Mechanical vs. Inflatable Deployable Structures for Large Apertures

or

Still No Simple Answers

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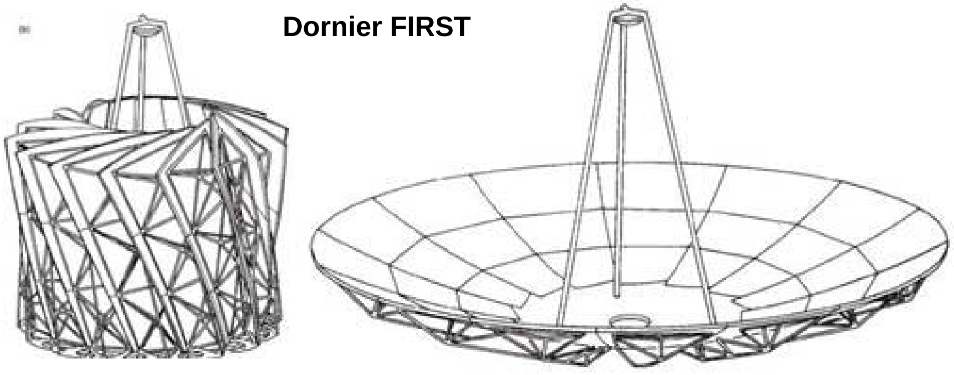
Aperture Range Addressed

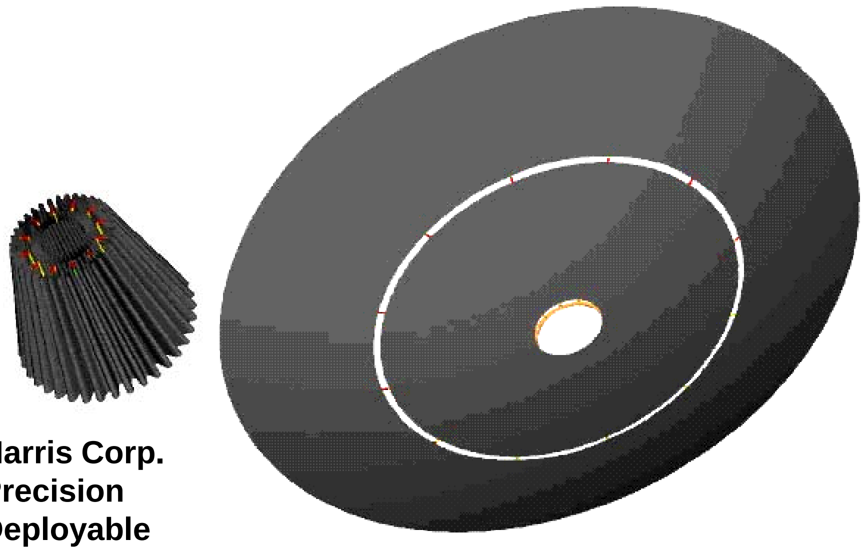
- Radio Frequency (RF) Apertures
  - Less than 100 GHz ($\lambda > 3.3$ mm)
- Large
  - At lest one deployed aperture dimension is larger than the largest available launch vehicle fairing
  - 5+ m diameter

Aperture Types Not Addressed

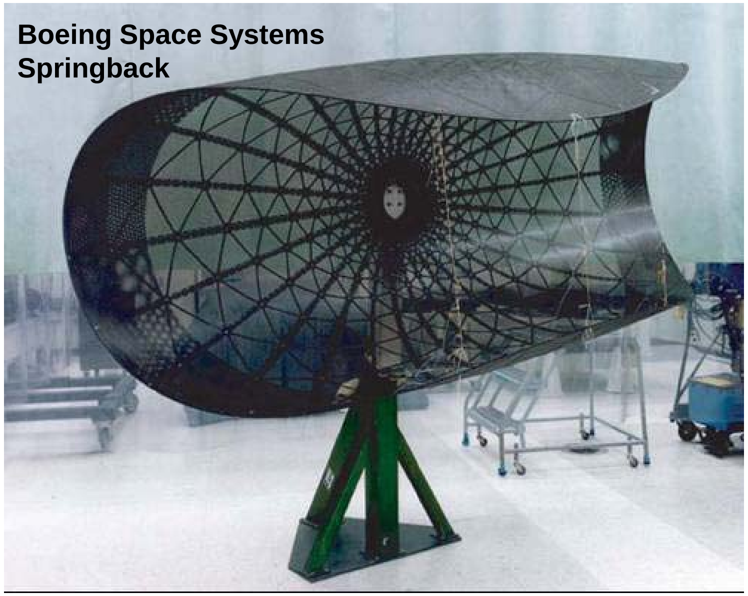
- **Semi-rigid petals/panels deployed into a contiguous curved surface**
- **Spring-back**
- **Phase transition, “Shape Memory” or “Rigidizable” material systems and related structural concepts**
- **Hybrids**



Dornier FIRST



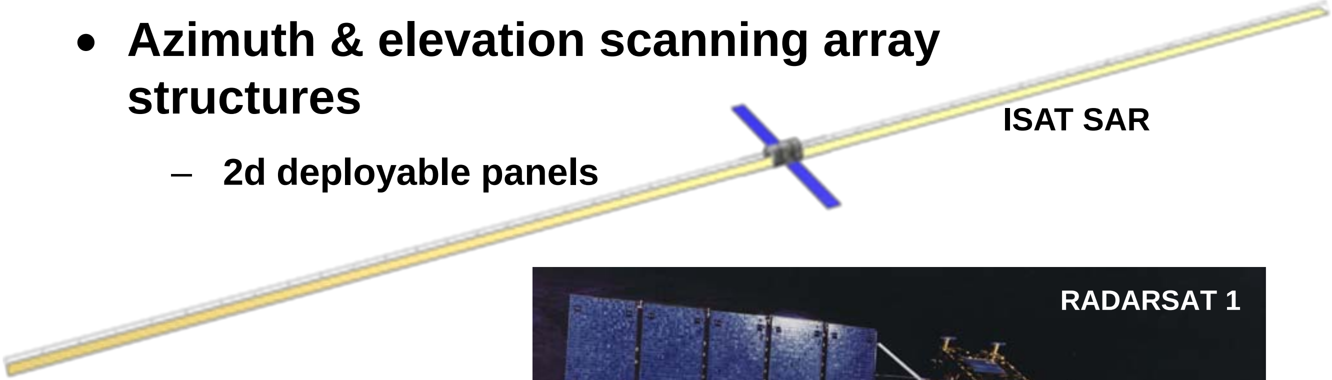
Harris Corp. Precision Deployable Surface

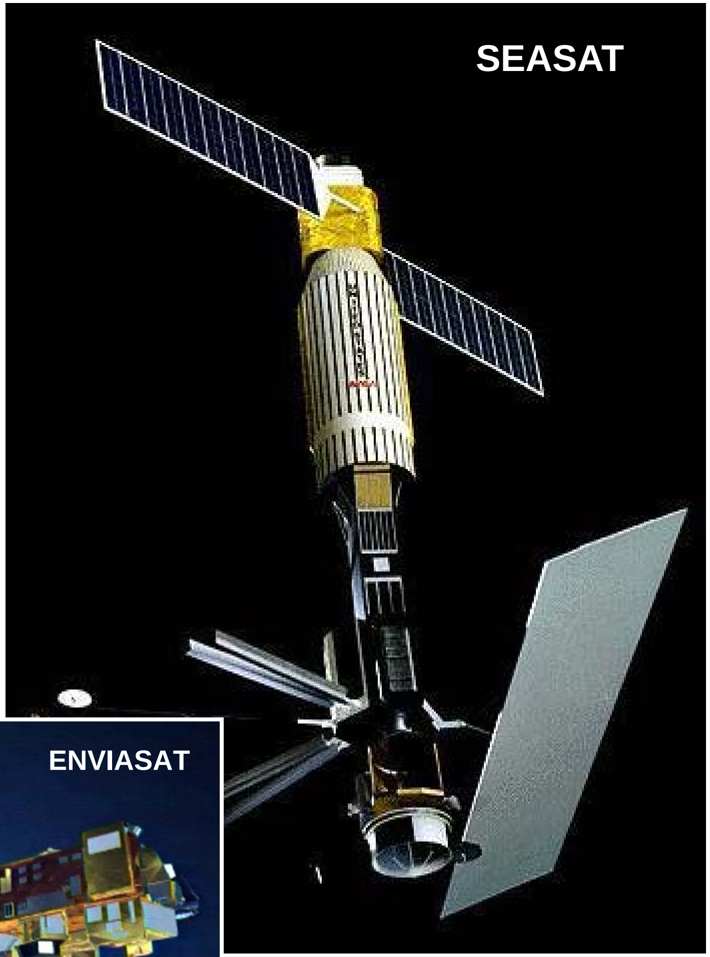


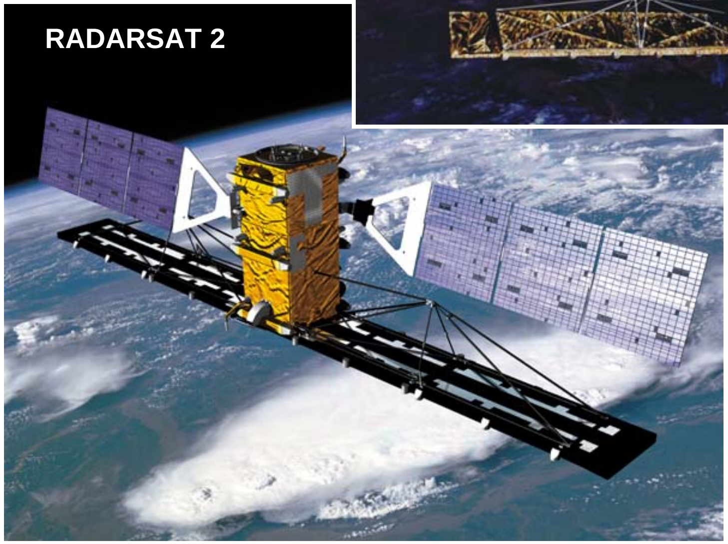
Boeing Space Systems Springback

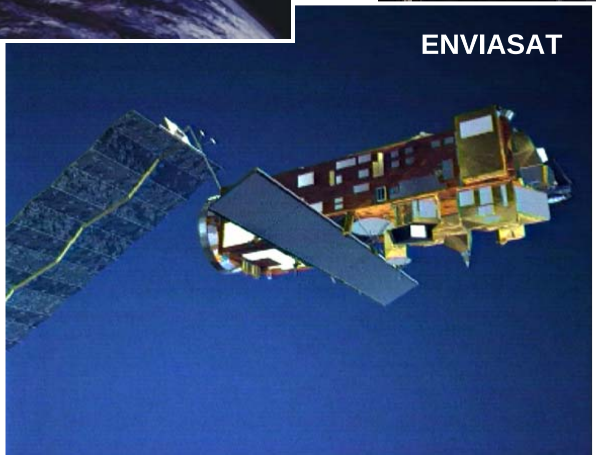
More Aperture Types Not Addressed

- **Azimuth scanning array structures**
  - **1d deployable, i.e. one aperture dimension << launch vehicle I.D.**
- **Azimuth & elevation scanning array structures**
  - **2d deployable panels**





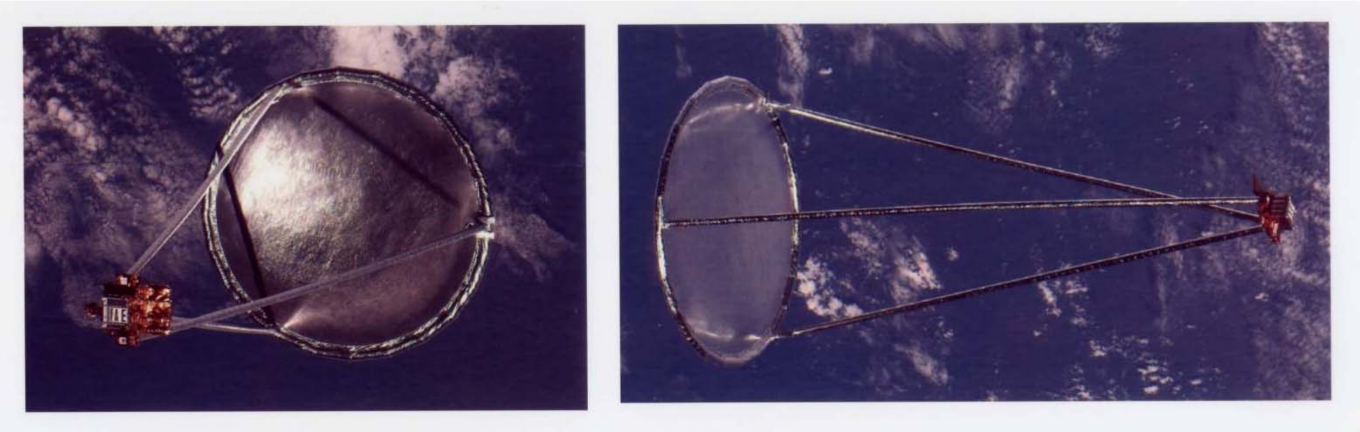




Aperture Types Addressed

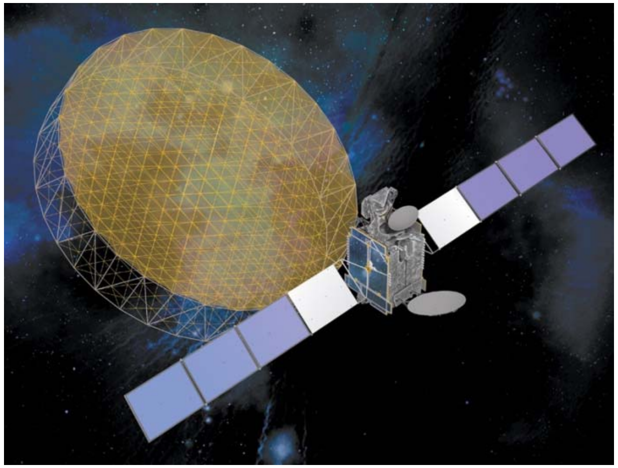
- **Doubly-curved parabolic reflectors**
  - Non-rigid, tensioned reflector surfaces
  - Passive control of structural precision

Thuraya
AstroMesh Reflector



IAE
Inflatable Antenna experiment

Mechanical vs. Inflatable Reflectors?



Production Automobile

Personal Aircraft

Outline

- Deployable aperture state of the art (SOTA)
- SOTA performance limits
- Future Directions for any large deployable RF aperture
  - Higher performance
  - Larger reflectors
  - Larger arrays

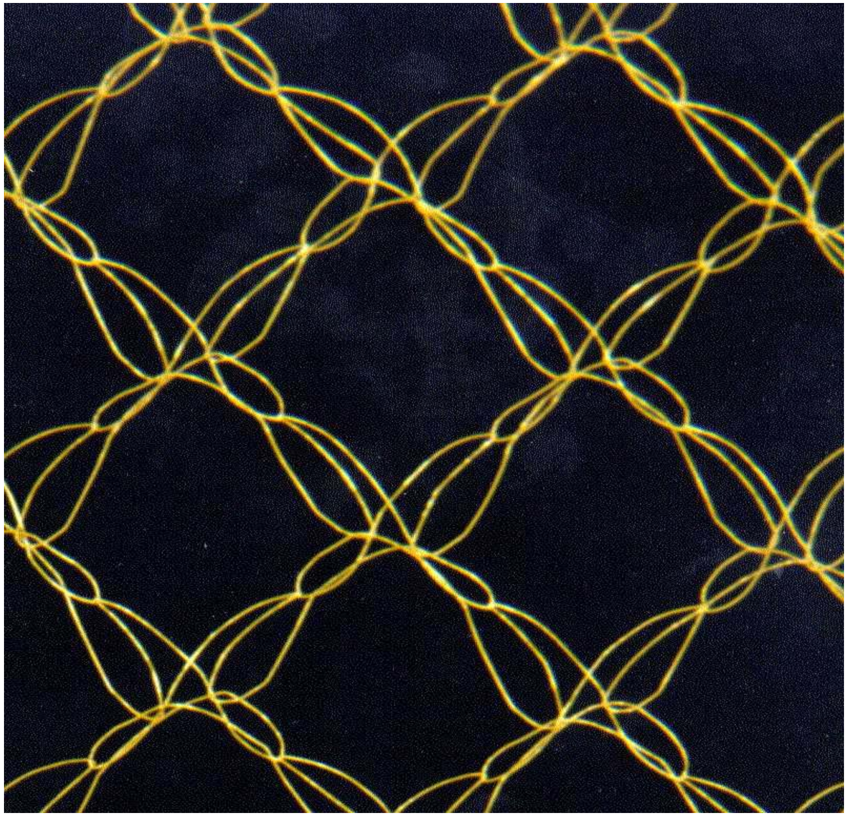
Deployable Aperture State of the Art

- SOTA has flown or selected for an operational Mission
  - Device is typically < 5% of Mission cost
  - Deployable fails = Science, Commercial or other Mission failure
- Mesh reflector apertures are the SOTA
  - Many doubly curved parabolic mesh reflectors
    - Harris Corp. and NGST Astro Aerospace are regularly competed

Mesh Reflector State of the Art

What is Mesh?

- Gold plated molybdenum wire
  - Approximately 0.030mm (0.001”) Ø
- Tricot warp knit fabric
  - Highly elastic behavior
  - Non-linear, anisotropic stiffness
- Limited to RF frequencies below 100 GHz
- Performance is unaffected by, thermal, radiation, micrometeorite, UV & atomic oxygen environments

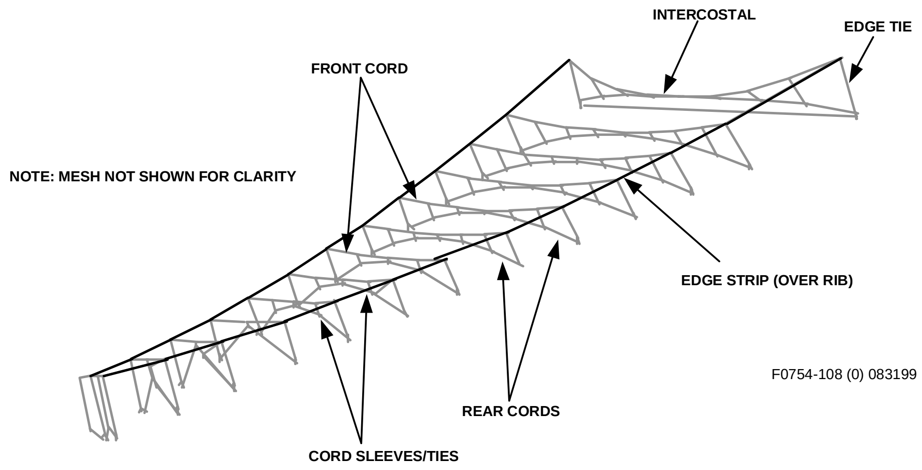


Mesh Reflector Principles

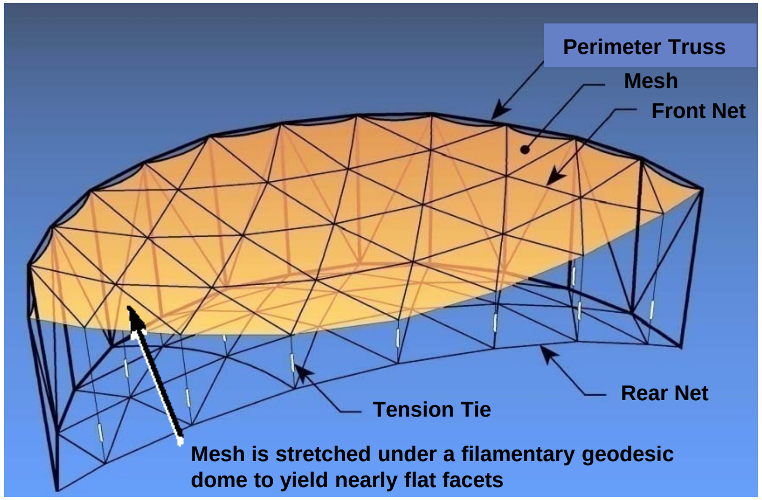
- A stiff and stable deployable structural framework stretches highly elastic mesh into an approximation of the required RF surface
- Low mesh stiffness allows structurally redundant coupling with the composite support structure to remain a second-order effect
  - Mesh-imparted loads are relatively low
  - Thermal stability of the reflector is unaffected by the presence of mesh

Mesh Reflector Characteristics

- Deployable structural framework
  - Lightweight composite members; high stiffness and thermal stability
  - Members linked kinematically for mechanical stowage and deployment
- Filamentary mesh support structure
  - Assembly of highly stable linear elements such as cords and tapes
  - Approximation of the required surface achieved with tie points and/or lines
  - Periodicity and geometry of mesh support structure defines systematic errors
  - Manufacturing & global thermal stability of framework is controlled



Radial rib reflector mesh support network
Deployable ribs not shown (Harris Corp)



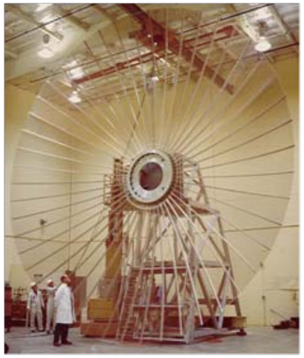
Perimeter truss mesh support network
(NGST Astro Aerospace)

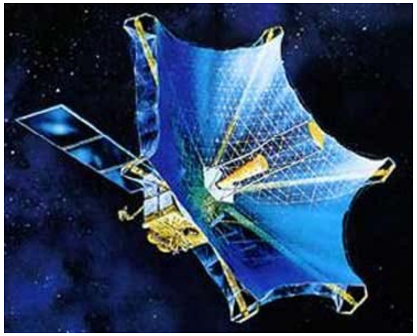
Mesh Reflector Characteristics

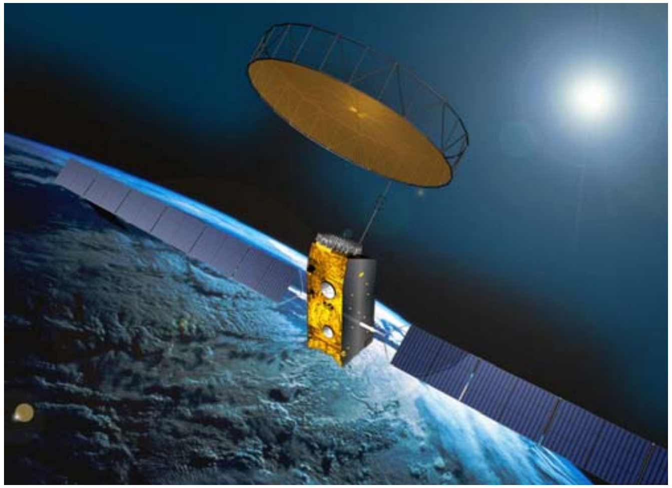
- Additional mesh surface errors are inherent to how it is shaped
  - "Pillowing" & "reverse lampshade" effects
  - Faceting errors
  - "Bow-back" from mesh loads on tensioned cords
    - Structural redundancy in the mesh support structure (and between it and the deployable framework) lead to variations in tension. This results in further mesh deformation during thermal extremes
  - The presence of hardware causes local surface errors

Mesh Reflector Flight History

- **A minimum total of 51 NASA, Commercial & Navy units have or will be flown by 2011**
  - **35 reflectors to 13m flown to-date**
  - **At least 16 more units with apertures to 22m by 2011**





JPL

35 Mesh Reflectors On-Orbit

- NASA, Commercial and Navy Satellites

Name	Aperture (m)	Qty.	Date	Vendor	Comments
ATS-6	9.1	1	5/74	Lockheed	Wrap-rib; axisymmetric
FLTSATCOM	5	6	1978-89	TRW	Radial Rib with 80” solid center; axisymmetric
TDRS A,C,D,E,F,G	4.9	12	4/83 - 7/95	Harris	Curved Radial Rib; axisymmetric
Galileo	4.9	1	10/89	Harris	Curved Radial Rib; axisymmetric
HALCA	8	1	2/97	ISAS	Extendible Rib (AstroMasts); axisymmetric
Garuda	12	2	2/00	Harris	Folding Rib; Offset edge-mounted design
Thuraya 1-3	12.25	4	10/00 - 2/08	NGST	AstroMesh Perimeter Truss; Offset edge-mounted design
N-STAR c	5.1	1	7/02	Harris	Straight Radial Rib; Offset edge-mounted design
MBSat	12	1	3/04	NGST	AstroMesh Perimeter Truss; Offset edge-mounted design
INMARSAT	9	2	3/05 & 10/05	NGST	AstroMesh Perimeter Truss; Offset edge-mounted design
JCSat-9	5.1	1	4/06	Harris	Straight Rib; Offset edge-mounted design
JAXA ETS-8	13	2	12/06	Toshiba	Mesh Modules; Offset edge-mounted design; Test Satellite
ICO	12	1	4/08	Harris	Folding Rib; Offset edge-mounted design

32 Successful Deployments; 2 anomalies; 1 failure

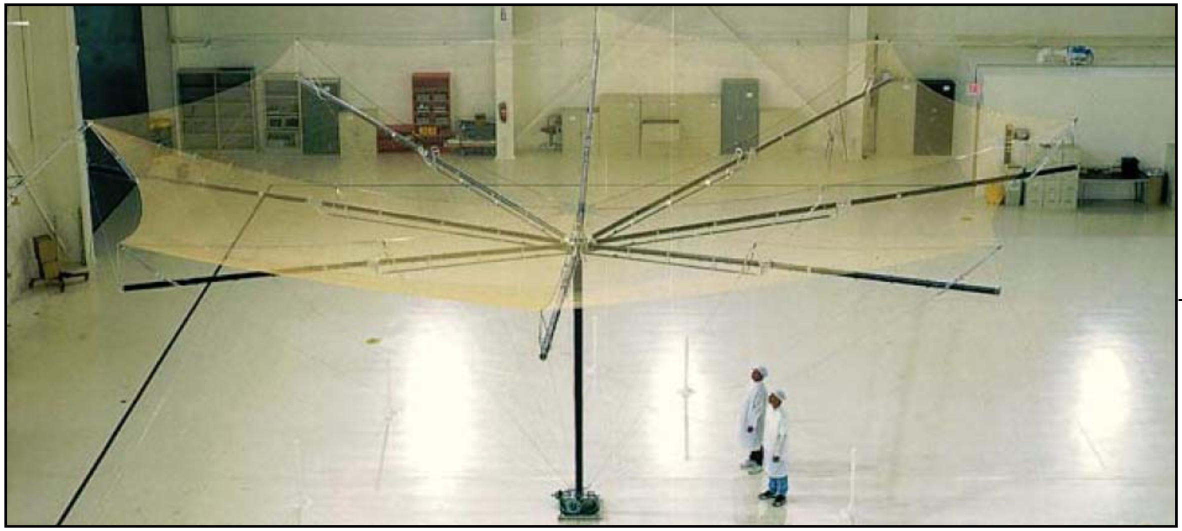
16 Mesh Reflectors Pending Launch

- Commercial and Navy Com Satellites in design & fabrication

Name	Aperture (m)	Qty.	Vendor	Comments
MUOS (Navy)	6	3	Harris	Straight Rib
XM Radio	9	2	Harris	Straight Rib
SIRIUS	9	1	Harris	Straight Rib
ALPHA-SAT	11	1	NGST Astro	Perimeter Truss
CMB-Star	12	1	Harris	Folding rib
W2A	12	1	Harris	Folding rib
MUOS (Navy)	14	3	Harris	Folding Rib
Terrestar	18	2	Harris	Folding rib:
MSV	22	2	Harris	Harris Hoop (perimeter truss)

16 reflectors to 22m will be flown by 2011

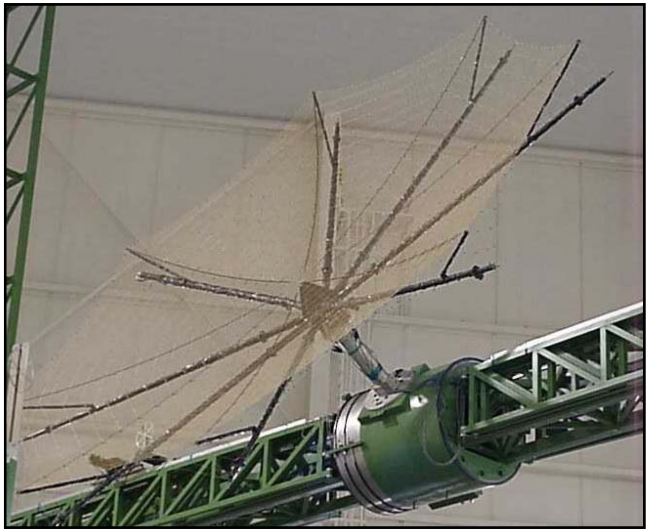
Harris Corp. Examples



12m
ACeS
Folding
Rib

Deployed

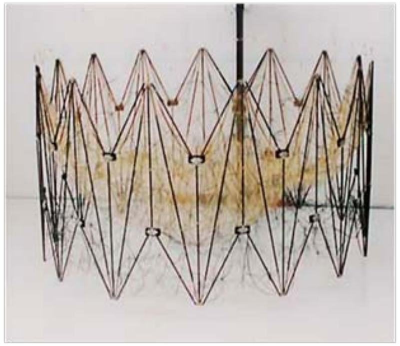
Stowed

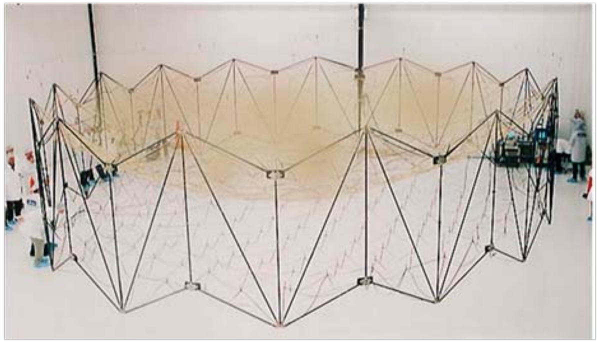


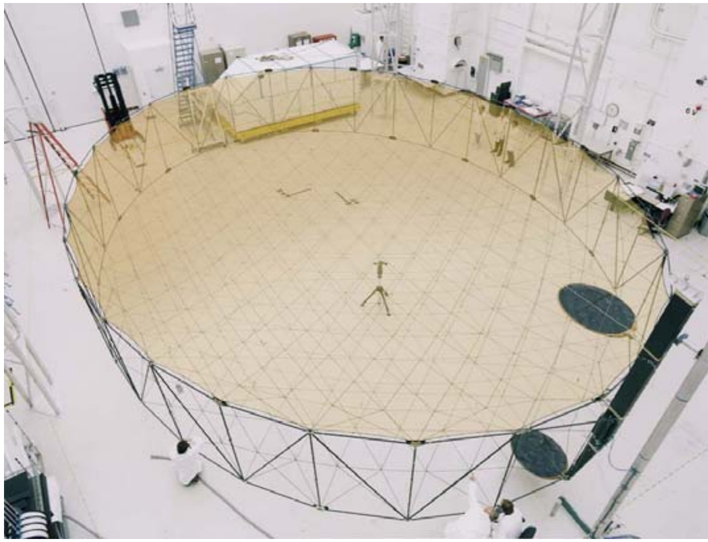
5m NStar-c Radial Rib

ACeS Folding Rib in RF Test

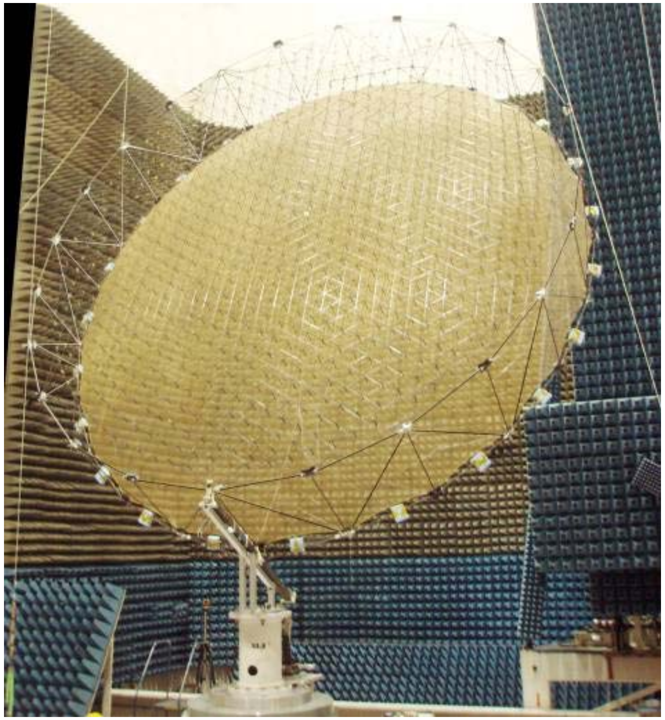
NGST Astro Examples







12m AstroMesh



- **AM-Lite RF testing at NASA GRC**
  - Pre & Post Deployment Measurements
  - 50 GHz performance matches that of a perfect 4m reflector

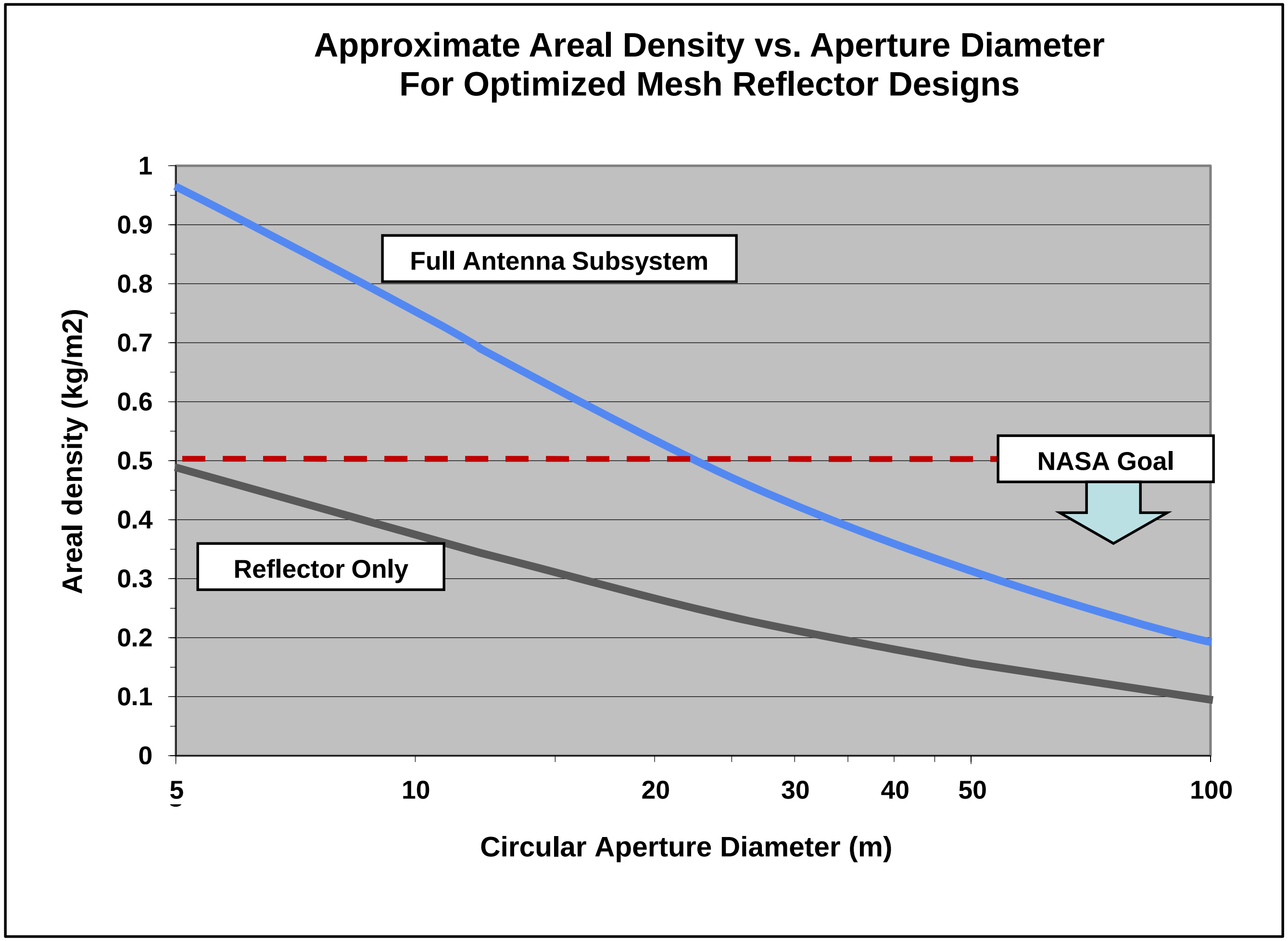
12m AM-1
6 to 25-Meter Class

12m AM-2
18 to 50-Meter

Limits of Design & Performance

Mesh Reflector Areal Density

- A full antenna subsystem includes:
  - Reflector
  - Boom
  - Launch restraints
  - Harnesses
  - Etc.
- Reflector-only mass may be approx ½ total subsystem
- We must be specific



Mesh Reflector Frequency Potential

- **Surface figure approximation capability: $D/W_{RMS} = 30{,}000$**
  - **D = circular aperture diameter**
  - **W_{RMS} = RSS sum of all RMS errors:**
    - **Systematic**
    - **Manufacturing**
    - **Orbital thermal**
    - **Deployment repeatability**
    - **Material effects: radiation, creep, dry-out, load/thermal hysteresis, property scatter (CTE, modulus), life**
    - **Pillowing/bow-back**

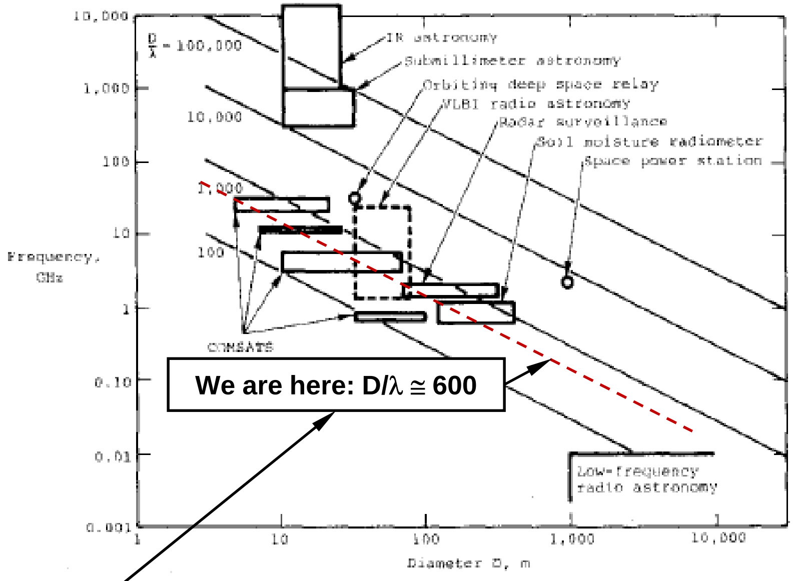


Fig. 1 Large space antenna requirements.

[17] Hedgepeth, J. M., "Accuracy Potentials for Large Space Antenna Reflectors with Passive Structure," *J. Spacecraft and Rockets*, vol. 19, No. 3, May-June 1982, pp. 211-217.

- **30 GHz (Ka band) with λ/50 with a 6m aperture**
- **Mesh reflection loss**
  - **Mesh can be knitted densely enough for very low loss through Ka band**
  - **Low aperture efficiency systems (VLBI for instance) to under 100 GHz**

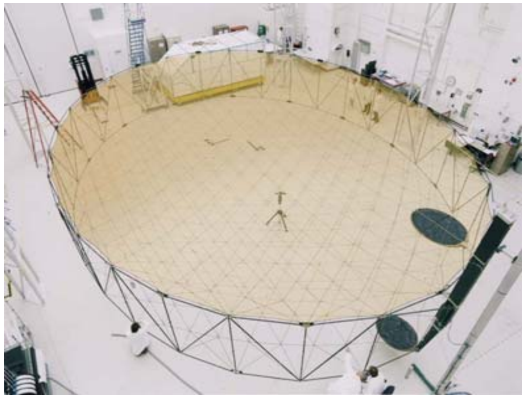
Other Performance Factors

- **Lifetime required for most heritage mesh reflectors:**
  - **15 years at GEO**
  - **50 deployment cycle life (not verified)**
- **Effective orbital drag area and solar transmissivity**
  - **Approximately 20 to 25% of the total frontal projected area**
  - **Helps S/C fuel consumption to remain low**
- **Stowage volume and form factor for launch**
  - **Difficult to generalize**
  - **Current launch vehicles may limit SOTA mesh apertures to about 100 meters maximum**
- **Launch loads**
  - **10g to 30g quasi-static**

Ground Testing and Verification

- “Test-as-you-fly” criteria are often waived
  - Marsis & Sharad FFT antennas by NGST displayed uncontrolled synchronous deployments
  - End-to-end RF performance & thermal distortion
- Attempts to fly a deployable main mission antenna without 100% demonstration of deployment in the minimum relevant environment will be met with significant resistance
  - For mesh reflectors: room temperature and pressure in 1-g with appropriate offloading
  - Over 10 deployments may be required to complete an initial qualification campaign
  - Controlled synchronous or sequential deployments
- Flight experiments will not defray ground test requirements significantly for operational Missions

ACeS Folding Rib in RF Test



12 m AstroMesh supported on 3-points retains shape

Advancing the Large Aperture State of the Art

- **Any new technology must meet or exceed key requirements satisfied by mesh reflector state of the art to supplant it**
- **Future Directions**
  - **Larger reflectors? Max capability of mesh has not been required**
  - **Higher frequency capacity with lower loss – mesh is leaky**
    - **Active structural shape control**
  - **Larger azimuth scanning arrays (1d)**
    - **ISAT**
  - **Azimuth and Elevation scanning arrays (2d)**
    - **No one know how to do this yet (well)**
  - **Singly curved parabolic deployable reflectors**
  - **Materials:**
    - **0 CTE membranes with tailorable Poisson's ratio**
    - **High and/or low stiffness membranes**
    - **Electroactive phase-change materials**