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MODEL NO. R & D CONTRACT NO. NAS 7-165

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## I SUMMARY

The objective of this program was to fabricate a high optical quality, lightweight solar concentrator using a five-foot diameter glass convex master as a reference optical surface. The concentrator was to be made by extending an existing Boeing process which employs filled epoxy resin, aluminum honeycomb, and fiberglass cloth, to include the use of a glass master. The glass convex master used as a reference optical surface was supplied by NASA for use in this contract.

The lightweight concentrator to be fabricated in this program was scheduled for delivery to NASA-Langley for evaluation.

Although the complete objective of the program was not realized, significant refinements in the replica process were made. Several succesaful aspects of the program were; excellent replication of the optical surface of the glass master on the filled-epoxy substrate, successful demonstration of preparation and support techniques developed for use of glass masters and development of a new spraying technique for applying the multiple layers of epoxy resin which form the optical substrate.

Proof of compatability of the Boeing replication process with glass masters was demonstrated by making several 8 inch diameter specimens and a 1/5 scale model concentrator on glass masters. In all cases the substrate was intact after curing and cooling. Nothing was disclosed in these precautionary experiments to indicate that difficulty would be experienced in proceeding with fabrication of the 60 inch diameter concentrator. However, the filled-epoxy optical substrate of this larger concentrator ruptured while cooling after exposure

to the same high temperature cure cycle which was used successfully for fabricating the 1/3 scale model.

It has been concluded that the loss was due to the effects of larger than anticipated tensile stresses which developed because of the difference in contraction on cooling between the glass master and the filled epoxy optical substrate. Reactions of this type had not been experienced previously on 60 inch replications because filled epoxy masters having the same contraction characteristics as the optical substrates were used.

There is sufficient lattitude in the choice of cure temperature for epoxy resins, (particularly as is true in this usage where the service loads are light and the temperature to which the product will be exposed is low), to elect the use of a lower cure temperature which will provide sufficient relief from the contraction differential problem to insure successful fabrication of lightweight parabolic concentrators by the Boeing process from glass masters. Although high temperature (300 - 400°F) cure temperatures are normally used for epoxy-fiberglass structural laminates, the requirement for this thermal treatment for replica substrate applications such as ours has not been established. In fact, curing at high temperature on large glass masters appears to degrade rather than enhance the Boeing replica mirror process.

By limiting the maximum cure temperature to 250°F and making other minor adjustments during the cure, the problem associated with the use of a glass master is expected to be overcome. The other components of the concentrator including the honeycomb-fiberglass sandwich, the stiffening rim, and the support brackets are still useful because they were not assembled to an optical substrate. The availability of these items, representing a major cost of the program, minimizes the cost of making another concentrator because only the substrate need be formed. It is felt that because of the minimum cost required and the nearness to completion of a good concentrator, that this program should be continued.

## II INTRODUCTION

The work described in this report was done to fulfill NASA Contract No. NAS 7-16[illegible] and Mod. 1 to the contract. A general description of the work to be accomplishe[illegible] is given in Ref. 1 entitled, "Fabrication of Lightweight Parabolic Concentrators From a Glass Master ". Ref. 1 was originally submitted in response to Jet Propulsion Laboratory (JPL) RFQ 14191 which covered a much broader scope of work than was required in this contract. The existing contract required only the delivery of one five-foot diameter lightweight concentrator and this final report.

Techniques for fabricating lightweight solar concentrators with suitable optical quality to power thermionic converters in space, have been developed at Boeing over the past four years. After considerable experimentation with various processes for fabricating concentrators, a replica technique employing filled-epoxy resin, fiberglass, and aluminum honeycomb was chosen. This replication process and these materials were chosen for four primary reasons; (1) an excellent optical surface replica can be made from either a concave or convex tool; (2) the structural strength and design of the concentrator can be varied to satisfy nearly any environmental requirement; (3) the weight can be made low due to the low densities of the materials involved; and (4) the

materials are nonmagnetic, a desirable feature for most space experiments.
Since the primary object of the contract was to demonstrate feasibility, it decided to obtain the best possible optical quality and more-than-adequate structural strength. This would result in a concentrator weight slightly higher than that which would be obtainable with a structurally and opticall optimized design.

Prior to the contract Boeing fabricated and tested a five-foot diameter str tural prototype concentrator. This prototype was subjected to and withstoo both static and dynamic tests outlined in the original JPL RFQ 14191. The detailed results of these tests were presented in the appendix of the final report (Ref. 2) on the first pahse of this contract.

## III ACCOMPLISHMENTS

### A. Glass Master Preparation

The potential problems associated with the use of a glass master were consid so that the master would not be damaged or broken during the fabrication process. The following environmental conditions had to be withstood by the master and its associated mounting structure during the fabrication process:

1. Temperatures as high as 300°F;
2. Suspension of the glass by its periphery in any of three orthogonal directions;
3. Pressures as low as $1 \times 10^{-6}$ Torr;
4. A force on the convex surface of 0.5 psi in the axial direction of the paraboloid.

The high temperature is encountered when curing the epoxy resin. The suspension requirement is dictated by the fact that the convex surface must face downward during vacuum deposition of a silver parting film and must face upward during resin application. High vacuum is encountered during vacuum deposition. The requirement of reacting to 0.5 psi by peripheral supporting results from vacuum bagging when the honeycomb-fiberglass paraboloidal sandwich is bonded to the resin substrate on the glass.

The technique for supporting the glass master which best satisfied the above environmental conditions involved potting the edge of the glass into a steel support ring assembly with a silicone potting compound (General Electric RTV-40) A scale drawing of the support ring assembly is shown in Fig. 1. One feature is that the glass does not touch the metal support rings at any point. This is important because of the difference in coefficient of expansion between glass and steel. The gap of about 1/4 inch between the glass and the rings was filled with RTV-40 as shown. The steel clips which extend over the edge of the glass were also covered with RTV-40. These clips would have prevented the glass master from falling out of the ring assembly in the event of potting compound failure when the master was in a convex down position. The RTV-40 potting compound served a second purpose in addition to supporting the glass; it provided a feather edge transition from the glass to the support assembly, thus preventing trapping or bonding of the epoxy resin to the edge of the glass. It should be noted that the vacuum deposited silver parting film covered both the glass and RTV-40 compound.

The procedure which was followed in preparing the glass master for layup of epoxy resin is described below. After a thorough chemical cleaning the master was placed in the ring assembly as shown in Fig. 1. All of the potting operations were carried on in a clean room. A number of 1/4 inch thick RTV-40 spacers were placed between the concave side of the glass and the support rings. Then, the edge volume was filled with RTV primer so the pri coated about a one inch wide circumferential strip of the edge of the conve surface. The application of primer is shown in Fig. 2. The filling ring w clamped onto the assembly during this operation to provide a dam for the RT primer. This forced the primer higher up on the glass master. The primer was then drained out and the film was left to dry for 2 hours. Then, the edge volume was filled with RTV-40 so that a 3/4 inch wide circumferential strip of the glass was covered. Care was taken to keep the level of RTV-40 below that of the primer. Application of the RTV-40 compound is shown in Fig. 3. The final step in the potting operation was to remove the filling ring and allow the RTV-40 to flow down over the edge of the support rings a clips. The result was a complete coating of RTV-40 on the support rings an the edge of the glass. After the RTV-40 had gelled, the master and support ring assembly were taken from the clean room and placed in a vacuum coater where a parting film of silver and a protective film of silicon monoxide wer applied. These films covered both the glass and the potting compound. The coated master was then removed from the vacuum chamber and placed in a 160°F oven where the coatings of epoxy resin were applied. Fig. 4 shows the glass master in the oven prior to the layup. This completes the discussion on the preparation of the glass master.

## B. CONCENTRATOR FABRICATION

Fabrication of the solar concentrator which included layup of the optical substrate onto the glass master, fabrication of the honeycomb-fiberglass san wich and its stiffened edge, fabrication of the support brackets, and the assembly of these components, has been treated in detail in Refs. 1, 2. and 3 and will not be discussed here. An assembly drawing of the concentrator identifying the various components is shown in Fig. 5. The honeycomb-fiber-glass paraboloidal sandwich and rim stiffener were successfully fabricated before the optical substrate layup was started. This would allow the sandwich to be joined to the optical substrate as soon as the substrate was cured. However, since a good optical substrate was not made at this time as will be subsequently explained, the sandwich, rim, and brackets are still available for assembly to a good optical substrate. It should be noted that immediately prior to contract work the complete process was successfully demonstrated on both 8 and 20 inch diameter glass masters. The stresses on these smaller trial parts were apprently low enough to avoid rupture.

The first layup of an optical substrate was done by spraying the first two coats of filled epoxy resin and brushing the remaining layers onto the glass master. The first two coats were applied by spraying to minimize the chance of disturbing or scratching the silver parting film. This layup was aborted during application of the second brush coat after a small piece (3/8 inch diameter) of silver parting film was lifted from the master when removing a brush hair. After this occurrence it was decided to abandon the brushing completely and to spray all coats of resin. A trial layup in which all coats were sprayed onto a 20 inch diameter glass master produced a good optical surface. From this it was concluded that the next optical substrate would be formed by spraying all coats. The advantages of the spraying technique are: (1) it minimizes the possibility of disturbing the silver parting film on the glass master; (2) it allows thinner, more constant thickness coatings to be applied; and (3) it shortens the length of time that shop personnel must be exposed to hot ovens during resin application. It is believe that the spraying technique developed herein is a significant improvement to the Boeing process.

After the second layup of an optical substrate by spraying all coatings and curing, a fracture was experienced while cooling. The loss as described below. was not attributed to the spraying technique for forming the substrate. The spray technique resulted in a good optical surface and a constant substrate thickness. An explanation for the loss of the substrate follows:

The layup of the multilayer, filled-epoxy substrate onto the glass master was successfully completed. A typical high-temperature cure cycle was then run in which the resin was subjected to 180°F for two hours, 250°F for two hours, and 300°F for four hours. Care was taken in this thermal cycle to assure uniform part temperature and reasonably small temperature changes per unit of time. After the 300°F cure the temperature was slowly reduced. During this reductior in temperature, the epoxy optical substrate exhibited cracking due to the effects of tensile stresses. The crack occurred at a temperature of 125°F, with an elapsed time of 7 hours after the reduction from 300°F began. It was observed from fractured sections of the epoxy optical substrate that the replic optical surface was of excellent specular quality as expected. It is assumed that the high stresses preceeding the loss were due to the larger than expected difference in contraction between the glass master and the filled-epoxy substrate. This problem had never occurred previously because epoxy masters having the same contraction characteristics as the substrate were used on 60 inch diameter replications.

It is believed that three factors contributed to the loss; first, and probably most important, the 300°F post-cure temperature which is a desirable heat treatment for this epoxy resin in other applications, may be detrimental to the resin when compounded with our fillers and used for large solar concentrator configurations. Second, the rate of cool down from the 300°F cure temperature was too fast for the resin compound to obtain stress relief as a function of time. Third, although no significant thermal gradients were detected on the concave surface of the glass master which was monitored, there may have been convection currents in the curing oven which caused a small but critical thermal gradient between the glass master and the exposed convex surface of the resin.

The cure cycle will be altered sufficiently in the fabrication of future concentrators to retain high specular surface characteristics, and to eliminate the possibility of the substrate cracking during cool down.

## IV CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were made as a result of work accomplished in the contract:

1. The honeycomb-fiberglass paraboloidal sandwich and its associated stiffening rim can be successfully fabricated using an existing epoxy convex tool, for use with an optical substrate formed on the glass master;

2. The support ring assembly and potting technique for holding the glass master worked satisfactorily;

3. A new spraying technique used for applying resin to the glass master was a significant improvement in the process;

4. The cause of the substrate loss was the difference in contraction between the filled-epoxy and glass. Thus it was concluded that a good concentrator could be made from a glass master by adjusting the cure cycle for the substrate to limit the amount of contraction on cooling to a non-critical level.

It is recommended that an additional effort be made to complete a concentrator for the following reasons:

1. It is believed that current material-property tests on the epoxy resin will show that an optical substrate can be completed without loss if minor adjustments are made in the cure cycle;

2. The cost of an additional attempt would be minimum because only an optical substrate need be made for assembly with other existing completed parts.

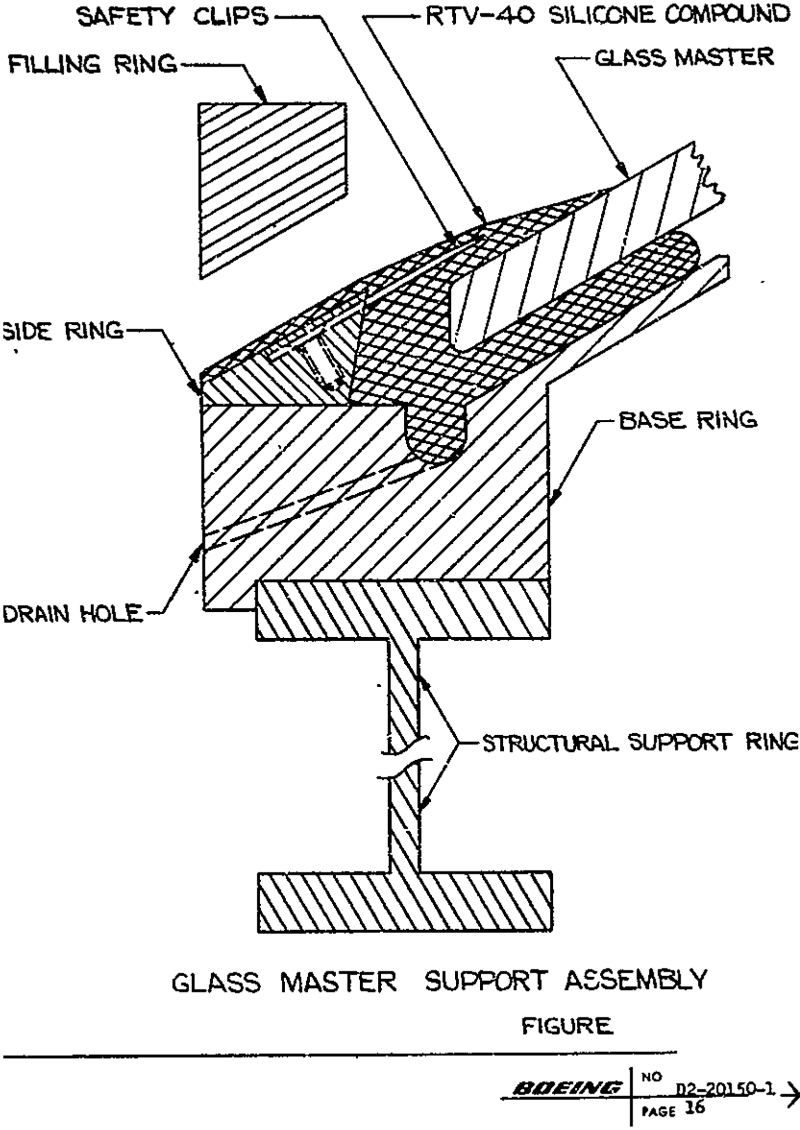
V. REFERENCES

1. "Fabrication of Lightweight Parabolic Concentrators From a Glass Master", Boeing Document D2-90112 dated January 1962.

2. "Fabrication of Lightweight Parabolic Concentrators from an Epoxy Convex Master - Final Report," Boeing Document D2-35084, dated December 1962.

3. "Development and Testing of Lightweight Solar Concentrators", Boeing Document D2-10107, dated June 1961.

4. "Vibration Tests of Prototype Five-Foot Solar Concentrator", Boeing Document D2-20877, dated May 1962.




GLASS MASTER SUPPORT ASSEMBLY

FIGURE

FIGURE 2. APPLICATION OF SILICONE PRIMER

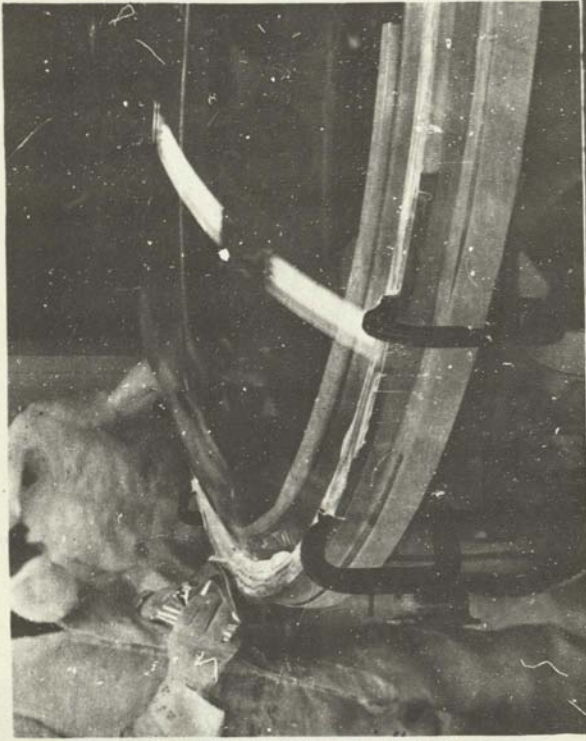


FIGURE 3. APPLICATION OF SILICONE POTTING COMPOUND

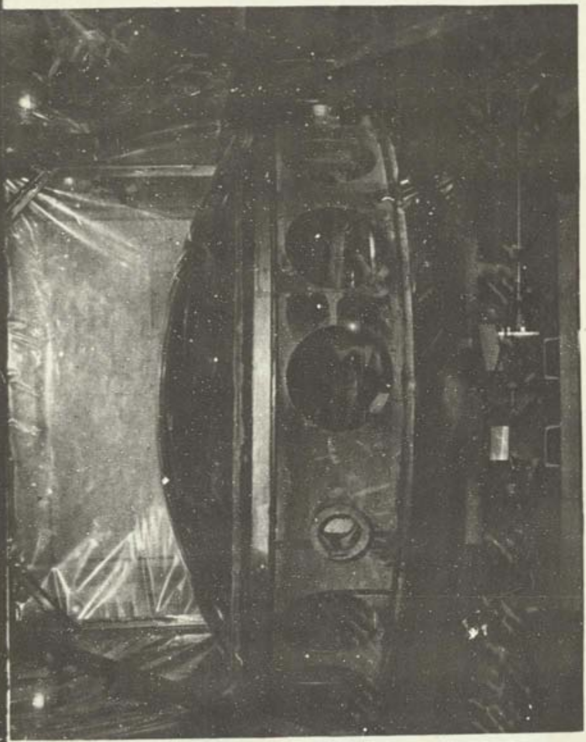
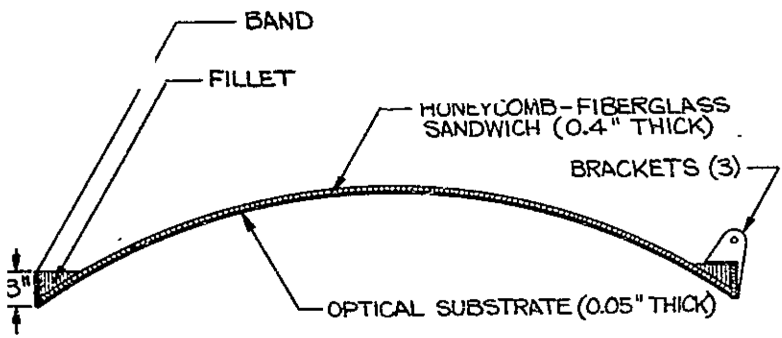


FIGURE 4. GLASS MASTER COATED WITH SILVER PRIOR TO LAYUP




ASSEMBLY OF 5-FOOT DIAMETER
LIGHTWEIGHT SOLAR CONCENTRATOR

FIGURE 5