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DESIGN AND FABRICATION OF A LOW-SPECIFIC-WEIGHT PARABOLIC DISH SOLAR CONCENTRATOR

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SUMMARY

A segmented design and fabrication and assembly techniques were developed for a 1.8-m- (6-ft-) diameter parabolic concentrator for space application. This design and these techniques should be adaptable to a low-cost, mass-produced concentrator. Minimal machining is required. Concentrator segments of formed magnesium were used. The concentrator weighed only 1.6 kg/m^2 (0.32 lbm/ft^2).

INTRODUCTION

The development of Brayton-cycle space power systems is being pursued at the Lewis Research Center in order to provide reliable electric power for space applications. Development of these systems has been oriented toward an isotope heat source. A solar-powered Brayton power system would provide a lower cost alternative to the isotope-powered system. A prototype 6-meter- (20-ft-) diameter solar concentrator was designed and fabricated for a 2- to 10-kilowatt Brayton-cycle power system. At the time this prototype was developed, it was considered an advanced design with a specific weight of 5 kg/m^2 (1 lbm/ft^2). Extensive machining was required to obtain this specific weight.

A program was begun to further the state-of-the-art of lightweight solar concentrators. Under this program a 1.8-meter- (6-ft-) diameter parabolic solar concentrator was developed that required minimal machining. This concentrator is applicable to the mini-Brayton system currently under development (ref. 1) for the 0.5- to 2.5-kilowatt-electric power range. This system requires a solar concentrator with a projected surface area of 7.5 square meters (81 ft^2) to supply the 7.2-kilowatt-thermal input required to produce a 2.5-kilowatt-electric output. Temperatures measured at the focal plane were greater than 1370° C (2500° F) within a 3.81-centimeter (1.5-in.) diameter area during ground tests in sunlight.

This report details the segmented design and the fabrication and assembly techniques used in developing the 1.8-meter- (6-ft-) diameter solar concentrator. These techniques are well suited to low-cost construction.

CONCENTRATOR DESIGN

The concentrator is a 1.8-meter- (6-ft-) diameter paraboloid of revolution with a 0.9-meter (3-ft) focal length, on a 55° rim angle. The diameter was limited by the size of the machines available for generating the mirror-segment-forming die.

The 0.9-meter (3-ft) focal length is compatible with material formability limits and the design objectives, which were

(1) Minimal specific weight
(2) Minimal machining time
(3) Minimal requirements for special tooling and facilities
(4) Maximum geometric accuracy
(5) Reflective side of concentrator free of toolmarks and surface distortion

These objectives reflect three factors that are paramount in the design of a solar concentrator: efficiency, weight, and cost.

The theoretical minimum size of a solar concentrator is determined by the specific thermal output requirements of the heat receiver based on 100 percent concentrator efficiency. In actual practice, the theoretical size is increased to account for the losses resulting from imperfections, surface defects, and geometric inaccuracies. The resultant efficiency establishes the size of the concentrator, which also establishes the specific weight.

Specific factors that contribute to concentrator inefficiency include

(1) Absorption losses due to reflective and protective coatings
(2) Diffuse reflectance due to surface irregularities and imperfections (total reflectance is equal to specular plus diffuse reflectance)
(3) Localized surface error due to toolmarks; and distortions due to physical restraint and thermal effects (net effect is misorientation at focal plane)

The losses due to the first factor were considered as fixed and beyond the scope of this program. The effects of factors 2 and 3 could be minimized by discarding some of the design and fabrication techniques used in the past.

Previous rigid-concentrator concepts were based on a design in which the parabolic shell consisted of an assembly of sectors that were bolted or bonded together, depending on the diameter. A continuous rim attached to the assembled shell provided additional stiffness and mounting points. Each sector incorporated an integral support structure on its underside. In one concept, this support structure was of bonded honeycomb, a sandwich construction wherein the honeycomb is bonded between two formed aluminum sheets. In another concept, a sector was machined from a single 2.54-centimeter- (1-in.-) thick magnesium plate and formed to shape. A waffle-pattern, integral support structure was machined on the underside of the sector. In either case the designer had to make a trade-off between weight and concentrator surface quality. The intent was to minimize material thickness. Although both integral support structures provided strength and stiffness, localized distortion problems resulted from surface temperature gradients.

In previous concentrator concepts, the reflective surface was subjected to continuous handling in the fabrication process, increasing the potential of damage and surface degradation. Although the reflective surface was coated with a sprayed plastic film to improve surface quality, the film would reproduce scratches and toolmarks. The film was effective only in leveling minute defects and large surface graininess. Finished surfaces require precise quality control throughout fabrication in order to minimize surface degradation.

The design selected for this concentrator has a fabricated, unitized parabolic structure. The design incorporates the following desirable weight and cost reduction features:

(1) The number of parts is held to a minimum.

(2) All parts are made by commercial fabrication techniques.

(3) Sectors are made from select sheet stock and require minimum handling.

(4) The only special tooling required is for forming of the petals.

(5) Sectors do not incorporate dissimilar materials; varying cross-sections; or residual stresses or stress risers, which are instrumental in creating local distortions.

CONCENTRATOR DEVELOPMENT

Development of the concentrator involved extensive investigation of materials, structural design, and assembly processes. Magnesium was selected as the structural and parabolic surface material. Three properties of magnesium make it an ideal material for this application: its strength-weight ratio, creep properties, and formability at low temperatures. Magnesium can be easily formed over a die heated to 260° C (500° F) by using only a vacuum to pull the material into shape. Magnesium does not warp or distort during cooling after it has been formed. The only major disadvantage of magnesium for this application is the difficulty encountered in developing a suitable joining technique.

Structural Design

The concentrator design incorporates six major component assemblies:

(1) Surface petals (12)
(2) Radial struts (12)
(3) Hub (1)
(4) Outer rim (1)
(5) Intermediate circumferential struts (12)
(6) Outer locking ring (1)

The concentrator surface consists of 12 identical petals, or segments. Each segment is 30° of the parabola. The segments are formed from standard stock 0.051-centimeter- (0.020-in.-) thick AZ31B-H24 magnesium sheet. Finished thickness is approximately 0.043 centimeter (0.017 in.).

The radial struts are I-beam structures placed between the concentrator segments and are the main structural elements in the design. The concentrator segments fit freely into slots in these struts. The concentrator segments are not distorted at these joints because they are in a nonrestrained, or floating, condition and the exposed area of the struts is contoured to continue the parabolic shape.

Each radial strut actually consists of four pieces, as shown in figure 1. The T-shaped pieces are milled (for this concentrator), or can be extruded, and are joined to the 0.102-centimeter- (0.040-in.-) thick web. The T-shaped members are used for the top and bottom of the I-beam and also at the outer end for fastening to the outer rim. At the center of the concentrator the concentrator segments and radial struts are joined to the hub as shown in figure 2. The hub is the mounting point of the mirror; there are no additional supports around the periphery. A small cover is used to help hold the radial struts to the hub. The outer ends of the radial struts are bonded and riveted to the outer rim by using a U-channel formed from 0.102-centimeter- (0.040-in.-) thick magnesium. The outer rim supports the concentrator segments at the circumference and positions the radial struts. The outer rim is shown in figures 3 and 4.

The intermediate circumferential struts are shown in figure 3. These struts stiffen the radial struts but do not contact or support the concentrator segments. The assembly shown in figure 3 is the complete support structure; only the concentrator segments and the outer locking ring are required to complete the assembly.

The outer locking ring is a machined U-channel (fig. 4) that joins the mirror segments to the outer rim, locking the segments in position. It fits circumferentially around the entire structure.

Investigation of Fabrication Techniques

Several techniques for joining the concentrator segments and the support structure were investigated. Welded construction was unsatisfactory for several reasons. Magnesium, an alkali metal, is chemically reactive and must, therefore, be welded under a controlled environment to eliminate fire safety hazards. Additionally, because of its rapid oxidation, it is difficult to maintain a sufficiently clean surface for welding. Gas tungsten-arc welding produced significant distortions in the concentrator geometry. Resistance or spot welding produced local distortions in the weld areas. Also, a large spot size was necessary to ensure an adequate weld due to the rapid oxidation of the metal. Spot welding of components was considered unrealistic.

Riveted construction was also investigated, including pop rivets, hand riveting, and rivet guns. Riveting the concentrator segments caused severe surface distortion; in one instance, 50 percent of the surface would not focus satisfactorily. The holes could not be punched because of distortion and had to be hand drilled.

Bolting techniques were tried. This reduced distortion slightly and allowed larger hole tolerances than did riveting. But surface distortion was still unacceptable, and the assembly of several hundred bolts with washers, lock washers, backup plates, and countersinking was unrealistic.

A design using formed interlocking pieces was also investigated but was rejected. The granular structure of magnesium precludes small bending radii except at elevated temperatures. Thus, the framing fixtures requires to obtain the required shapes would have been quite complex and inconsistent with the objective of low cost.

Adhesive bonding was finally selected as the primary joining technique for concentrator assembly. An epoxy adhesive was used with an aluminum filler to improve thermal conductivity. Uniform thermal conductivity is desirable to eliminate stress and warpage caused by temperature differentials. In the segmented concentrator design, most joints are of tongue-and-groove construction, so the adhesive does not see high stresses. The structural elements were also riveted to each other as a backup for the adhesive bonding. The adhesive adds rigidity but is not required to hold the concentrator together.

As previously mentioned, riveting can cause unacceptable distortion of the magnesium. The riveting used for the support structure did not affect the optical surface. The rivets are a positive locking device and are used because of the uncertainties of vibration effects during flight. Chemical cleaning of magnesium is required prior to epoxy bonding in order to remove the oxide film on the magnesium. This oxide film adversely affects bond strength.

Fabrication

All components of the concentrator except the concentrator segments were machined or formed. In an earlier concentrator program, the petals were also machined from

AZ31B-H24 magnesium tool stock, but the structure was heavy and the machining costs were too high. A thin magnesium sheet can be formed at low (260° C, 500° F) temperature and pressure (103.4 kN/m^2, 15 psi) on a die with improved accuracy and greatly reduced cost as compared with the machined concentrator.

An aluminum die was made on a 1.8-meter (6-ft) vertical lathe. An accurate parabolic template was used to control the lathe, and an aluminum block larger than a concentrator segment was machined. Heaters were installed in the block, and vacuum passages were added to distribute the forming pressure (fig. 5). The concentrator segments would distort at the vacuum slots in the forming die, so a 0.152-centimeter- (0.060-in.-) thick magnesium sheet was formed over the die, with 0.034-centimeter- (0.0135-in.-) diameter holes drilled over the vacuum slots to distribute the vacuum and eliminate the distortion. This distribution sheet is a permanent part of the die (fig. 6).

The concentrator segments were rough cut from 0.050-centimeter- (0.020-in.-) thick magnesium sheet and were approximately 2.5 centimeters (1 in.) oversize on all exterior dimensions. The sheet was lapped (fig. 7) before it was cut in order to smooth the surface. The sheet was then placed lapped side down on the die and taped in place with special high-temperature tape to form a vacuum seal. A locating pin was used to allow accurate placement for later trimming. (A segment on the die ready for forming is shown in fig. 8.) After forming, each segment was clamped on a wooden mandrel for trimming. A low-speed slitting saw following a radial guide was used in an overcutting mode (figs. 9 and 10) to make the radial cuts without deforming the segment edges. Circumferential edge trimming was accomplished with a high-speed mill as the segment was rotated slowly on the vertical lathe (fig. 11).

Assembly

The concentrator was assembled over a wooden mandrel. The hub was placed in the center and the radial struts were assembled. Bolts were used to temporarily position the parts (fig. 12) while the outer rim and intermediate circumferential struts were assembled. All the rivet holes were drilled. The components were then disassembled; final assembly was performed using epoxy and rivets. A special nozzle was built to inject the epoxy into the segment grooves in the radial struts (fig. 13). This support structure was then completely self-supporting (fig. 14) and was ready for final assembly with the concentrator segments and the outer locking rim, which are bonded in place. The final operation is the application of the epoxy and aluminum coatings on the concentrator front surface.

Magnesium itself cannot be polished to a high-quality mirror finish. To attain better optical quality, a coating process developed for a 6-meter- (20-ft-) diameter magnesium mirror (ref. 2) was used. Basically, the surface was chemically cleaned and sprayed with an epoxy coating to level it and to make it glasslike, that is, free of scratches and defects. An aluminum film was then vapor deposited on the epoxy to achieve a highly reflective surface. The coatings were applied after the concentrator was completely assembled, but they could be applied to the individual segments before assembly. If required, a silicon monoxide film could then be added to protect the aluminum coating. (The completed solar concentrator, including the support stand, is shown in figs. 15 and 16.)

Although the design and fabrication techniques used for this concentrator were oriented toward space application, they can also have terrestrial uses.

CONCLUDING REMARKS

This design effort produced an ultra-lightweight parabolic dish concentrator. Ground test measurements showed a focused temperature of 1370° C (2500° F) within a 3.81-centimeter (1.5-in.) diameter area. This design is well suited for low-cost production because elaborate or extensive machining is not required. The concentrator segments are produced by a simple forming operation. The segmented design requires minimal machining.

The concentrator is completely self-supporting, with a specific weight of only 1.6 kg/m^2 (0.32 lbm/ft^2). With the fabrication and assembly techniques developed, magnesium is an ideal material for this application, although other materials such as aluminum, plastics, or glass could be used.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 11, 1977,
778-32.

REFERENCES

1. Mroz, Thaddeus S.; and King, Robert B.: Polymer-Film Coating of Magnesium for Parabolic Mirrors. NASA TN D-4734, 1968.

2. Macosko, Robert P.; et al.: Isotope Brayton Electric Power System for the 500 to 2500 Watt Range. NASA TM X-68072, 1972.

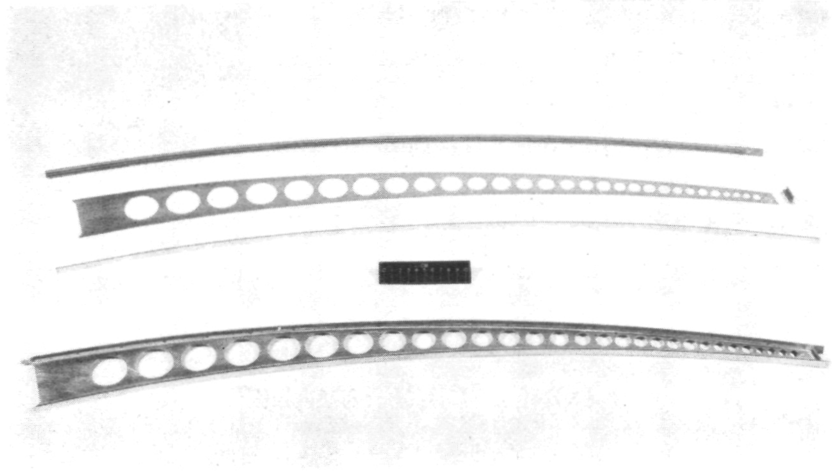

Figure 1. - Radial strut before and after assembly.

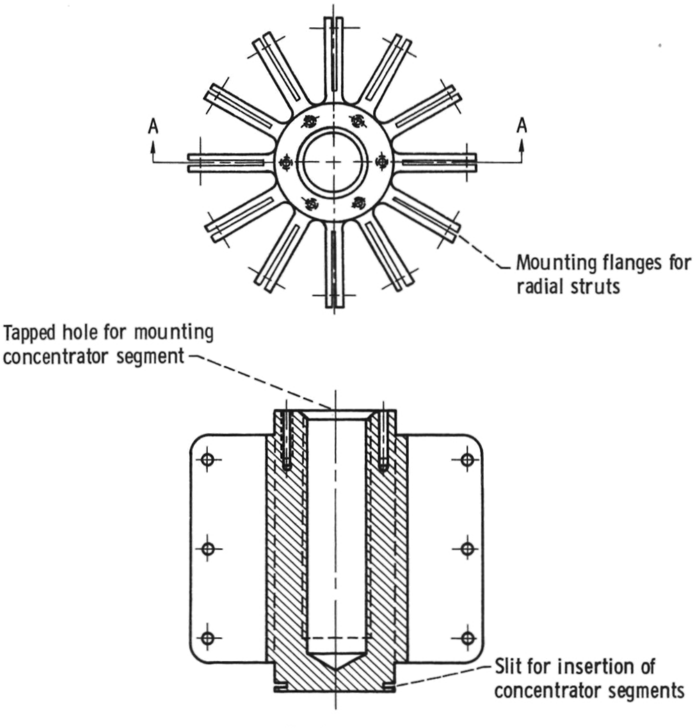

Figure 2. - Joining of concentrator segments and radial struts to hub.

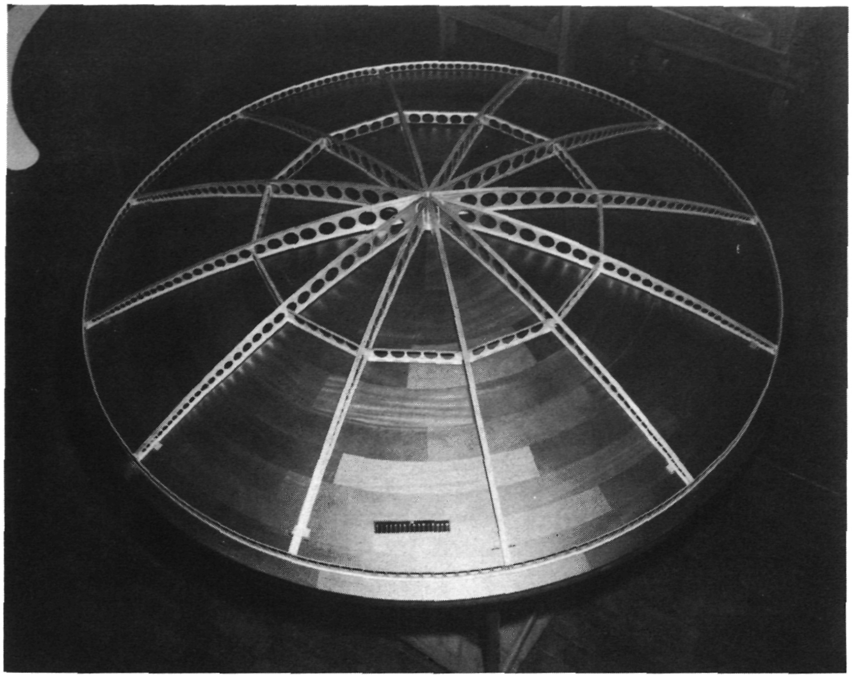

Figure 3. - Complete assembly of support structure.

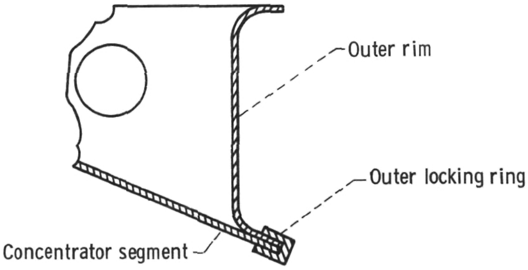

Figure 4. - Details of outer locking ring assembly.

Figure 5. - Petal-forming die complete with heaters, thermocouples, and vacuum slots.

Figure 6. - Petal-forming die with attached distribution sheet.

Figure 7. - Polishing of concentrator segment.

Figure 8. - Concentrator segment taped to forming die.

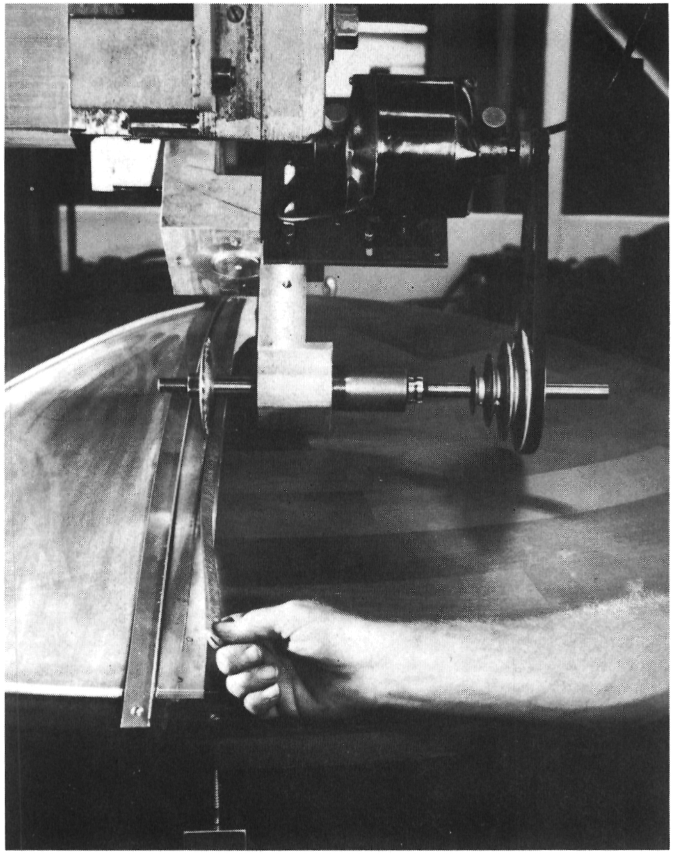

Figure 9. - Radial trimming of concentrator segment.

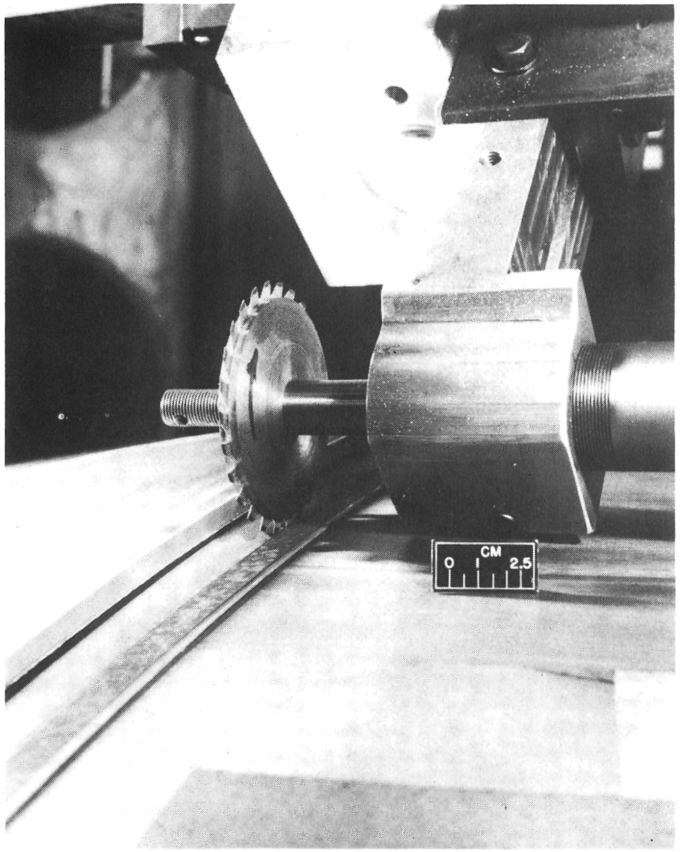

Figure 10. - Slitting saw used for radial trimming of concentrator segments.

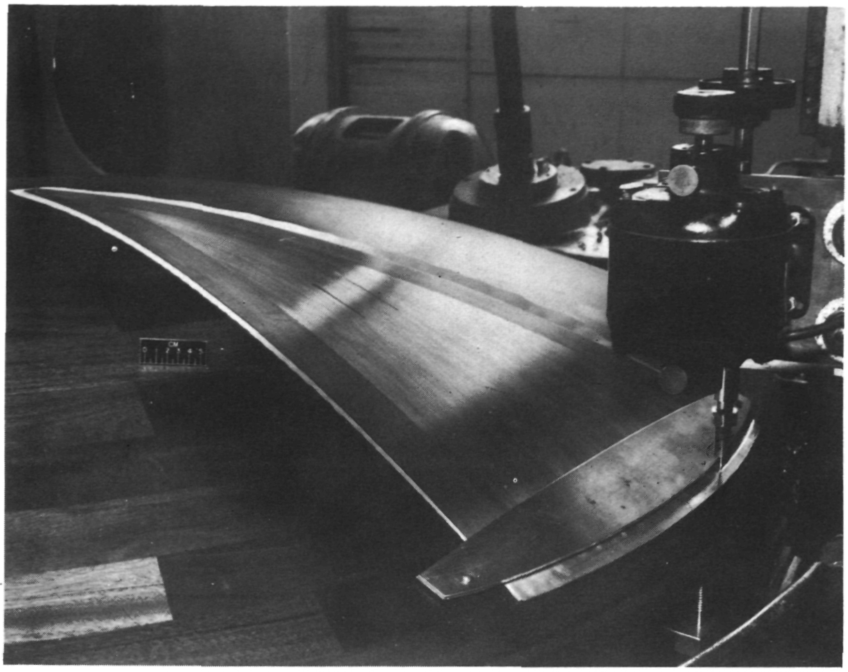

Figure 11. - Circumferential trimming of concentrator segment.

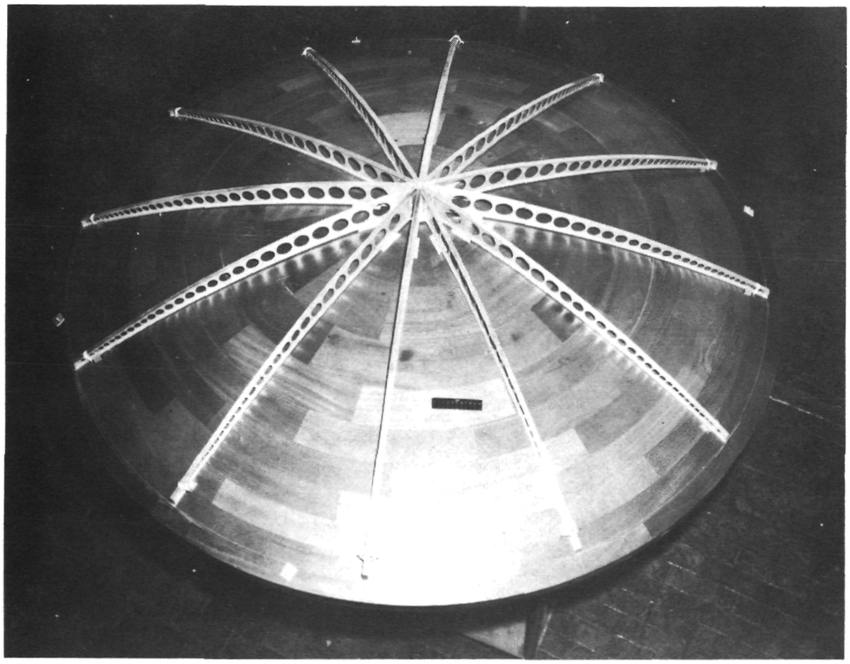

Figure 12. - Central hub and radial strut assembly on wooden form.

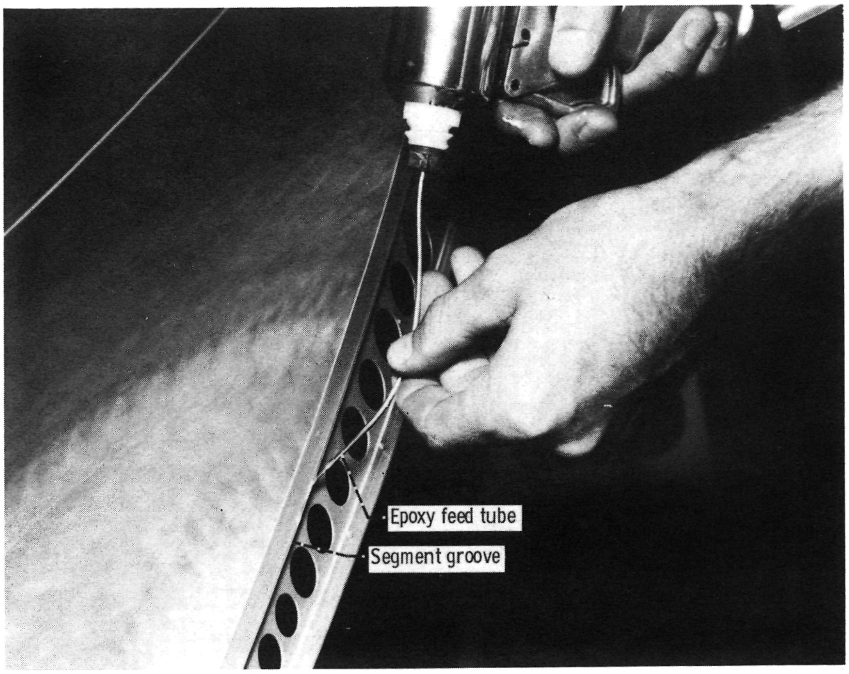

Figure 13. - Injection of epoxy adhesive into segment groove of radial strut.

Figure 14. - Concentrator support structure.

Figure 15. - Front view of assembled concentrator.

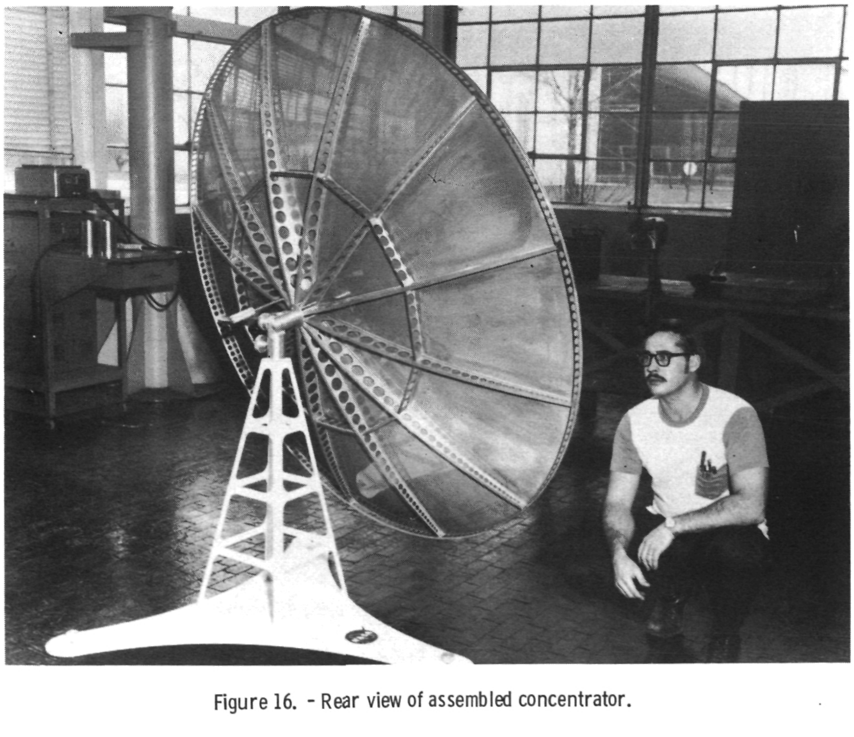

Figure 16. - Rear view of assembled concentrator.

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