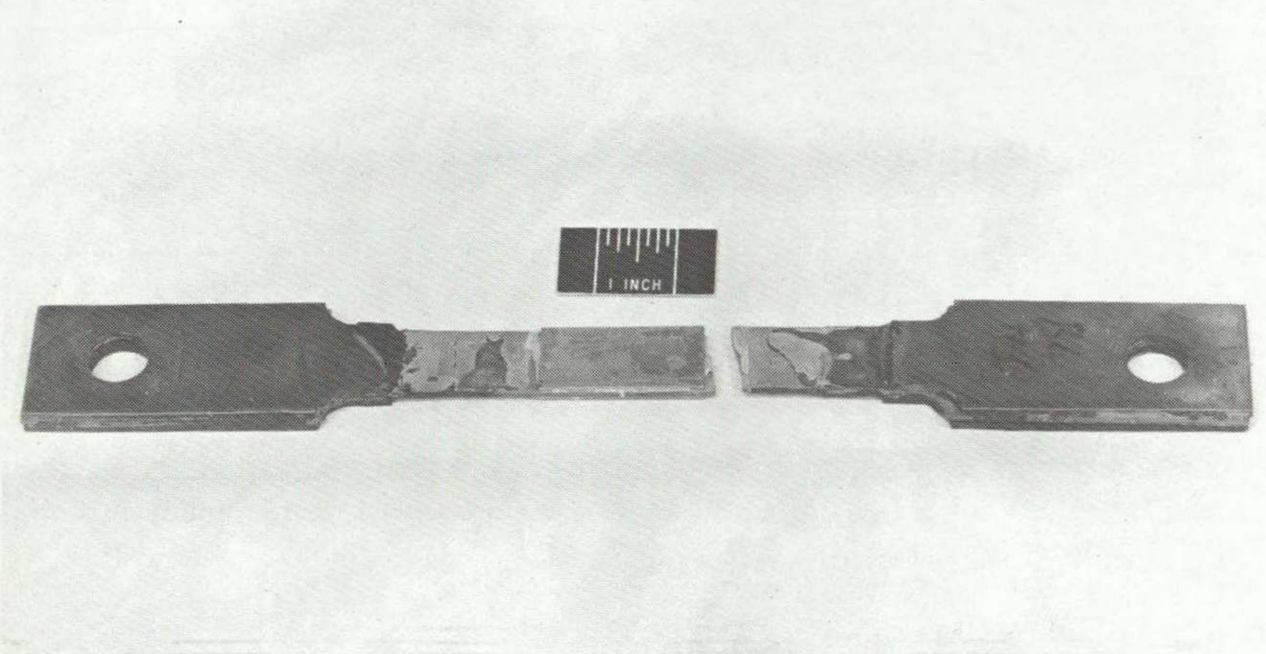
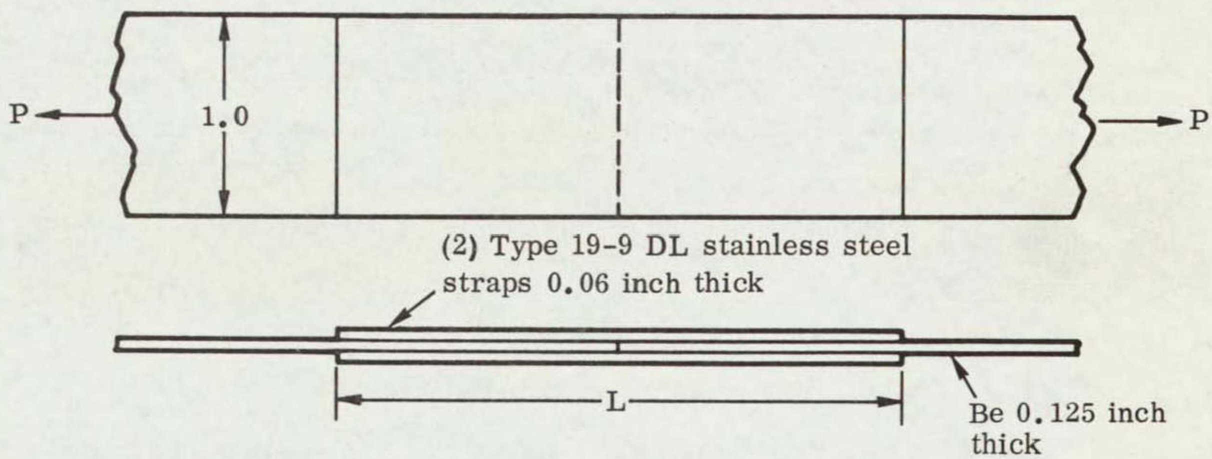


FIGURE 3. LAP JOINT TEST SPECIMEN (BL6)

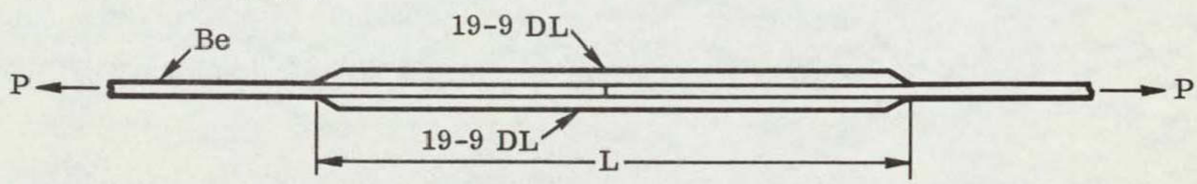
TABLE III. ADHESIVE BONDED JOINT TESTS



Bloomingdale Rubber BR 92 (liquid epoxy)

Specimen Number	Lap (in.)	Failing Load (lb)	Failure Mode	Bond Shear Stress (psi)	Be Tensile Stress (psi)	Joint η* (%)
BL1	4.0	4265	Bond	1066	44,500	81
BL2	4.0	1730	Bond	432	18,000	33
BL4	4.0	4800	Bond	1200	50,000	91
BL5	2.0	1304	Bond	652	13,500	25
Bloomingdale Rubber FM-1000 (epoxy film)						
BL 3	4.0	5760	Tension in Be	1400	62,000	112.5
BL 6	2.0	4930	Tension in Be	2540	54,000	98
BL 7	1.0	4520	Tension in Be	4520	46,800	85

The specimens below are identical to preceding ones except for a chamfer at each end of the lap straps.



BL 8	1.0	4870	Bond	5100	43,100	78.5
BL 9	0.75	4460	Bond	6070	41,250	75.0

* Based on F_{tu} = 55,000 psi for beryllium cross-rolled sheet and extruded tube.

efficiency dropped from 112.5 percent for L = 4.0 to 85 percent for L = 1.0. This efficiency drop was attributed to the more abrupt transfer of load in the shorter lap joints.

- Lowest stress at which shear failure of an FM-1000 bonded joint occurred in this series was 5100 psi. A design shear stress of 3000 psi is therefore considered conservative for this adhesive system.

The FM-1000 adhesive in the double-shear configuration using Type 19-9DL straps and the process techniques established, gave the strongest, most reliable joints obtained during this investigation. Therefore, the tube assembly configuration was established using FM-1000 adhesive and the process parameters outlined in this report.

4.2 BRAZING

Since the joint between beryllium and Type 19-9DL stainless steel was of interest (to facilitate construction of lap joints with a ductile strap material), the investigation was concentrated on silver-base braze alloys which were compatible with both materials. The approach favored was to use a lower melting point alloy to minimize metallurgical damage to the beryllium due to brazing above the anneal temperature, and to augment the naturally poor wetting of those allows by preplating the substrates.

Preliminary braze bond and wettability tests were made on fifteen 0.75 by 0.75-inch preplated lap joint type beryllium to 19-9DL specimens. The results of metallographic examination of the filler metal and interface reactions are summarized in Table IV. A microhardness survey revealed a thin (0.0002 in.) brittle (RC-71) diffusion layer between silver plating and the 19-9DL after braze. However, later work has shown that the brittle zone was eliminated completely by closer control of braze temperature and the elimination of various sources of contamination. The hardness of the diffusion zone between the braze alloy and beryllium varied depending upon the braze alloy and braze temperature. The hardness of the BAg-8 (Braze BT) interface is due to the formation of silver/copper berylides.

Electro-deposited silver platings gave the best results of wetting and bonding in a dry H_2 atmosphere. Adherence of electro-deposited nickel platings to beryllium after an elevated temperature cycle (> 1300 F) proved to be poor.

Three specimens of an interlocking finger design were fabricated using BAg-8 and Ag-Li braze alloys, and were subsequently tested. Figures 4 and 5 show

TABLE IV. METALLOGRAPHIC EXAMINATION

Beryllium to TYPE 19-9 DL Stainless Steel Braze Joints

Specimen Number	Braze Alloy	Surface Preparation	Hardness Survey	Joint Integrity	Comments
A	H&H 630	Not plated	---	Very poor, mostly unbonded areas in joint.	Wide gap, one small area is bonded.
B	H&H 630	Not plated	---	Joint separated in cutting.	---
C	BAg 3 (Easy flo 3)	Not plated	19-9 DL-R/B 97.0 Easyflo-R/B 60.0 Be - R/B 95.0	Good bonding	Diffusion zone at Be-filler alloy interface.
D	H&H 630	Ag plated	---	Good bonding	Diffusion zone at Be-filler alloy interface.
E	BAg 8 (BT)	Ni plated	BT - R/B 88.0 Ni - R/C 71.0 Be - R/B 95.0	Bonding intermittent, but generally very poor.	Plating separated from parent material.
F	BAg 8	Ni plated	---	Limited bonding extensive voids	Plating separated from parent material, some bonding under detached plating.
G	BAg 8	Ag plated	19-9 DL-R/B 100 Unknown-R/C 71.0 Ag - R/C 41.0 BT - R/B 73.0 Be - R/B 96.5	Good bonding	Restricted areas of stainless steel appeared to show plating at brazed joint
H	BAg 8	Ag plated	---	Good bonding	---
I	BAg 8	Not plated	---	Joint separated in cutting	---
J	BAg 3	Ni plated	---	Very poor	---
K	BAg 3	Ag plated	---	Limited bonding	---
L	BAg 3	Ag and Cu plated	Be - R/C 21.0 Cu flash - not readable Ag - R/C 42.0 Easy flo-R/B60.0 19-9 DL-R/B 98.0	Good bonding	---
M	BAg 3	Ni plated	---	Very poor, mostly unbonded areas in joint.	---
N	BAg 3	Ag and Cu plated	---	Good bonding	---
O	None	Ni and Cu Plated	---	Parent material specimen	Very thin, discontinous plating on one side, with vestiges of plating on other side.

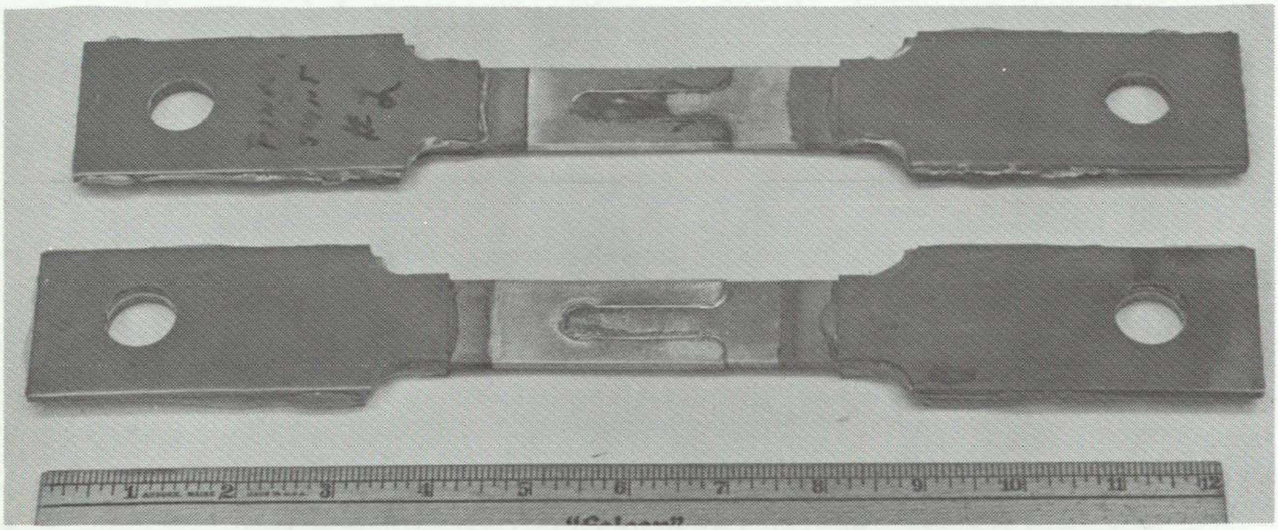


FIGURE 4. BRAZE JOINT SPECIMENS BEFORE TEST

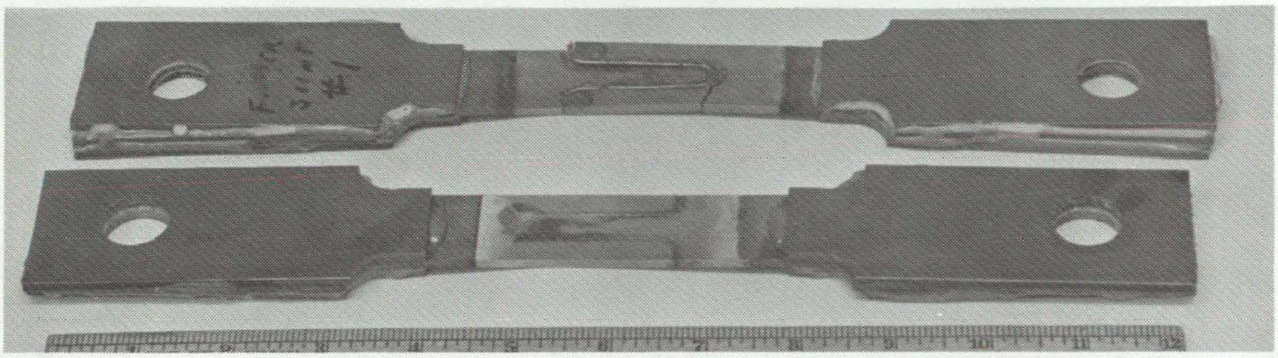


FIGURE 5. BRAZE JOINT SPECIMENS AFTER TEST

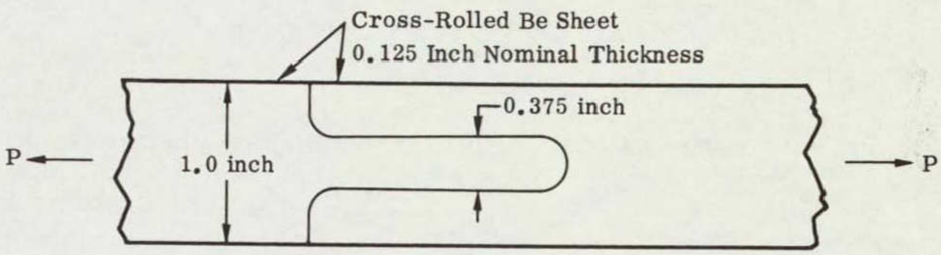
two of these specimens before and after test. The contempated advantage of this design was to eliminate the eccentricity in the joint, thus, theoretically, there were no bending stresses to cause delamination of the beryllium in the sensitive Z direction.

This type of joint had two major disadvantages:

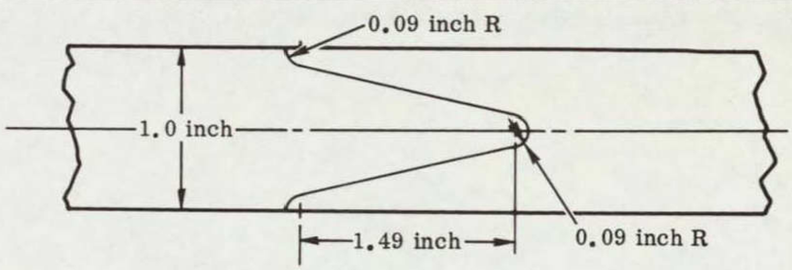
- The shear area available for brazing was small, i.e., the perimeter length of each finger times its thickness. Therefore, a very high shear strength was required from the selected braze alloy.
- The net tension section of the parent material was severely reduced.

The results of tests on three examples of this type of joint are reported in Table V. All three failed at an unacceptable load. The first two failed because of

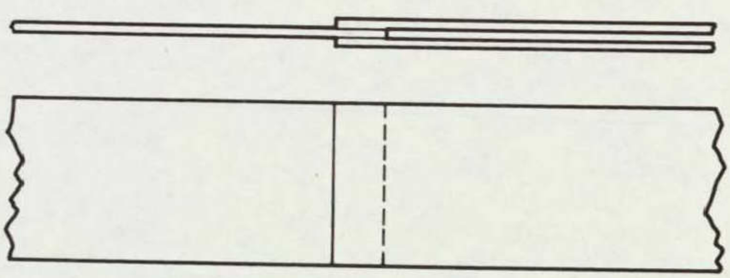
TABLE V. BRAZED JOINT TESTS



Specimen Number	Braze Alloy	Failure Mode	Failing Load (lb)	Equivalent Tube Load (lb)	Fraction Required Load (%)	Braze Shear Stress
1	BAg 8	Asymmetric braze shear	1465	29,300	36.7	4500
2	BAg 8	Asymmetric braze shear	798	15,960	20.0	2060
3	Sterling Silver and Li	Tension base of finger	1340	26,800	33.5	3270



Tapered finger	Ag-Li	Braze shear	2684	41,200	51.5	6580



Double - lap shear	BAg-19	Braze shear	3860	59,000	74.0	6500

insufficient braze shear strength, and the third (Fig. 6) because of the reduced tension section at the base of the finger.

To evaluate the inherent difficulties in this design, a tapered finger specimen was tested before abandoning the concept altogether. The completed specimen is shown in Figure 7 prior to test. Test results are contained in Table V.

Although the results were an improvement over those obtained with parallel finger joints, there did not seem to be sufficient promise of meeting design requirements to justify further development. Further work on brazed joints was therefore directed towards an investigation of double-lap configurations similar to those successfully employed for adhesive-bonded joints.

One such double-lap brazed tensile specimen was fabricated and tested using BAg-19 braze alloy. The results are quoted in Table V.

The results were considered encouraging since a higher load can be obtained by increasing the length of the lap straps. However, in view of the results obtained with the adhesive systems investigated, combined with the inherent difficulties that would be encountered using this configuration on the full-scale assemblies, brazing was eliminated as the final method of fabrication.

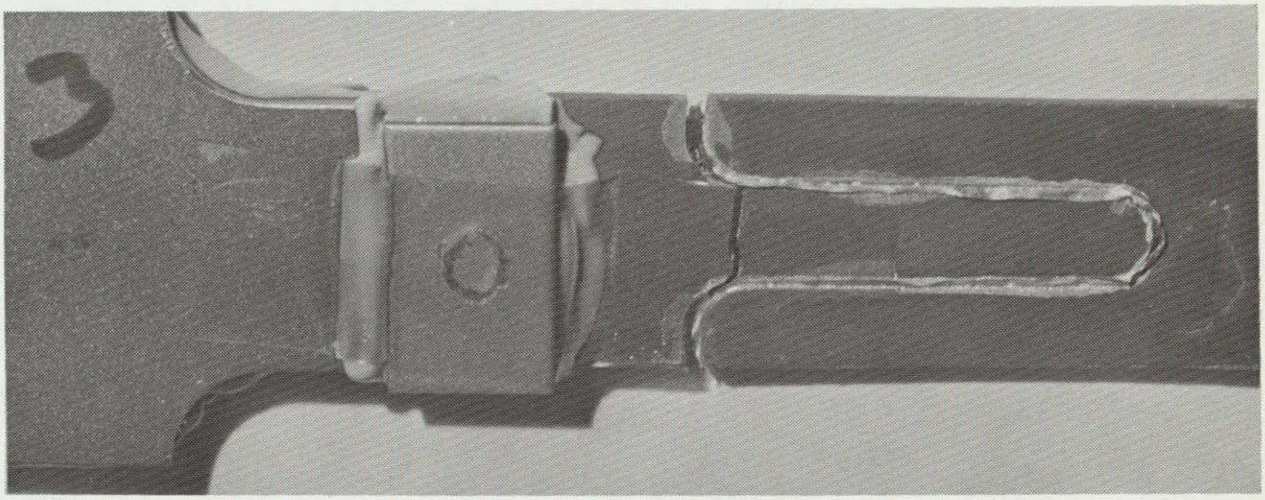


FIGURE 6. BRAZED FINGER JOINT; SPECIMEN NUMBER 3

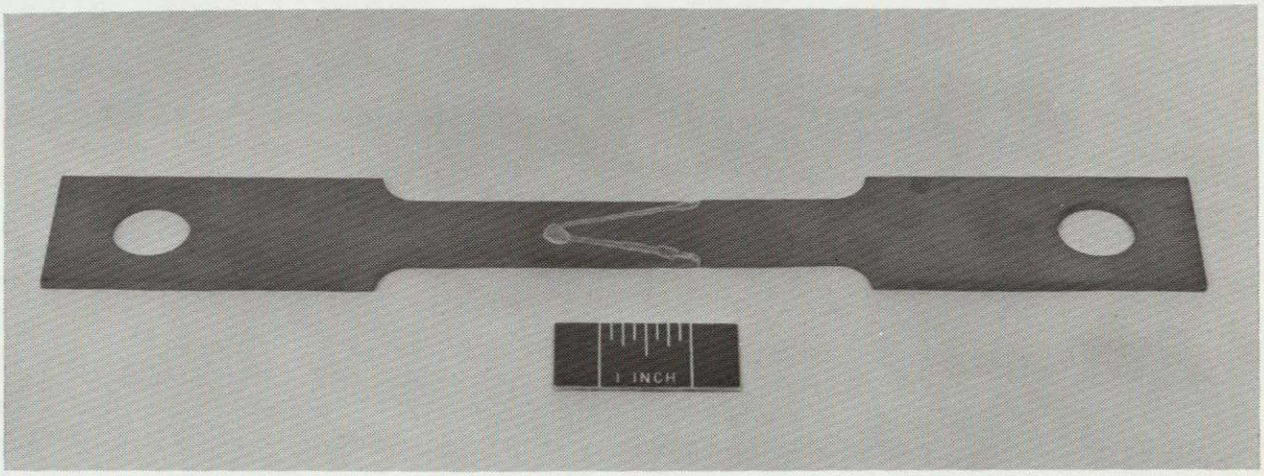


FIGURE 7. TAPERED FINGER JOINT SPECIMEN

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5

COMPONENTS

The principal components of the beryllium structural tube assembly, the forged end fittings, and the structural tubing, are both vendor-supplied articles. Since beryllium is in a constant state of development it is not possible to procure these items by standard procedures. Consequently, a considerable effort was expended in the initial stages of this program to investigate the position of the various potential suppliers. Specifications were prepared based on the best experience available from qualified vendors and these specifications were issued through procurement channels to control the purchase of the required parts.

5.1 FORGINGS

This procurement was discussed with cognizant potential vendor personnel (Ladish Company and Wyman Gordon Company) at their plants. As a result of these contacts the following transpired:

- Vendor technical personnel were solicited for ideas which would improve the original Solar design technically and/or reduce its cost. These suggestions were incorporated in two revised designs. One design incorporates only minor improvements over the original whereas the other is a suggestion by one vendor to substantially reduce the beryllium input weight, and thus the cost of the forging. That vendor also claims that the geometry of this design will permit more uniform working of the material during forging, resulting in better balance between longitudinal and circumferential properties. There is, however, a possible penalty in higher local stress at the intersection of the conical section and the cylindrical section.

- By combining the comments of each vendor, a revised version of Solar's preliminary procurement specification was issued. The revision incorporates more stringent control of source material and mechanical property testing (App. C).

- The potential vendors were briefed on the technical objectives of this program to improve their understanding of the end application of the forging. Both vendors, in return, contributed valuable metallurgical inputs to the specification and designs.

As a result of the competitive bidding, the Ladish Company was selected to supply forged blanks for the end fittings to the reduced input weight configuration.

The first forging produced was destructively tested, as planned, by Ladish and was found to be slightly under specification requirements for minimum elongation at two locations. (Minimum Specification requirement was 2.5 percent.) The results of these metallurgical and mechanical property tests are shown in Appendix D. The test section dimensions for forging property tests were 0.125 inch diameter by 0.500 inch long.

After reviewing the test results, Solar requested that an attempt be made to improve the elongation value at location Long Transverse Number 3 by modifying the forging technique. The low value at Long Transverse Number 1 was accepted as a deviation from the specification because its location is not considered critical. A cutoff ring was provided in the forging design at Location Number 3 for the purpose of obtaining critical location property data, thus enabling a review of the improvement made on forging Serial Number 2.

This forging was reported to have shown considerable improvement in elongation, the Long Transverse Number 3 value being raised from 2.0 to 5.5 percent (average of three tests). Solar then gave Ladish approval to proceed with the balance of the order.

Subsequently, Ladish advised that a tooling fault had developed part way through the production run and caused cracking of five of the total quantity of nine forgings. The fault consisted of metal flow interference due to improper seating of the part ejector. This fault was corrected by providing a seating gage. These forgings were replaced and delivered to Solar. All nine of the delivered forgings appear to be of excellent quality. One of the forgings is shown in Figure 8.

5.2 END FITTINGS

Five forgings were machined to the 46763-2 configuration, Figure 9, and three to the -3 configuration, Figure 10. These end fittings were used on the six tube assemblies. Each end fitting was chemically etched 0.002 to 0.004 inch all over to remove surface microcracks and then dye penetrant inspected. Except for the surface cracks in one -3 fitting described in Section 7, no defects were noted.

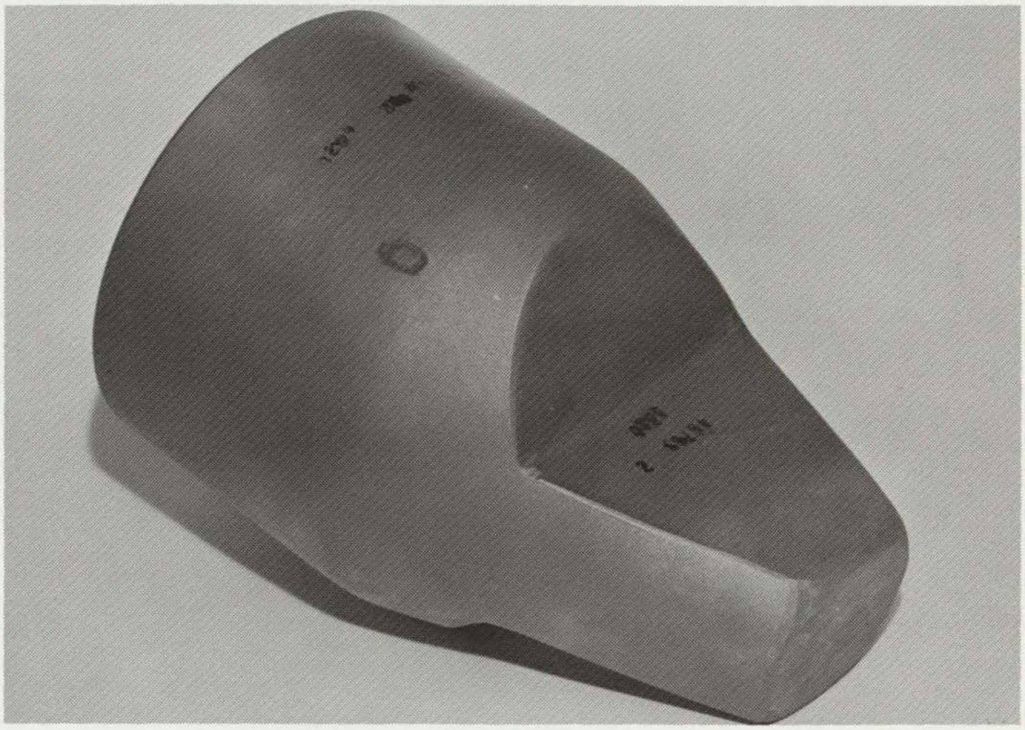


FIGURE 8 END FITTING FORGING

A revision of the machining drawing was made after the test of the first two short tube assemblies. Basically, this revision removed excess material in low-stress areas of the fittings increasing the lug flat length on the -2 and making the face of the -3 conical. The revised drawing, 46763, Sheet 2, is included in Appendix A.

5.3 TUBING

Meetings with both potential tubing vendors (Brush and Berylco) were conducted. The technical aspects of this procurement were discussed and both vendors made contributions to a revised and more detailed procurement specification (App. C). Both vendors appear to be well qualified to produce the tubing. Formal requests for quotation for the tubing to the revised specification were sent to both. Berylco was selected to supply the tubing on the basis of lowest cost. The tubing produced exceeded the procurement specification (App. D).

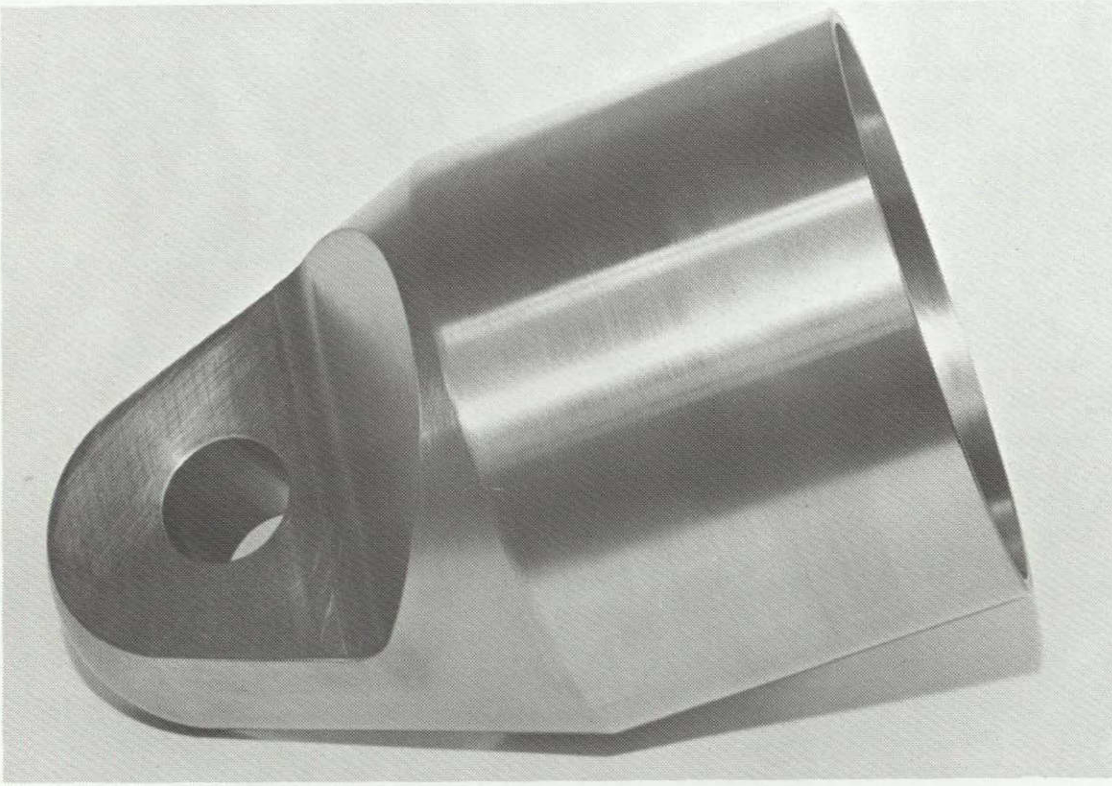


FIGURE 9 FIXED END FITTING

FIGURE 10 ADJUSTABLE END FITTING

6

TEST ASSEMBLIES

Four short tube test assemblies were fabricated and tested. Each assembly consisted of a dummy-steel end fitting; a 5.0-inch diameter beryllium tube with 0.125-inch thick wall, 6.0 inches long; and a beryllium end fitting. Two specimens of each of the two beryllium end fittings were included. The end fittings were joined to the tube by adhesive bonding with FM-1000 adhesive and Type 19-9DL stainless steel lap straps.

The lap strap was split into halves to permit the ring to conform to the contour of the butted end fitting and tube. Details of the ring are shown on Drawing 44858, Appendix A.

A fixture was used for alignment and support of the detail parts during the bonding operation, (Fig. 11). Loading was applied to the ring and the adhesive by use of a pressure pillow arrangement. A sleeve of dimpled stainless steel foil was welded to the inside of a steel tube and the cavity was pressurized to approximately 40 psig during adhesive cure. This pressure forced the dimpled foil into contact with the lap strap half rings and applied a uniform load on the adhesive joint. Since only three psig were necessary to achieve initial contact between the foil and the ring halves, almost all of the pressure applied was transmitted to the joint. Two pressure pillows were used, one on the joint at each end of the tube. The pressure pillow active area extended approximately 0.25 inch beyond each end of the lap strap.

The first fixed end test fitting (Fig. 12) failed at a tensile load of 75,900 pounds. The failure occurred in the adhesive joint, largely as an adhesive failure at the beryllium surface (Fig. 13). There are two possible causes of the premature (80,000-pound design strength) failure. The most likely explanation is the nonuniformity of the adhesive film thickness after cure which varied from approximately zero to 0.0055 inch. This nonuniformity resulted in concentration of the load in local areas of the joint. The concentration was confirmed by the patterns developed in the stress coat applied to the lap strap and the beryllium tube (Fig. 14 and 15). The

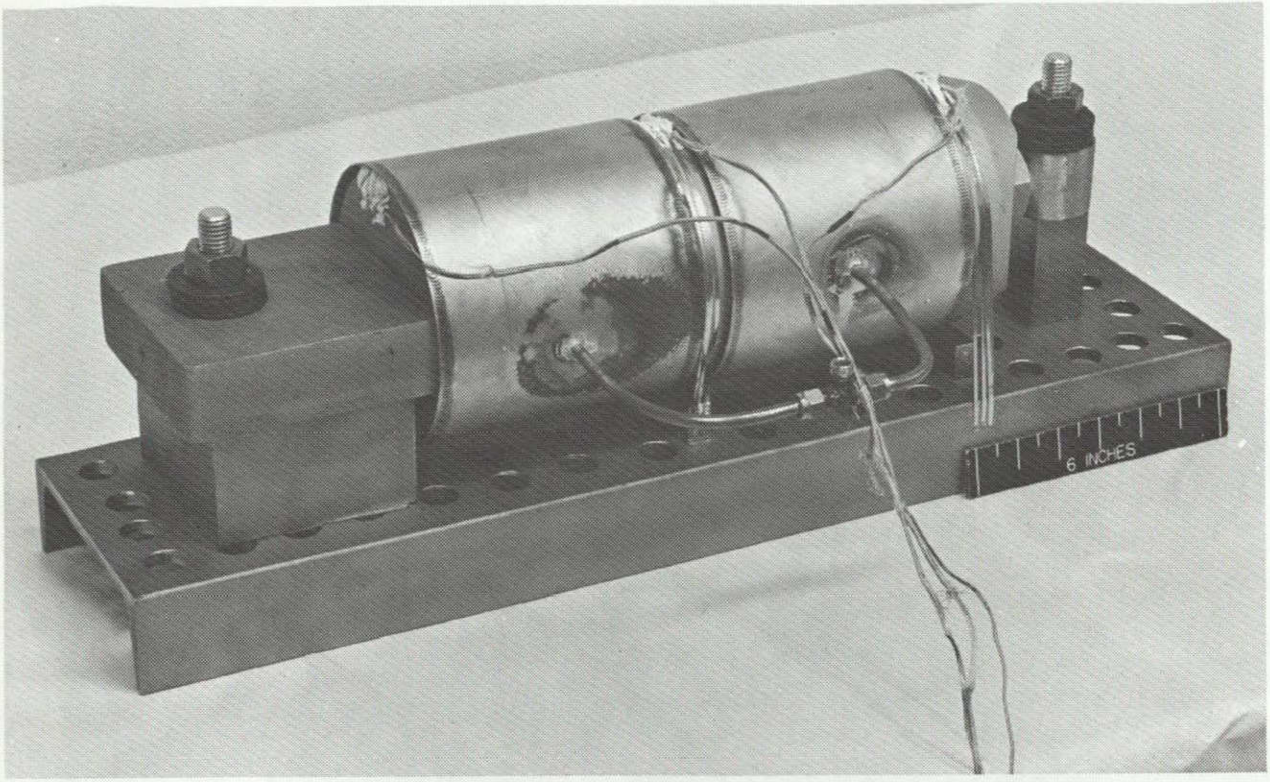


FIGURE 11 BONDING FIXTURE

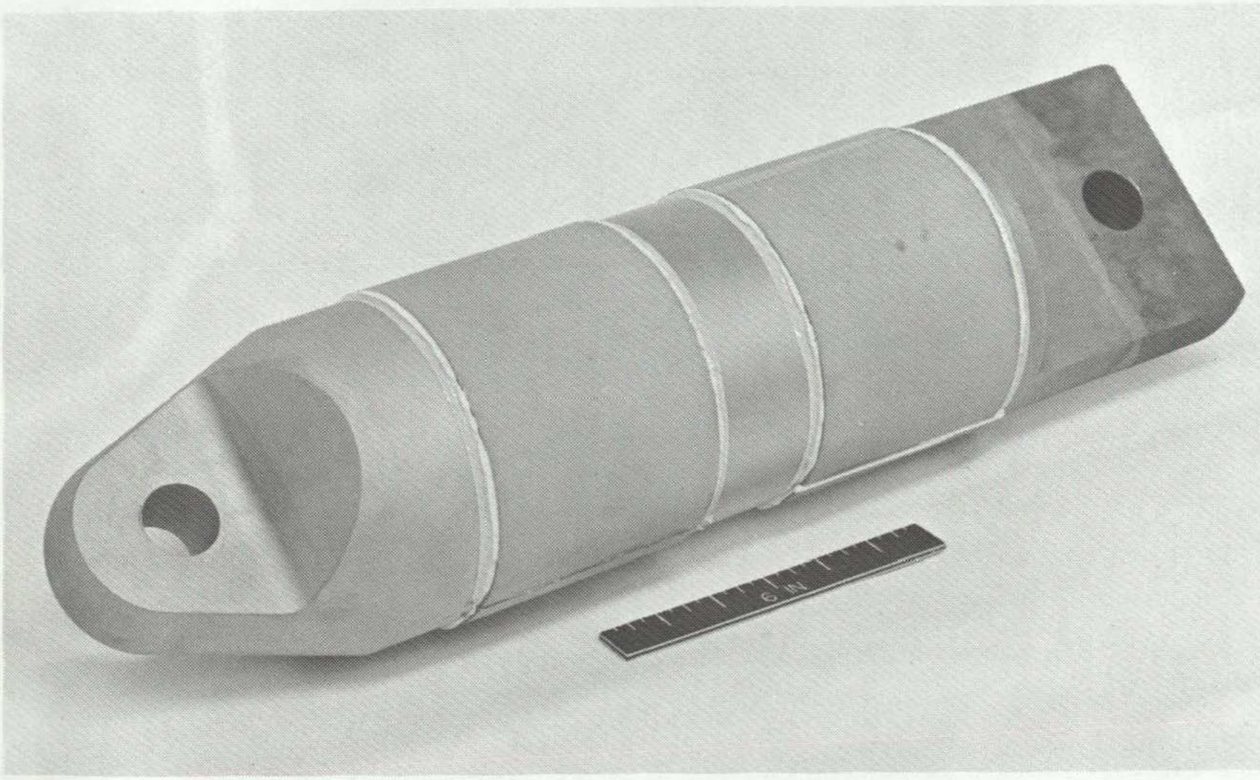


FIGURE 12 FIXED END TEST ASSEMBLY

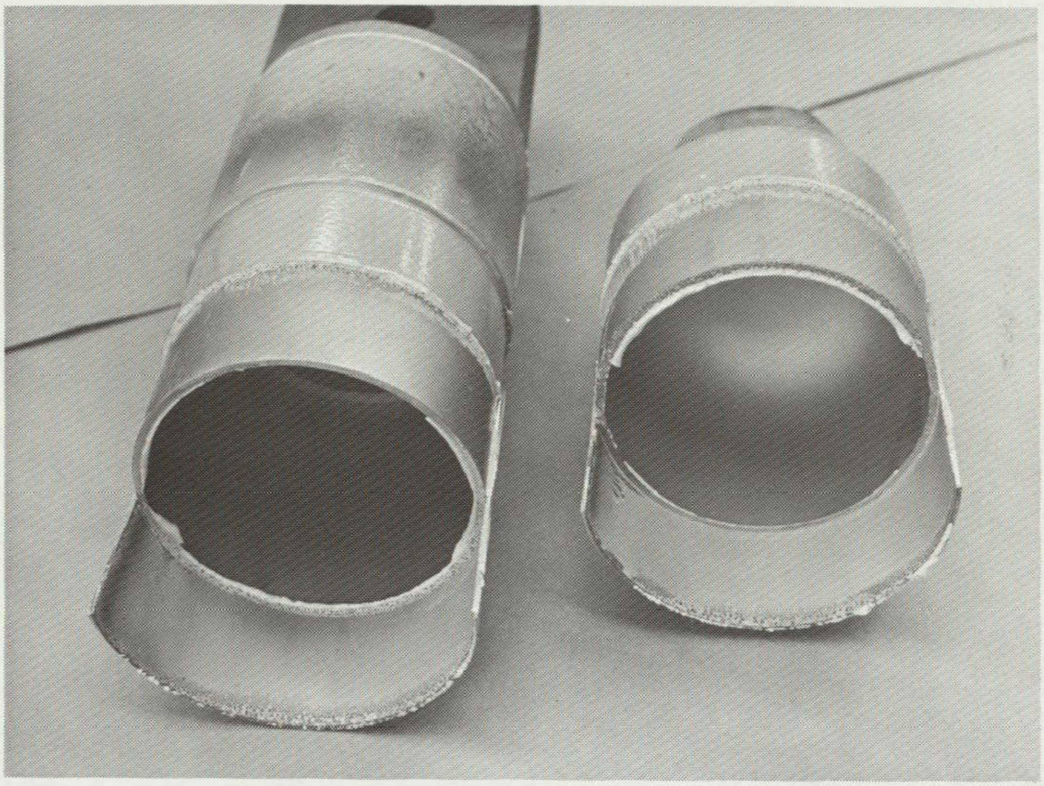


FIGURE 13 FAILED TUBE JOINT

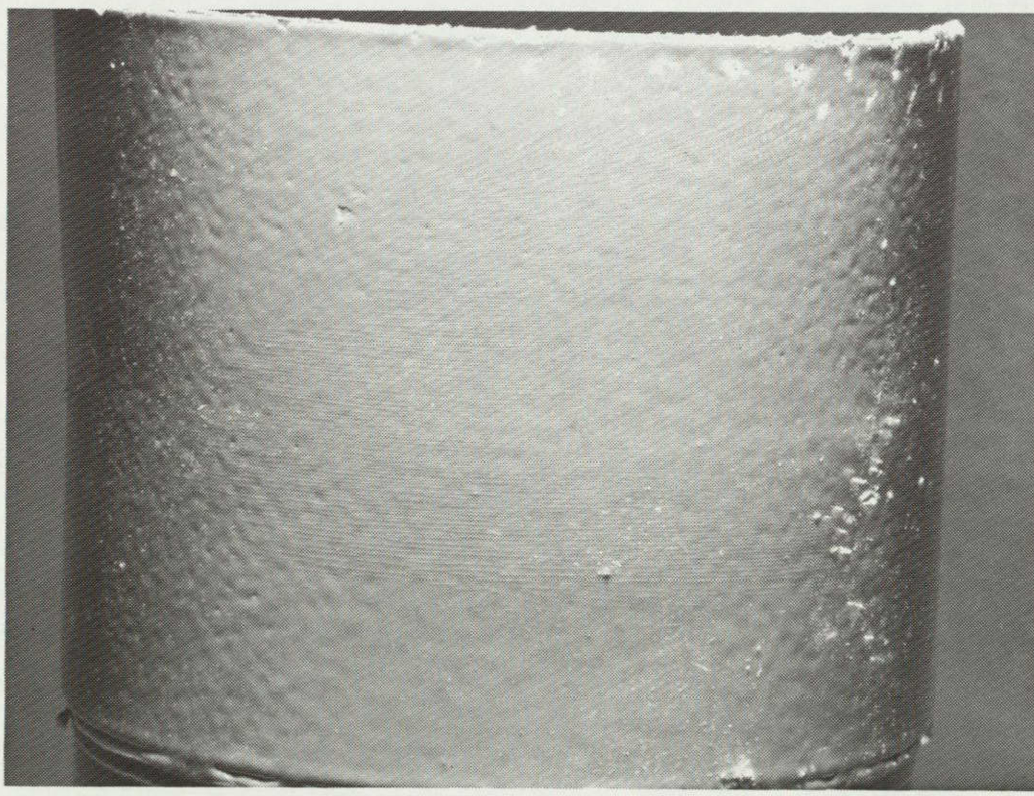


FIGURE 14 LAP STRAP STRESSCOAT PATTERN

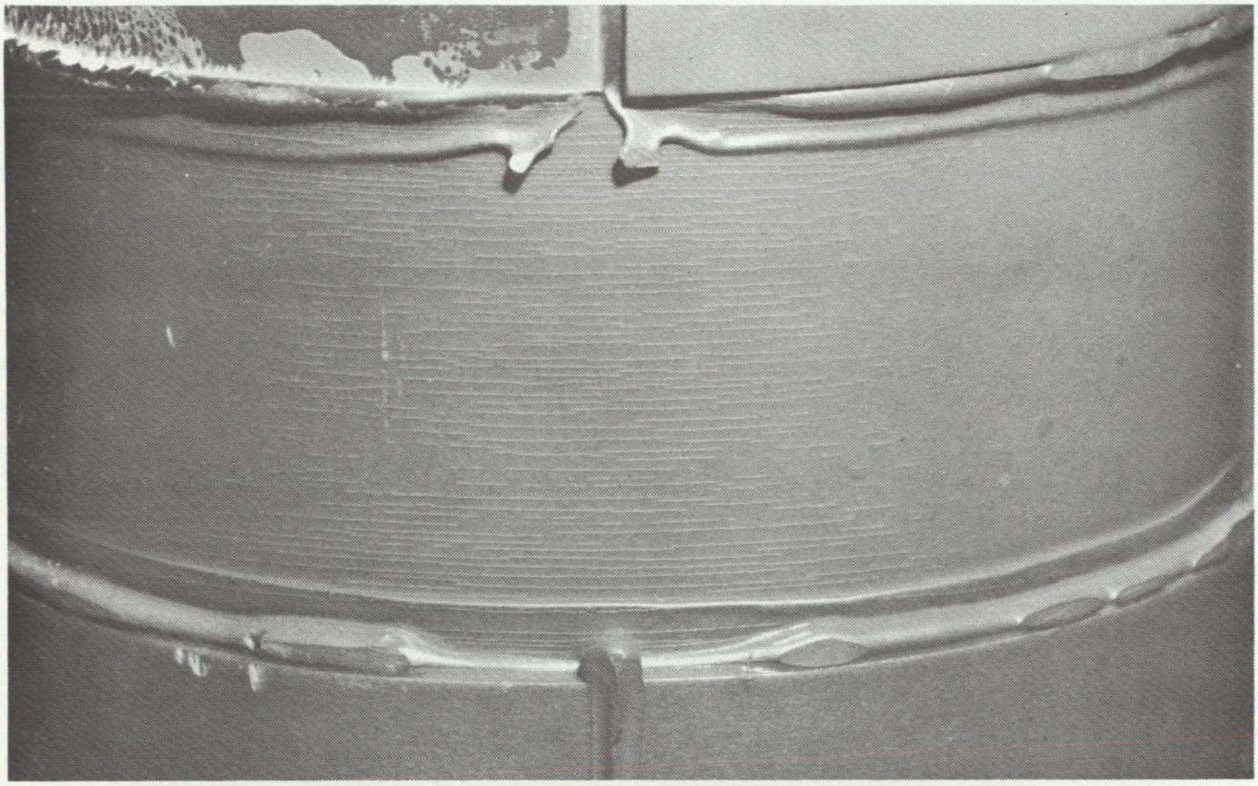


FIGURE 15 STRESSCOAT PATTERN

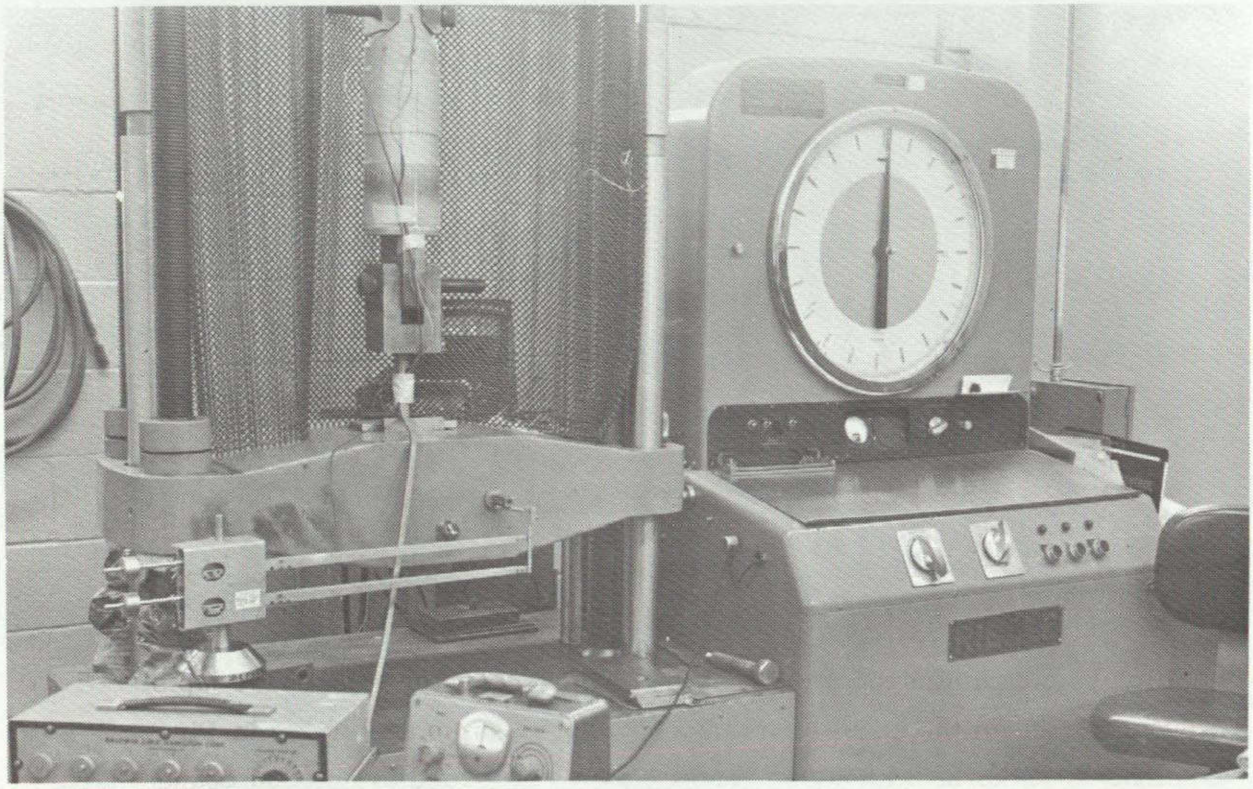


FIGURE 16 TEST EQUIPMENT

thickness variation was corrected on assemblies, Numbers 3 and 4, by applying small shims of 0.006 inch diameter wire to the lap straps before assembly. The other possible cause of failure is inadequate preparation or contamination of the beryllium surface prior to bonding. This cause is not considered likely since the procedures used were the same as those employed on other parts and the cleaning, layup, and cure were performed essentially as one continuous operation.

A mild steel bushing 1.125 by 1.000 inches in diameter was used in the end fitting pinhole to reduce stress concentrations which would arise due to bending and local bearing of the pin. Strain gages on the beryllium end fitting showed low stresses on the surface indicating that the fitting design is probably quite conservative. Strain gages were located on the cylindrical portion of the end in the plane of the lug and at 45 and 90 degrees from the plane, and also on the tapered face of the transition section and on the side of the lug. None of these gages indicated stress in excess of 15,000 psi at 60,000 pounds load. The low stress levels were partially confirmed by no indication in the stress coat of reaching the threshold level of approximately 35,000 psi. The test equipment is shown in Figure 16.

The first adjustable-end test fitting (Fig. 17) failed at a tensile load of 88,900 pounds. The failure, in this case, was in shear of the eyebolt and nut threads (Fig. 18). The eyebolt was made of 4340 steel, heat treated to Rockwell C-34. One nut was bonded to the inside of the end fitting and a jam nut was used on the outside. Swivel adjustment is provided by loosening the jam nut to allow the eyebolt to rotate in the bonded nut. Two 0.030-inch thick aluminum washers were used inside and out to distribute the load to the beryllium. Threads on the eyebolt were one inch-14 NS. The threaded portion of the eyebolt passed through the 1.00 inch diameter hole in the end fitting. The nuts used were Type 303 stainless steel. Stresscoat indicated much more uniform load distribution than on the fixed-end test piece (Fig. 19). Measurements also indicated a more uniform adhesive thickness (0.0035 to 0.0065 inch). This greater uniformity tends to substantiate the probable cause of failure on the first test since the otherwise identical joint did not fail at the higher load on this part.

The configuration of the joint for the second set of two test assemblies was modified by attaching short pieces of 0.006 inch diameter wire to the lap straps prior to layup to control the bond line thickness. These units are shown in Figure 20. Assembly Number 3, with a fixed end fitting, was loaded to 112,800 pounds in tension when the test was stopped resulting from failure of the bolt which attached the clevis

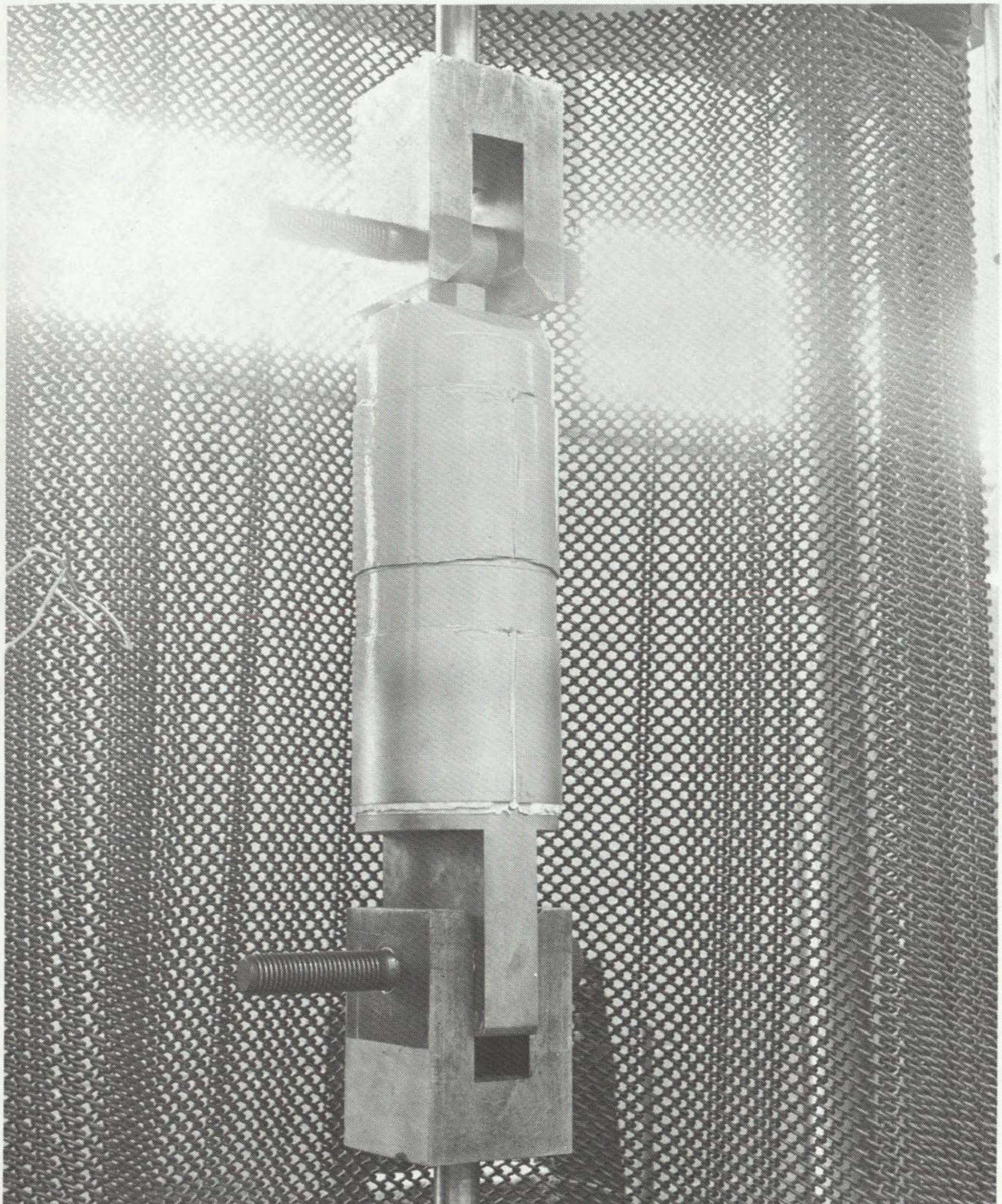


FIGURE 17 ADJUSTABLE END TEST SPECIMEN

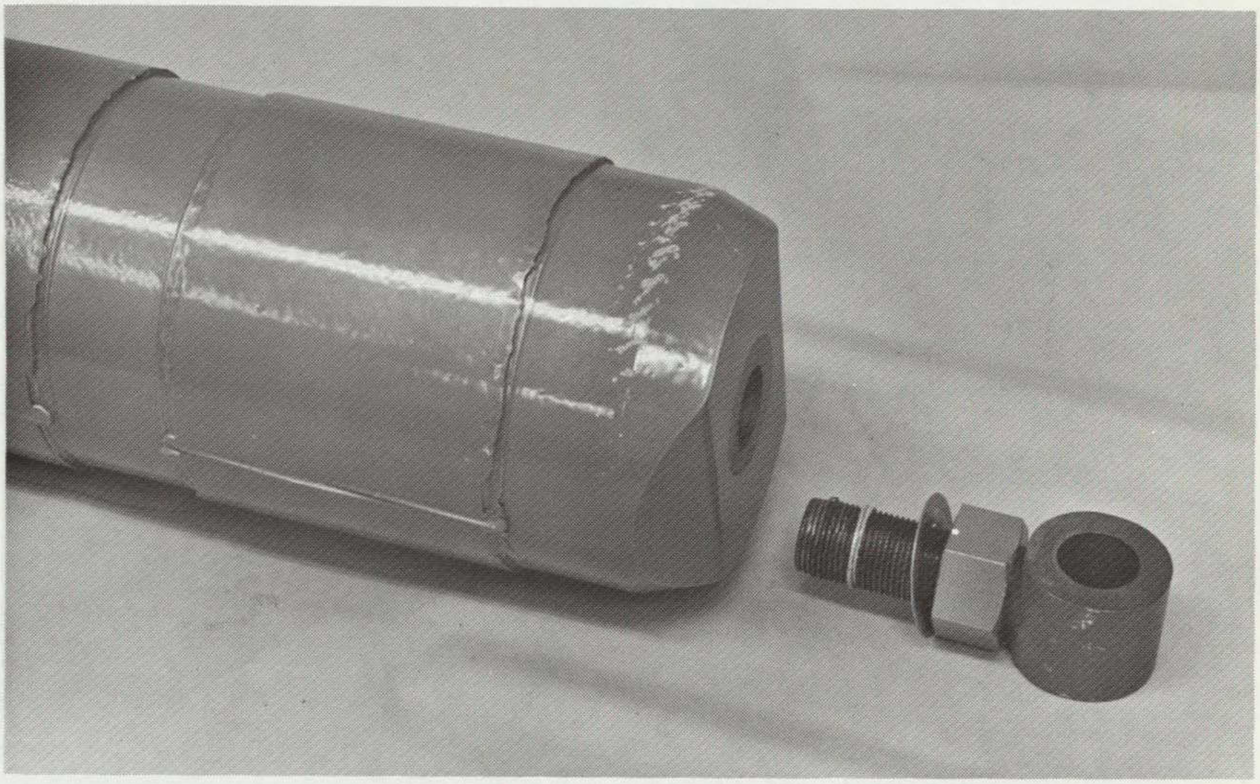


FIGURE 18 FAILED TEST SPECIMEN

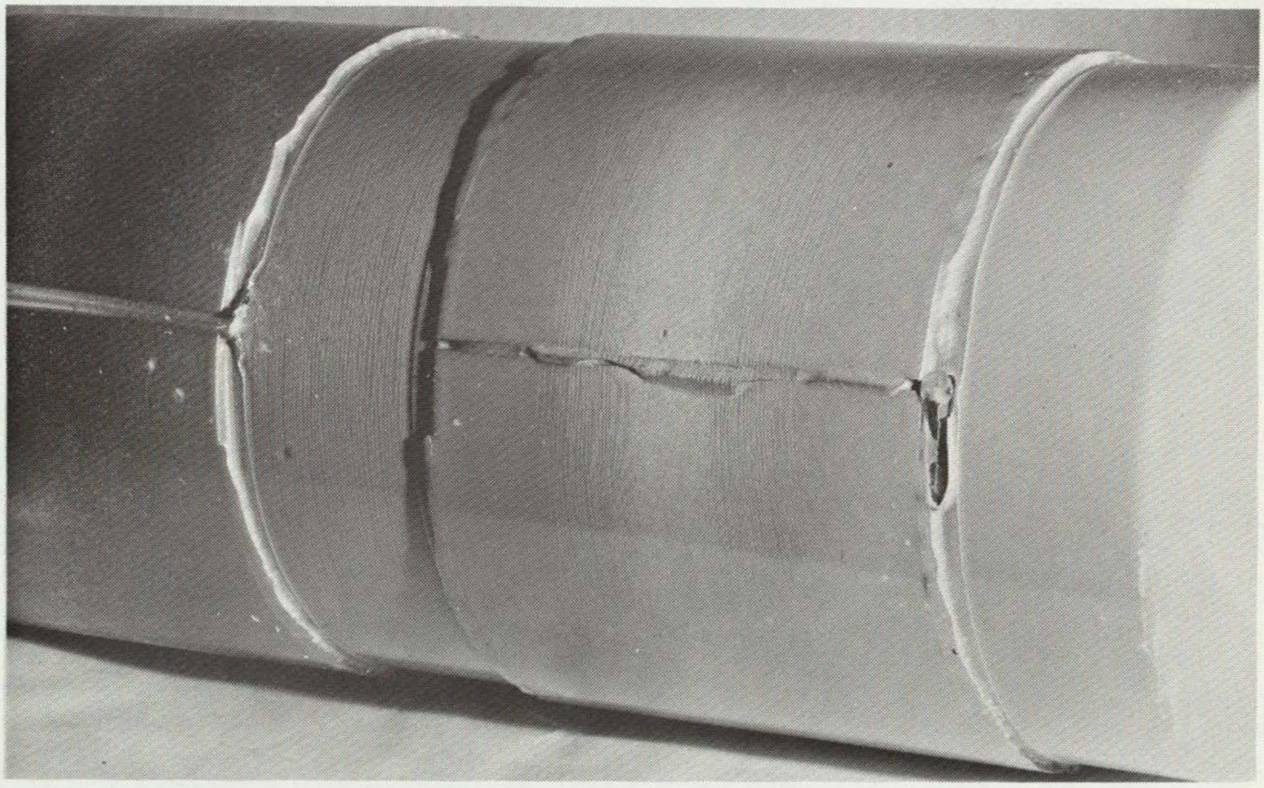


FIGURE 19 STRESSCOAT PATTERN

FIGURE 20 TEST ASSEMBLIES 3 AND 4

fitting to the test machine. The stresses at maximum load were 3760 psi joint shear, 58,200 psi beryllium tension, and 87,500 psi lap-strap tension. Dye penetrant inspection of the lug area after this test revealed no defects.

Assembly Number 4, with an adjustable end, failed at a load of 50,400 pounds tension. The failure occurred in the adhesive joint to the beryllium end fitting at a shear stress of 1610 psi. Examination of the failed assembly showed that only 30 to 40 percent of the lap area was bonded. The most likely explanation of the poor bond is that air, entrapped within the tube and joint area, prevented contact between the adhesive film and the beryllium during cure. The factors leading to this conclusion are the pattern of the bonded areas which shows good bond around the periphery of the lap strap with no indication of fingerprints or other signs of handling contamination, the strength exhibited by the bonded area (over 4000 psi) tends to rule out inadequate surface preparation, and the fact that the adhesive film thinned from 0.010 to 0.007 inch indicates that adequate pressure and temperature existed during the cure.

The intersection of the ends of the lap strap with the butted fitting and tube provided relief of the pressure built up within the tube during the heatup portion of the cure cycle. Examination of this area showed that it was blocked at some time during the cure and therefore might not have provided the necessary venting. Since the adhesive around the edges of the lap strap would soften and flow first during the warmup, it could effectively seal the gas in the tube and result in an internal pressure buildup as well as pocketing gas between the adhesive and the beryllium as the assembly stabilized at cure temperature. The FM-1000 adhesive used on these parts is very viscous even at cure temperature. This property further supports the air-pocket explanation of the failure.

In summary, one assembly with each style of end fitting sustained loads in excess of the 80,000-pound design level, demonstrating the adequacy of the design and components. One assembly of each type failed in the adhesive joint at a load below the 80,000-pound level. Table VI presents the short tube test results. The failures were analyzed, the probable causes determined, and corrective action established for assembly of the 40.60-inch struts as follows:

- Use shims of 0.006 inch diameter wire to control minimum bond line thickness
- Provide positive venting of the tube interior by drilling a hole in the end fitting or maintaining the joint intersection clear of adhesive.

TABLE VI

SHORT TUBE TEST RESULTS

Spec Number	End Configuration	Maximum Load	Average Stress at Maximum Load			Yield Load	Yield ϵ In 9 Inches	Type Failure	Probable Cause
			Adhesive Shear	Be Tension	19-9 Tension				
1	Fixed	75,900	2530	39,200	58,900	60,000	.060*	Adhesive to beryllium fitting and tube	Thin-nonuniform bond line thickness
2	Adj.	88,900	2960	45,900	69,000	58,200	.060*	Eye bolt threads	Loose thread fit
3	Fixed	112,800	3760	58,200	87,500	56,900	.091	Clevis bolt threads	Exceeded design
4	Adj.	50,400	1680	26,000	39,100	33,000	.092	Adhesive to beryllium fitting	Trapped air pockets

*Estimated - Based on 0.166 Measured ϵ in 46 inches

11.5-inch clevis bolts (2) = 0.046 inch calculated
18.0-inch test assy = 0.120 ÷ 2 = 0.060 in 9 inches
5.0-inch clevis fitting = 0.000

7

PROTOTYPE FABRICATION

Two strut assemblies (Fig. 21) have been fabricated for evaluation by NASA-MSFC. One of the struts has fixed end fittings on each end of a beryllium tube and the other has one fixed end fitting and one adjustable end fitting.

The fixed end strut was bonded prior to completion of testing of Specimen Number 4. This assembly was, therefore, not provided with a vent hole in the end fitting. Fortunately, one of the joint intersections remained clear through the cure cycle and provided the venting necessary to prevent pressure buildup within the assembly. The weight of this assembly is 12.82 pounds compared to the 35.14 pounds which the comparable aluminum strut would weigh.

The assembly with the adjustable end fitting was provided with a 0.125 inch diameter vent hole in the fixed end fitting. The hole was located in an area of low stress on the tapered face of the fitting, 90 degrees from the plane of the lug. The total weight of this assembly is 13.62 pounds.

Dye penetrant inspection of the end fittings after the surface etch revealed shallow cracks over part of the conical surface of the adjustable beryllium end fitting. Since these cracks are shallow in a thick section of the fitting and do not extend over the entire surface, they should not impair the assembly strength.

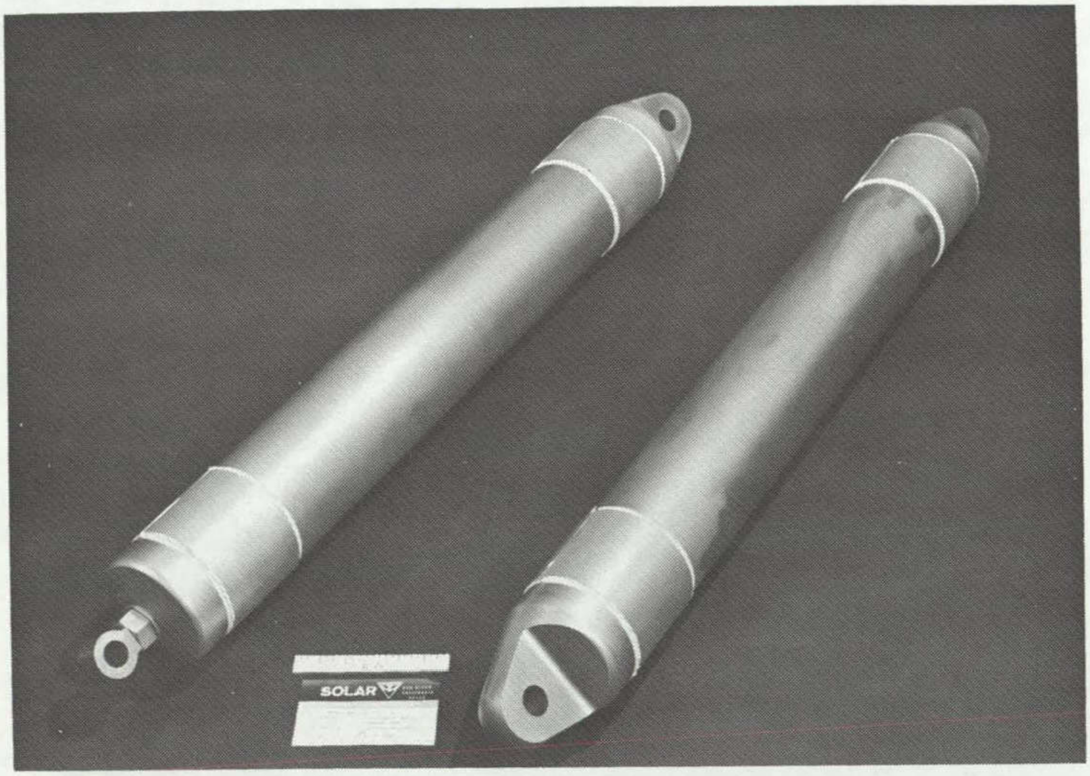
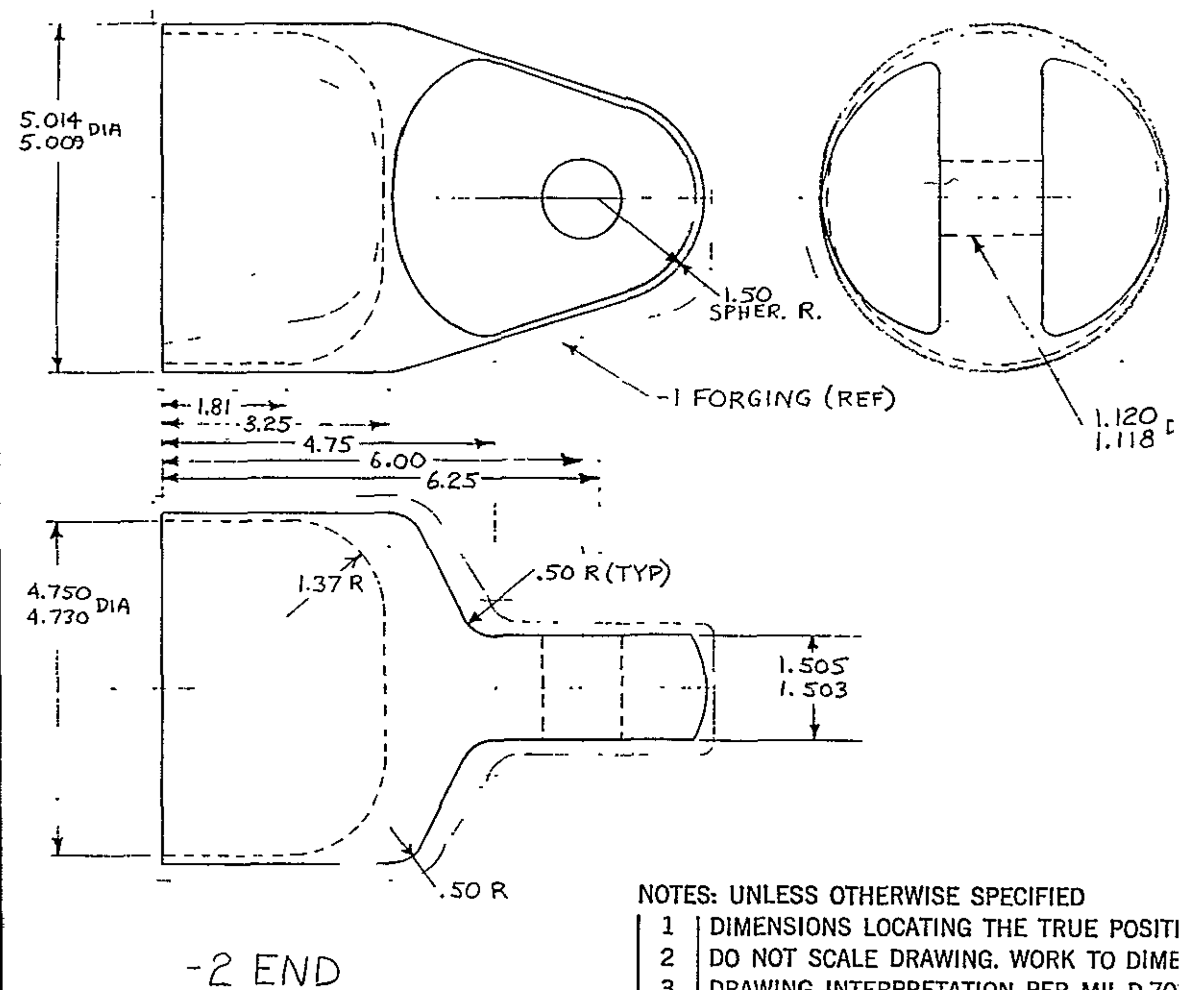


FIGURE 21 STRUT ASSEMBLIES

APPENDIX A

DRAWINGS

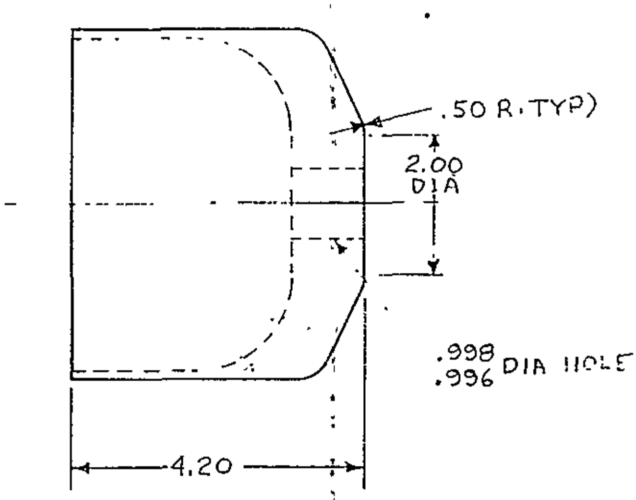


NOTES: UNLESS OTHERWISE SPECIFIED

1	DIMENSIONS LOCATING THE TRUE POSITI
2	DO NOT SCALE DRAWING. WORK TO DIME
3	DRAWING INTERPRETATION PER MIL-D-70 AND SOLAR SPEC 9-4, SECT
4	MAKE FROM -1 FORGING
5	FINAL MACHINE CUT NOT TO
6	NO CUT TO EXCEED 50 % OF PF
7	FINISH TO BE 63 RMS OR BE
8	BREAK SHARP EDGES 45° x .01
9	ID AND OD TO BE CONCENTRIC
10	DIMS. SHN. FOR MACHINING
11	TOL ON DIMS MARKED X.XX

SADI 1207 REV

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL
B	REDRAWN - LUG FLAT [illegible] REDIMENSIONED, TO END [illegible] FORGING [illegible] ADDED	12/19	



-3 END

SAME AS -2 EXC. AS NOTED

A HOLE

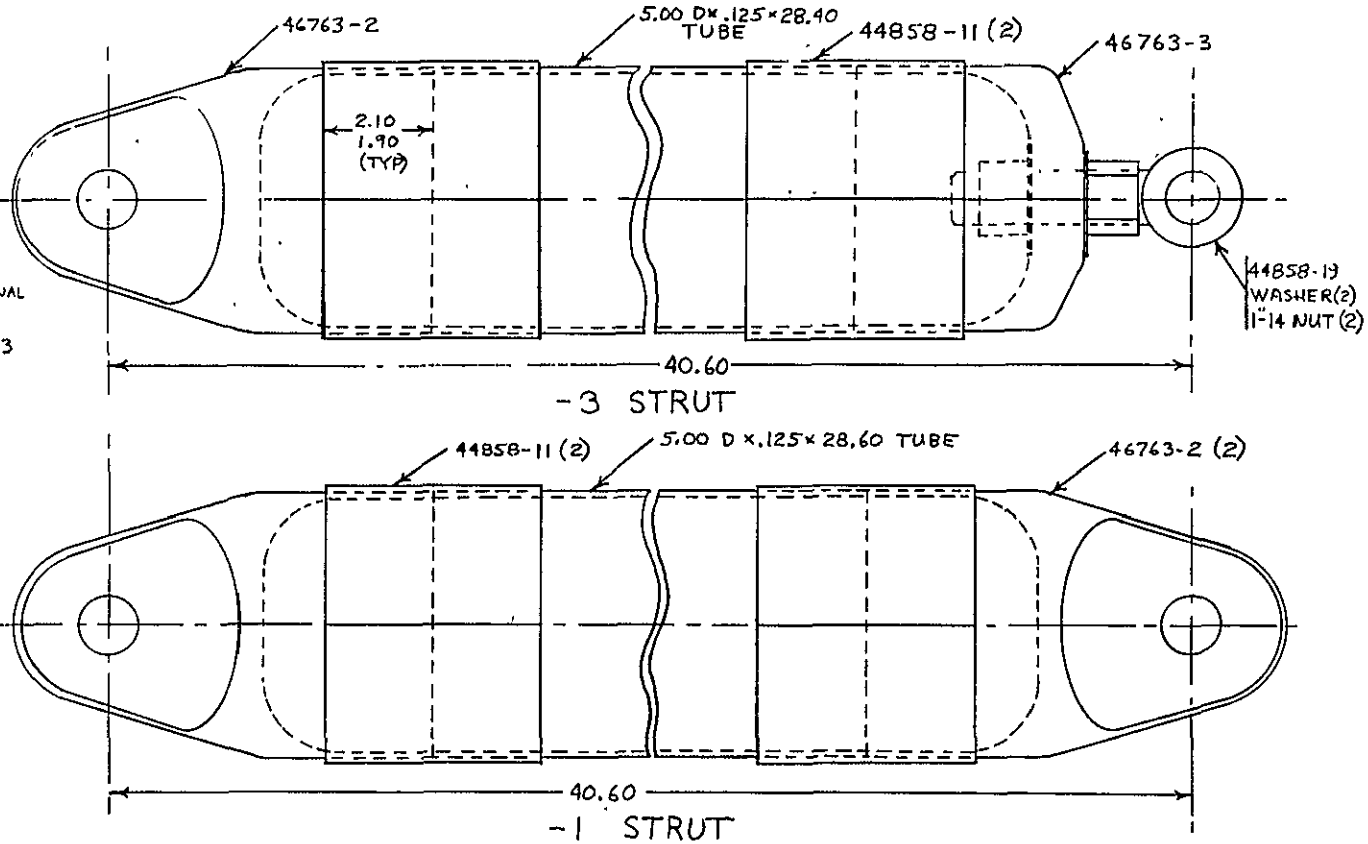
...N ARE BASIC
...SIONS GIVEN
...27

EXCEED .002
EXCEEDING CUT
...TER
...
WITHIN ...5
...NLY
...020

REQD	PART NO.	DESCRIPTION	MATL	MATL SPEC	UNIT WT
	← ASSY NO.	LIST OF MATERIAL (PARTS LIST)			

APPROVED BY	SOLAR — SAN DIEGO 12, CALIFORNIA — A Division of International Harvester Company
GOVT CONTRACT NO.	
PROJECT TKS 12/19/66	DRAWING TITLE: FITTING END - MACHINING BERYLLIUM
DESIGN	
CHECK	
DRAFT	SIZE B — CODE IDENT NUMBER 55820 — DRAWING NUMBER 46763
DESIGN ACTIVITY	
CUSTOMER	SCALE 1/2 — TOTAL WT. — SHEET 2 OF 2

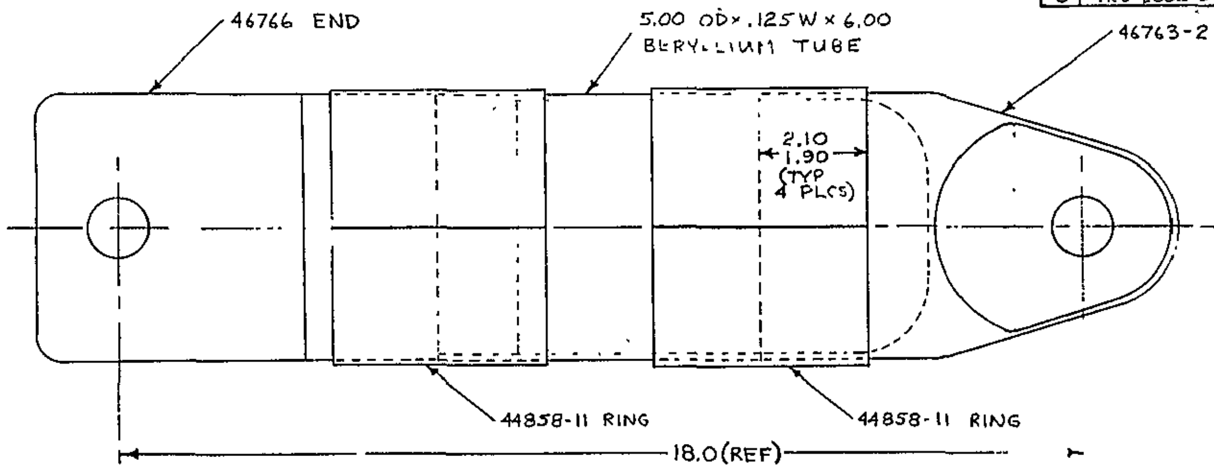
NOTES:
1) RING SPLIT LINE TO BE 90±5° FROM PLANE OF LUGS
2) ASSEMBLE WITH FM 1000 ADHESIVE .010 FILM. CURE AT 350°F, 50 PSI, 60 MIN.
3) INSIDE NUT ON -3 ASSY TO BE BONDED TO INTERNAL SURFACE OF FITTING
4) LENGTH TOLERANCE ±.03



BERYLLIUM STRUT ASSY

DWG. NO. 44858 Sh. 1 of 5

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL
A	Sht. 2 Redrawn	1/4/67	TRS
B	Rev Load Seq & Lap Ring	5/22/67	TRS.



TEST LOAD SEQUENCE

20,000 LB TENS.

40,000 LB. TENS.

60,000 LB TENS.

LOAD TO FAILURE IN TENSION

NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS LOCATING THE TRUE POSITION ARE BASIC
2. DO NOT SCALE DRAWING. WORK TO DIMENSIONS GIVEN
3. DRAWING INTERPRETATION PER MIL-D-70327 AND SOLAR SPEC 9-4, SECT
4. RING SPLIT LINES TO BE 90±5° FROM PLANE OF LUGS
5. ASSEMBLE WITH FM1000 ADHESIVE .010 FILM. CURE AT 350°F, 60 MINUTES

REQD	PART NO.	DESCRIPTION	MATL	MATL SPEC	UNIT WT
	← ASSY NO	LIST OF MATERIAL (PARTS LIST)			

APPROVED BY

GOVT CONTRACT NO

PROJECT T Stockham

DESIGN

CHECK

DRAFT

DESIGN ACTIVITY

CUSTOMER

SOLAR SAN DIEGO, CALIFORNIA
A Division of International Harvester Company

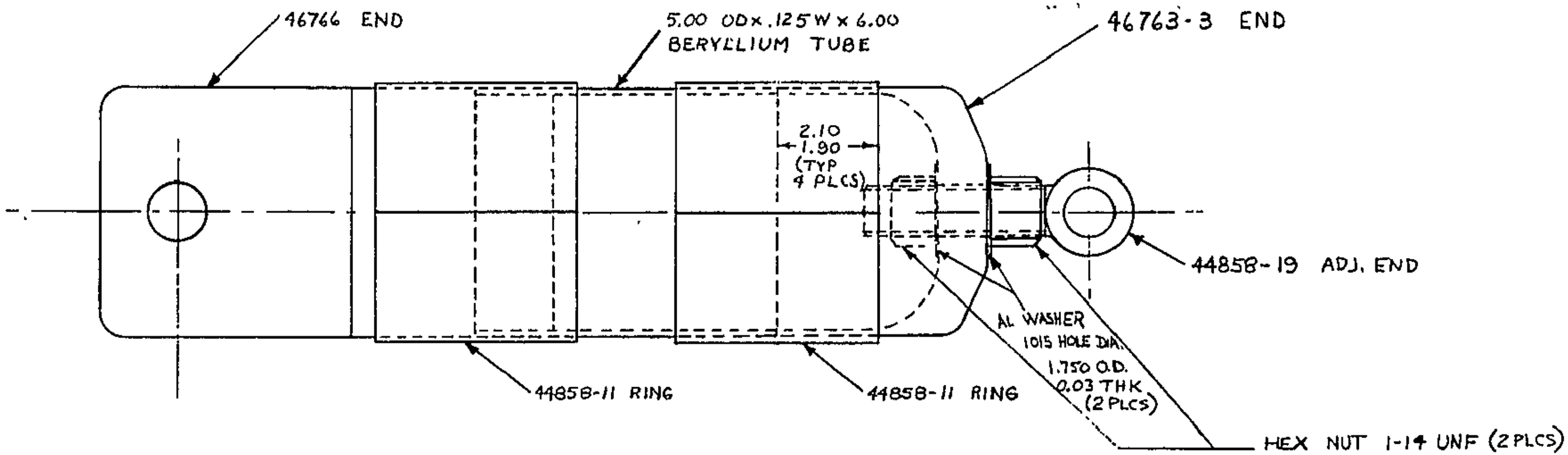
DRAWING TITLE: SHORT TUBE TEST ASSY BERYLLIUM STRUT

SIZE	CODE IDENT NUMBER	DRAWING NUMBER
B	55820	44858

SCALE 1/2 | TOTAL WT | SHEET 2 OF

SADI 1207 REV

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL
A	REV. LOAD SEQ., LAP STRAP & END FTG	5/22/67	TLS



TEST LOAD SEQUENCE

20,000 LB. TENS.

40,000 LB. TENS.

60,000 LB. TENS

LOAD TO FAILURE IN TENSION

NOTES: UNLESS OTHERWISE SPECIFIED

1. DIMENSIONS LOCATING THE TRUE POSITION ARE BASIC
2. DO NOT SCALE DRAWING. WORK TO DIMENSIONS GIVEN
3. DRAWING INTERPRETATION PER MIL-D-70327 AND SOLAR SPEC 9-4, SECT
4. RING SPLIT LINES TO BE 90 ± 5° FROM PLANE OF LUGS
5. ASSEMBLE WITH FM 1000 ADHESIVE .010 FILM. CURE AT 350°F, 50 PSI, 60 MIN.
6. HEX NUT INSIDE -3 END FITTING TO BE BONDED TO INSIDE SURFACE AS SHOWN WITH FM 1000 ADHESIVE .010 FILM.

REQD	PART NO.	DESCRIPTION	MATL	MATL SPEC	UNIT WT
	← ASSY NO.	LIST OF MATERIAL (PARTS LIST)			

APPROVED BY

GOVT CONTRACT NO.

PROJECT T.L.S.

DESIGN

CHECK

DRAFT J. ANDERSON

DESIGN ACTIVITY

CUSTOMER

SOLAR SAN DIEGO, CALIFORNIA
A Division of International Harvester Company

DRAWING TITLE: ADJUSTABLE END SHORT TUBE TEST ASSY BERYLLIUM STRUT

SIZE: B | CODE IDENT NUMBER: 55820 | DRAWING NUMBER: 44858

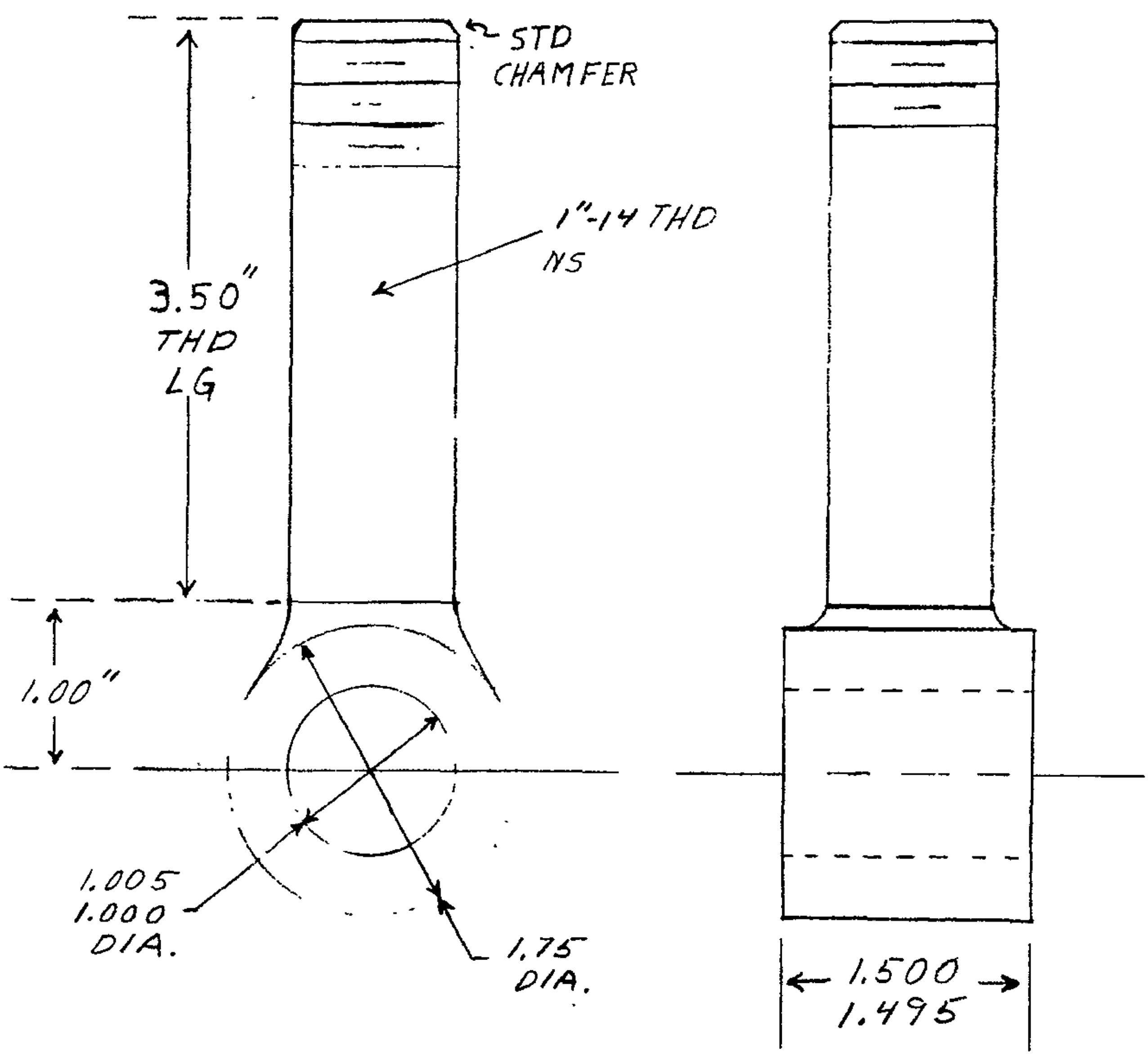
SCALE 1/2 | TOTAL WT. | SHEET 3 OF

SA01 1207 REV

REV	DESCRIPTION	DATE	APP

MAT'L : 4340 STEEL

HT TREAT TO RC 40 (RC 34 MIN)

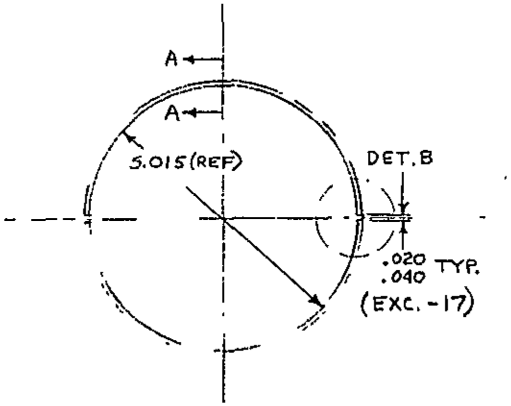


.XX = ± .015

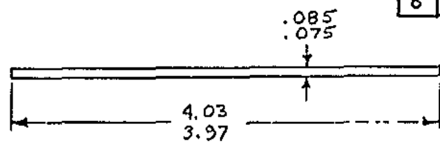
DRAWN	DATE	SCALE	NAME
K.A. LAYTON	5/12/67		ADJ. END ATTACHMENT
CHECKED			
APPROVED [signature]	5/12/67	This is a proprietary design of Solar, a Division of International Harvester Company. Reproduction, manufacture, or use of any assembly, sub-assembly, or part indicated herein or the use of the design of any such assembly, sub-assembly or part, is permissible only if expressly authorized in writing by Solar, A Division of International Harvester Company.	SOLAR IH — DWG NO. 44858-19 SHT 4
APPROVED			
REF.			

SAD1 1894 REV. 12/65

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL
A	Redrawn	12/16/66	TLS
B	Revised Ring for Double Split	5/23/67	TLS



LAP RING



VIEW AA -11 RING

NOTES: UNLESS OTHERWISE SPECIFIED
1 DIMENSIONS LOCATING THE TRUE POSITION ARE BASIC
2 DO NOT SCALE DRAWING. WORK TO DIMENSIONS GIVEN
3 DRAWING INTERPRETATION PER MIL-D-70327
AND SOLAR SPEC 9-4, SECT
4 MATERIAL 19-9 DL STAINLESS STEEL
5 ESTABLISH END GAP WITH RING STRAPPED TO MANDREL

REQD	PART NO.	DESCRIPTION	MATL	MATL SPEC	UNIT WT
	← ASSY NO.	LIST OF MATERIAL (PARTS LIST)			

APPROVED BY
GOVT CONTRACT NO
PROJECT T.L.S. 12/16/66
DESIGN
CHECK
DRAFT
DESIGN ACTIVITY
CUSTOMER

SOLAR SAN DIEGO 12, CALIFORNIA
A Division of International Harvester Company

DRAWING TITLE
STRUT ASSY-BERYLLIUM

SIZE B | CODE IDENT NUMBER 55820 | DRAWING NUMBER 44858

SCALE 1/1 4 NOTED | TOTAL WT | SHEET 5 OF 5

SADS 1207 REV

APPENDIX B

PROCESS SPECIFICATIONS

CLEANING SPECIFICATION FOR BERYLLIUM AND 19-9DL STAINLESS STEEL PARTS

1.0 APPLICABILITY

This specification shall apply only to beryllium and 19-9DL stainless steel parts for use on NASA Contract NAS8-20151.

2.0 PROCEDURE

2.1 Beryllium Cleaning

2.1.1 Use clean nylon or cotton gloves when handling all beryllium and stainless 19-9DL parts.

2.1.2 Using a slurry made by mixing 0.3 micron mesh aluminum oxide and deionized water (Al_2O_3 - 30 ±10% by weight) and an ultrasonically cleaned short bristle brush, thoroughly brush all faying surfaces.

2.1.3 Flush with deionized water for not less than 3 minutes to completely remove all traces of aluminum oxide.

2.1.4 Ultrasonically clean parts by immersing for not less than three (3) minutes, but no more than fifteen (15) minutes in reagent pure acetone.

2.1.5 Remove parts from tank and spray rinse immediately and thoroughly with deionized water, distilled water and/or acetone for a minimum of two (2) minutes, and then place part(s) in vacuum dryer or oven set at 230°F minimum, 400°F maximum for one hour or until completely dry.

2.1.6 Check all parts with black light (using gloves at all times), and if part fluoresces repeat 2.1.4 through 2.1.6.

2.1.7 Using a solution comprised of 25% reagent grade nitric acid (HNO_3), and 0.25% hydrofluoric acid (HF), with the balance being deionized water, etch faying surfaces for 1-3 minutes at room temperature, not allowing the acid bath temperature to exceed 120°F.

2.1.8 Rinse surfaces thoroughly for a minimum of three (3) minutes with deionized or distilled water. Spot check wet surface with blue litmus to assure all acid has been removed. If litmus turns red, repeat rinse operation above.

2.1.9 Place part(s) in vacuum dryer or oven until completely dry (a minimum of one (1) hour at a minimum temperature of 230°F).

2.1.10 Protective wrap part(s) using a lint free material prior to a bonding or brazing operation. Do not let part(s) stand before bonding or brazing for more than 24 hours after cleaning. If so, repeat 2.1.7 through 2.1.10 before continuing fabrication.

2.2 Stainless Steel 19-9DL Cleaning

2.2.1 Lightly hand rub with clean stainless steel wire brush or light abrasive cloth to remove surface contamination and any residual stains.

2.2.2 Perform operations 2.1.4 through 2.1.10.

BONDING SPECIFICATION

BERYLLIUM TO 19-9DL STAINLESS STEEL

FM-1000 ADHESIVE

1.0 APPLICABILITY

This specification shall apply only to beryllium and 19-9DL stainless steel parts for use on NASA Contract NAS8-20151.

2.0 PROCEDURE

2.1 Clean parts to be bonded per applicable specification.

2.2 Use clean nylon or cotton gloves at all times when handling parts to be bonded.

2.3 If necessary for ease of layup, use a tack primer on only one of the surfaces to be bonded. Apply with ultrasonically cleaned bristle brush, however, do not exceed 10% of bonded surface area.

2.4 Apply FM-1000 adhesive film to either surface to be bonded, cut to bonded surface area size, (or to surface with tack primer applied).

2.5 Position metal details and apply required pressure for bonding (25-50 psi). Make sure details and adhesive film do not shift position while pressure is being applied.

2.6 Place part in a temperature controlled oven and raise part's temperature to $350^{\circ} \pm 10^{\circ}$ F in less than one hour.

2.7 Maintain the required pressure and temperature (350°F) for a period of not less than one hour, and not more than two hours.

2.8 Remove part from oven and let cool to room temperature while under pressure.

2.9 Remove pressure source.

2.10 Remove adhesive flash if required.

APPENDIX C

PROCUREMENT SPECIFICATIONS

PRELIMINARY PROCUREMENT SPECIFICATION FOR BERYLLIUM TUBING (REVISION 3)

1.0 APPLICABILITY

This specification shall apply only to beryllium tubing for use on NASA Contract NAS8-20151.

This tubing is being procured for Engineering Development Test purposes only. No production procurement activity may be controlled with this specification.

2.0 CONFIGURATION

The parameters of the tubing shall conform with Figure A.

2.1 The outlines and dimensions shown are required for an acceptable, deliverable item. Necessary extra material to provide test pieces per paragraph 5.0, for certification, will be added by the vendor and removed before delivery. Excess not to exceed 3 inches and added to only one tube of each lot.

3.0 MATERIAL

3.1 Source

The source material shall be beryllium metal powder containing not more than 2 percent by weight of Be O. One material lot only to be used for each order. In addition, the following maximums are specified:

Carbon	1500 ppm
Aluminum	1800 ppm
Titanium	400 ppm
Silicon	800 ppm
Chromium	200 ppm
Iron	2000 ppm
Nickel	300 ppm
Manganese	350 ppm
Magnesium	800 ppm

The remainder shall be beryllium. Grain size shall be less than 100 mesh for 98 percent of the material and less than 200 mesh for 75 percent of the material. There shall be no inclusions larger than .05 inch diameter.

4.0 CONDITION

Each tube length shall be processed as follows:

(a) Extruded

(b) Rotated (at vendor option to control ovality)

(c) Annealed (at vendor option provided mechanical property requirements of paragraph 5.0 and dimensional tolerances of 6.0 are not affected)

(d) Finish machined all over (maximum RMS 63); allow for material removed during etch (Reference 4.0 (f).

(e) Inspected (visual and non-destructive test) and warranted free from cracks, laps, inclusions, and other latent defects

(f) Acid etched all over to remove .002 minimum. No further material removal permitted after this operation.

(g) Identify by lot number and serial number by means of rubber stamp directly on the tubing, not within three inches of either finished end.

5.0 MECHANICAL PROPERTIES AND TESTING

Mechanical properties are to be determined by the tubing vendor using the optional excess material allowed in paragraph 2.1. Properties shall be measured in the longitudinal and circumferential directions and shall meet the following minimum requirements:

F_{tu} = 55,000 psi

F_{ty} = 40,000 psi

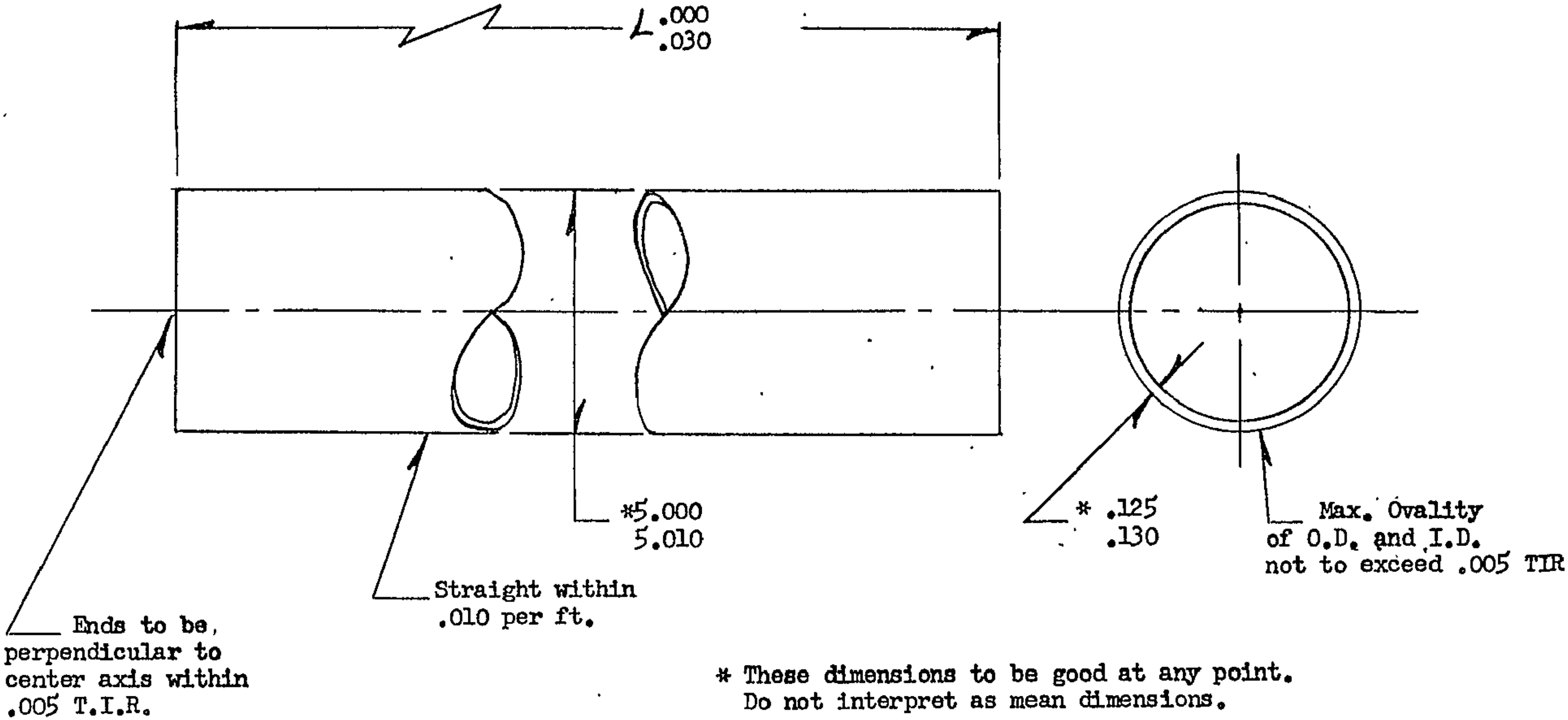
Elongation = longitudinal 5% (on a 1-inch gage length)

6.0 DIMENSIONS AND TOLERANCES

Dimensions and tolerances shall conform to Figure A, after processing.

7.0 CERTIFICATION

Certification of compliance with this specification, by individual item, is required for each tube delivered, and includes the polished and etched test piece. Certification requires two copies, one accompanying the hardware and one mailed directly to the Solar Project Engineer, Mr. H. Jones, Department 299.



* These dimensions to be good at any point.
Do not interpret as mean dimensions.

Machining Note: Each succeeding machine cut depth not to exceed 50% of the preceeding machine cut depth. The final machine cut shall not exceed .002.

Note: All dimensions and tolerances are to apply after final Chem-Etch. See para. 2.1 and 4.0 (d)

FIGURE A

9 May 1966

FORGING SPECIFICATION FOR BERYLLIUM FORGINGS (REVISION 2)

1.0 APPLICABILITY

This specification shall apply only to beryllium forgings for use on NASA Contract NAS8-20151 shown on Solar drawing 46763.

These forgings are being procured for Engineering Development Test purposes only. No production procurement activity may be controlled with this specification.

2.0 CONFIGURATION

The preferred forging shapes are shown as solid outlines on both drawings. Deviations from this shape, such as that indicated by Note 6 on the drawings, are acceptable if they improve the forgeability of the part. Such deviations will increase machining and "lost metal" costs, however, and should be avoided if possible.

2.1 The outlines shown (and their dimensions) are those desired upon delivery. Cropping, surface grinding, or rough machining to expedite inspection and non-destructive testing at the forging vendor's plant is acceptable, provided that the final shape and dimensions are within the stated tolerances.

2.2 The base of each configuration has been extended to provide a cut-off ring for property measurement. The exact size of this ring is to be at the option of the forging vendor. The ring is to be removed from every forging by the vendor and the testing prescribed in paragraph 5.0 performed prior to shipment. The ring shall be removed only by means of processes which create surfaces not rougher than RMS 63.

3.0 MATERIAL

3.1 Source material shall be S200 grade or equivalent.

3.2 Forging Input

The form of the material is optional with the vendor. Composition will be within the limits established in paragraph 3.1.

3.3 Forging

The first piece to be forged successfully shall be sectioned along an axial center line to give two complete half sections. A series of microspecimens (four locations) to be used to examine structure. Microspecimens and balance of sectioned forgings would be delivered to Solar. The other half will be retained by the vendor for property testing per paragraph 5.0.

4.0 CONDITION

Each delivered forging shall be in the following condition:

(a) Forged

(b) Annealed

(c) Rough machined or ground all over (Max. RMS 63)

(d) Inspected (visual and non-destructive test). Average inclusion limited in size to .03 maximum and that the combined volume of inclusions shall not exceed the volume of a .032" sphere per cubic inch of Be. Warranted free from cracks and laps at time of delivery.

(e) Acid etched all over to remove .002 minimum. No further metal removal permitted after this operation.

(f) Identified by drawing number and serial number by rubber stamp directly on the forging.

* Annealing is optional provided vendor can meet mechanical property requirements of paragraph 5.0. If forgings are annealed, full details of the process used should be submitted with certification.

5.0 MECHANICAL PROPERTIES AND TESTING

The half of the sectioned forging will be used per paragraph 3.3. These locations are defined approximately on the attached sketch:

Locations #1L&1LT	Longitudinal and Long Transverse
Locations #2L&2LT	Longitudinal and Long Transverse
Locations #3L&3LT	Longitudinal and Long Transverse
Locations #4S.T.	Short Transverse

Locations 1, 2, and 3 are controls and must meet the following minimum values:

F_{tu} - 55,000 psi

F_{ty} - 40,000 psi

Elongation - 2-1/2 percent (on a 1/2-inch gage length)

Location #4 (short transverse properties) is included for information only and no minimum properties are specified.

Following approval of the above property value test results, by Solar, the vendor may proceed with production of forgings for delivery.

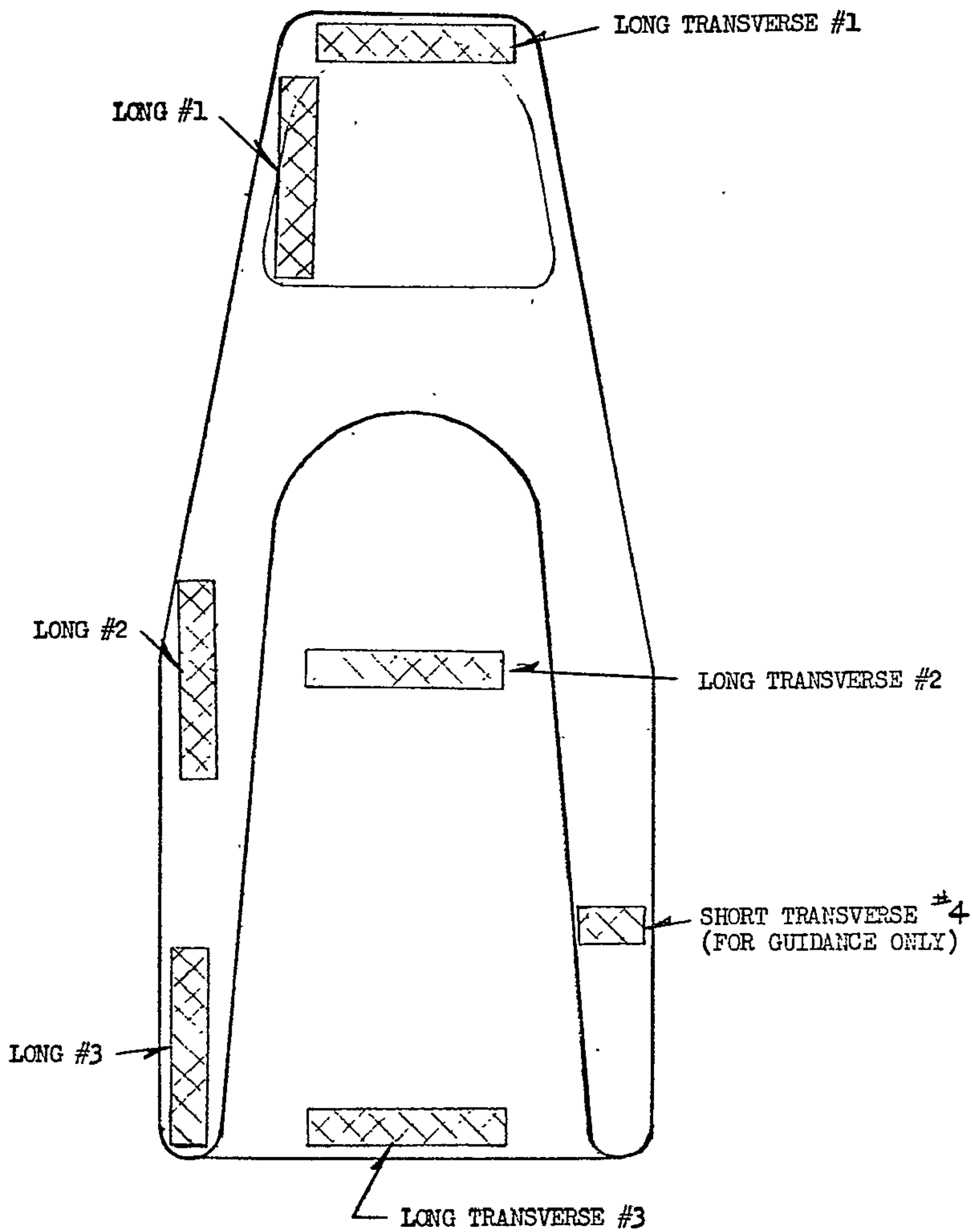
6.0 CERTIFICATION

Certification of compliance with this specification, by individual item, is required for each forging delivered, including the half prototype.

Certification shall be in two copies, one accompanying the hardware and one mailed directly to the Solar Project Engineer (Mr. H. Jones - Department 299).

PREPARED BY: H. Jones
H. Jones
Project Engineer

APPROVED BY: M R Licciardello
M. R. Licciardello
Chief Project Engineer


LONG TRANSVERSE #1
LONG #1
LONG #2
LONG TRANSVERSE #2
SHORT TRANSVERSE #4
(FOR GUIDANCE ONLY)
LONG #3
LONG TRANSVERSE #3

PRELIMINARY PROCUREMENT SPECIFICATION

BERYLLIUM STRUCTURAL SHEET

Beryllium Assay	%	98.0 Min.
Beryllium Oxide	%	1.4 Max.
Aluminum	%	0.16 Max.
Carbon	%	0.15 Max.
Iron	%	0.18 Max.
Magnesium	%	0.08 Max.
Silicon	%	0.08 Max.
Other Metallic Impurities, each	%	0.04 Max.
Ultimate Tensile	70,000 psi min.	
Yield	50,000 psi min.	
Elongation	5% in 1" min L & 3% in 1" min. Transversly	
Thickness	.125 ± .005	
Flatness within 2%		

Certification of the above to accompany shipment

APPENDIX D

MATERIAL CERTIFICATION

LADISH CO. CUDAHY • WISCONSIN • 53110

MATERIAL ANALYSIS REPORT METALLURGICAL DEPARTMENT

PART NUMBER	SPECIFICATION	Forging(s) included in this shipment was (were) process controlled and identified per 300 and 310	DATE	INV. NO.
46763	S200 Beryllium	dcs	7-22-66	2526

CONDITION OF FORGINGS: Forged and annealed 1 hour at 1300°F., furnace cooled. Surface of sectional forging is in as forged condition, production forgings will be rough machined or ground all over.

FORGING HARDNESS IS WITHIN SPECIFIED RANGE OF:

Mechanical property acceptance of listed forgings based on results, from which conforms to material specifications listed above are tabulated below:

Forgings produced per titanium alloy process sheet No.
Forgings fluorescent penetrant inspected
Welding performed per print
Material proof tested
Forgings magnetic particle inspected

APPLICABLE WHEN NOTED [x]
Equipment certified to MIL-W-6873
Free from continuous carbide network
Micro structure satisfactory
Free from cast structure

Code	Serial	Blank Notarized Report Mo. Da. Yr. No.	Test Identity	Yield Str. KSI % of st.	Ultimate Strength KSI	% Elong. IN	% Red. Of Area	BHN	S R	KSI	Temp. of Test °F.	Hours at Load	% Elong. IN	% Red. Of Area

Brush Lot No. 4220
Ladish Lot No. P6-2080
Serial No. 1

Tensile properties of the sectional forging are as follows:
Locations are as defined in Solar Specification.

Long. #1	66.1	83.4	3.0	4.0
Long. #2	59.6	81.3	9.0	9.0
Long. #3	57.4	79.4	4.7	4.7
Long. Trans. #1	50.6	61.3	1.2	2.4
Long. Trans. #2	58.0	78.9	3.7	6.8
Long. Trans. #3	51.2	62.0	2.0	3.0

Short transverse tensile properties have not been completed at this time, but will be reported as soon as available.

Material has been inspected VIA X-ray, dye penetrant and ultrasonic technique and found to be free of defects as defined in Solar Beryllium Forging Specification dated 5/9/66.

+ STRESS INCREASED TO ____ KSI AFTER ____ HOURS
* DID NOT FRACTURE
V = V-NOTCH
S = SMOOTH
C = COMBINATION

MATERIAL AND PARTS COVERED BY THIS REPORT HAVE BEEN TESTED AND ACCEPTED TO THE SPECIFICATIONS INVOLVED.

I HEREBY CERTIFY THAT TO THE BEST OF MY KNOWLEDGE AND BELIEF THIS MATERIAL ANALYSIS REPORT IS TRUE AND CORRECT.

A. F. Hayes
METALLURGIST

SWORN AND SUBSCRIBED TO BEFORE ME THIS ____ DAY ____ 19 ____

MY COMMISSION EXPIRES

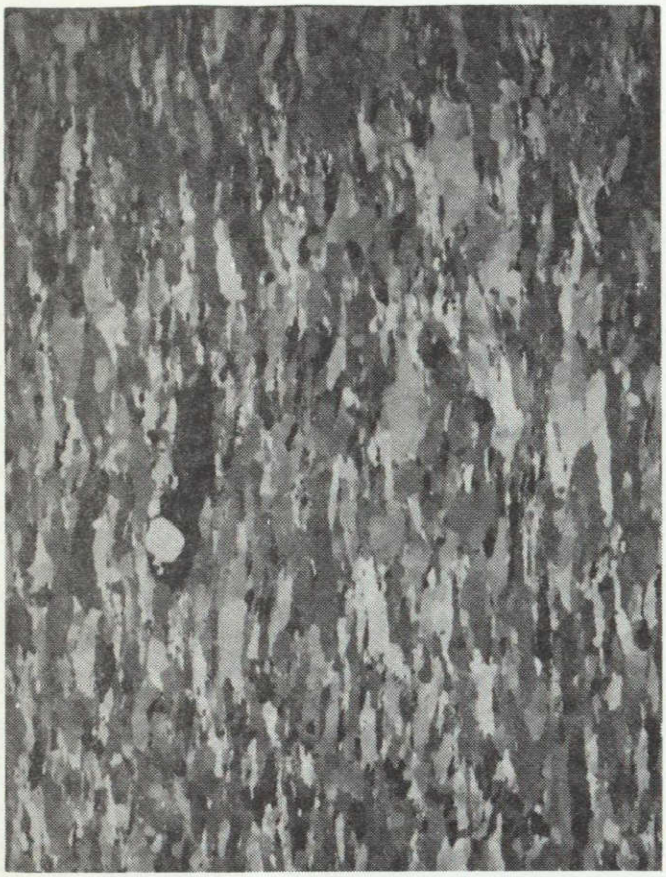
CODE | MILL | HEAT NO. | STOCK SIZE | GRAIN SIZE | HARDENABILITY | CHEMISTRY REPORTED IN %

Be Assay	Be O	Al	Si	Fe	Mg	Other Metallics	C
98.51	1.72	.060	.030	.140	.005	<.040	.130

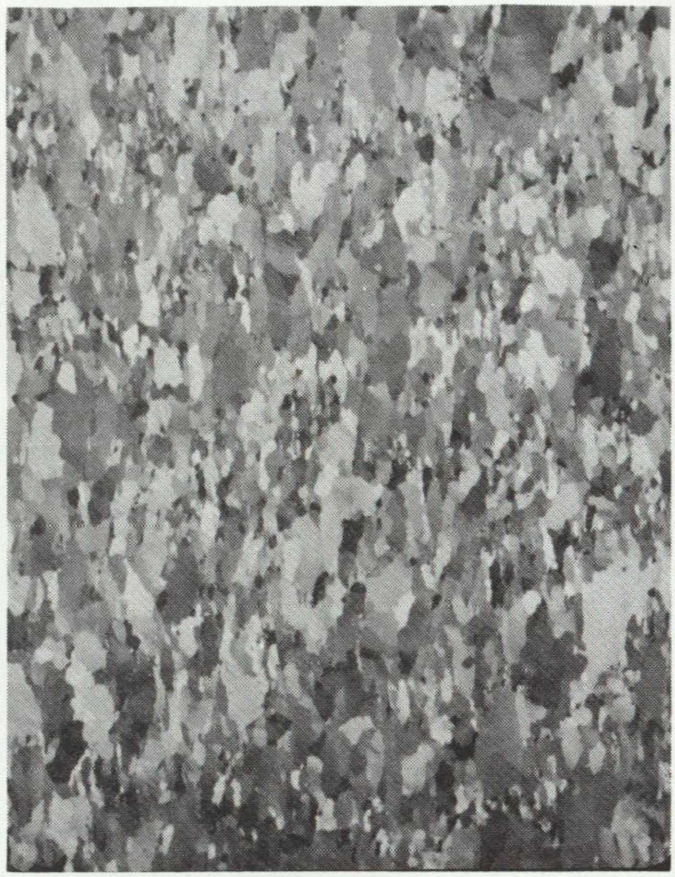
Solar,
Division of International Harvester Co.
2200 Pacific Highway
San Diego, California 92112

cc: With Shipment (1)
H. Jones Dept. 299 (1)
Purchasing Dept. (1)

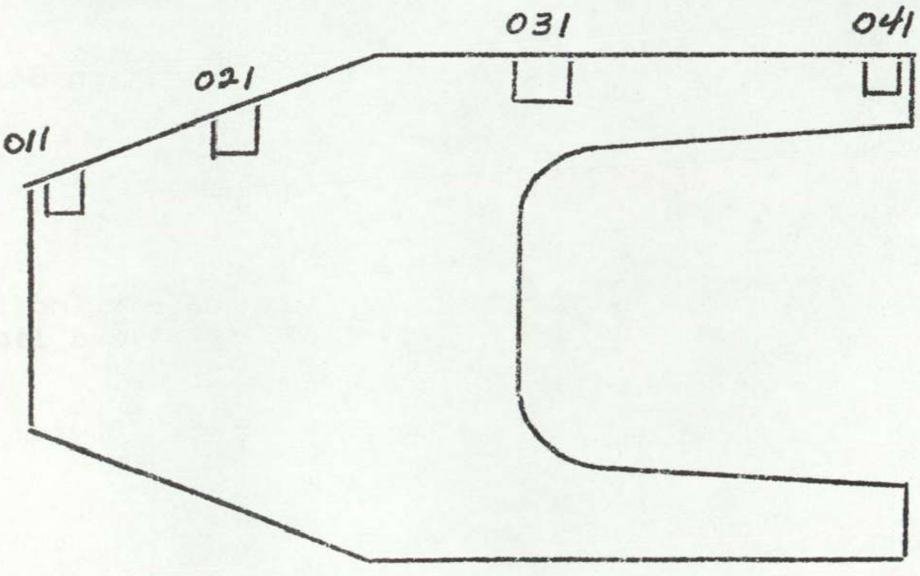
LCO 1540 F



Position 011



Position 021



Metallographic survey of sectioned beryllium end fitting for Solar program. Circumferential viewing direction, polarized light, 160X, as polished.

LADISH CO.
METALLURGICAL DEPARTMENT

Position 031

Position 041

Metallographic survey of sectioned beryllium end fitting for Solar program. Circumferential viewing direction, polarized light, 160X, as polished.

LADISH CO. CUDAHY • WISCONSIN • 53110

MATERIAL ANALYSIS REPORT

METALLURGICAL DEPARTMENT

PART NUMBER	SPECIFICATION	Forging(s) included in this shipment was (were) process controlled and identified per 300 and 310	DATE	INV. NO.
45063	S200 Beryllium	Les	11/2/66	

CONDITION OF FORGINGS: Forged and annealed 1 hour at 1300°F., furnace cooled, machined and etched for 15 minutes in 5% H_2SO_4.

FORGING HARDNESS IS WITHIN SPECIFIED RANGE OF:

Mechanical property acceptance of listed forgings based on results, from which conforms to material specifications listed above are tabulated below:

Forgings produced per titanium alloy process sheet No.

Forgings fluorescent penetrant inspected

Welding performed per print

Material proof tested

Forgings magnetic particle inspected

APPLICABLE WHEN NOTED [x]

Equipment certified to MIL-W-6873

Free from continuous carbide network

Micro structure satisfactory

Free from cast structure

Code	Serial	Blank Notarized Report Mo. Da. Yr. No.	Test Identity	Yield Str. KSI % of st.	Ultimate Strength KSI	% Elong. IN	% Red. Of Area	BHN	S R	KSI	Temp. of Test° F.	Hours at Load	% Elong. IN *	% Red. Of Area

Brush Lot No. 4220
Ladish Lot No. P6-2080
Serial No's. 2, 3, 8 & 9
Tensile properties of integral test rings are as follows:

Serial No.	Test Direction				
2	Circ.	57.1	74.1	5.4	5.5
	"	57.4	74.8	6.0	6.3
	"	58.2	75.4	6.0	6.3
3	Circ.	56.8	72.9	4.0	6.0
	"	56.2	72.4	5.0	6.0
8	Circ.	55.6	74.1	5.0	7.0
	"	56.9	75.2	6.0	7.0
9	Circ.	56.3	71.7	4.0	6.0
	"	56.6	72.0	3.0	5.0

Material has been inspected VIA X-ray, dye penetrant and ultrasonic technique and found to be free of defects as defined in Solar Beryllium, Forging specification dated 5/9/66.

+ STRESS INCREASED TO ______ KSI AFTER ______ HOURS
* DID NOT FRACTURE
V = V-NOTCH
S = SMOOTH
C = COMBINATION

MATERIAL AND PARTS COVERED BY THIS REPORT HAVE BEEN TESTED AND ACCEPTED TO THE SPECIFICATIONS INVOLVED.

I HEREBY CERTIFY THAT TO THE BEST OF MY KNOWLEDGE AND BELIEF THIS MATERIAL ANALYSIS REPORT IS TRUE AND CORRECT.

A. F. Hayes

METALLURGIST

SWORN AND SUBSCRIBED TO BEFORE ME THIS ______ DAY ______ 19 ______

MY COMMISSION EXPIRES

CODE	MILL	HEAT NO.	STOCK SIZE		GRAIN SIZE	HARDENABILITY		CHEMISTRY REPORTED IN %
Be	Assay	BE O	AL	SI	FE	MG	Other Metallics	O
98.51		1.72	.060	.030	.140	.005	.040	.130

Solar,
Division of International Harvester Co.
2200 Pacific Highway
San Diego, California 92112

cc: With Shipment (1)
H. Jones Dept. 299 (1)
Purchasing Dept. (1)

LCO 1540 R5

LADISH CO. CUDAHY • WISCONSIN • 53110

MATERIAL ANALYSIS REPORT METALLURGICAL DEPARTMENT

PART NUMBER	SPECIFICATION	Forging(s) included in this shipment was (were) process controlled and identified per 300 and 310	DATE	INV. NO.
46763	S200 Beryllium	eb	1-6-67	

CONDITION OF FORGINGS Forged and Annealed 1 hour at 1300°F., furnace cooled machined and etched for 15 minutes in 5% H_2SO_4.

FORGING HARDNESS IS WITHIN SPECIFIED RANGE OF:

Mechanical property acceptance of listed forgings based on results, from which conforms to material specifications listed above are tabulated below:

Forgings produced per titanium alloy process sheet No.
Forgings fluorescent penetrant inspected
Welding performed per print
Material proof tested
Forgings magnetic particle inspected

APPLICABLE WHEN NOTED [x]
Equipment certified to MIL-W-6873
Free from continuous carbide network
Micro structure satisfactory
Free from cast structure

Code	Serial	Blank Notarized Report Mo. Da. Yr. No.	Test Identity	Yield Str. KSI % of st.	Ultimate Strength KSI	% Elong. IN	% Red. Of Area	BHN	S R	KSI	Temp. of Test° F.	Hours at Load	% Elong. IN	% Red. Of Area

Brush Lot No. 4220

Ladish Lot No. P6-6757.

Serial No's. 12, 13, 14, 15

Tensile properties of integral test rings are as follows

Serial No.	Test Direction				
12	Circ.	59.0	75.7	6.4	7.8
		60.3	79.0	10.0	10.1
13	Circ.	59.2	76.6	5.0	5.0
		58.7	75.3	4.0	4.0
14	Circ.	59.0	77.0	3.0	5.0
		58.2	77.2	6.0	6.0
15	Circ.	58.1	76.8	8.4	9.4
		59.3	76.2	6.2	6.3

(Continued on Page 2)

\+ STRESS INCREASED TO ______ KSI AFTER ______ HOURS
* DID NOT FRACTURE
V = V-NOTCH
S = SMOOTH
C = COMBINATION

MATERIAL AND PARTS COVERED BY THIS REPORT HAVE BEEN TESTED AND ACCEPTED TO THE SPECIFICATIONS INVOLVED.

I HEREBY CERTIFY THAT TO THE BEST OF MY KNOWLEDGE AND BELIEF THIS MATERIAL ANALYSIS REPORT IS TRUE AND CORRECT.

Arthur F. Hayes
METALLURGIST

SWORN AND SUBSCRIBED TO BEFORE ME THIS ______ DAY ______ 19 ______

MY COMMISSION EXPIRES

CODE Be	MILL Assay	HEAT NO. BeO	STOCK SIZE Al	Si	GRAIN SIZE Fe	Mg	HARDENABILITY Other Metallics	CHEMISTRY REPORTED IN % C
4220	98.51	1.72	.060	.030	.140	.005	<.040	.130
4490	98.5	1.70	.080	.030	.130	.010	<.040	.120

Solar,
Division of International Harvester Co.
2200 Pacific Highway
San Diego, California, 92112

cc: With Shipment (1)
H. Jones Dept. 299 (1)
Purchasing Dept. (1)

LCO 1540 R5

2 PAGE
INVOICE NUMBER
BLANKET NOTARIZED REPORT NUMBER

Code	Serial	Blank Notarized Report Mo. Da. Yr. No.	Test Identity	Yield Str. KSI % of st.	Ultimate Strength KSI	% Elong. IN	% Red. Of Area	BHN	S R	KSI	Temp. of Test° F.	Hours at Load	% Elong. IN	% Red. Of Area	+ STRESS INCREASED TO ___ KSI AFTER ___ HOURS

Brush Lot No. 4490

Ladish Lot No. P6-6258

Serial No. 16

16	Circ.	60.5	80.9	9.2	9.4
		60.0	79.3	8.0	9.4

Material has been inspected VIA X-ray, dye penetrant and ultrasonic technique and found to be free of defects as outlined in Solar Beryllium, Forging Specification dated 5-9-66.

CODE	MILL	HEAT NO.	STOCK SIZE	GRAIN SIZE	HARDENABILITY	CHEMISTRY REPORTED IN %

CUSTOMER
Solar Aircraft Corp.

CUSTOMER LOCATION
San Diego, California

CUSTOMER P. O. NUMBER
1902-125832-AJE (GR)

THE BERYLLIUM CORPORATION

HAZLETON BERYLCO® PENNA.

QUALITY CONTROL MATERIAL TEST REPORT

DATE
May 16, 1966

BERYLCO ORDER NO.
58-4105

SPEC. NUMBERS
Solar Tubing Spec. Rev. 3

DESCRIPTION
6 pcs., 5.000" OD x .125" wall x 6" long Berylco Be tubing

Berylco Unit Nos. XT-570J-1 thru 6

NUMBER	Lot / Heat	5207 / XT-570J	
Be Assay		98.68	
BeO		1.16	
C		.038	
Fe		.075	
Al		.053	
Ni		.010	
Si		.049	
Ti		.014	
Cr		.005	
Mn		.008	
	Heat	XT-570J	
		1L	2L
U.T.S.		91,100	87,500
.2% Y.S.		50,500	49,500
% El.		7½	6½
DENSITY			

NOTE: ONE (1) THREE INCH TENSILE SPECIMEN ENCLOSED WITH THE SHIPMENT, 58-4104 AND 58-4105

REMARKS Penetrant and Density inspection conforms to the above Spec.
Six (6) copies of the certificate of compliance form enclosed with the shipment.
One (1) copy of the certification mailed to [illegible] H. JONES PROJECT ENGINEER DEPT 299

THE BERYLLIUM CORPORATION

By [signature]

R.B. ASHMAN

Title Q.C. FOREMAN

QC-1A

CUSTOMER: Solar Aircraft Corp.

CUSTOMER LOCATION: San Diego, California

CUSTOMER P. O. NUMBER: 1902-125832-AJE (CR)

THE BERYLLIUM CORPORATION

HAZLETON BERYLCO PENNA.

QUALITY CONTROL MATERIAL TEST REPORT

DATE: May 16, 1966

BERYLCO ORDER NO: 58-1104

SPEC NUMBERS: Solar Tubing Spec. Rev. 3

DESCRIPTION: 2 pcs., 5.000" OD x .125" wall x 32" long Berylco Be metal tubing

Berylco Unit Nos. XT-570J-7, 8

NUMBER	Lot / Heat									
	5207 / XT-570J									
Be Assay	98.68									
BeO	1.46									
C	.038									
Fe	.075									
Al	.053									
Ni	.010									
Si	.049									
Ti	.014									
Cr	.005									
Mn	.008									
Heat	XT-570J									
U.T.S.	1L	2L								
	91,100	87,500								
.2% Y.S.	50,500	49,500								
% El.	7%	6%								
DENSITY										

NOTE: ONE (1) THREE INCH TENSILE SPECIMEN ENCLOSED WITH THE SHIPMENT.

REMARKS Penetrant and Density inspection conforms to the above Spec.
Three (3) copies of the certificate of compliance form attached (One for each piece)
One (1) copy of the certification mailed to H. Jones Dept. 299 Project Engineer.

THE BERYLLIUM CORPORATION

By Donald B. Pehaman

R.E. ASHMAN

Title O.C. [illegible]

HQC-1A