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ADVANCED CONCENTRATOR PANELS

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ABSTRACT

Acurex Corporation, under contract to the Jet Propulsion Laboratory (JPL), has completed the prototype fabrication of a lightweight, high-quality cellular glass substrate reflective panel for use in an advanced point-focusing solar concentrator. The reflective panel is a gore shaped segment of a 11-m paraboloidal dish.

This paper briefly describes the overall concentrator design and the design of the reflective panels. Prototype-specific panel design modifications are discussed and the fabrication approach and procedure outlined. The optical quality of the prototype panels appears to be excellent, although no quantitative results are yet available.

BACKGROUND

JPL first developed the concept of using cellular glass in conjunction with thin backsilvered mirror glass to form lightweight, structurally efficient reflective panels for high-flux solar concentrators. Cellular glass is a low-cost, noncritical material with a very high stiffness-to-weight ratio. It is easily machinable and can be formulated to provide an excellent coefficient of thermal expansion match to most glass types. Gore shaped reflective panels (Figure 1) fabricated from a composite of cellular glass and sheet glasses form the basis of the JPL Advanced Concentrator concept first proposed in 1977. The largely self supporting gores are used to displace much of the structural framework normally required to maintain an adequate dish stiffness.

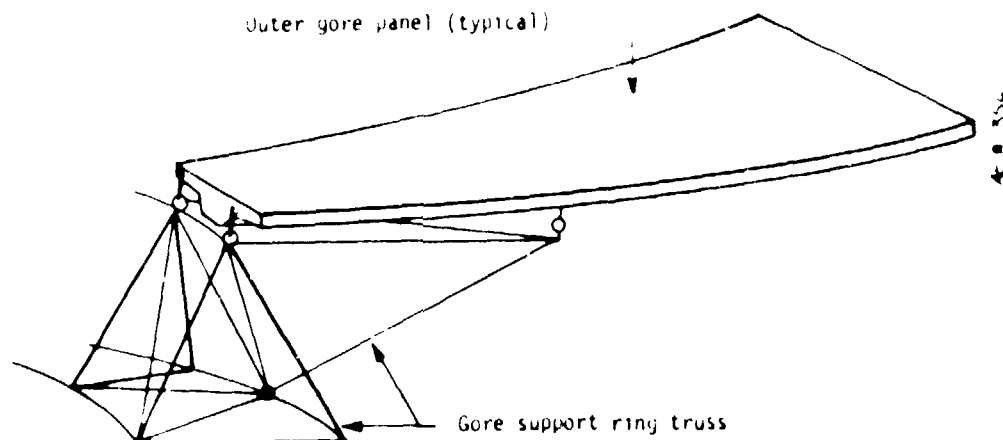


FIGURE 1. CELLULAR GLASS GORE

Acurex, under contract to JPL, performed the preliminary design of the Advanced Concentrator and carried the design of the outer reflective gore through the detailed level. A preliminary cost assessment confirmed the cost-effectiveness of reducing the structural framework required for the reflective dish, but also identified a problem with regard to the balance of the concentrator design. The installation costs associated with site preparation, foundation installation, and field erection of the wide-base/perimeter drive configuration accounted for a major fraction of the total installed concentrator cost.

A concept-level trade-off study resulted in a more cost-effective design which retains the advantages of the cellular glass panels, but eliminates the costly wide base configuration.

CONCENTRATOR DESCRIPTION

The resulting Acurex/JPL Advanced Concentrator concept is shown in Figure 2. It consists of 64 lightweight cellular glass substrate gores (40 outer and 24 inner gores), simply supported from a tubular steel ring truss which is hinged in elevation from an intermediate space frame structure. The intermediate structure is mounted to a motor driven turret azimuth drive which sits atop a single concrete column. The reflective dish is driven in elevation by an electric ball screw actuator which couples the gore support ring structure to the intermediate structure. A guyed truss-legged quadripod receiver support structure provides a rigid support for the power conversion package while providing a minimal amount of shading or blocking of the incident and reflected insolation.

The turret drive/pedestal mount configuration requires a more massive and more costly drive unit than the original wide-base/perimeter drive configuration. The significant reduction in site assembly and foundation installation costs more than offset this penalty, however. It is estimated that the installed cost of the single pedestal configuration will be 10 to 20 percent less than the wide base design.

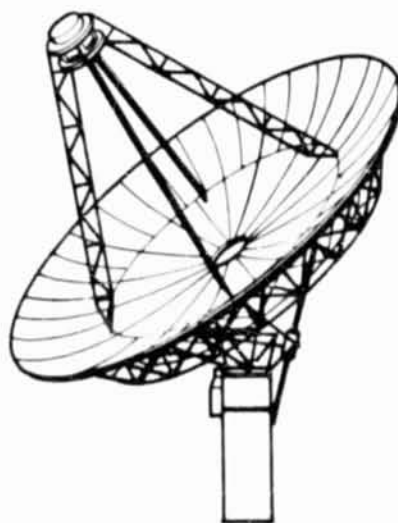


FIGURE 2. ACUREX/JPL ADVANCED CONCENTRATOR

REFLECTIVE PANEL DESIGN

The key element of the Advanced Concentrator is clearly the cellular glass substrate reflective gore. As shown in Figure 3, each gore is fabricated from a composite of 1.0-mm Corning Glass Works 7809 borosilicate glass and a Pittsburgh Corning Foamsil® 75 cellular glass core. The Foamsil® 75 has been specially formulated to match the thermal expansion characteristics of the 7809 sheet glass. A single sheet of backsilvered thin glass is continuously bonded to a contoured substrate of the cellular glass material. A narrow strip of unsilvered thin glass is bonded to the outer face of the cellular glass spar running longitudinally along the backside of the gore. The face sheets and the cellular glass core form a composite structure in which the mirror glass and the spar cap carry a significant portion of the aerodynamic and gravitationally induced bending loads. Three compression molded glass reinforced polyester (GRP) pads are bonded to the gore to serve as attachment points for the interface with the support structure.

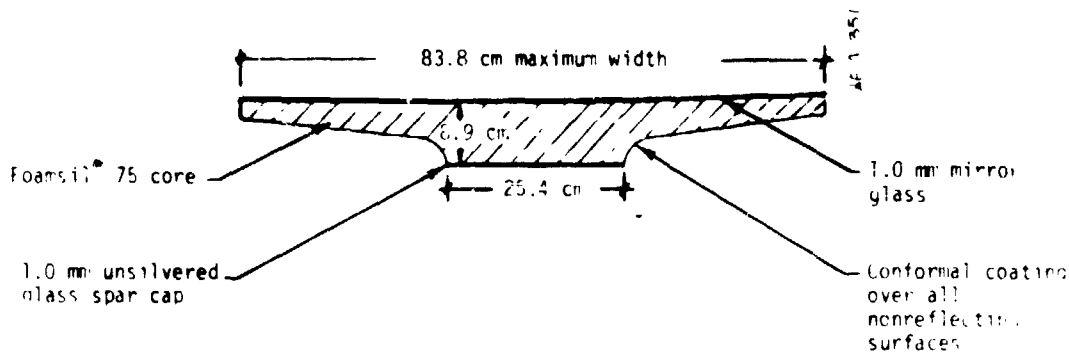


FIGURE 3. OUTER GORE CROSS SECTION

Two panel types form the paraboloidal surface. Forty outer gores and twenty-four inner gores are required. The masses of the outer and inner gores (less attachments) are 23.2 kg and 15.8 kg, respectively. The width of each gore type is limited by the maximum steady-state curvature stress which the sheet glass can withstand. A maximum panel width of 84 cm for the outer and inner gore limits the steady-state stresses to 14.9 MPa.

A detailed design was developed for the outer gore type only. The resulting gore is stress limited with a 5 percent probability of failure in the cellular glass core under a governing load condition of a 1 minute cumulative exposure to a 110 km/hr wind at the worst-case orientation. The peak tensile core stress is 275 kPa under this condition with a corresponding mirror glass stress of 20.1 MPa. Under worst-case operating conditions, the outer gore panel yields a peak deflection slope error of less than 0.3 mrad and an area weighted rms deflection slope error of less than 0.2 mrad.

Due to current manufacturing limitations, the maximum block size for the Foamsil® 75 material is 46 cm by 61 cm by 10 cm. Near-term production therefore requires the bonding of several blocks of cellular glass into a large core blank prior to machining. Future developments in cellular glass production may lead to full size monolithic core blanks or even foamed to shape cores.

PROTOTYPE PANEL FABRICATION

To verify the fabricability and integrity of the gore design, Acurex has fabricated several full-scale prototype gores. These gores will be tested by JPL to determine the structural and optical characteristics of the design.

Prototype Design Modifications

Several prototype-specific design modifications were incorporated to reduce cost. Due to limited availability of the 1.0 mm Corning 7809 sheet glass and the Pittsburgh Corning Foamsil® 75, the prototype gores were fabricated from 1.5 mm Corning O317 glass and Pittsburgh Corning's standard Foamglas® material. While these materials are not ideally thermally matched, and the thicker sheet glass provides a shorter panel life, much insight into the gore design has still been gained. Steel weldments were substituted for the compression molded GRP attachment pads at a penalty of approximately 2.3 kg per gore.

In addition to these prototype material changes, two significant dimensional changes were also incorporated. To simplify the core machining operation, the rearside contour was modified from a constant edge thickness configuration to a constant contour angle design and the spar depth was increased to avoid a local bond joint problem. This change added approximately 10 percent to the core mass, but allowed the use of a simplified contouring scheme. The frontside contour was also modified to simplify the prototype machining operation. In lieu of the more perfect paraboloidal contour, a compromise of a parabolic contour in the radial direction and a constant radius of curvature in the circumferential direction was selected. The effective area-weighted slope error impact of this modification is approximately 0.3 mrad rms.

Fabrication Approach

To minimize prototype fabrication cost, Acurex developed a simple contouring scheme which allows accurate, repeatable substrate fabrication with a minimal investment in tooling. The prototype gore fabrication procedure is essentially a ten step operation:

- Cut cellular glass blocks
- Bond blocks to form core blank
- Cut core blank to planform
- Machine core backside
- Bond sheet glass spar cap
- Machine core frontside
- Bond mirror glass
- Bond attachment pads

- Apply conformal coating
- Package and ship

Since the optical accuracy of the gore is directly dependent upon the accuracy of the substrate contour, the core contouring apparatus was a key element of the prototype fabrication effort. As shown in Figure 4, the cellular glass contouring apparatus consists of a pair of reversible precision parabolic rails which support a hand-drawn cutter carriage. The carriage is designed to accept several interchangeable contoured scraper blades. Two blade configurations are required to generate the rearside contour, while only one constant-radius blade configuration is required for the frontside contour.



FIGURE 4. CELLULAR GLASS CONTOURING APPARATUS

Preliminary Results

While no quantitative data have yet been taken, the optical quality of the prototype gores appears to be excellent. Visual inspection does indicate a slight "print-through" of the bond lines where the cellular glass blocks were joined, but the total distorted area is very small. Simple hand held imaging tests with the sun as the light source provide a clearly defined image on the order of 10 cm at a focal distance of approximately 6.6 m. This corresponds to roughly a 60 percent increase over the sun's theoretical image as would be expected for a 1 mrad rms mirror.

Continued developmental work is required in the fabrication and processing of cellular glass as a structural material. Much can be done to expand upon the prototype gore fabrication technique. The labor intensive contouring operation could easily lend itself to increased automation. Further refinements in machinable cellular glass bonding agents could improve machinability and reduce print-through.

With adequate effort expended on its development, the cellular glass substrate reflective panel appears certain to have a significant impact on the future of point-focus solar technology.