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TEST BED CONCENTRATOR MIRRORS*

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ABSTRACT

The Test Bed Concentrator (TBC) was designed to test components of point-focusing distributed receiver (PFDR) systems. The reflective surface of the concentrator was fabricated using mirror-facet designs and techniques previously developed at JPL. The facets are made by bonding mirrored glass to spherically-contoured substrates. Several aspects of the earlier work were reevaluated for application to the TBC: optimum glass block size, material selection, environmental test, optical characteristics, and reliability. A detailed explanation of tooling, substrate preparation, testing techniques, and mirror assembly is presented.

INTRODUCTION

In an earlier program at JPL, development work was performed on mirror facets which were made by bonding a second-surface mirror to a spherically-contoured substrate of a variety of materials including quartz, plastics, honeycombs, metal weldments, fiber resins and spun epoxy.

Foamglas,** a soda-lime cellular glass material used for insulation, was selected as the substrate for the mirror facets due to its coefficient of expansion compatibility with the mirror, light weight, ease of shaping, general stability and durability.

Rectangular blocks, 46 cm x 61 cm (18 in. x 24 in.) were the largest available, therefore facet shapes were restricted to a maximum area of .28 m^2 (3 sq ft). Tests indicated that mirrors fabricated with a radius of curvature of 13 m (43 ft) had slope errors less than 0.1° (1.74 mr). Figure 1 shows a mirror at this early stage of development.

APPROACH

A review of existing facet designs indicated that revisions in block size, selection of materials, and structural characterization of Foamglas were required to adapt these designs to the TBC.

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**Pittsburgh Corning Corporation.

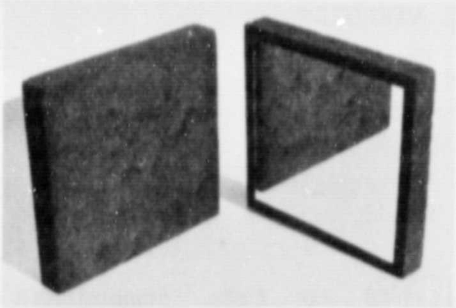

FIG. 1. EARLY DEVELOPMENT MIRROR FACET

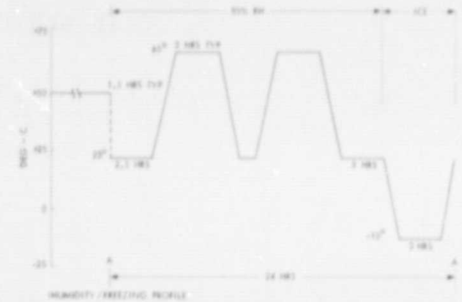

FIG. 2. ENVIRONMENTAL TEST CYCLE

Analysis showed that block sizes greater than 46 cm (18 in.) would give satisfactory performance. Somewhat larger sizes would be no more difficult to fabricate and a smaller number of facets would be required for the TBC. Pittsburgh Corning Company produced a 61 cm x 71 cm x 5.1 cm (24 in. x 28 in. x 2 in.) block as a special run through their commercial process. This was adopted as the maximum envelope from which to make the TBC mirrors. In addition, the rectangular facet configuration was analyzed for its structural adequacy to withstand 160 km/hr (100 mph) wind loads. A support geometry was chosen using three flexure tabs bonded to the edges of the facet substrate.

An investigation was made of readily available materials which would best perform the functions required for the facet. This included the mirrors, adhesive for the mirrors and support tabs, and sealant coatings for the substrate edge of mirror to substrate interface. Several candidates were reviewed for each function.

A composite test program was undertaken to select the material combination to be used for fabrication. In addition to the important criterion of ease of workability, an environmental test program was used to screen the materials. A severe temperature-humidity cycling test was used to demonstrate the mechanical integrity of the materials. This test cycle, Figure 2, consisted of three cycles per day, two from 23°C to 65°C (73°F to 150°F) and one from 23°C to -13°C (73°F to 8.6°F). Humidity was maintained at over 95% during the heating cycles and ice was formed on the mirrors during the freezing cycle. The test uncovered no mechanical degradation. However, degradation of some mirror surf ces in the form of black speckles began to occur after 16 days. This was attributed to the adhesive system used to bond the mirror to the substrate, aggravated by the moisture penetrating the edge to wet the mirror-substrate interface.

Laboratory tests had shown that a system having a near neutral pH caused the least mirror degradation. To confirm this, eight facets were fabricated using different adhesive systems. Half of the facets were edge-sealed. All were subjected to the cyclic environmental test. Evaluation of the speckling degradation of the mirror and considerations of previous experience at JPL led to the decision to use Furane 9427 with the Dow Epoxy Resin 332 as the adhesive system.

A short test program was also conducted to evaluate the strength sensitivity of Foamglas to freeze-thaw cycles at a 95% humidity environment. Samples were tested both uncoated and coated with Pittcote 404/Chemglaze. It was concluded that the coating greatly increased the freeze-thaw resistance of Foamglas and that the sealant must be carefully applied to prevent pinholes in the coating through which water might penetrate.

Although hail is not expected to be a severe hazard at the Parabolic Dish Test Site near Lancaster in the California desert, tests were conducted with ice balls impacting the facet perpendicular to the surface. Balls 3.2 cm, 2.54 cm and 1.9 cm (1-1/4 in., 1 in. and 3/4 in.) in diameter were fired into the coated Foamglas back side and mirror surface. All tests were at approximately 96.6 km/hr (60 mph). Figure 3 shows the effects. The 1.9 cm (3/4 in.) diameter ball caused no damage. Additional tests are planned with impact on the edge of the facet.

ASSEMBLY

The materials selected for construction of the TBC mirror facets are listed in Table 1. The glass for the mirrors was procured from the Corning Glass Works, who subcontracted Falconer Plate Glass for the silvering process. The substrate blocks were made using special molds. However, Pittsburgh Corning's standard commercial process was employed for the special production run.

Mirrors with three silvering configurations were purchased and will be evaluated on the TBCs. Most mirrors were cut to size and silvered, but some were silvered and then cut. Some have a 4.83 mm (3/16 in.) silk screen protective edge seal. A small number of mirrors were assembled using Epicure 855 with an accelerator as a near-neutral pH epoxy-resin catalyst.

All materials were shipped to JPL on the same non-commercial carrier truck to ensure minimum damage from handling and the road environment. Precautions not withstanding, flaws were present in the materials and significant damage occurred in shipping. The suppliers replaced all material not meeting specification.

Tooling for the mirror assembly was arranged to produce groups of ten facets daily. The typical flow for the assembly starts with trimming the substrate to size. Rough-grinding to a nominal radius of curvature of 1524 cm (600 in.) was accomplished using a fly cutter tool on a milling machine (Figure 4). The final radius of curvature was obtained by a hand-grinding operation on a master spherical mold covered with 120 grit abrasive paper (Figure 5).

The back surface of the mirror was cleaned in preparation for bonding. A thin layer of adhesive was applied to the painted back surface using a paint roller (Figure 6). The mirror is placed on the contoured surface of the substrate and vacuum-bagged and cured for eight hours (Figure 7). After cure, the facet was inspected, dated and serialized.

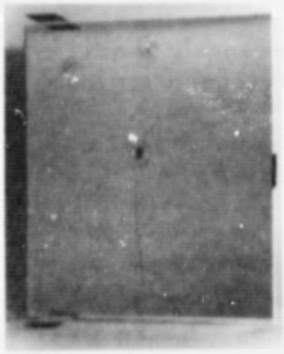

FIG. 3. RESULTS OF HAIL TEST

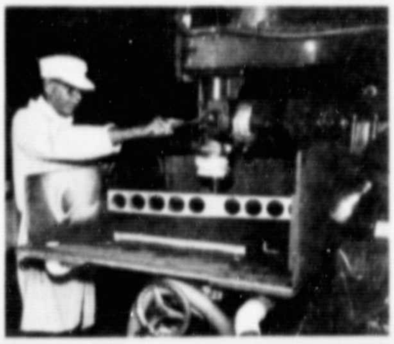

FIG. 4. MACHINE-GRINDING

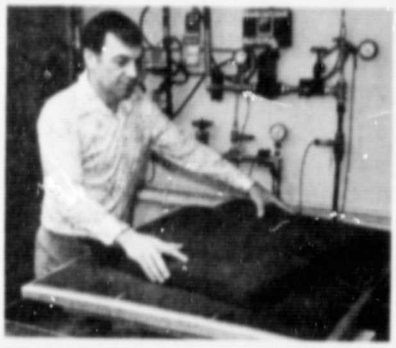

FIG. 5. HAND-GRINDING

FIG. 6. ADHESIVE APPLICATION

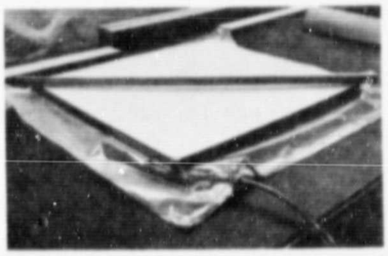

FIG. 7. VACUUM BAGGING

TABLE 1. MATERIALS SELECTED FOR TBC MIRROR FACETS

Substrate	61 cm x 71 cm x 5.1 cm (24 in. x 28 in. x 2 in.) Foamglas High Load Bearing 136.17 kg/m^3 8.5 lbs/ft^3 density) - Pittsburgh Corning
Mirror	60 cm x 70 cm x .15 cm (23-3/4 in. x 27-3/4 in. x 0.058 in.) Corning Glass Code 0317 - Silvered by Falconer
Mirror Adhesive	DER 332 - Dow Epoxy Resin 9427 Hardener-Furane Plastics
Support Tabs	0.032 Aluminum with 5.1 cm x 7.6 cm (2 in. x 3 in.) contact area with Foamglas
Support Tab Adhesive	PC-88 two-part adhesive - Pittsburgh Corning
Mirror Edge Seal	Vulkem 116 Urethane Sealant - NAMECO
Foamglas Sealant	Pittcote 404 Acrylic Latex - Pittsburgh Corning
Paint	Chemglaze II A276 White Polyurethane

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Before proceeding with assembly, the optical characteristics of each facet were measured and compared to the acceptance criteria. The focal length and slope error were measured in an optical tunnel assembled for this purpose (Figures 8 and 9). The technique used for slope error acceptance tests is described in the PFDR Technology Project's Annual Technical Report for FY 1978 (JPL Publication 79-1). For our case, discs of varying sizes (Figure 10) determined by the calculated aperture size of cones of 0.29 mr to 1.74 mr (1 to 6 minutes) slope error were mounted sequentially on the optical axis of the system. Each disc will block light from points on the mirror with slope errors less than that for which the disc is sized. Thus, a photograph of the lighted image will show the area with slope errors greater than the error represented by the disc diameter (Figure 11).

A technique was devised to determine the amount of light reflected from the mirror by utilizing a photometer in lieu of the camera. The appropriate spread of discs was sequentially placed in front of the Fresnel lens and the percentage change in energy received at the photometer taken as a figure of merit for the mirror.

It was difficult to obtain high sensitivity in measurement of the focal length. Many mirrors were checked by measurement to the location of the smallest image using the sun or the moon as the light source. Tests using the moon gave good results, but the image using the sun was too bright to be used.

Reflectance measurements were made at five positions on each facet to give an initial reference value for use in later degradation and cleaning tests. Figure 12 shows the reflectometer equipment.

The mirror supports, consisting of three flexure tabs, were bonded to the substrate using a fixture for accurately locating the tabs relative to the mirror surface. Set-up time for the adhesive permitted bonding of tabs on two facets per day in each of ten fixtures (Figure 13).

FIG. 8. TEST INSTRUMENTATION

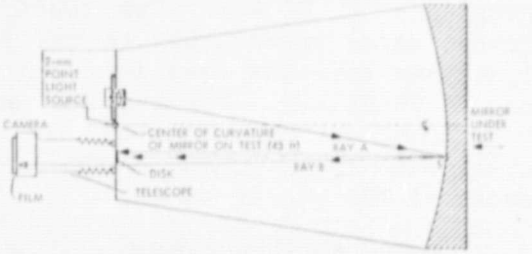

FIG. 9. TEST SET-UP DIAGRAM

After a 24-hour cure of the tab bonding adhesive, substrate corners were rounded and the mirror was cleaned in preparation for application of the sealant along the interface between the substrate and the edge of the mirror. The Vulkem 116 sealer was applied with a syringe, forcing the sealer into the cells at the joint and completely covering the mirror edge (Figure 14). The excess on the mirror surface was removed and the seal allowed to cure for eight hours.

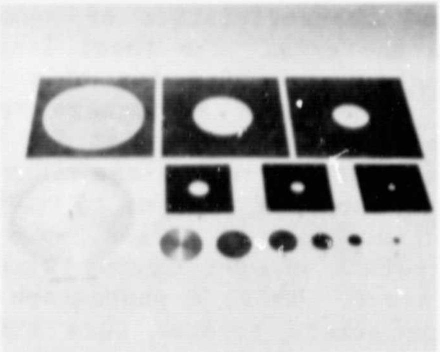

FIG. 10. CALIBRATED APERTURES AND DISCS

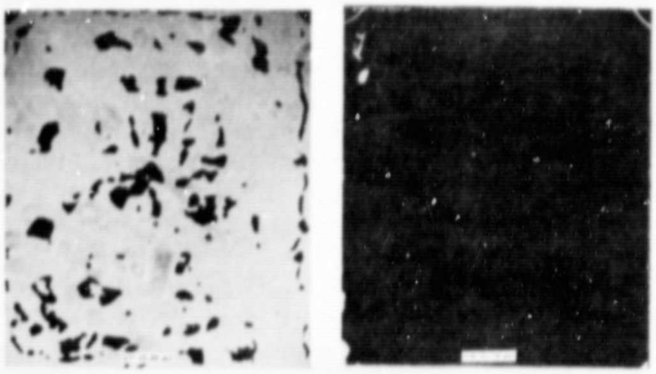

FIG. 11. MIRROR SLOPE TEST RESULTS

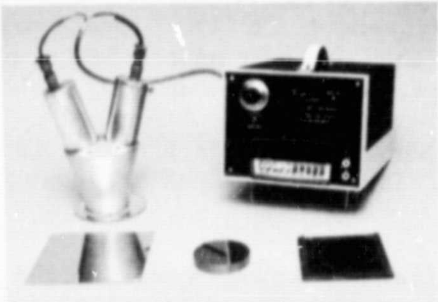

FIG. 12. REFLECTOMETER

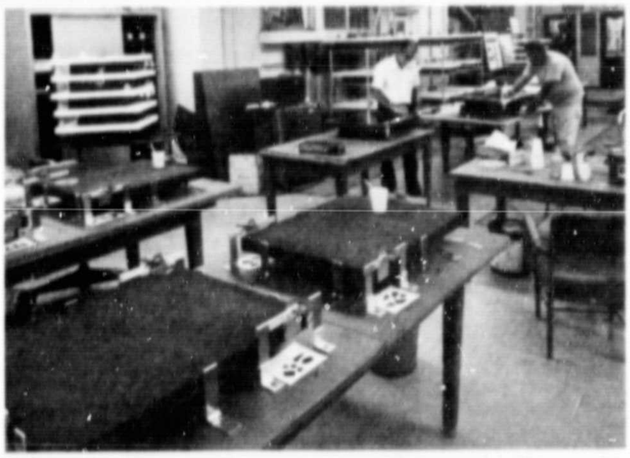

FIG. 13. TAB INSTALLATION

The final step in the assembly process was to cover the entire exposed Foamglas with PC 404. Two coats were applied to fill the open cells and prevent water penetration to the Foamglas through pinholes in the seal. An eight-hour cure was used for each coat. The surface was then painted with a coat of Chemglaze. The mirrored surface on each completed facet was given a final cleaning with alcohol and a commercial glass cleaner and the facet serial number stenciled on the back of the facet. Figure 15 illustrates a completed TBC mirror facet.

FIG. 14. EDGE SEAL

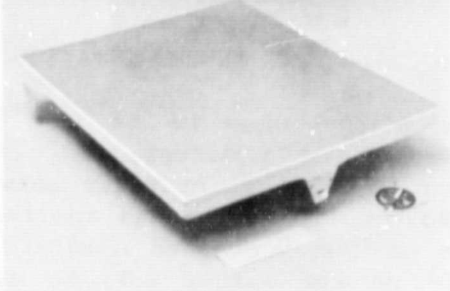

FIG. 15. TBC MIRROR FACET