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FABRICATION OF EXPERIMENTAL THREE-METER SPACE TELESCOPE PRIMARY AND SECONDARY MIRROR SUPPORT STRUCTURE

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16. Abstract

The purpose of this research program was to fabricate the prototype titanium alloy primary and secondary mirror support structures for a proposed experimental three-meter space telescope. The structure was fabricated entirely of Ti-6Al-4V tubing and plate. Fabrication included the development of procedures including welding, forming, and machining. Most of the structure was fabricated by gas-shielded tungsten-arc (GTA) welding with several major components fabricated by high-frequency resistance (HFR) welding.

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PREFACE

The objective of this research program was to fabricate the prototype titanium alloy primary and secondary mirror support structures for a proposed experimental three-meter space telescope. These structures were fabricated entirely from Ti-6Al-4V tubing and plate by gas-shielded tungsten-arc welding and high-frequency resistance welding. Procedures were developed for welding, forming, and machining. The fabricated structures were shipped to Goddard Space Flight Center for evaluation and testing.

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by

H. W. Mishler

INTRODUCTION

The purpose of this research program was to fabricate the prototype titanium primary and secondary mirror support structures for a proposed experimental three-meter space telescope. The fabrication included the experimental development of fabrication procedures including machining, forming, and welding procedures. Most of the structure was fabricated by gas-shielded tungsten-arc (GTA) welding with several major components fabricated by high-frequency resistance (HFR) welding. The application of this latter process to fabrication of titanium structural shapes was developed by Battelle-Columbus for the U. S. Air Force. The telescope structure was the first application of these HFR welding techniques to aerospace components.

The design of the secondary and primary mirror support structures is contained in the following NASA drawings.

1297300, 2 sheets, Primary Mirror Support, 3-Meter LST, Revision D, November 29, 1971

1297301, 2 sheets, Secondary Mirror Support, Revision G, July 7, 1971.

MATERIALS

All components of the secondary and primary structures were constructed of Ti-6Al-4V alloy sheet and plate. This material was furnished by the Government from stock originally procured by Boeing for the supersonic transport program. This material was used in lieu of purchased material because a strike in the titanium industry caused uncertain and excessively long delivery times. The material was transferred to the telescope structure program after cancellation of the SST program. Because of a resulting drastic reduction in staff by Boeing, it was impossible to procure heat records for this material. As a result, the actual compositions of the Ti-6Al-4V sheet and plate were not known.

The composition of the welding filler wire was:

Heat No.	3204-D1
Al	6.09
V	4.18
C	0.010
Fe	0.100
O	0.08
N	0.007
H	0.0022
Ti	Bal

All filler wire was 0.063-inch diameter and was obtained from Astro Metallurgical Division, Waukeshaw Industries, Wooster, Ohio. Welding grade argon and helium shielding gases were used in all welding operations.

SECONDARY MIRROR SUPPORT

The five bay secondary mirror support consisted of six 129-inch-diameter rings connected by longitudinal and diagonal members to form a structure 310 inches long (Figure 1). The base ring was made from 1-inch-thick plate; the front ring was an H-section fabricated from 1/8-inch-thick sheet. The other four rings were of 3-inch O.D. by 1/8-inch-wall tubing. The longitudinal and diagonal members were 2-1/2- and 3-inch diameter by 1/8-inch-wall tubes.

Tubing

The tubing was fabricated by the Valley Metal Works, Inc., El Cajon, California, using 1/8-inch-thick sheet material from the SST stock. The

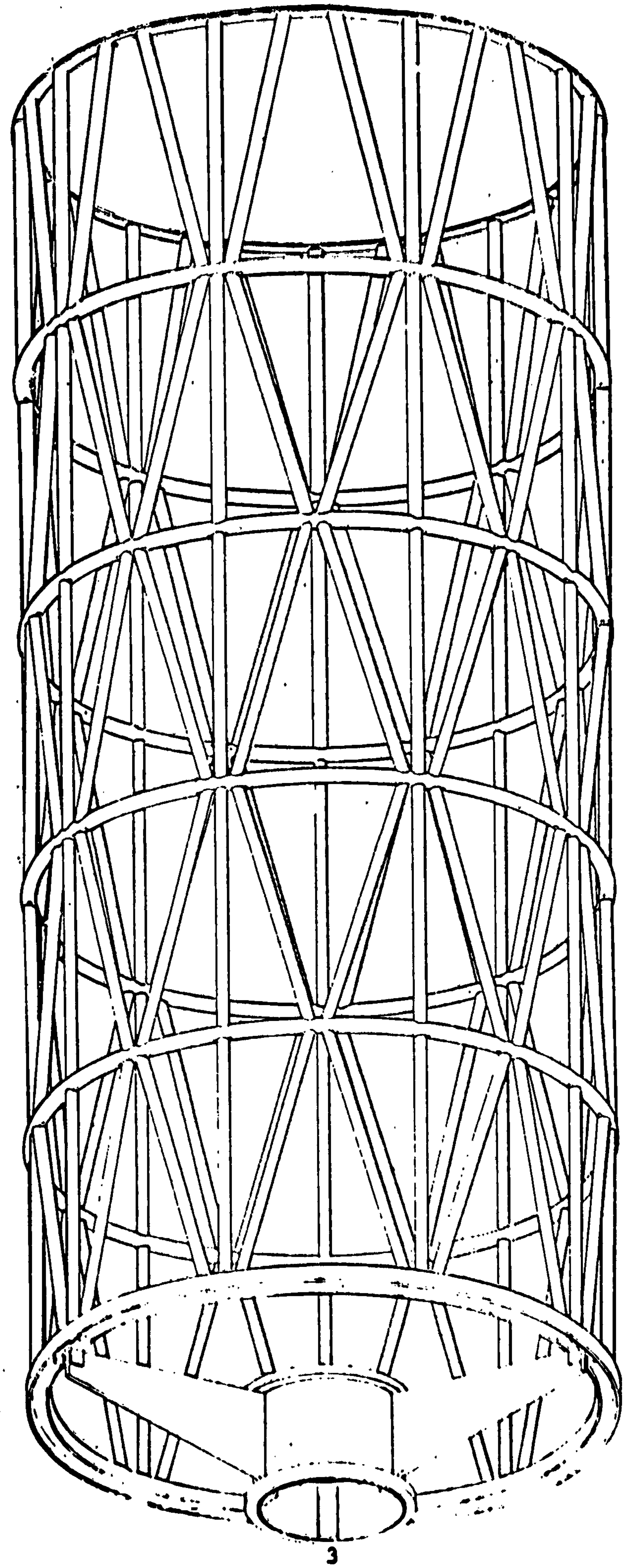


FIGURE 1. SECONDARY MIRROR SUPPORT

supplied length of the tubes was 63 inches. The tubes were formed on a press brake followed by degreasing and pickling. The tube blanks then were jigged and plasma-arc welded.

The plasma-arc welds were of excellent quality and superior in shape and size to similar welds made by GTA welding. The width of the plasma-arc welds was 1/3 to 1/2 that of GTA welds. Plasma-arc welding also is faster than GTA welding and the nature of the process is such that tungsten inclusions in the weld metal will not occur. The welds were shielded in both inside and outside by argon during welding. Following welding, the tubes were drawn through sizing dies to insure straightness.

The sheet stock used for these tubes apparently came from a large number of heats as there was a wide variation in springback from one sheet to another. Springback in titanium will vary considerably from heat to heat but not within the same heat. These variations caused considerable difficulty in forming the tubes as press brake settings could not be standardized. Each sheet required a different set of forming parameters. If the sheet could have been purchased, it probably would have been all from one heat and the forming would have been considerably easier.

Tubular Rings

The four tubular rings were fabricated by welding lengths of tubes together end-to-end to form a piece approximately 34 feet long and roll forming these welded lengths into 3-meter diameter rings.

The butt welds between the lengths of straight tubes were made automatically by rotating the tubes under a stationary GTA welding torch. These joints as well as all other joints in these structures were degreased with acetone immediately prior to welding. The interior of the tubes was purged with helium prior to welding. The welding torch and the ends of the tubes being welded were contained in an argon-filled clear plastic box during welding. Pieces of sponge rubber sealed the openings where the tubes entered the box and prevented argon leakage as the tubes were rotated.

The weld joint was a single-vee butt having a 75-degree included angle and a 1/64-inch root face and zero root opening. Two passes were made - the root pass without filler and the second with filler added. The welding conditions were:

	Root Pass	Fill Pass
Arc voltage, volts	14	15
Current, amps	100	110
Travel speed, ipm	8	8
Wire feed speed, ipm	None	15

The 34-foot-long welded sections were roll formed into rings by the Zink Pipe Bending Company, Harrisburgh, Pennsylvania. A three-roll bending stand was used. Initially, problems were encountered with breakage of the girth welds. Breakage was eliminated by torch annealing the girth welds. The joint areas were heated to a dull red using a slightly oxidizing oxyacetylene flame to prevent pickup of hydrogen. The joints were allowed to air cool. The weld reinforcement was left on the girth joints which may have contributed to the breakage problems.

Difficulties with variation in springback again were encountered using the ring forming. Since each individual tube length was from a different heat, each tube that made up a welded length had a different curvature after roll bending. Since the ring diameter had to be maintained within 1/8 inch, additional forming operations were required at Battelle-Columbus. The rings were stress relieved in air in a slightly oxidizing atmosphere at 1100 F prior to these additional forming operations.

The diameter and concentricity of the rings were measured using a sizing gage made by scribing a three-meter diameter circle on the surface of a steel table. The table was assembled from 1-inch-thick steel plate. By placing the ring on this scribed circle, variations in the diameter and concentricity of the ring were determined. A hydraulic pipe bender was then used to locally straighten the ring or bend it more as needed. The final diameter and concentricity tolerance was ± 1/8 inch. This was a very tedious and time consuming operation. Two people, working together, required about one week to size each of the four rings.

Prior to sizing, the weld joints that broke during forming were rebeveled and rewelded manually. After sizing, the ends of the ring were trimmed to length and the closure weld was made, also manually. In these manual welding operations, small holes were drilled in the ring so the interior of the ring could be purged with argon to provide protection for the root and backside of the weld. Externally, small auxiliary gas shields were used to blanket the weld area with argon. While argon flows through the welding torch, this gas flow is insufficient to provide proper protection when welding titanium. Thus, additional shielding must be provided. These shields were placed along the sides of the joint and directed a flow of argon across the joint. The shields were, in reality, small boxes made from brass sheet with a square cross section about 1 inch on the side (Figure 2). The side facing the weld joint was made from porous sintered copper. Argon was fed into the box and flowed through the porous copper to cover the joint. A shield was positioned on each of the weld joint and about 3/4 inch from the joint.

The base and front rings were fabricated by Boeing. The base ring was made from six segments plasma-arc cut from 1-inch-thick plate. These segments were joined by manual GTA welding. The front ring was manually GTA welded up from pieces of 1/8-inch sheet. After welding, the rings were stress relieved and the base ring was machined to size. Supporting spiders were bolted to the two rings to provide support during shipping. The front ring spider was bolted to the supporting pads for the secondary mirror spider. Holes were drilled in the base ring for attachment of its spider.

An internal stiffener was welded into the tubular rings at each point on the tubular ring where longitudinal and diagonal tubes would be intersecting. These stiffeners were machined from 1-inch-thick plate. The stiffeners were inserted into slots that were milled in the rings. Fillet welds were made manually to attach the stiffeners to the rings. Auxiliary gas shields again were used to provide additional protection during welding. These shields were straight instead of curved, however, as straight joints were being welded.

Secondary Support Assembly

The assembly of the secondary support was performed in stages. In the first stage, Bays 1, 3, and 5 were assembled individually. In the

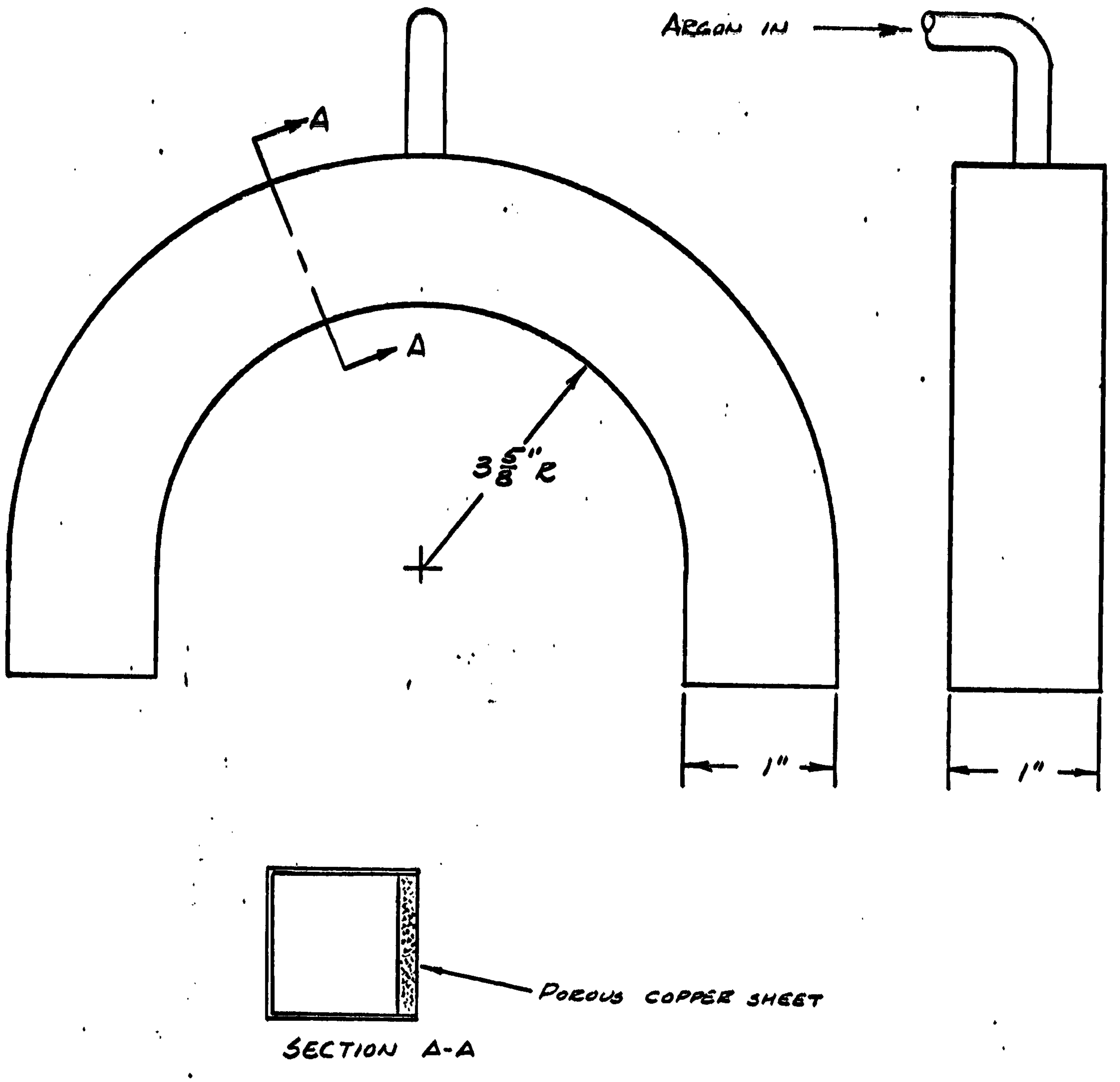


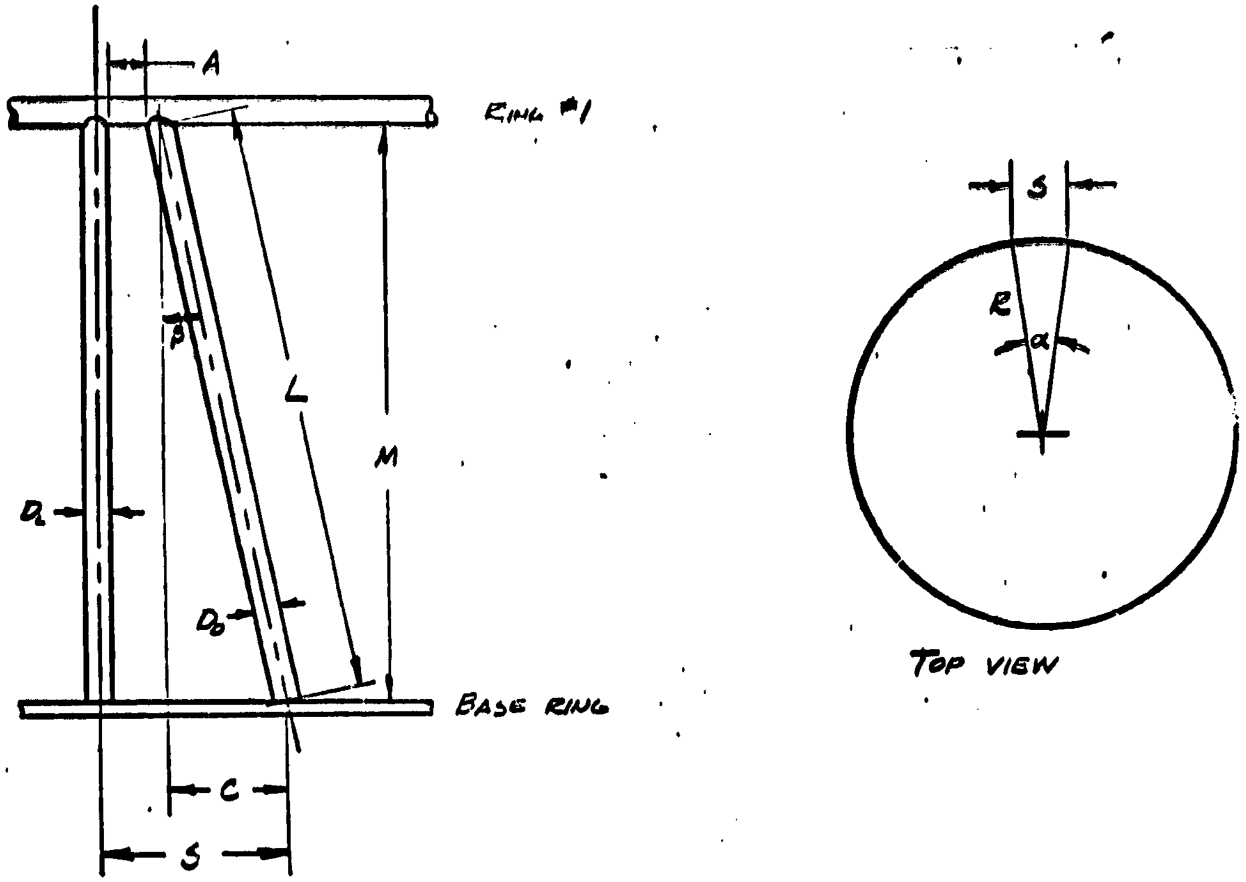
FIGURE 2. AUXILIARY GAS SHIELD

second stage, these three bays were joined together by the diagonal and longitudinal members of Bays 2 and 4.

Bays 1, 3, and 5 were assembled in a vertical orientation. The gaging table used in the sizing of the tubular rings was used as an assembly base. The table also served as a surface plate for aligning the longitudinal members. A special measuring jig was constructed that rested on the table and held the longitudinal members perpendicular to the table surface during welding. One ring of the bay being assembled was clamped to this table. The longitudinal members of the bay were positioned vertically on the ring and tack welded in place. The second ring of the bay was positioned on top of the longitudinal members and clamped in place with long shackle bolts that extended through holes in the table. The diagonal members then were positioned and tack welded. The welds then were completed.

The ends of the longitudinal members were machined to a saddle configuration to fit against the tubular rings. In the longitudinal members, the saddles were oriented 90 degrees to the tube axis. The lengths and angles of the diagonal members in Bays 1 and 5 were calculated as indicated in Figure 3. The dimensions of the diagonal members in Bays 2, 3, and 4 were determined by direct measurement after the longitudinal members had been tack welded in place.

Bays 2 and 4 were assembled by placing the completed Bays 1, 3, and 5 in the horizontal position and joining them with the diagonal and longitudinal members that constituted Bays 2 and 4. A steel frame was fabricated to hold the bays in correct alignment for welding and also to serve as a shipping frame. Bearing-support blocks were positioned under each of the secondary support rings. These were wooden blocks covered with a sheet of Teflon which served as a bearing material so that the bays could be easily rotated to place the joints in a position convenient for welding. The bearing blocks also served to align the bays. Three cross strings were attached to each ring to locate the central axis of each ring. A surveyor's transit was used to sight along the secondary support axis. The heights of the bearing blocks was adjusted as necessary to bring each ring axis in alignment with the secondary support axis as determined by the line-of-sight of the transit. Axial alignment was maintained within 1/8 inch.



FROM DRAWING NO. GE 1297301:

α = ANGULAR SPACING BETWEEN TUBES = 15°

R = RADIUS OF RING = 63.0"

M = RING SPACING = 59.06"

A = 0.75"

$D_L = D_D$ = TUBE DIAMETER = 3.0"

BAY NO. 1

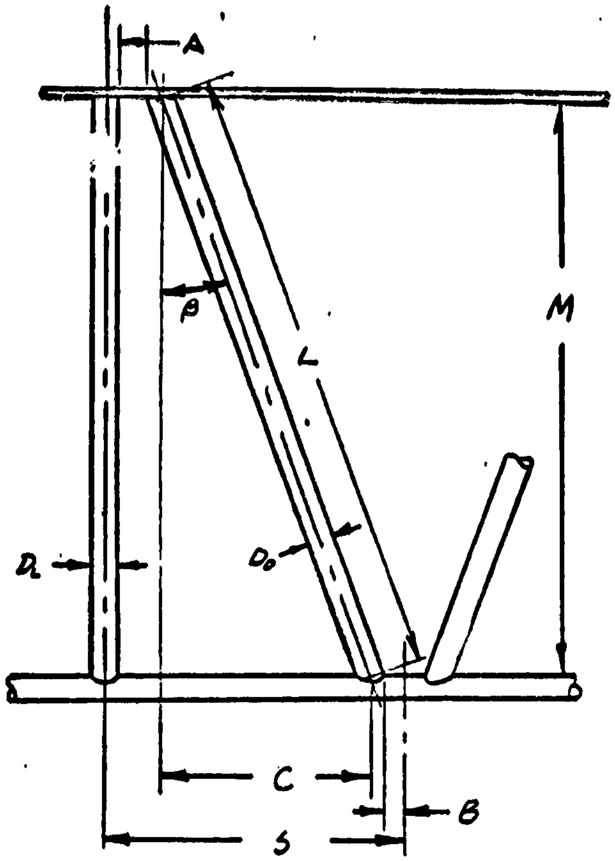
$$S = 2R \sin\frac{\alpha}{2} = 16.5"$$

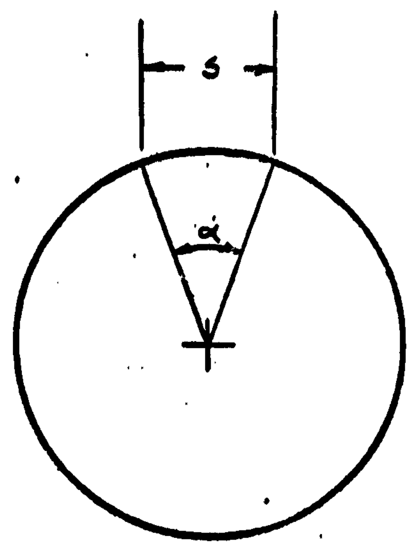
$$C = S - \frac{D_L}{2} - A - \frac{D_D}{2} = 12.75"$$

$$\tan\beta = \frac{C}{M} = 0.216 \qquad \beta = 12.2°$$

$$L = \frac{C}{\sin\beta} = 60.5"$$

FIGURE 3. DETERMINATION OF LENGTH OF DIAGONAL STRUTS





TOP VIEW

FROM DRAWING NO. GE, 1297201:

$\alpha = 20°$

$R = 63.7''$

$M = 60.0''$

$A = 0.75''$

$B = 0.37''$

$D_L = D_O = 2.5''$

$$S = 2R \sin\frac{\alpha}{2} = 22.2''$$

$$C = S - \frac{D_L}{2} - A - \frac{D_O}{2} - \frac{D_O}{2} - B = 17.3''$$

$$\tan\beta = \frac{C}{M} = 0.289 \qquad \beta = 16.1°$$

$$L = \frac{C}{\sin\beta} = 62.5''$$

BAY NO. 5

FIGURE 3. (Continued)

All welding was done manually. Small holes were drilled in each tubular member so that the interior of the member could be purged with argon or helium. Helium was used when the upper ends of the tubes were being welded. The helium would rise to the upper ends to provide better protection. Conversely, argon was used when the bottom ends of the tubes were being welded. Auxiliary gas shields were used as described previously to shield the joint externally. All welds were single-pass fillet welds with 1/16-inch-diameter filler wire fed manually into the joint as needed. Prior to welding, each joint was degreased with acetone and cleaned with an air-powered stainless steel wire brush.

All secondary mirror support welds were inspected visually to detect any undercut or overlapping folds, check weld surface color and fillet weld size. Twenty percent of the welds were dye-penetrant inspected following MIL-1-6866B, Inspection, Penetrant Method, to detect any cracking.

PRIMARY MIRROR SUPPORT

The primary mirror support was wheel shaped with 12 radial arms connecting the hub with the rim (Figure 4). The diameter of the support was 131 inches. The hub and rim were channel rings made by welding two flat 1/2-inch-thick flange rings to a 3/8-inch-thick web ring. The radial arms were I-beams fabricated by high-frequency resistance welding. The I-beams had 1/4-inch-thick webs and 3/8-inch-thick flanges. The ends of the I-beams were welded to the hub and rim. Forty-eight support arms were bolted to the raidal arms. The support arms were welded modified channel sections made from 1/4- and 3/8-inch-thick plate.

The components of the primary mirror support were machined and flame cut from the various thicknesses of plate. Machining was used to cut all straight sections and the hub flanges. The rim flanges were flame cut in segments to be subsequently welded together to form the complete flange. The segments were deliberately flame cut oversized so that the flame-cut edges and heat-affected zones could be machined away to remove material embrittled by the flame cutting. Before machining, the flame-cut segments were stress releived. This was found to be necessary to prevent distortion

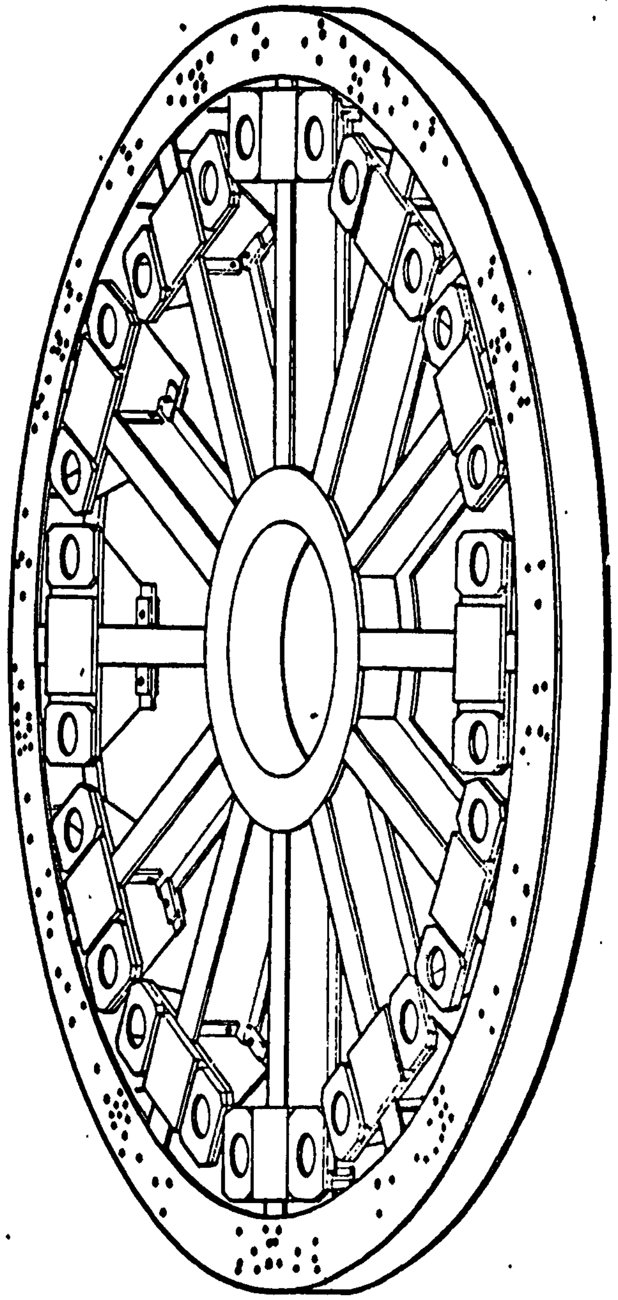


FIGURE 4. PRIMARY MIRROR SUPPORT

of the parts during machining. Long straight sections were cut on a planer. Small sections were sheared to rough size and shaped to final size. The sheared edges were not square so subsequent machining was necessary.

The radial arms were fabricated by high-frequency resistance welding of the two flanges to the web. This is a high-speed welding process that utilizes high efficiency heating of high-frequency (450 kHz) electric current. These beams were welded at a speed of 40 feet per minute. Welding procedures were utilized that had been developed for the Air Force on Contract No. AF33615-70-C-1416. The I-sections were made in 30-foot lengths and then cut and machined to the length required for the radial arms. This process was used as it is many times faster than arc welding and the welded component can be made with much less distortion than would occur in a similar arc welded component.

Fillet, corner and butt arc welds were used to assemble the primary support components. The butt welds were used to join subcomponents of parts too large to be machined from a single piece of plate (rim and I-beam flanges and webs). All welding was done by the GTA process; all welds were made manually except for the welds joining the components of the support arms. These latter welds were made automatically. The butt joints were double vee with 60-degree included angle, 1/64-inch root face and 1/16-inch root opening. The butt joints were made in four passes with filler wire being added to each pass. The fillet welds were made in two passes. The first pass was made without filler, the second pass with filler. Auxiliary gas shields of the type used in welding the secondary minor support were used to protect the joints during welding. The support arms were held in jigs during welding to minimize distortion. Other components were held in alignment by tack welding.

The primary support was assembled on the gage table with the table serving as a surface plate to assist in locating the components in a flat plane. The components were clamped to the table with spacer blocks being placed between the components and the table. The heights of these blocks were varied as necessary to keep the components in a flat plane.

In the assembly sequence, the radial arms, the hub flanges, and the rim flanges were positioned on the table and tack welded. The ends of the arm webs were welded to the flanges. In the next step, the stiffener gussets were welded in place between the rim flanges. Finally, the rim and hub webs were added to the assembly and tack welded. The following step would have been the completion of the welds attaching the rim and hub webs to the assembly and the radial arm flanges to the rim and hub flanges. However, the program was terminated before these welds were made.

QUALITY ASSURANCE

A quality assurance system was prepared to meet the requirements of the Defense Contract Administration Services Office in Columbus. This system covered purchasing and receiving operations, receiving inspection, material control, welding inspection and qualification, corrective actions, and acceptance and rejection criteria.

As far as this program was concerned, the significant part of this system was welding inspection and qualification and the acceptance and rejection criteria. Prior to welding, the welding procedures and personel were evaluated to determine if the quality of the welds that were produced were acceptable. These welds were examined visually and radiographically and the bend and tensile properties of the welds were determined. All welds met these requirements and all tensile specimens failed in the base metal indicating that the weld was stronger than the base metal. The welds made in the secondary and primary structures were inspected visually and with dye penetrant as indicated previously. Only a few repairs were required to correct some undercut that occassionally occurred.

PROGRAM COMPLETION

Several items contemplated were not done since the LST program at GSFC was cancelled before fabrication of the structures was completed. These were:

(1) Both completed structures were to be stress relieved by Boeing.

(2) The mating surfaces of the secondary and primary mirror supports were to be machined at Boeing. This machining was to include drilling bolt holes for the joining of the two structures.

(3) Welding of the primary mirror support was not completed. All of the parts were assembled but some of the parts were only tack welded. Thus, the primary support structure could be used at least for display purposes.

The secondary mirror support structure was shipped to GSFC after welding was completed; the primary mirror support structure was shipped to GSFC at the completion of the program.

* * * *

Data are recorded in Battelle Laboratory Record Book No. 29230.