

# THE ASTROMESH DEPLOYABLE REFLECTOR

Mark W. Thomson  
TRW Astro Aerospace  
6384 Via Real  
Carpinteria, CA, USA  
93013-2920

7510-220D-01

## 1.0 Abstract

The AstroMesh is a mesh reflector for large aperture space antenna systems. It embodies a new concept for deployable space structures: a pair of ring-stiffened, geodesic truss domes, in which the ring is a truss deployed by a single cable. Compared to other mesh reflectors, the AstroMesh achieves uncharacteristically low levels of total mass, stowed volume, surface distortion, cost, and program schedule duration.

Several large AstroMesh reflectors are being produced for a series of U.S. built commercial geosynchronous mobile communications spacecraft; first flight is planned for early 2000. Figure 1 depicts the AstroMesh on the Euro-African Satellite Telecommunications (EAST) System, an example of a large aperture mobile communications satellite conceived by Matra Marconi Space.

Two large models have been qualified for space flight with as-manufactured shape errors of less than  $D(6 \times 10^{-5})$  RMS, and repeatability errors below  $D(5 \times 10^{-6})$  RMS (where D is the aperture diameter). With current materials and manufacturing techniques, the AstroMesh design can achieve a surface accuracy from all error sources, including in-orbit environments, of  $D(2.5 \times 10^{-5})$  RMS. Large margins on a very demanding passive intermodulation (PIM) specification have been achieved consistently.

## 2.0 Background

Since the late 1960's, mesh reflectors have been favored for their potential to fill large apertures with extremely lightweight hardware. Development of this new genre continued with impressive devices that were expensive, heavy, and bulky when stowed. They also proved to be difficult to deploy, test and characterize on the ground. Great effort was required to achieve tolerable surface precision with apertures larger than 6 meters.

Models that have flown are of a ribbed or umbrella nature, often with a network of cords for fine shaping of RF reflective mesh.<sup>1,2</sup> Many designs tended to impose manufacturing errors, products of kinematic and/or static indeterminacy with high redundancy. Thus, they were difficult to pre-stress uniformly throughout.<sup>3</sup> The inherent tendency of mesh to saddle back into the dish with a positive curvature and its highly anisotropic mechanical qualities exacerbated inherent structural problems. The presence of the ribs leads to large-scale systematic surface errors, particularly during thermal extremes between full sun

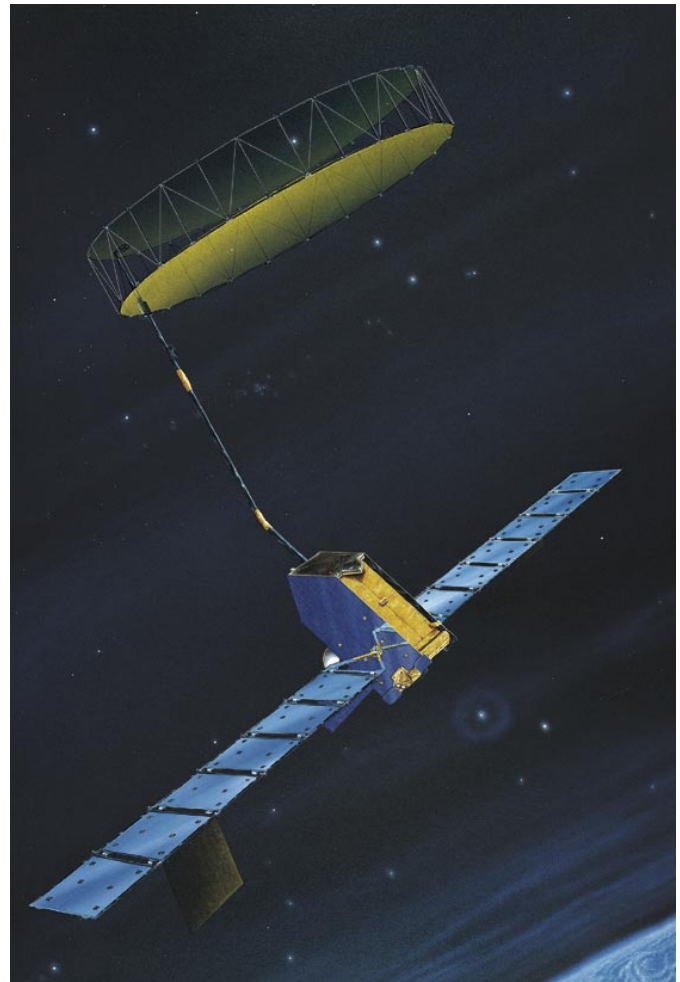


Figure 1.

and eclipse in high orbits. Such problems, combined with reliability and mesh management issues, led to the undoing of several past designs.

Communications, imaging, and scientific satellite missions demand antennas with ever larger and more precise apertures. At the same time, satellite procurements are being streamlined to better match a commercial model. The programs require rapid, low-cost design and development turnarounds without sacrificing reliability. Ever larger reflectors with superior performance will always be in demand if competitive designs are available. Thus the goal of my project: to produce a better, faster, and cheaper deployable reflector.

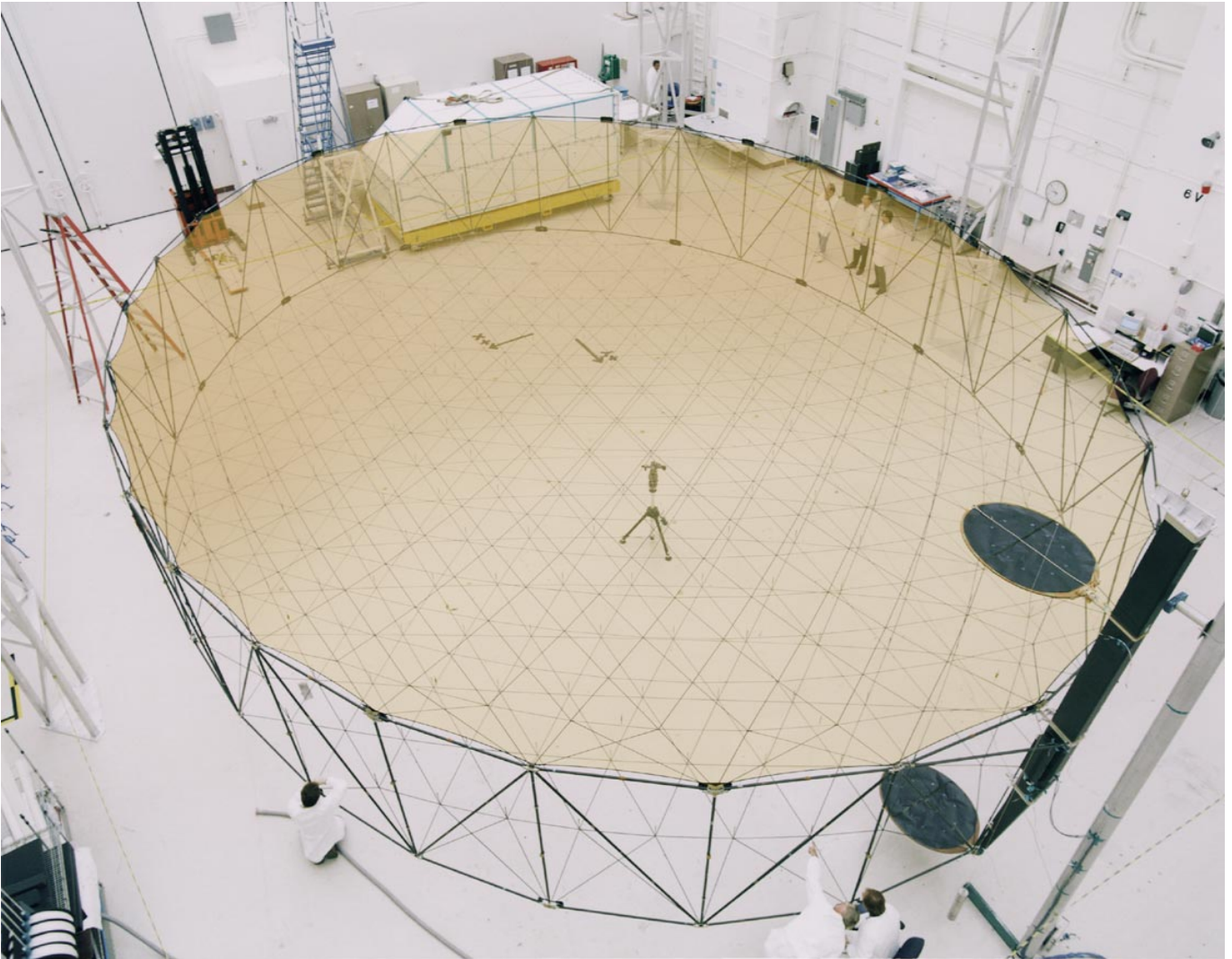


Figure 2.

### 3.0 Introduction

The patented AstroMesh technology is mature.<sup>4</sup> Both the 6-meter and the much larger flight models have been fully qualified for space flight through a comprehensive program of environmental testing. The flight hardware is shown in Figure 2. The design is readily scalable and supports low-cost, minimum schedule programs with rapid hardware delivery for commercial satellite competitiveness.

The AstroMesh utilizes a simple and efficient structural approach. When deployed, it is significantly stiffer, more precise, thermally stable, and lower in weight than existing mesh reflectors. When stowed, it requires less than usual volume. Apertures up to 25 meters can be integrated with large spacecraft buses and yet be launched aboard a number of available medium-size boosters. Reflector areal mass densities of  $0.37 \text{ kg/m}^2$  have been demonstrated with flight hardware. For larger reflectors the areal density drops quickly due to an economy of scale in structural efficiency. For passive intermodulation (PIM) sensitive antenna systems, significant margins on the most rigorous PIM specifications have been achieved.

The AstroMesh is practical to build. With existing materials and technology, a maximum surface distortion of  $(2.5 \times 10^{-5})D$  from all sources (including worst-case orbital thermal influences) can be achieved. For example, a 40 GHz antenna with an aperture of 12 meters can have a surface accuracy of 0.3 mm or  $1/25$  RMS. Current knitted wire mesh designs can be used up to about 40 GHz with adequate reflectivity. For lower frequencies such as L band, aperture size is limited by existing launch vehicles to about 150 meters. The basic design of the reflector is the same regardless of aperture size, so it is inherently scalable.

Compared with other mesh reflectors, the simplicity and structural efficacy of the AstroMesh yields low fabrication and ground test costs. Although compatible with axisymmetric antenna geometry, the design is inherently compatible with off-axis antenna systems, as shown in Figures 1 and 2. The AstroMesh is appropriate for the majority of applications where very large apertures are required. It is being considered for missions that include communications, synthetic aperture radar, radiometry, radio astronomy, and interferometry.

### 3.1 Development Status

AstroMesh technology is the result of five generations of hardware development over 8 years. A record of over 220 deploy and stow cycles has been accumulated by three models without any failures to fully deploy unaided.

Two large flight versions have been built and successfully qualified by a suite of electrical and environmental tests. The performance of both reflector subsystems met or exceeded all design requirements.

### 4.0 AstroMesh Concept

Deployable reflectors based within circumferential rings are recognized as superior, in principle, to historic ribbed types.<sup>5</sup> The AstroMesh was conceived with this in mind; it is a light and inherently stiff structure that precisely and repeatedly deploys reflective mesh, regardless of environment (Figure 3). The reflector is composed of a pair of doubly curved geodesic trusses, called *nets*, that are placed back-to-back in tension across the rims of a deployable graphite-epoxy ring truss. This forms a drum-like structure of exceptional structural efficiency, thermal dimensional stability, and stiffness-to-weight ratios. Figure 2 reveals additional reflector component nomenclature.

### 4.1 Geodesic Nets

The nets are made of stiff unidirectional composite filaments called *webs*, attached in a pseudo-geodesic truss dome geometry. Webs can be configured to follow reflector contours that are spherical and parabolic with single or double curvature, and shaped, as long as negative curvature is present. The ideal mathematical shape is approximated by flat, triangular facets that are formed when the mesh is stretched over the geodesic truss dome.

Intersections of webs are located along the web lengths,  $L$ , with an accuracy better than  $(3 \times 10^{-7})L$  RMS using specialized equipment and material conditioning techniques. The intersections, or net “nodes,” become hard points in the deployed, tensed nets. A state of uniform tension averaging at least 50 N per meter between the mirrored net nodes is established by the action of tension tie assemblies. The nets are not adjustable, nor do they need to be to achieve the required surface accuracy.

### 4.2 Ring Truss

The articulated graphite composite and aluminum ring truss is deep and extremely stiff normal to the plane of symmetry between nets. Its structural depth and regularity provides high thermal stability and ease of manufacturing. Though the reflector is extraordinarily lightweight, overall stiffness allows its direct mounting from the edge of the ring truss to a boom (Figures 1 and 2).

During deployment, the deployable truss is a cable-actuated, synchronized parallelogram. During all phases of deployment, the truss retains sufficient stiffness in all directions to sustain significant attitude control, system-induced loads while remaining tightly coupled kinematically.

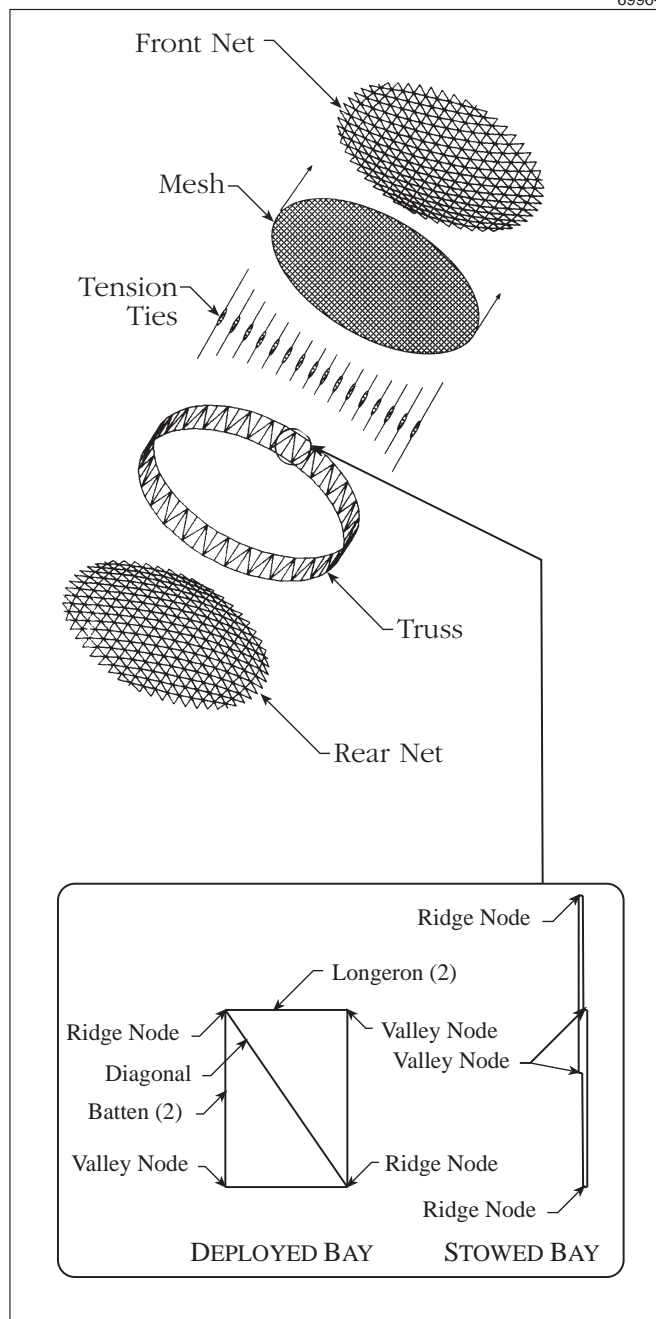


Figure 3.

### 4.3 Stowed Reflector

The AstroMesh is compactly stowed. Figure 4 shows an optimum interface arrangement. Fully stowed, the truss package is a narrow, hollow cylinder, deployable truss members adjacent to each other. The end-most members are preloaded against lightweight hoops that act as stiffening and debris-shielding end-caps for the stowed package. This forms a barrel-like structure that is strapped into lightweight cradles for launch. Certain members in the package are intentionally over-stowed so that the truss gently expands or “blooms” when the tie-downs are released.

#### 4.4 Reflector Deployment

Deployment behavior combines an initial release of stowed energy with a slow, highly controlled and kinematically robust motor-powered phase to complete deployment. A single deployment cable is given powerful geometric authority over reflector truss kinematics. The articulated truss deploys with synchronous, kinematically-coupled behavior and predominantly low levels of strain. The cable enjoys a large mechanical advantage over reflector kinematics; at the end of deployment it transfers significant work-energy to the dome and ring systems to develop the high overall pre-stress condition. Upon deployment the truss latches solidly, thus requiring no further cable tension. The mesh and nets are snag-free during deployment.

#### 4.5 Mass

The efficient truss and diaphanous mesh and net design gives the AstroMesh a dramatic downward trend in mass-to-aperture area ratios as diameter increases. Mass to reflector area ratios of  $0.37\text{kg/m}^2$  have been proven. It is estimated that ratios as low as  $0.2\text{ kg/m}^2$  are feasible for 25-meter class reflectors.

#### 4.6 Surface Accuracy

The lowest worst-case total contour distortion from all sources believed practical for the AstroMesh is about  $(2.5 \times 10^{-5})D$ , about 1/4 of what has been demonstrated thus far. The combination of denser geodesic net structures, tailoring of truss and net CTEs, and thinner webs with materials having ultra-low strain scatter characteristics, will boost accuracy to these levels when required.

#### 4.7 PIM and ESD

Every stride in the development of the reflector for flight systems has been driven by the unique requirements of offset-fed, extremely PIM-sensitive geostationary mobile communication systems. The elimination of PIM products and electrostatic discharge (ESD) events has been achieved in every component of the deployed reflector, regardless of location. Simple but specialized design and fabrication measures insure consistent PIM performance that is well below  $-150\text{ dBm}$  at the feed point.

#### 5.0 Summary

Easy achievement of high net tension is a key feature of the performance and economy of the AstroMesh. This capability is in part due to the statically determinate structure of the deployed system. This eliminates the need to characterize or control the inherently nonlinear characteristics of mesh tension and highly redundant shaping networks. It also contributes to the repeatability and uniformity of the structural shape during thermal extremes and after multiple deployments.

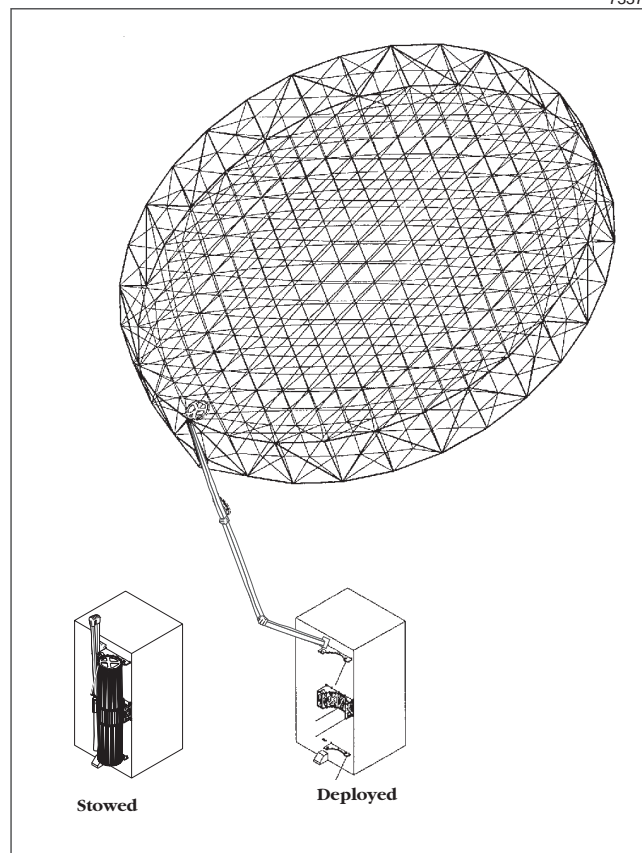


Figure 4.

- <sup>1</sup> Freeland, R.E., "Survey of Deployable Antenna Concepts," Proceedings of Large Space Antenna Systems Technology—1982, NASA-CP-2269, Nov.-Dec., 1982, pp. 381-421.
- <sup>2</sup> Roederer, A.G. and Rahmat-Samii, Y., "Unfurlable Satellite Antennas: A Review," Annales des Telecommunications, Vol. 44 No. 9, 10, 1989, pp. 475-488.
- <sup>3</sup> You, Z. and Pellegrino, S., "Cable-Stiffened Pantographic Deployable Structures Part 2: Mesh Reflector," AIAA Journal, Vol. 35, No. 8, 1996, pp. 1348-1355.
- <sup>4</sup> U.S. Patent No. 5,680,145.
- <sup>5</sup> Hedgepeth, J. M., "Influence of Fabrication Tolerances on the Surface Accuracy of Large Antenna Structures," AIAA Journal, Vol. 20, No. 5, May 1982, pp.680-686.