UNFURLABLE, CONTINUOUS-SURFACE REFLECTOR CONCEPT

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INTRODUCTION

Various concepts for large, deloyable reflectors have been developed and some have flown. In each case the surface material was either a continuous mesh of some sort or an assembly of rigid, continuous-surface facets or petals. Performance issues arise in each case. For mesh, reflectance diminishes with increasing frequency. For rigid sections, one has to deal with seams and relative positioning of the segments. These two issues prompted the evolution of our concept of an Unfurlable, Continuous-Surface Reflector. This paper describes the concept and presents what we've learned, what we suspect will be learned, and also raises questions yet to be addressed.

THE CONCEPT

The apparent need for large (greater than 4.3 meters) high-frequency (K_a band and beyond) antenna reflectors has prompted the development of a concept centered around a thin membrane antenna reflector shell that can be rolled into a semi-cylindrical volume for stowage and then allowed to unroll and register against a deployable substructure to re-form the fabricated shape. The result is a smooth, continuous surface that promises to provide surface accuracies to date unachievable with any other well known deployable reflector concept. The basis is straightforward: If in-plane membrane stiffness is high compared to section stiffness and if the membrane is registered accurately, the membrane should assume the shape to which it was fabricated.

What we did to "reduce the concept to practice" was to fabricate a reflector shell (Figures 1 and 2) on an existing mold in a manner that we've employed several times in the past. In this case, we started with a one-meter, offset geometry male graphite/epoxy mold whose focal length is 24 inches. We laid up P75S graphite fiber, preimpregnated with the 930 resin system. Each 0.0025-inch layer was oriented to satisfy $(\pm 45^{\circ})_S$ laminate schedule to yield a total shell thickness of .010 inches. The axis about which there is a minimum bending stiffness of the lay-up coincides with the reflector symmetry axis. A flat, rectangular 4x16-inch piece was also fabricated with the same material and ply orientation. This flat piece was intended for release-of-stored-energy tests. We wanted to learn how close a rolled up sheet would return to its unrolled shape when it was allowed to do so. We rolled this piece on a 10-inch diameter cardboard cylinder and put it away.

In the meantime, we fashioned a support ring 2-inches-square cross-section of the same graphite/epoxy laminate whose diameter is slightly smaller than the one meter reflector shell. We also added a curved beam with the same cross section to the ring across the symmetry diameter so that when the deployed shell is resting on the ring it also rests on this curved beam as well (Figure 3). We employed two sets of restraints; one to hold the rolled up shell on the support ring and one to retain the shell on the ring once the shell is fully unfurled.

To describe the first set of restraints one must first understand that the rolled up shell does not form a cylinder. It forms a slender "football" shape with the "points" removed. Also, the two spots on the shell that rest on the ring are different when the shell is unfurled from when it is rolled up. And, of course, the shell surface at the support points rotates when going from the stowed to the deployed configuration. To accommodate all this, we designed a restraint at one end that allows for rotation only and at the other that allows for rotation and radial translation (Figure 4).

The second set of restraints is a bit simpler. We fastened one flexible magnetic strip on the inside upper edge of the ring (Figure 5) and oriented the surface to be parallel to the surface of the deployed shell. We also bonded a ferrous metallic strip on the back side of the shell to mate with the magnet (Figure 6). We did the same thing along the diameter support and mating shell surface as well (Figures 7 and 8). This scheme not only provides a means to retain the shell in the unfurled position against the support structure, but also aids in the deployment process by applying a magnetic force of attraction between the unfurling shell and support ring. The detailed design of this feature will, from the magnetic force sizing standpoint, be dictated by the deployment strain-residual test on the flat piece. It will also serve as a means of overcoming some gravitational forces that it must do to gain acceptance via a ground demonstration/ test program. This, too, will likely contribute to sizing the magnetic forces.

What happened when we assembled the rolled up shell on the ring and deployed it was, if not surprising, at least very satisfying. Everything worked! We constrained the shell by placing a strip of paper around the shell with masking tape overlapping the seam just an inch or so. We peeled it off with a lanyard string attached to the tape and when the rolled shell became unrestrained it unfurled and slapped against the ring support structure. Although we did not measure the surface, it appeared that the shell returned to its original, as-manufactured shape. There were no residual gaps between the back side of the shell and the ring magnet. In the event that happens, it is felt that these can be brought in by increasing the magnetic attraction forces somewhat since the shell does not appreciably resist forces normal to the surface. Following the "cup up" deployment, we re-oriented the ring to a vertical position at the edge of a table and repeated the test. We got the same results. We then leaned the ring past vertical about 5 degrees. It still worked. But when we repeated the test at approximately 10 degrees, it did not completely deploy. Overall it "looked" good. And we expect it will prove to be as precise as the original shape provided that the shell is supported properly, i.e., the points or arcs or rings of support must be correctly located on the support structure so that they lay on the imaginary surface of the correct shell shape and there must be sufficient magnetic forces to attract the shell snugly against the supports.

During this scale model development, we returned from time to time to our flat panel that we had rolled up on a cylinder. What we learned was that residual strains, if present at all, will likely be very small and forces necessary to "complete deployment" if there were residual strains would also be very small. We allowed the strip to unroll somewhat crudely on edge until we felt all deployment stresses had vanished. We then compared its relaxed shape to the line we drew on some paper coinciding to the original shape. The deployed panel matched the original line very well. We repeated this test after two years had gone by. We got the same results. We then brought a magnet near to a ferrous strip on the back side of the panel at the edge. The panel moved easily. This was hardly rigorous, but clearly was indicative that any restoring forces needed to take out residual strain should prove to be small.

There was some design work done on folding the support ring and concepts to retain the whole package as well as provide for sequential deployment, but no detailed design was performed, nor did we build a deployable ring as part of the concept demonstration, feeling that that technology in the form we designed it is not particularly new. And if a deployable truss proved advantageous we would be venturing into a field in which we are not expert. Suffice to say, the feasibility of an unfurlable continuous surface reflector concept has been demonstrated even though there are many questions remaining:

What materials are best suited to the laminate make-up?

Can the deployed shell be supported at discrete points, and if so, how many? Or must it be supported by continuous line or area contact?

How large a reflector can this concept support?

How accurate will the surface be?

What form does the support structure take?

Is there a relationship between shell size and shell thickness?

Should the structure have (remote) adjustment capability?

What kind of ground test program would demonstrate zero g capability without compromising the design?

How do you achieve very homogeneous mechanical properties throughout the shell surface?

What form should the magnetic latching mechanism take?

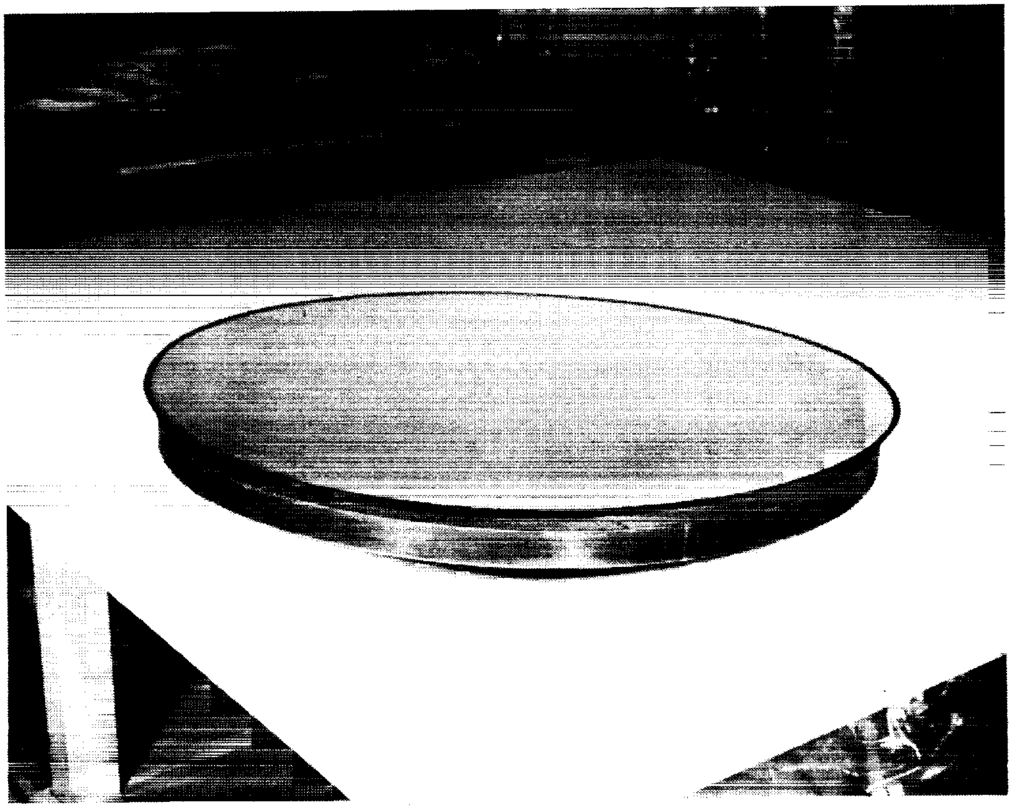

FIGURE 1

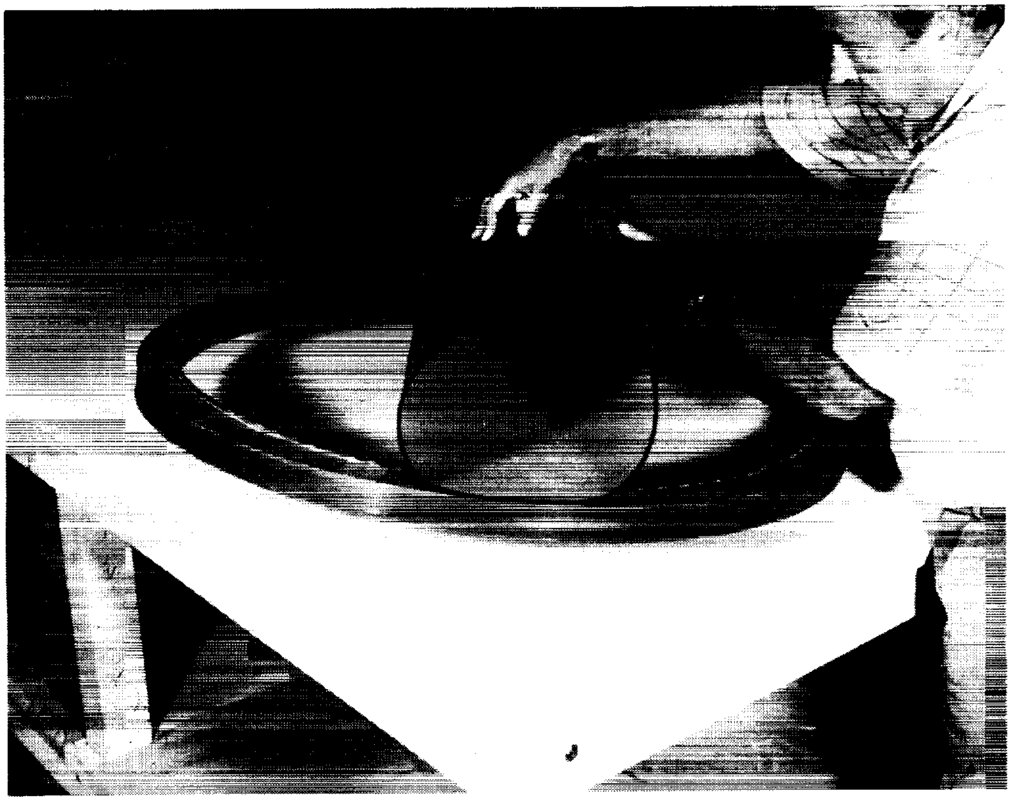

FIGURE 2

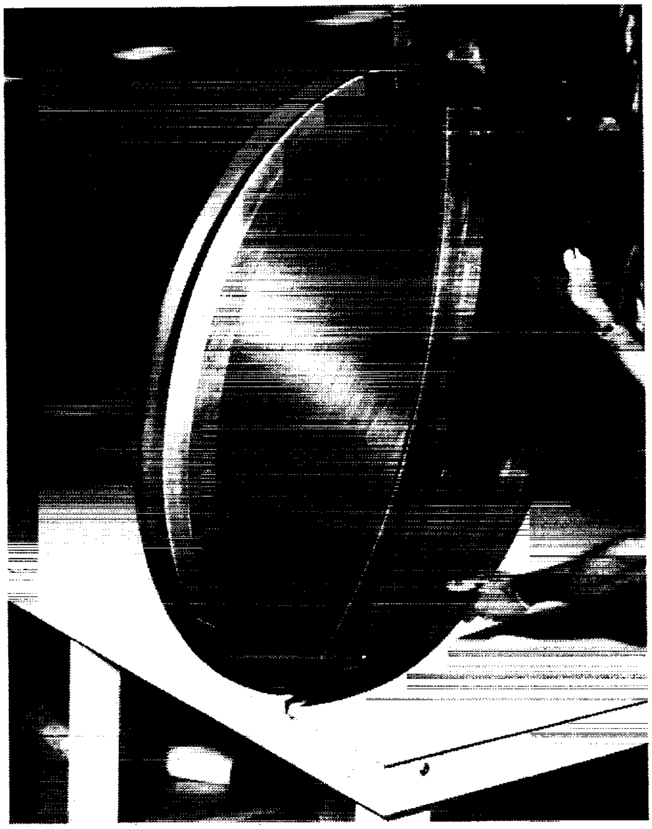

FIGURE 3

FIGURE 4

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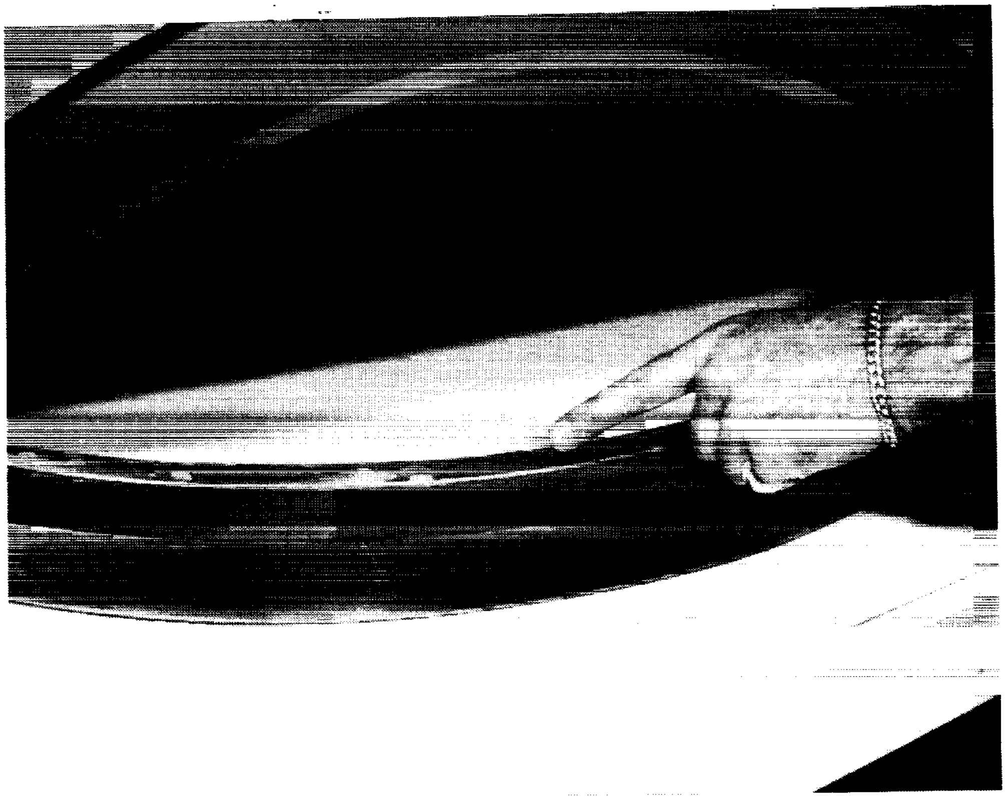

FIGURE 5

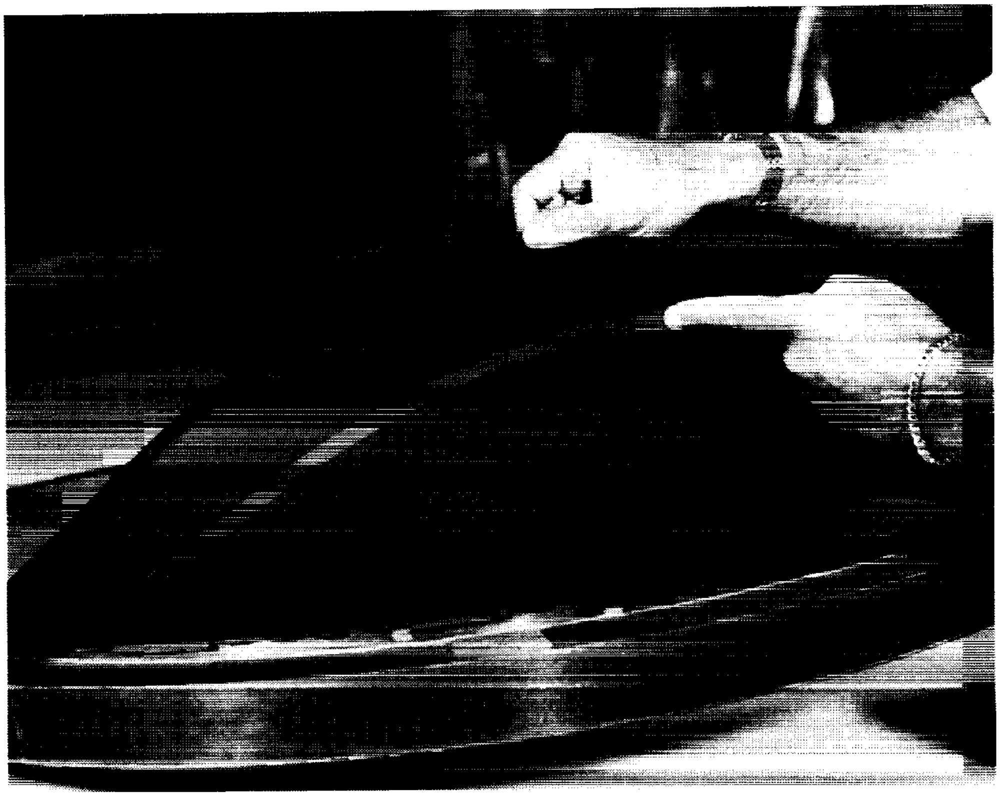

FIGURE 6

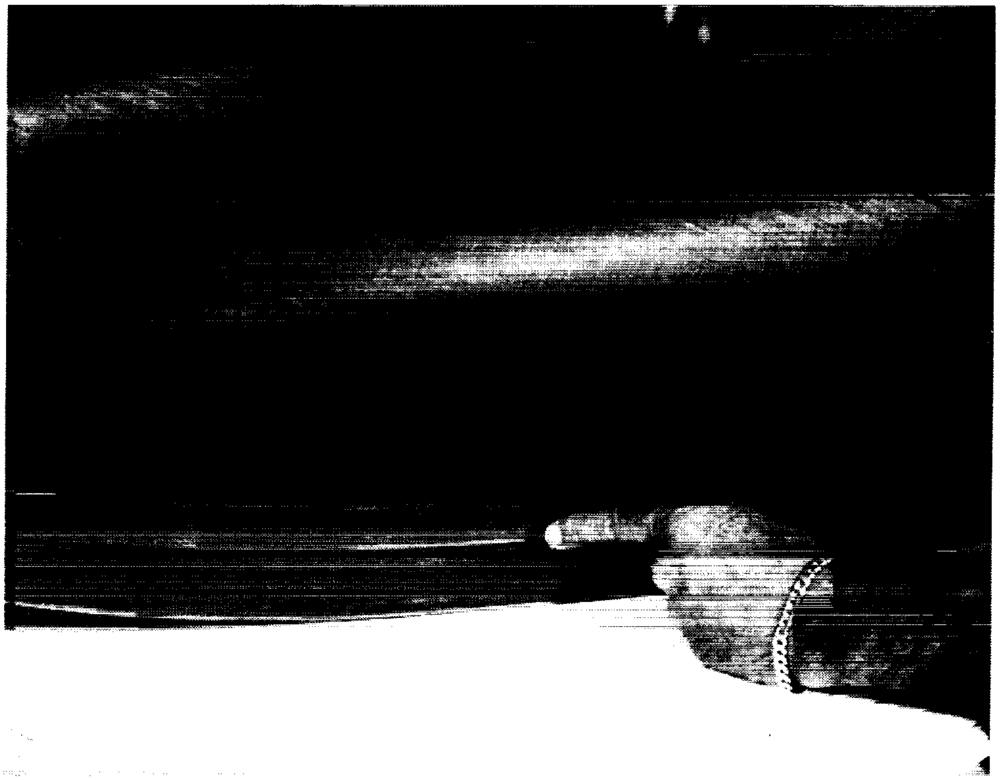

FIGURE 7

FIGURE 8

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