DEPLOYABLE ANTENNA STRUCTURES TECHNOLOGIES

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OUTLINE

- **Mechanical Structures Technology History**
  - Initial Concepts for Very Large Space Antennas
    - Self-Deployable
    - On-Orbit Assembly
    - On-Orbit Manufacturing & Assembly
    - Concept Development Limitations
  - Current Self-Deployable Antenna Concepts
    - State-of-the Art Examples
    - ISAT Mechanical Concept Developments
      - Harris PAFR Concept, AstroFold Truss
- **Inflatable Antenna Concepts Development**
  - Examples
  - Inflatables Technology Maturity Issues
- **Next Generation Technology**
  - Large Space Structures Technology Dev. Challenges

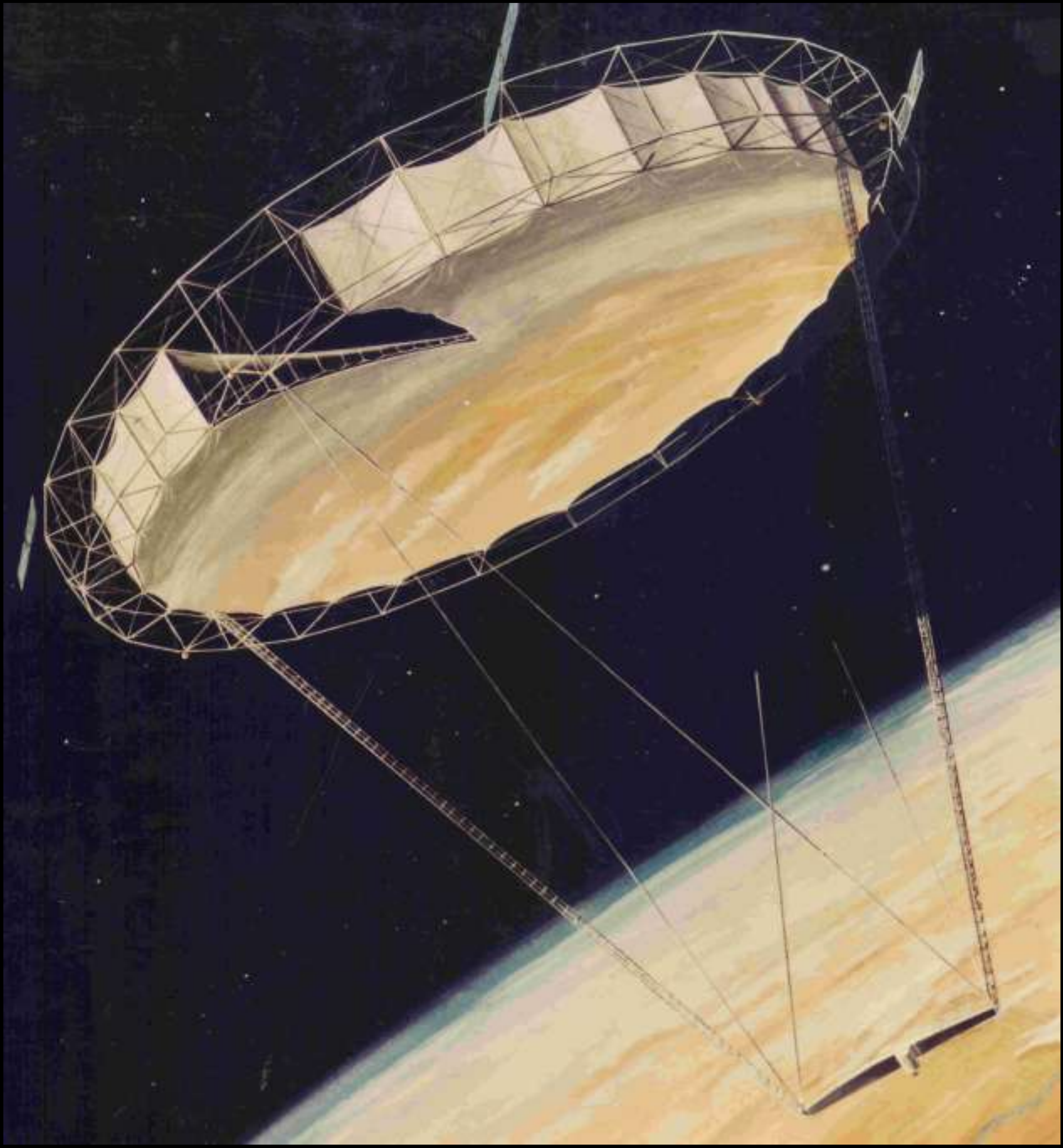
Size matters!!

EARLY INNOVATIVE CONCEPTS
FOR VERY LARGE SPACE STRUCTURES

Basic deployment classes of large space structures:

- **Self-deployable**
  - **Mechanical**
  - **Rigidizable/Inflatable (R/I)**
  - **Hybrid**
- **On-Orbit Assembled**
  - **EVA construction of structural elements, assemblies, and sub-systems**
  - **Robotic construction of elements, assemblies, sub-systems, and systems**
  - **Combined Robotic-EVA assisted construction**
- **On-Orbit Manufacturing of single elements up to 1000 meters in length, multiple elements (curved and circular), and, grids and panels of various types, sizes, and shapes.**

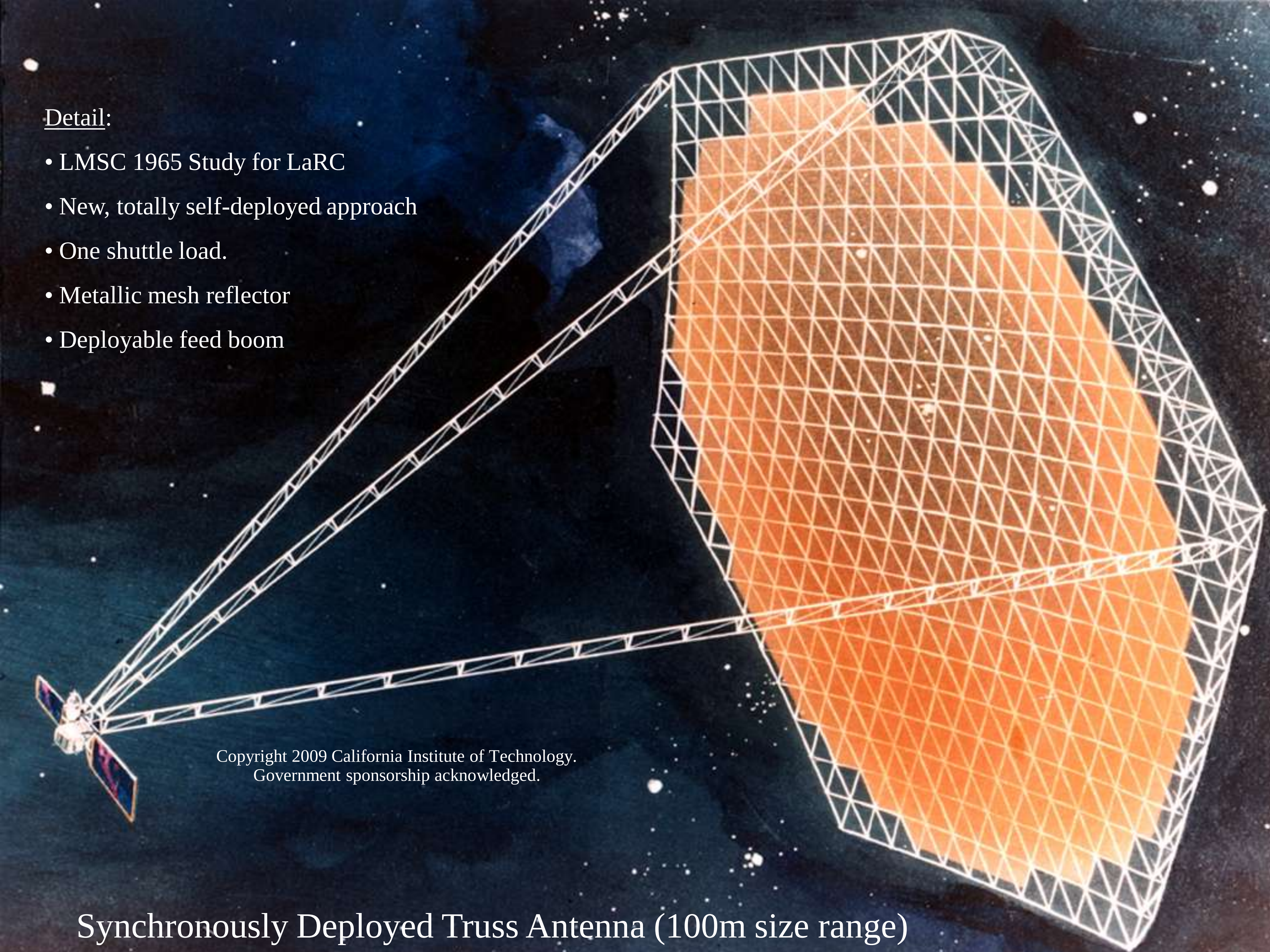
Box Truss Antenna
(100m dia.)



Detail:

- Martin Co. 1970’s Study
- Synchronized self-deployment
- One shuttle load.
- Metallic mesh reflector
- Surface shaping cable system
- Telescoping feed booms

Synchronously Deployed Truss Antenna (100m size range)



Detail:

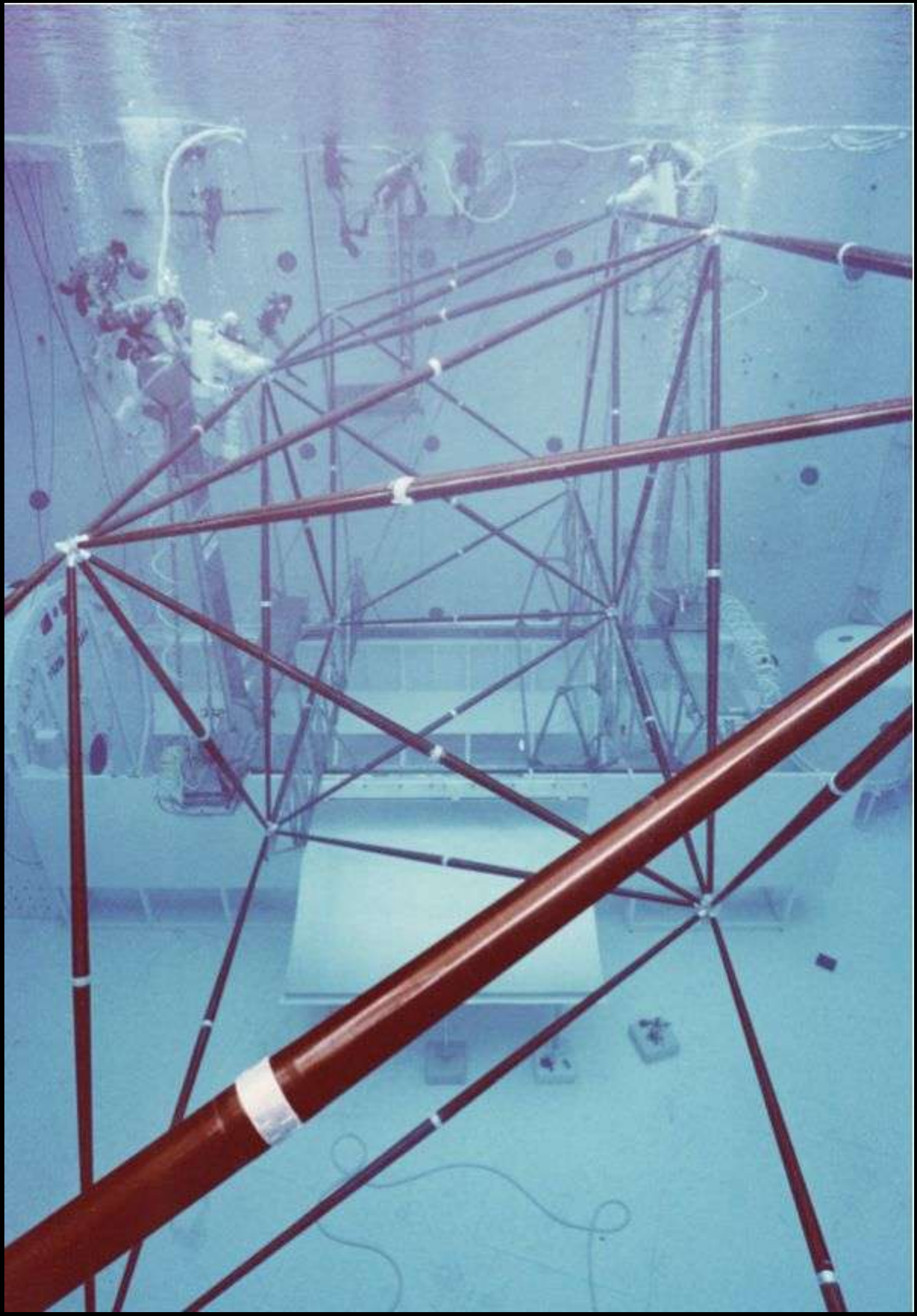
- LMSC 1965 Study for LaRC
- New, totally self-deployed approach
- One shuttle load.
- Metallic mesh reflector
- Deployable feed boom

On-Orbit Robotic/EVA Assembly
for Very Large Space Structures

Nestable Columns
Underwater Truss Assembly

<u>Detail</u>:

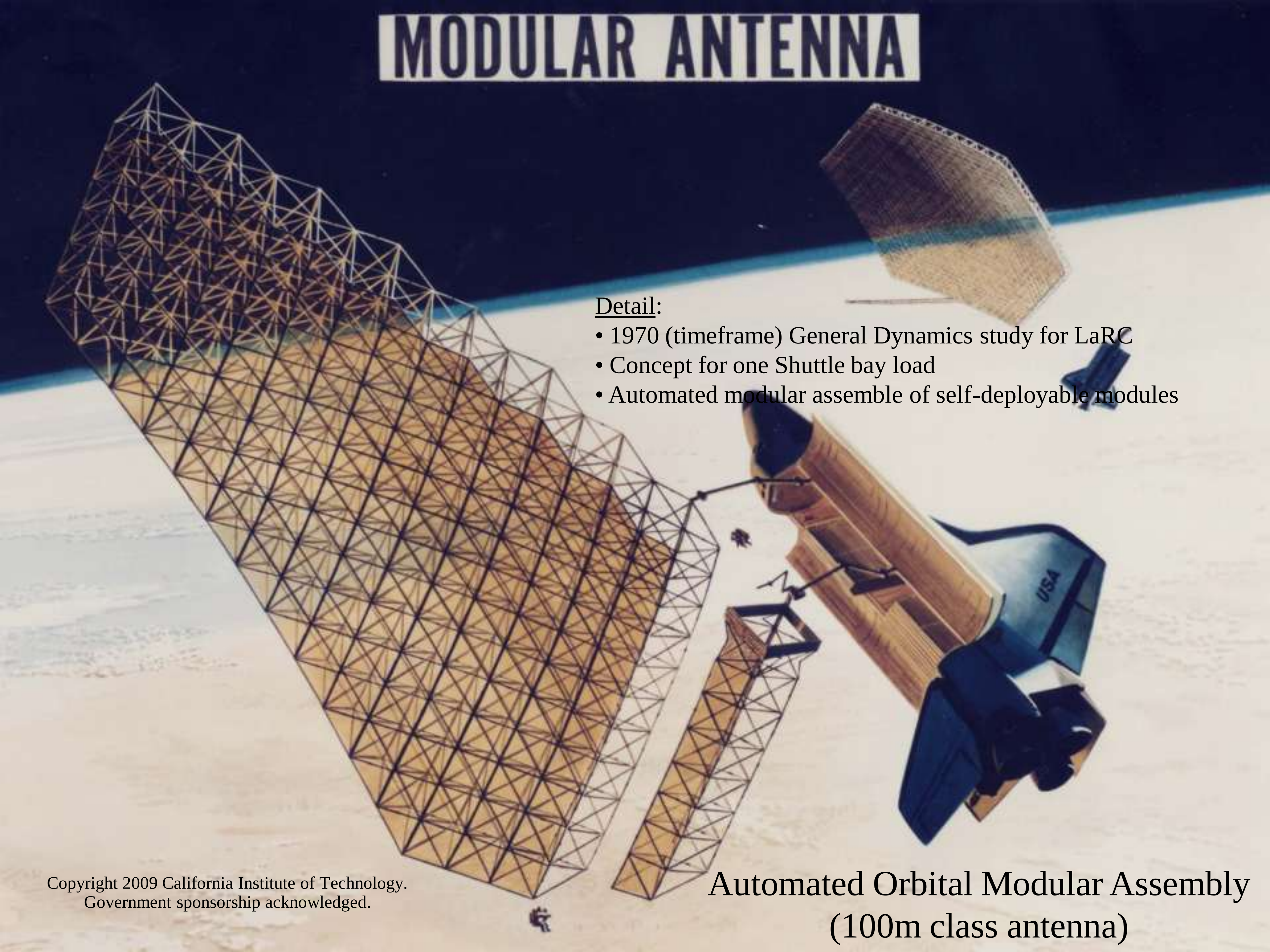
- LaRC Nestable Column concept
- Marshall SFC 0-g tank
- Largest space structure assembled using this concept
- Very long truss structure



Boeing HF Space Antenna: On-Orbit Assembly (33m dia.)

Detail:

- Launched in “kit” form for low orbit assembly
- One Shuttle flight
- Graphite/Epoxy structural elements
- RF up to 300 GHz / active
- High precision doubly curved gores with actuator(s)
- Robotically assembled



Detail:

- 1970 (timeframe) General Dynamics study for LaRC
- Concept for one Shuttle bay load
- Automated modular assemble of self-deployable modules

Automated Orbital Modular Assembly
(100m class antenna)

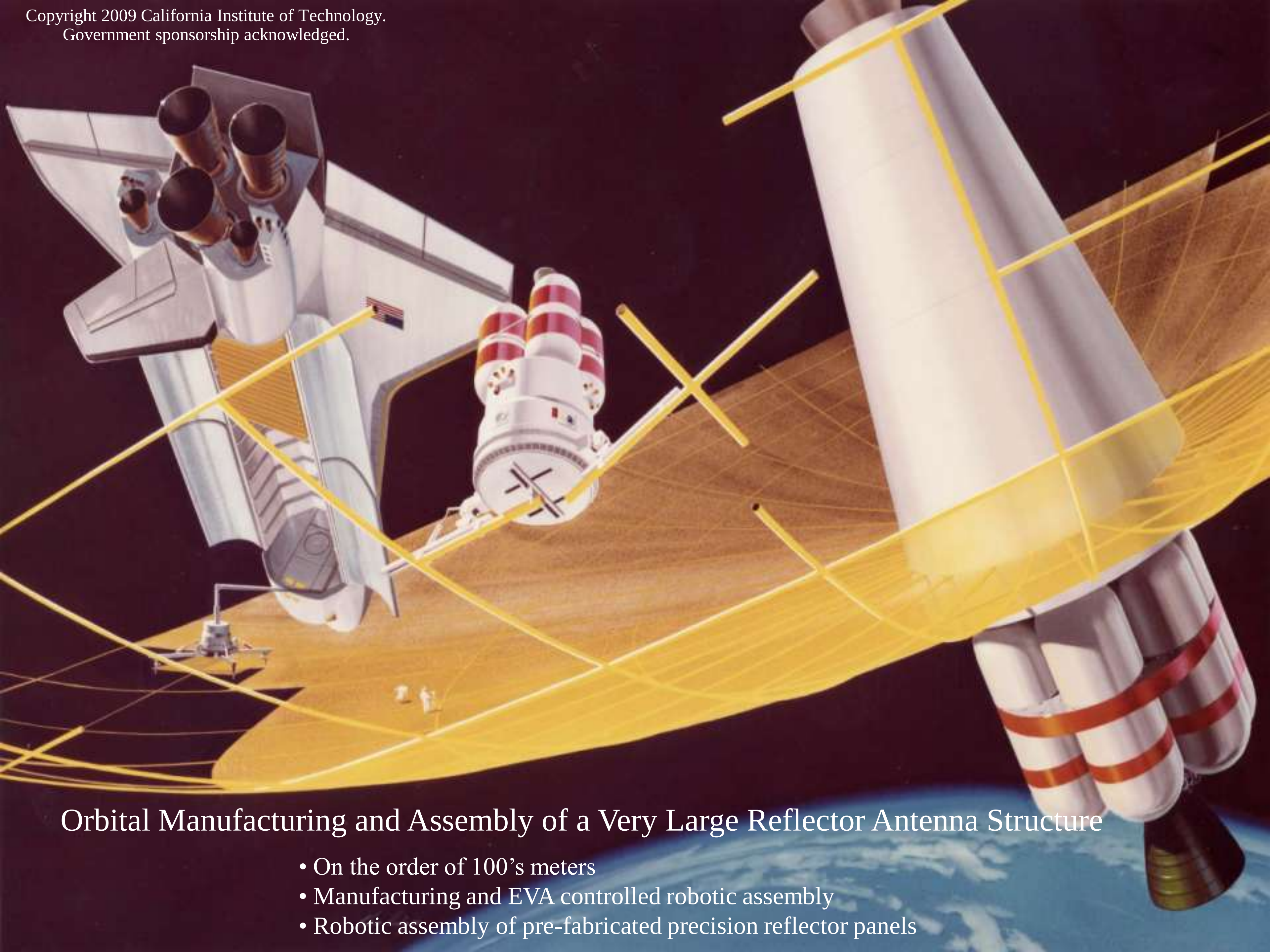
On-Orbit Manufacturing & Assembly

for Very Large Space Structures

Detail:
• JSC sponsored study (late 1970’s)
• Orbital manufacture of composite ribs and rings
• “Turntable” fixture automated assembly operation
• Central Astromast (deployable) with RF mesh reflector (EVA)
• Tension cables EVA assembled

Grumman Orbital Construction Demonstration Antenna (100m dia.)

Manufacture of Ribs and Structural Elements



Orbital Manufacturing and Assembly of a Very Large Reflector Antenna Structure

- On the order of 100’s meters
- Manufacturing and EVA controlled robotic assembly
- Robotic assembly of pre-fabricated precision reflector panels

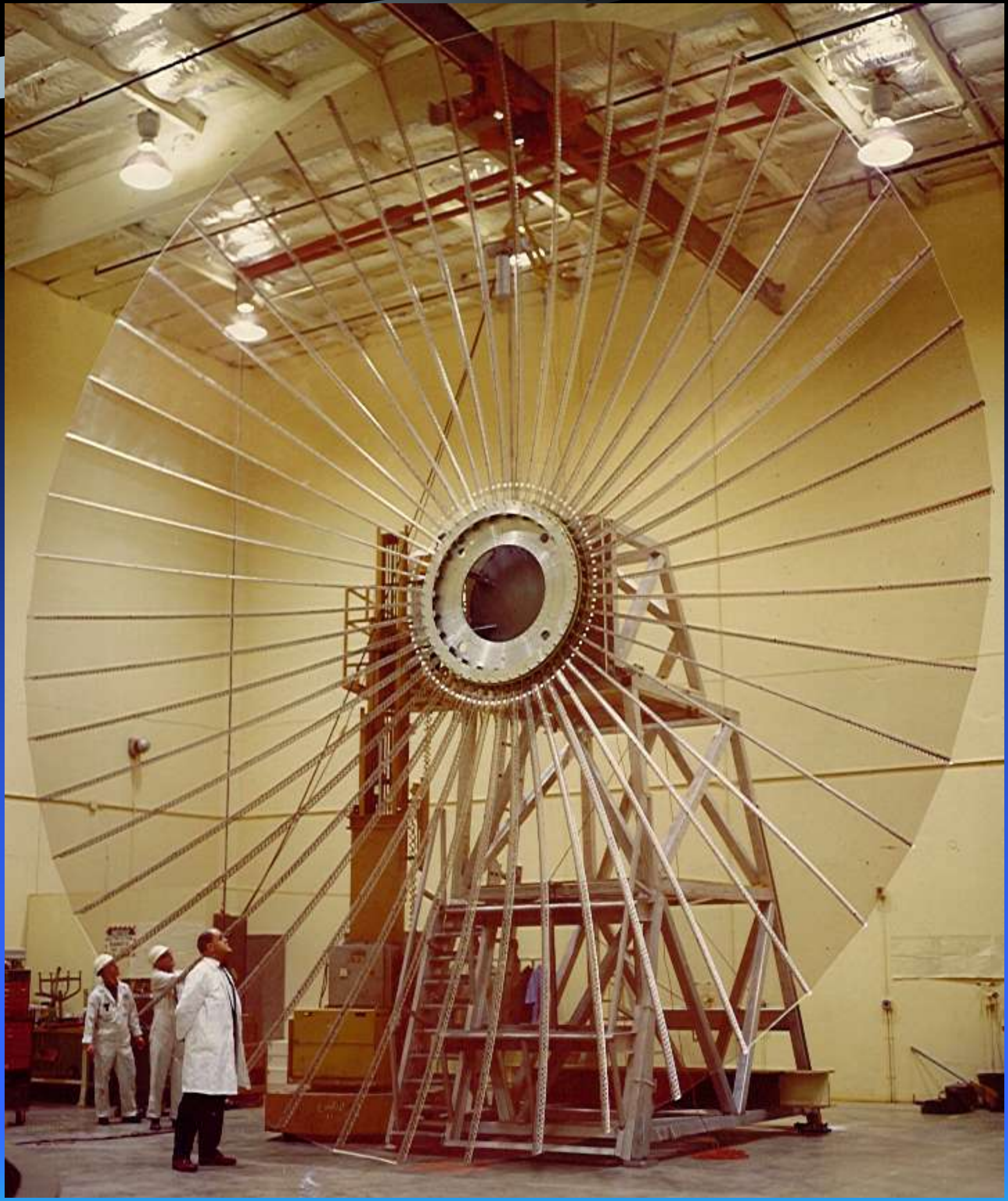
Concept Development Limitations

- Unfortunately, a lagging interest in going beyond the stage of "conceptual definition" primarily due to the "astronomical" costs of *advancing* the technologies to near flight readiness (especially on-orbit assembly and manufacturing) resulted in very little significant development.
  - $100's millions spent on various concepts and ground demos
- This unfortunate turn of events left only *self-deployable* structures technologies as a viable candidate for limited applications:
  - Started out with small size structures that lent themselves to meaningful ground-based evaluation
  - Over a period of time (~ 50 yrs.) self-deployables advanced to capabilities for 30 meter structures, mainly antennas.

Current State of the Art for Mechanical Self-Deployables

ATS – 6

Wrap-Rib Antenna (9.5 m)



Detail:

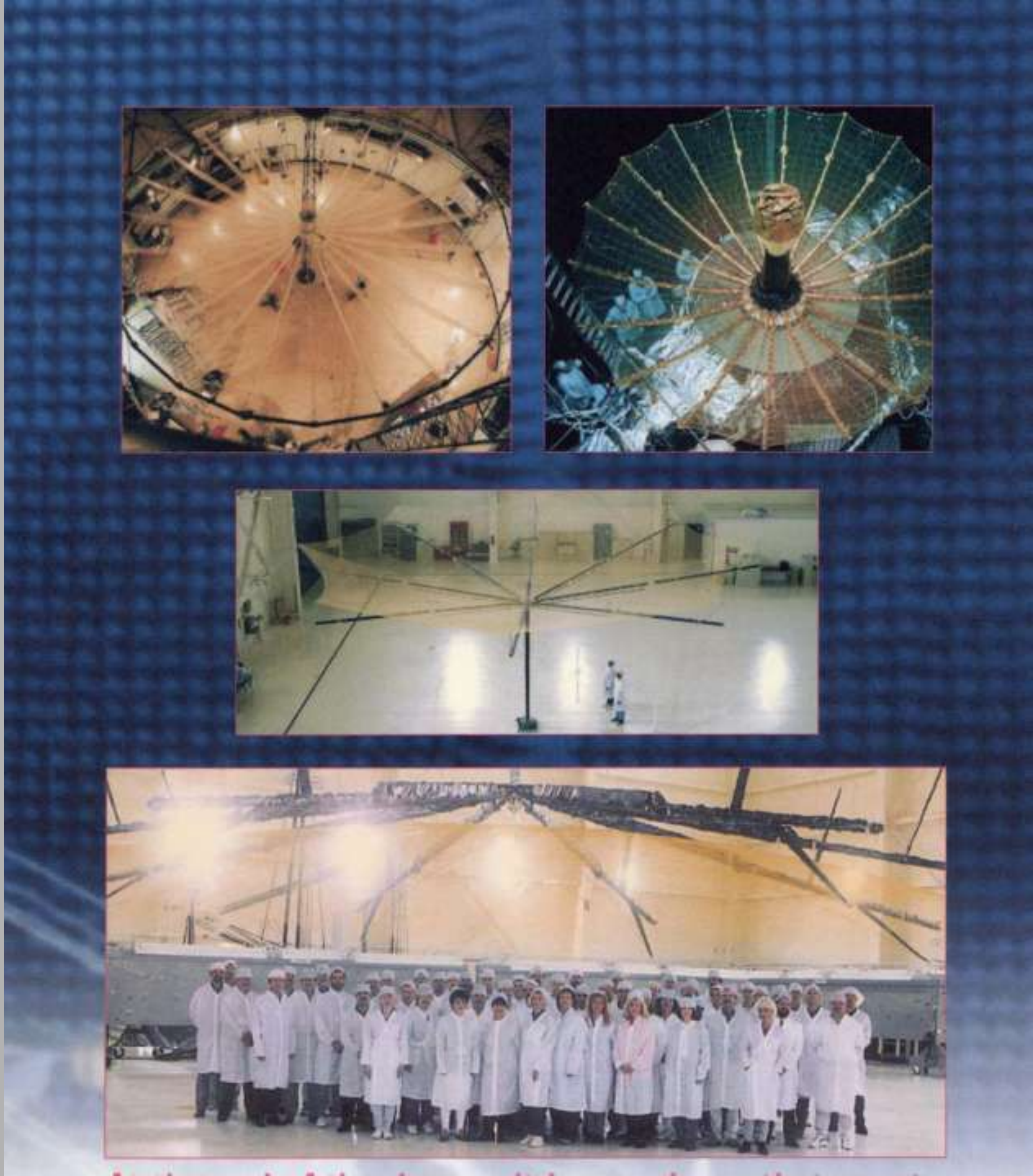
- Lockheed: first flown in 1960's
- Aluminum ribs
- Copper-coated Dacron mesh
- Deployed using strain energy release

Lockheed LSST: Wrap-Rib Antenna (sector of 55m dia.)

Detail:

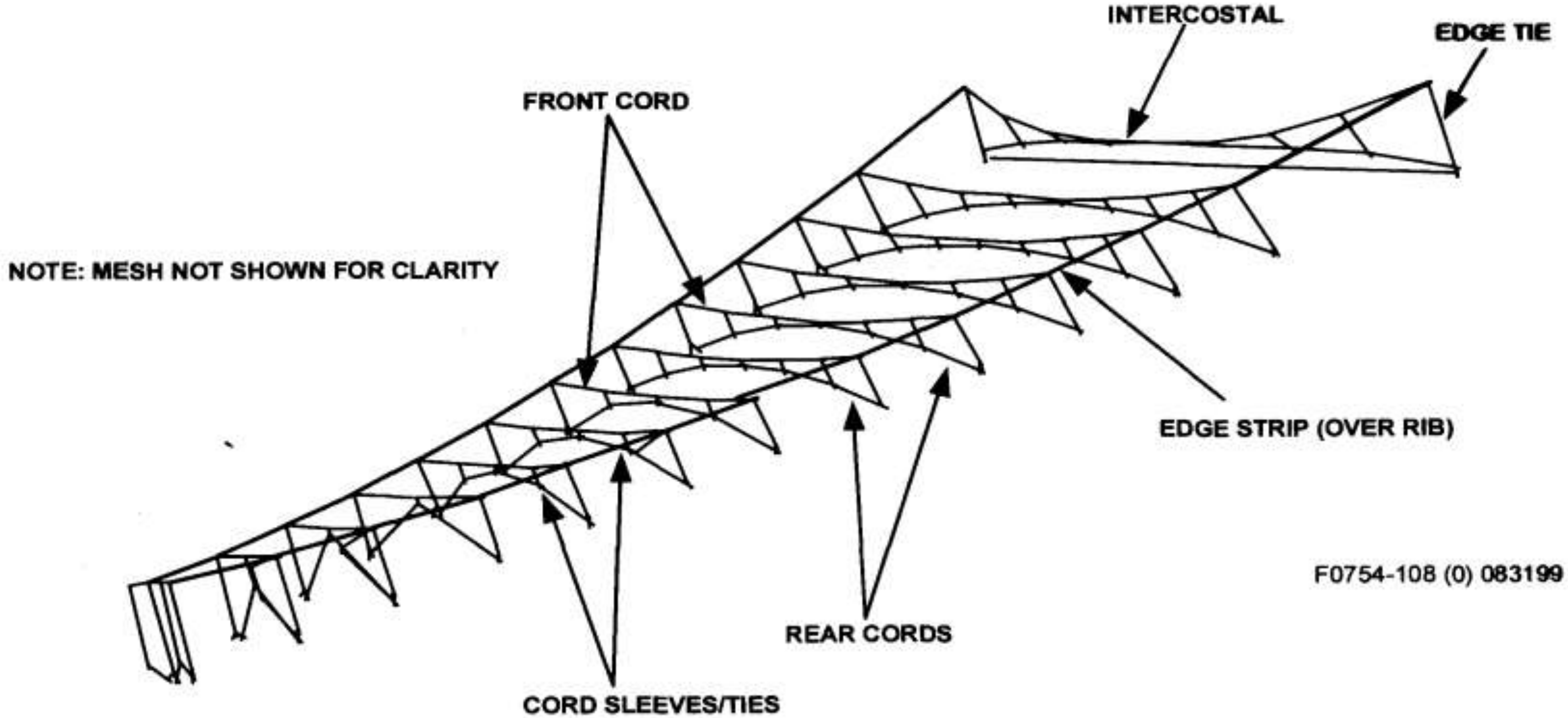
- Graphite/Epoxy lenticular ribs
- Gold plated Molybdenum wire mesh
- Kinematic deployment demo
- RF up to 3 GHz
- Intended operational size: 110 meters

Harris Mesh Reflector Antennas

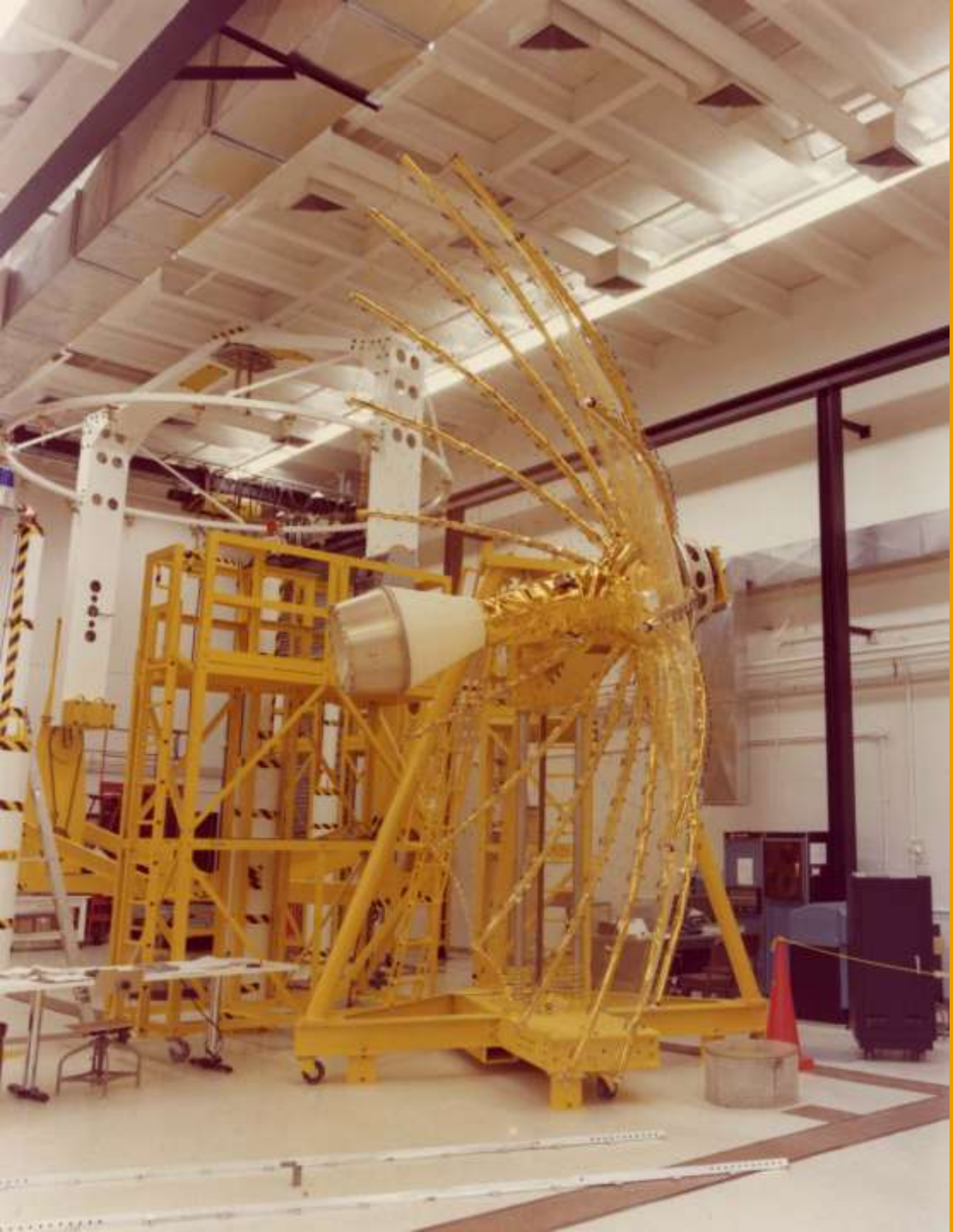


Mesh Reflector Surface Shaping

Dimensionally stable network of cords and ties shapes the **mesh surface**.



Surface shaping technique has more than 25 years of heritage.



HARRIS TDRSS ANTENNA

(6 meters)

<u>Detail</u>:

- NASA sponsored concept development
- Early 1960’s
- Radial rib development
- First “tunable” mesh reflector
- RF up to Ku band
- Basic concept flown at 6+ meters

ACeS Garuda 1 Satellite

Detail:

• Harris Corp

•Folding radial rib mesh reflector

• Flown at 12 meter diameter

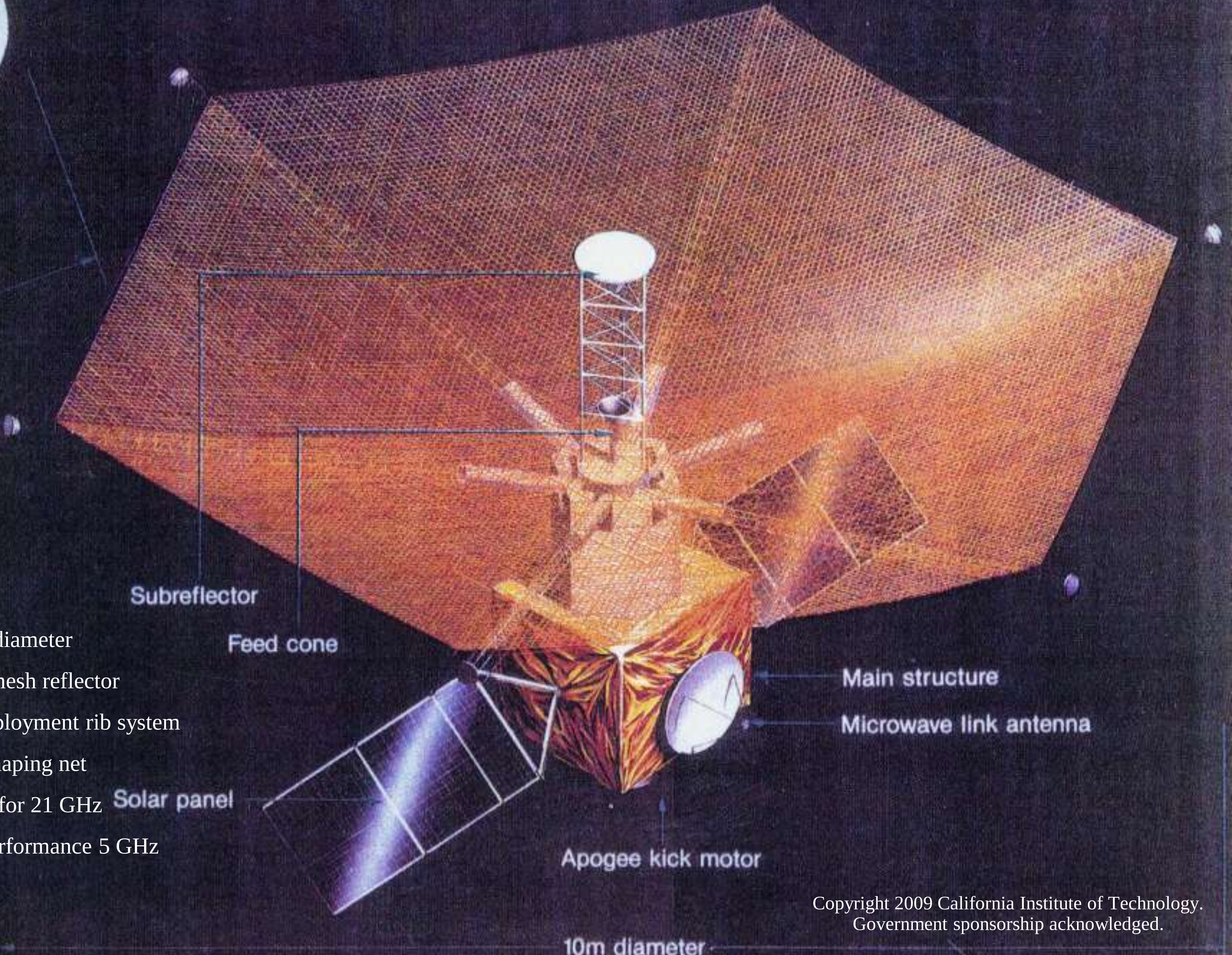
• Adjustable mesh aperture

• RF compatibility to 10 GHz

• Reflector rim support capability

• 1990's

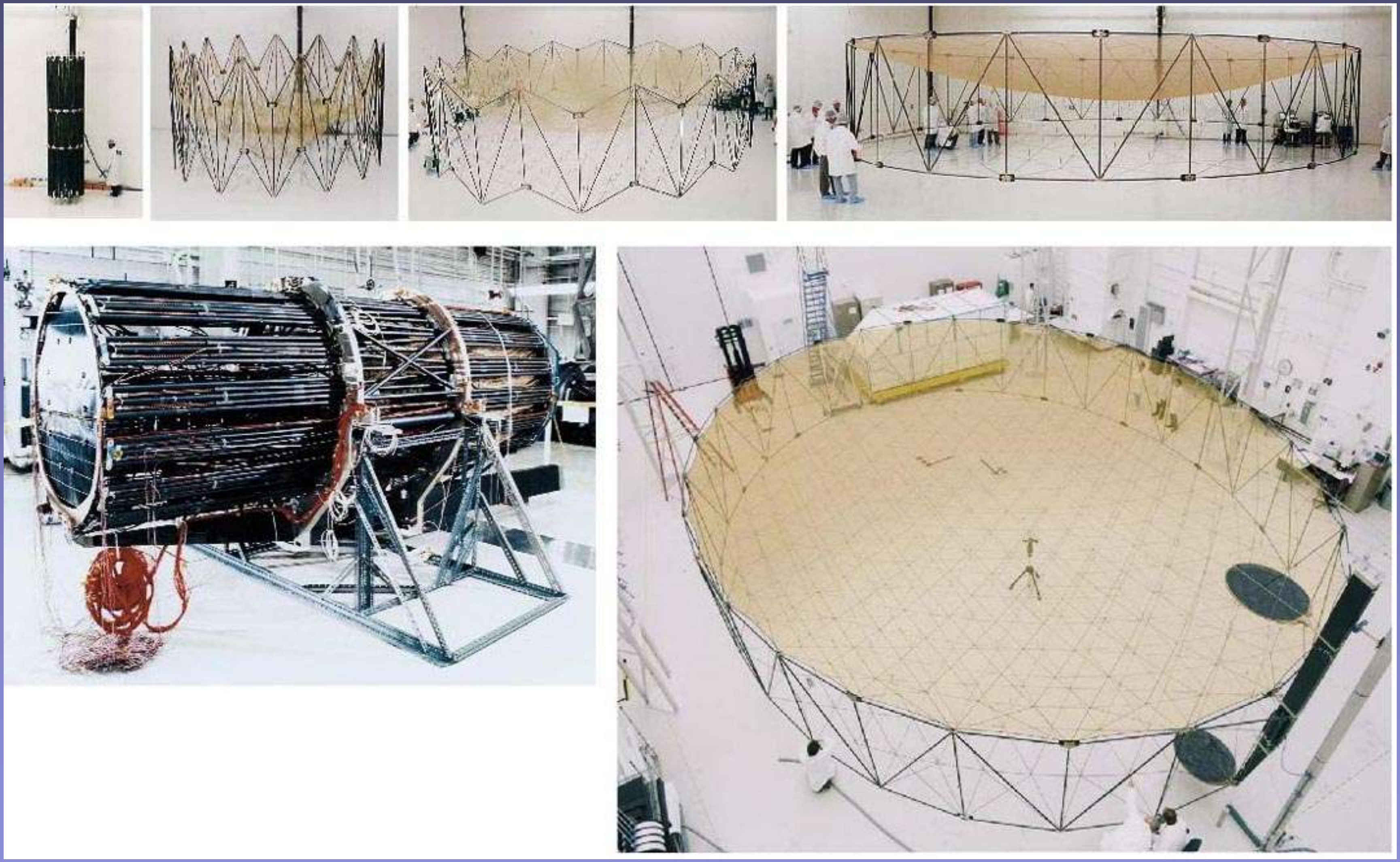
Japanese VSOP VLBI Antenna



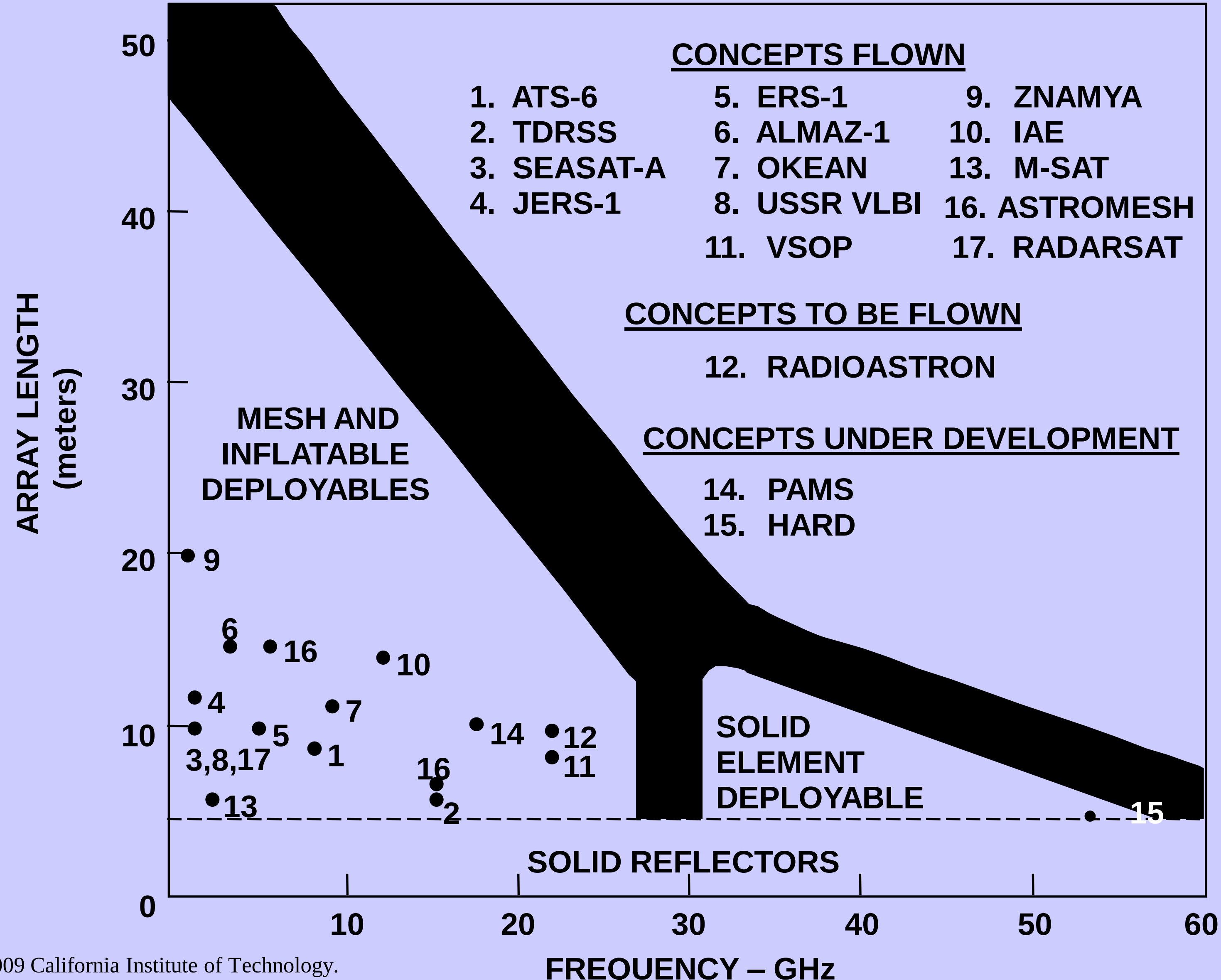
Detail:

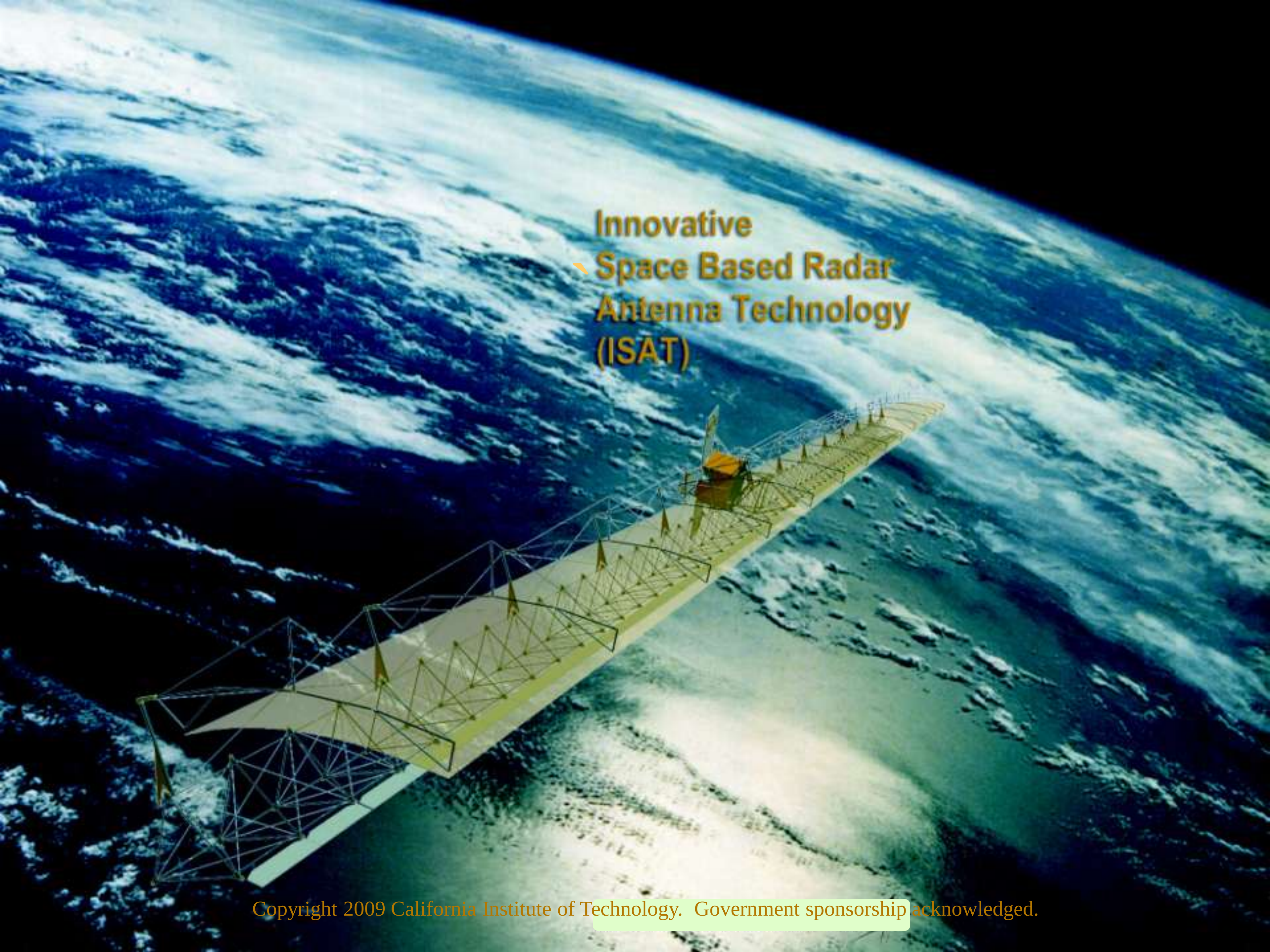
- 10 meter diameter
- Metallic mesh reflector
- Radial deployment rib system
- Surface shaping net
- Designed for 21 GHz
- Orbital performance 5 GHz
- 1990's

Thuraya AstroMesh
12.25-meter Reflector



DEPLOYABLE SPACE ANTENNA STRUCTURES




Innovative
Space Based Radar
Antenna Technology
(ISAT)
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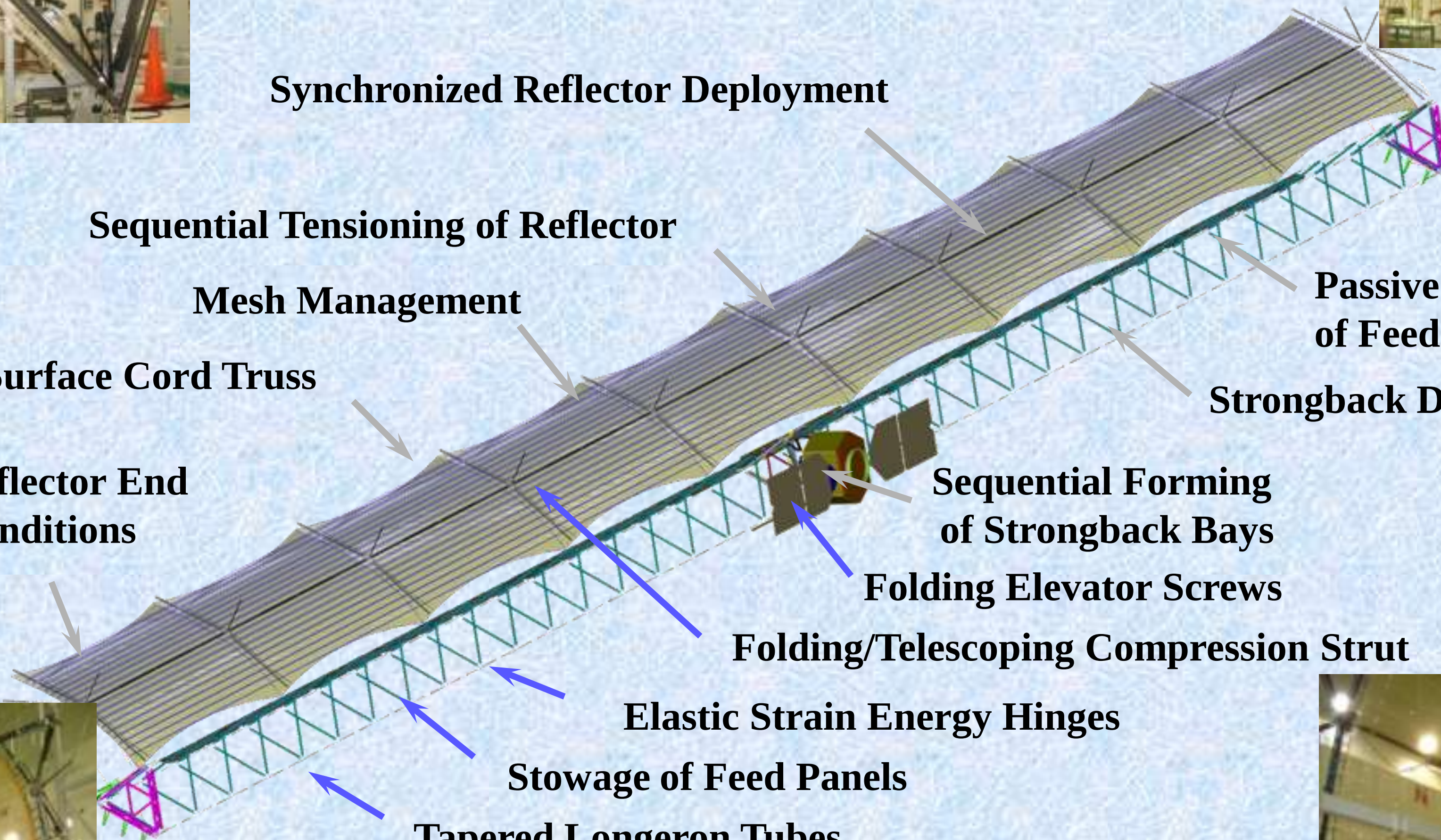
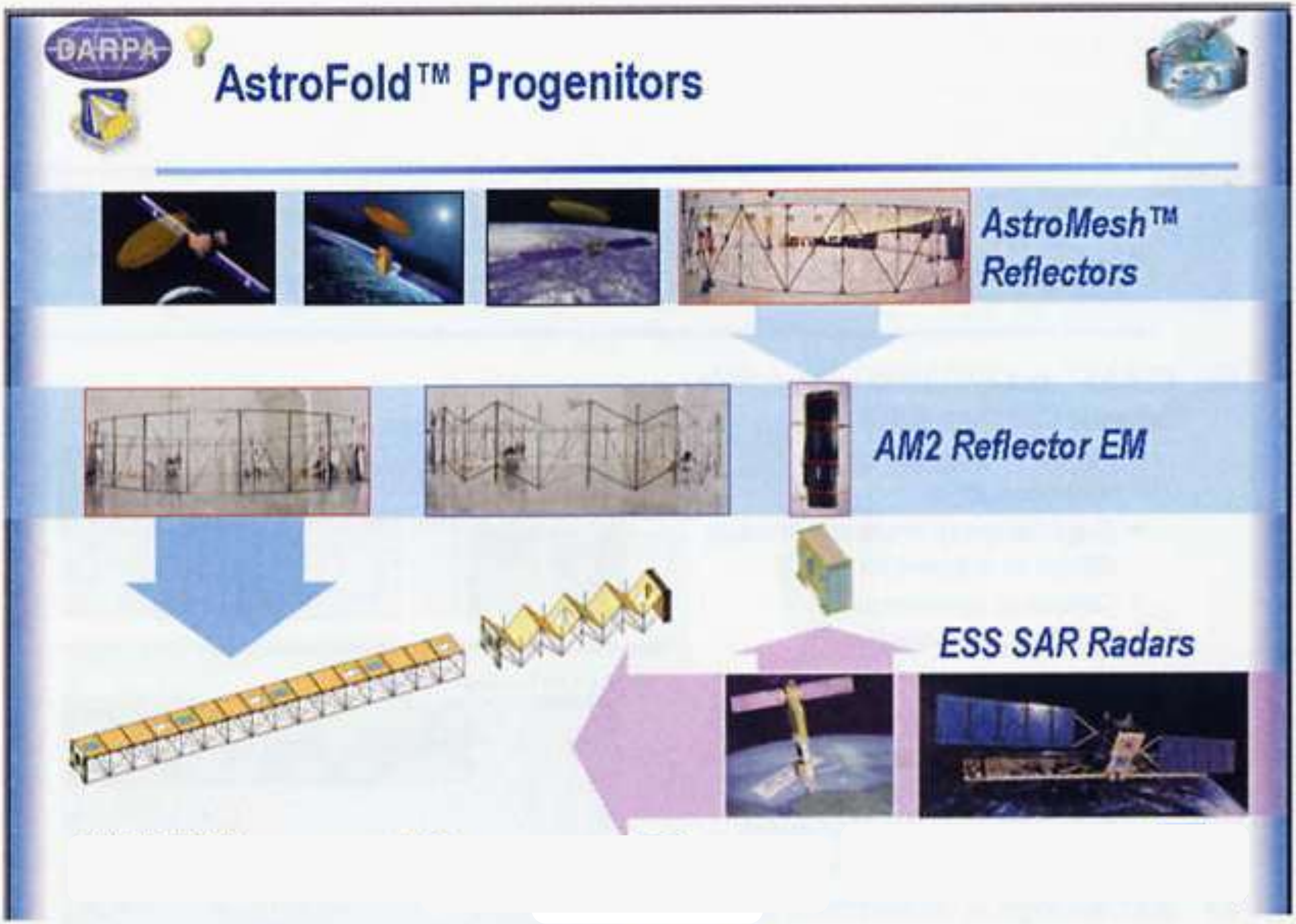
HARRIS ISAT PAFR




DARPA
AstroFold™ Progenitors
AstroMesh™ Reflectors
AM2 Reflector EM
ESS SAR Radars

INFLATABLE ANTENNA CONCEPT DEVELOPMENT

FOR VERY LARGE SPACE STRUCTURES

 Government sponsorship acknowledged.

HISTORY of INFLATABLE SPACE STRUCTURES

- A wide variety of inflatable space structures have been evaluated over the last *50 years.*
- It has only been recently that the *mechanical performance potential* has been recognized.
- *Early technology* advancements were derived primarily from *hardware demonstrations*.
- *Early concept* developments were critically limited by *"off-the-shelf" thin film* that had handling, processing, and fabrication issues.
- Although it was recognized early that there was a need for in-situ space rigidizable structures, it wasn't until the 1980's that the materials began to be available.

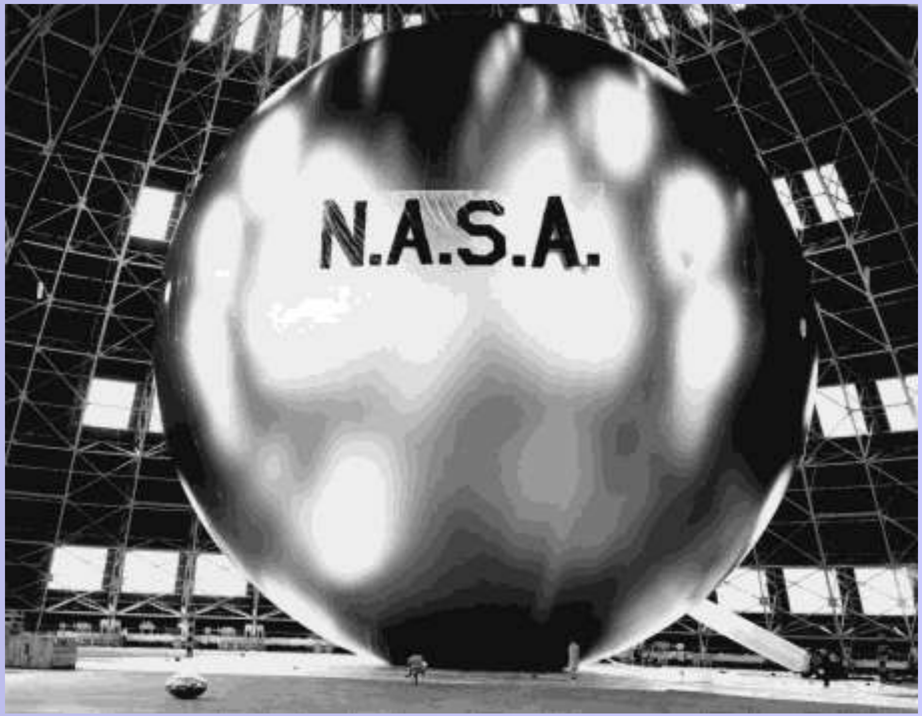
History of
SPACE INFLATABLE STRUCTURES

Technology Development

- NASA LaRC/GSFC/General Mills/Sheldahl
- Echo I Successfully Flown August 12, 1960
- Passive, Space Based Commun. Reflectors
- 100 Ft. Dia. /136 lbs/ 26 in Dia. Stowed Container
- Multiple, 12 μm Aluminized Mylar Gores
- Ballistic Flights Validation/Mechanical Packaging/Ejection/Inflation
- Delta Launch Vehicle/1000 km Orbit
- Operational for Months

Significance of Development

- Large Area Thin Film Handling/Processing/Fabrication/Assembly
- Orbital Deployment by Inflation
- Mechanical Packaging
- Launch Restraint/Release
- Vacuum Packaging Techniques
- Metalized Thin Film
- Operational Inflatable Space Structure
- First Successful Large Size, High Prec. Inflatable Space Structure on Orbit



ECHO BALLOONS
Flown August 1960

History of
SPACE INFLATABLE STRUCTURES

Technology Development

- Good Year
- 12 Meter Diameter Reflector Support Structure
- 10 Meter Lenticular Reflector
- Multiple Gore Reflector/Canopy Construction
- Multiple Element Torus
- Metalized Membrane for RF Reflectivity/Solar Energy Collection
- Foam Rigidization Techniques Evaluated

Significance of Development

- Thin Film Handling/Processing/Fabrication
- Inflatable Element Assembly/Alignment
- Deployment By Inflation
- Metalization of Thin Film
- Mechanical Packaging Techniques
- First Large Size Precision Inflatable Reflector Structure

LENTICULAR INFLATABLE PARAGORIC REFLECTOR
Technology Demonstration/Late 1950's

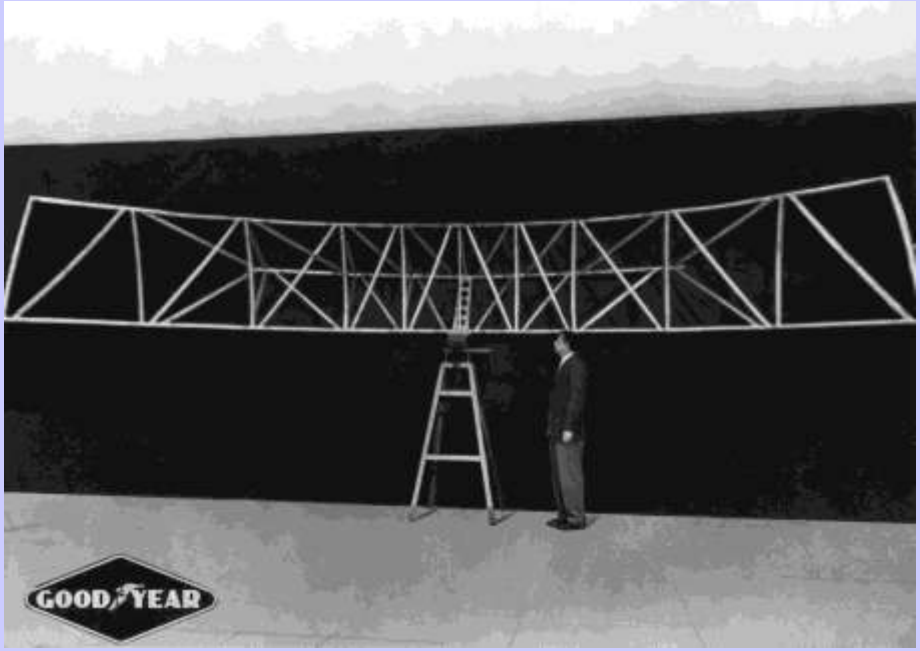
History of
SPACE INFLATABLE STRUCTURES

Technology Development

- Good Year
- 10 x 2 Meters
- Truss Support Structure
- Metallic Mesh Aperture
- Parabolic Reflector Surface
- Packaging Based on "Stacking" of 6 to 8 Flat Panels

Significance of Development

- Multiple Structural Element Fabrication
- Inflatable Element Assembly/Alignment
- Mesh/Support Structure Interface
- Deployment by Inflation
- Mechanical Packaging Techniques
- First Large Size Precision Inflatable Truss Structure



INFLATABLE SEARCH RADAR ANTENNA
Technology Demonstration/Late 1950's

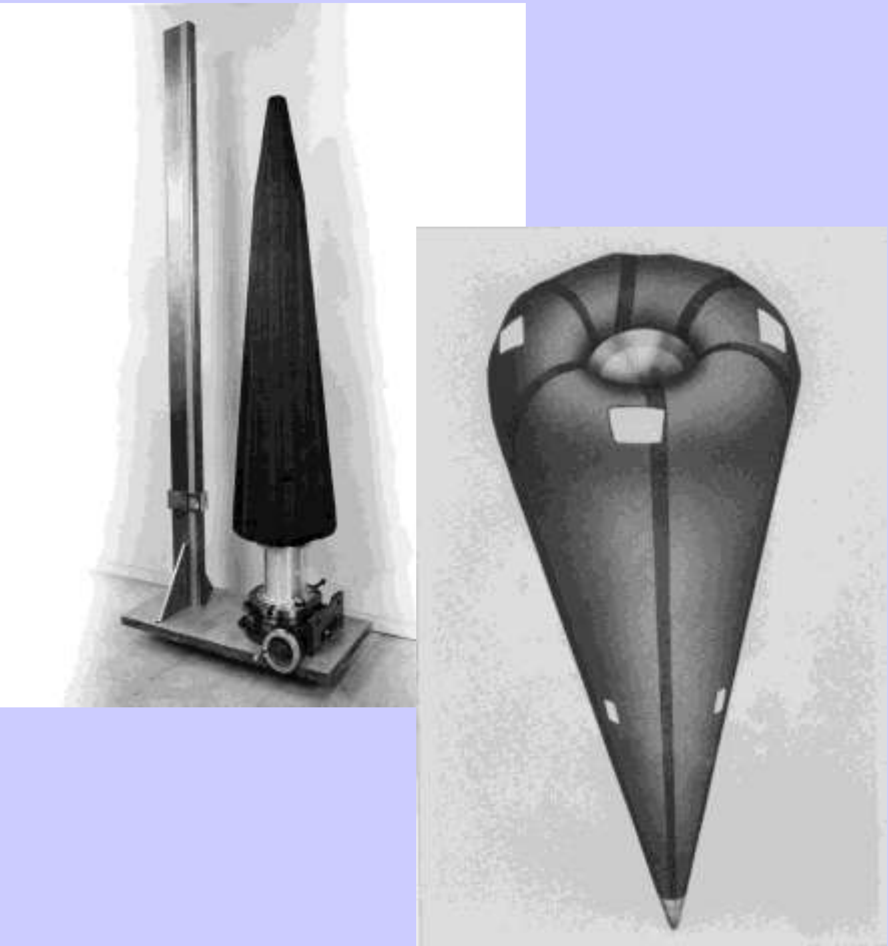
History of
SPACE INFLATABLE STRUCTURES

Technology Development

- L'Garde, Inc.
- Successfully Flown During the Late 1960's
- Re-Entry Vehicle Decoys/Single Structure Flights
- Size Range 1 by 2 Meters/100,000 Ft. Orbit
- On Board Down Link
- Configured to Simulate Pitch/Roll of Re-Entry Vehicle
- Simulated Radar / IR Signature
- Inflation ≈ Milli Seconds
- Materials EPDM / Nomex/Carbon Fiber

Significance of Development

- Thin Film Handling/Processing/Manufacturing/Assem.
- Residual Air Management
- Packaging/Launch Release
- On Orbit Deployment by Inflation
- Miniaturized Inflation System
- Metalized Flexible Materials
- First Successful Flight of "Shaped" Inflatable Space Structures
- Fully Instrumented Thin Membrane Structures

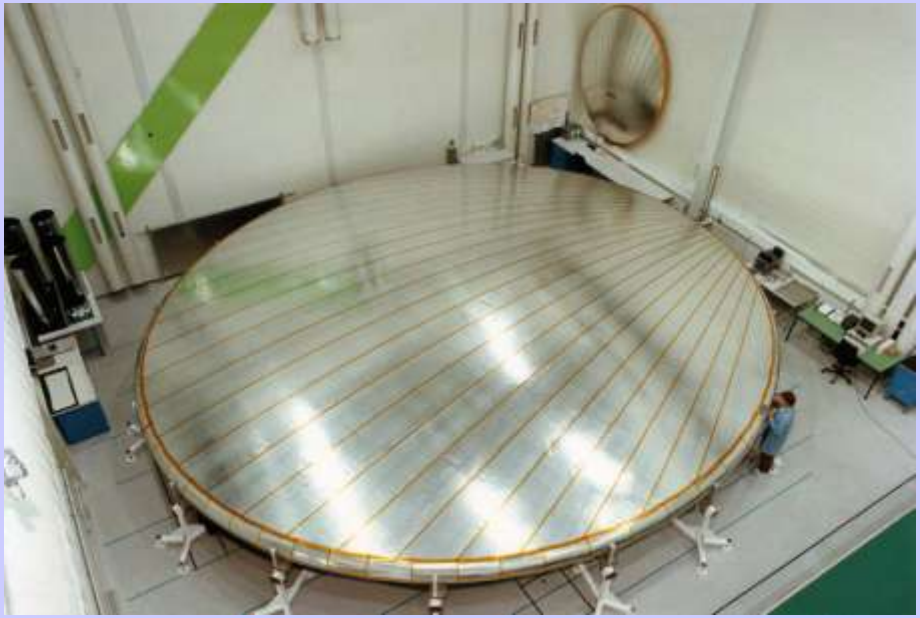


INFLATABLE EXO-ATMOSPHERIC OBJECT
Flown Late 1960's

History of
SPACE INFLATABLE STRUCTURES

Technology Development

- Contraves Space Division/ESA
- 10 x 12 Meter Offset Reflector Antenna Structure
- Surface Precision/Non-Rigidized/2 mm rms
- Multiple Gore Reflector Structure/Torus Support Structure
- Reflector/Canopy/Torus Structure Rigidized By Solar Heating
- Estimates of Orbital Mechanical Performance



Significance of Development

- Rigidization of Flexible Materials Concepts
- Handling/Processing/Fabrication of Rigidizable Materials
- Inflatable Element Assembly/Alignment
- Deployment by Inflation
- Metalization of Rigidizable Materials
- Mechanical Packaging Techniques
- First Large Inflatable Rigidizable Reflector Structure

LAND MOBILE COMMUNICATIONS REFLECTOR ANTENNA

Technology Demonstration/1980's

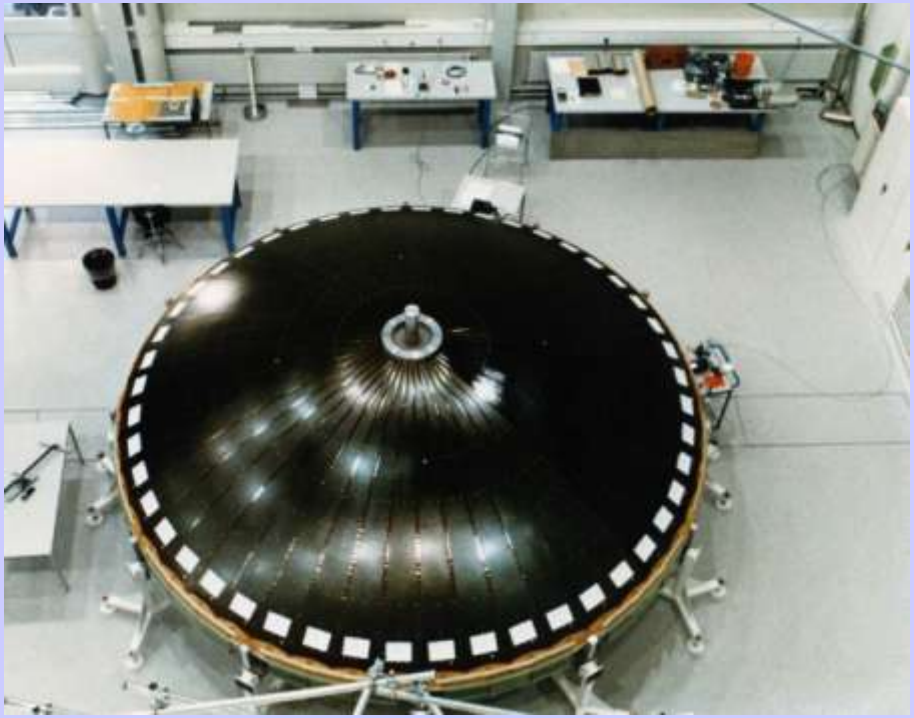
History of
SPACE INFLATABLE STRUCTURES

Technology Development

- Contraves Space Division/ESA
- 6 Meter Diameter/Axi-Symmetric Reflector
- Surface Precision/Non-Rigidized on the order of mm rms
- Multiple Gore Reflector Structure/Torus Support Structure
- Reflector/Canopy/Torus Structure Rigidized
- Estimates of Orbital Mechanical Performance
- Intended for 21 Ghz RF Operation

Significance of Development

- Rigidization of Flexible Materials Concepts
- Handling/Processing/Fabrication of Rigidizable Materials
- Inflatable Element Assembly/Alignment
- Deployment By Inflation
- Metalization of Rigidizable Materials
- Mechanical Packaging Techniques
- First Large Size Inflatable Rigidizable Reflector Structure



INFLATABLE VERY LONG BASELINE INTERFEROMETRY ANTENNA
Technology Demonstration/1980's

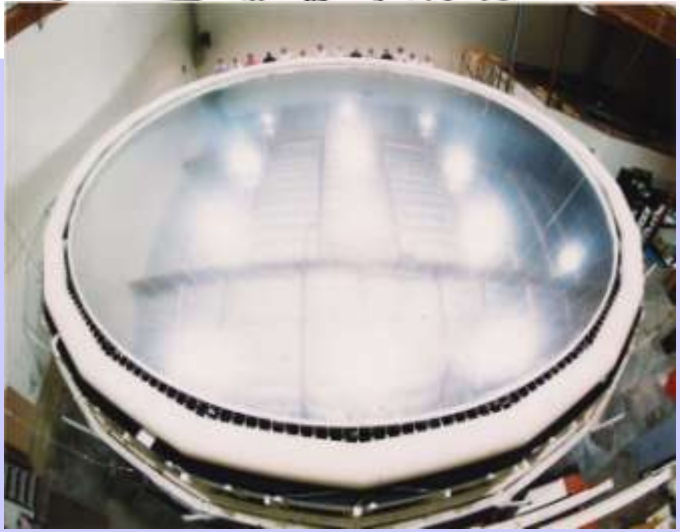
History of
SPACE INFLATABLE STRUCTURES

Technology Development

- L'Garde, Inc./NASA/JPL
- IAE Successfully Flown May 29, 1996
- Large Inflatable Antenna Structure Technology Demonstration
- Reflector Structure 14 Meters/Strut Structure 28 Meters
- Flown on STS Spartan 77/Recoverable Spacecraft Spacecraft/Experiment One Orbit
- Demonstrations/Low Cost Structure Hardware/High Mechanical Packaging Efficiency/Deployment Reliability/Large High Precision Membrane Reflector Manufacturing

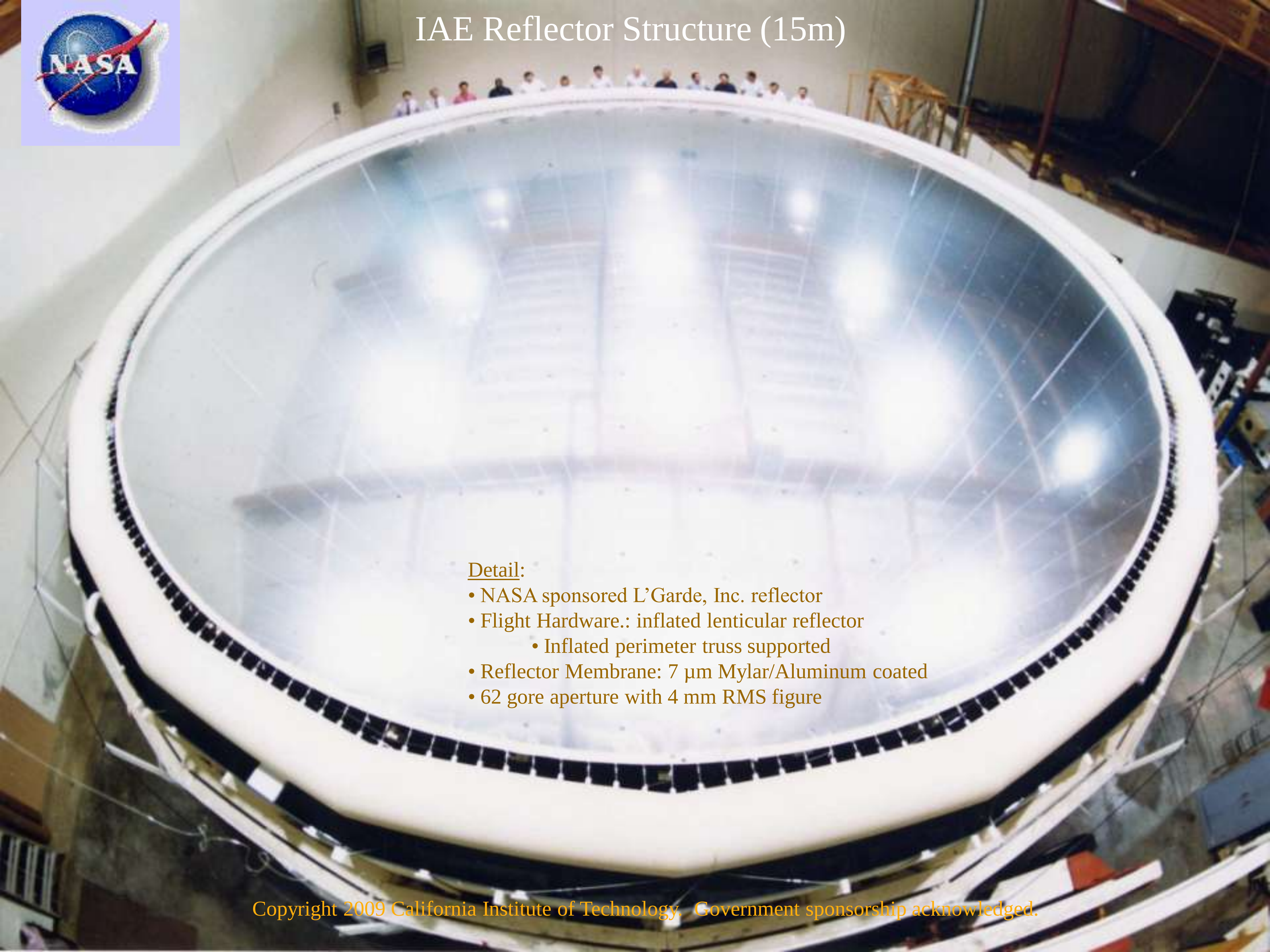
Significance of Development

- Large Size Complex Inflatable Structural Element Handling/Processing/Fabrication
- Manufacturing Validation
- Large Size Structural Element Assembly/Alignment
- Mechanical Packaging/Launch Restraint
- On Orbit Deployment by Inflation
- First Large Size Reflector Structure Deployed on Orbit
- Ground-based Surface Precision Measurement



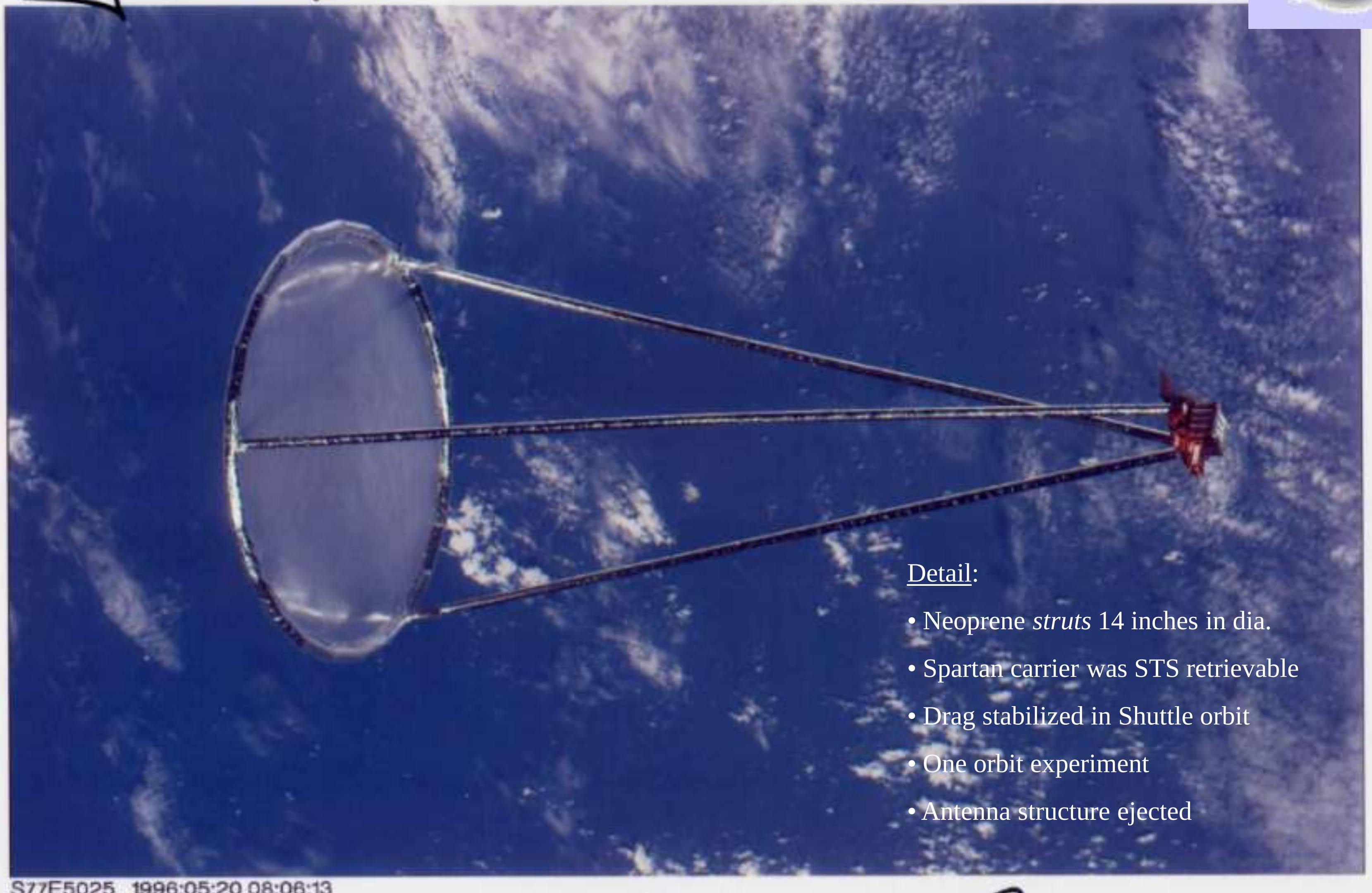
INFLATABLE ANTENNA EXPERIMENT
Flown Late 1996

IAE Reflector Structure (15m)



Detail:
- NASA sponsored L'Garde, Inc. reflector
- Flight Hardware.: inflated lenticular reflector
  - Inflated perimeter truss supported
- Reflector Membrane: 7 μm Mylar/Aluminum coated
- 62 gore aperture with 4 mm RMS figure

IAE Deployed On-Orbit
(30m struts)

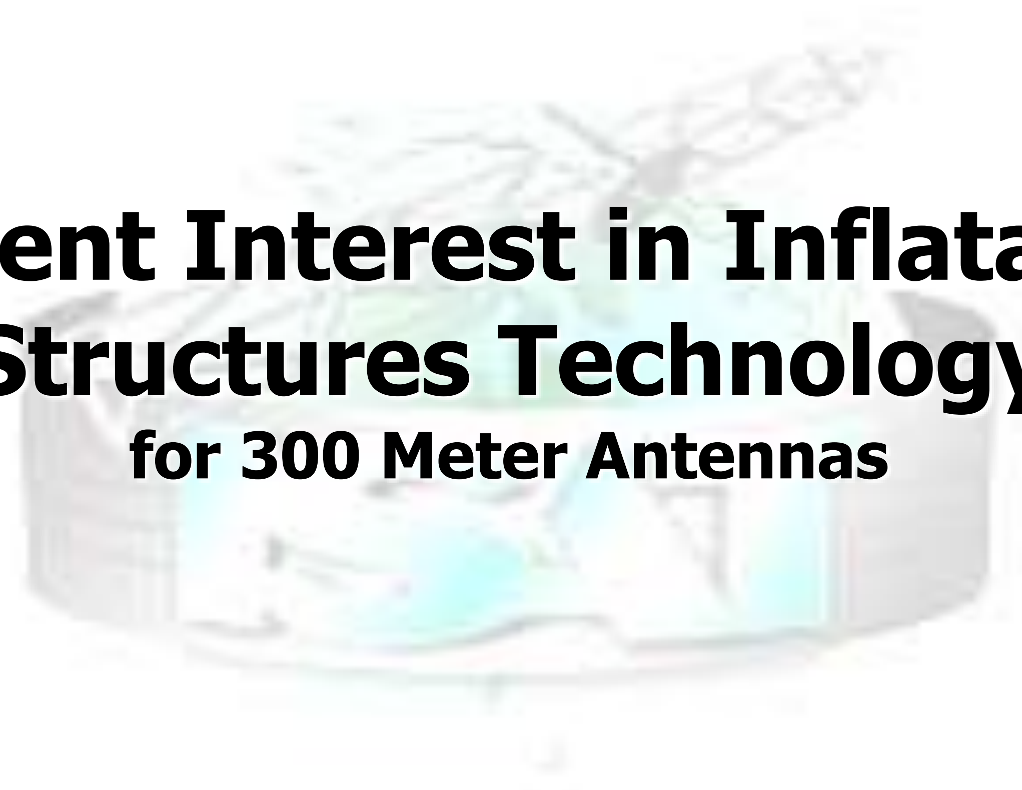


Detail:

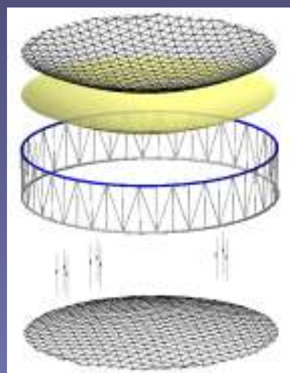
- Neoprene *struts* 14 inches in dia.
- Spartan carrier was STS retrievable
- Drag stabilized in Shuttle orbit
- One orbit experiment
- Antenna structure ejected

Recent Interest in Inflatable Structures Technology

for 300 Meter Antennas



BASELINE: INFLATABLE STRUCTURE/NET- MEMBRANE ANTENNA



Task Purpose/Objectives:

- Establish the suitability of the new inflatable space structures technology for a class of large reflector radar antenna concepts

Major Products:

- Large Inflatable Deployable Radar Antenna Concept Definition
- Advanced Concept Development for the Space Based Rigidization of Flexible Materials
- Inflatable Truss/Mesh-Net Integration

- Axi-Symmetric
- ≥10 GHz RF Operation
- High Orbit Operation
- Diameter: ≥ 25 Meters
- Surface Accuracy: ≤ λ/16 RMS
- Multiple Feed Element Support Structure

Potential Cost Advantages:

- High antenna stowed packaging efficiency allowing the use of smaller fairings and launch vehicles
- Conformable stowed geometries enabling a wide spectrum of height and width variations
- Application specific weight savings as much as ***3:1***
- Antenna *hardware* cost reduction greater than ***10:1***

 Government sponsorship acknowledged.

TECHNOLOGY DEVELOPMENT AND APPLICATION ENABLING
LARGE INFLATABLE ANTENNAS

1999	2000	2001	2002	2003	2004	2005

Phase II Study Results

30 M Antenna ***Conceptual*** Design Inflatable Perimeter Truss Mesh Surface Shaping System

- Rigidized Materials Concepts
- Truss Joints Concepts
- Analytical Simulations

- Rigidized Structural Elements
- Truss Joint Design
- Projections of Truss Performance
- Surface Precision Techniques

- **6M**. Struct./Mech/Thermal Testing
- Initial Geometry/Geometric Precision
- Kinematic Function Testing
- Deployment Control
- Deployed Stiffness

30M Antenna ***Configuration*** Design

Rigidized Materials Candidates

Mesh Shaping System Candidates

Structural Models

Truss Element Experiment Design

Truss Element Flight Test

6M Concept Evaluation Scale Hdw.

- Inflatable Truss Design Refinement
- Surface Shaping Techniques
- Est. of Functional Mechanical Performance
- 14M Deployment Control, Mech. Packaging, Ascent Venting
- Test Techniques

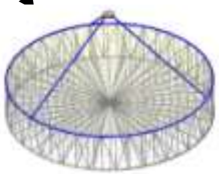
30M Antenna ***Detail*** Design

- Flight Test Evaluation
- Concept Evaluation Results
- Functional Performance Req.

14M Antenna Engineering Model

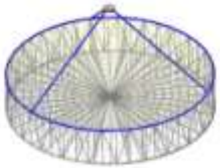
- Analytical Model Validation
- Ground Based Validation

- Design Validation Techniques
- Assembly Techniques/Handling
- Ground Test Techniques



30M Flight Hdw. Fab., Assembly, Functional Testing & Feed System Integration

Launch Vehicle Interface



30M Flight Unit Integration & Launch

FEASIBILITY ASSESSMENT STUDY	BASIC TECHNOLOGY ADVANCEMENT	BASIC TECHNOLOGY EVALUATION	ANTENNA DESIGN	FLIGHT HDW. FAB., ASSEMBLY, & TEST	ANTENNA SYSTEM INTEG. & LAUNCH	FLIGHT PERFORMANCE VALIDATION
2	**3**	**4+**	**5**	**6+**	**7,8**	**9**

TECHNOLOGY READINESS LEVELS

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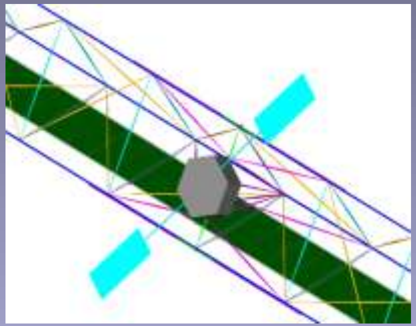
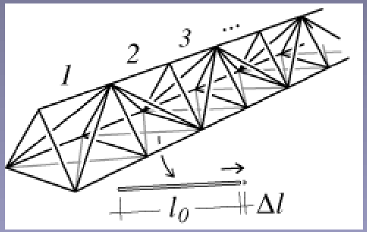
FY'02-'04 ISAT RI RISK *ASSESSMENT & MITIGATION* PROGRAM SUMMARY

Representative GMTI Antenna System Concepts





GMTI Space-Based Radar Antenna: Triagonal bay antenna support structure

Program Objectives:

- To assess the risk associated with the integration of rigidizable/inflatable antenna structures technologies with ISAT radar antenna designs

Major Technical Tasks:

- Candidate Baseline Truss Concept Design(s)
- Focused Mechanical Modeling & Experimentation
- High-Fidelity Steady State & Transient Simulations

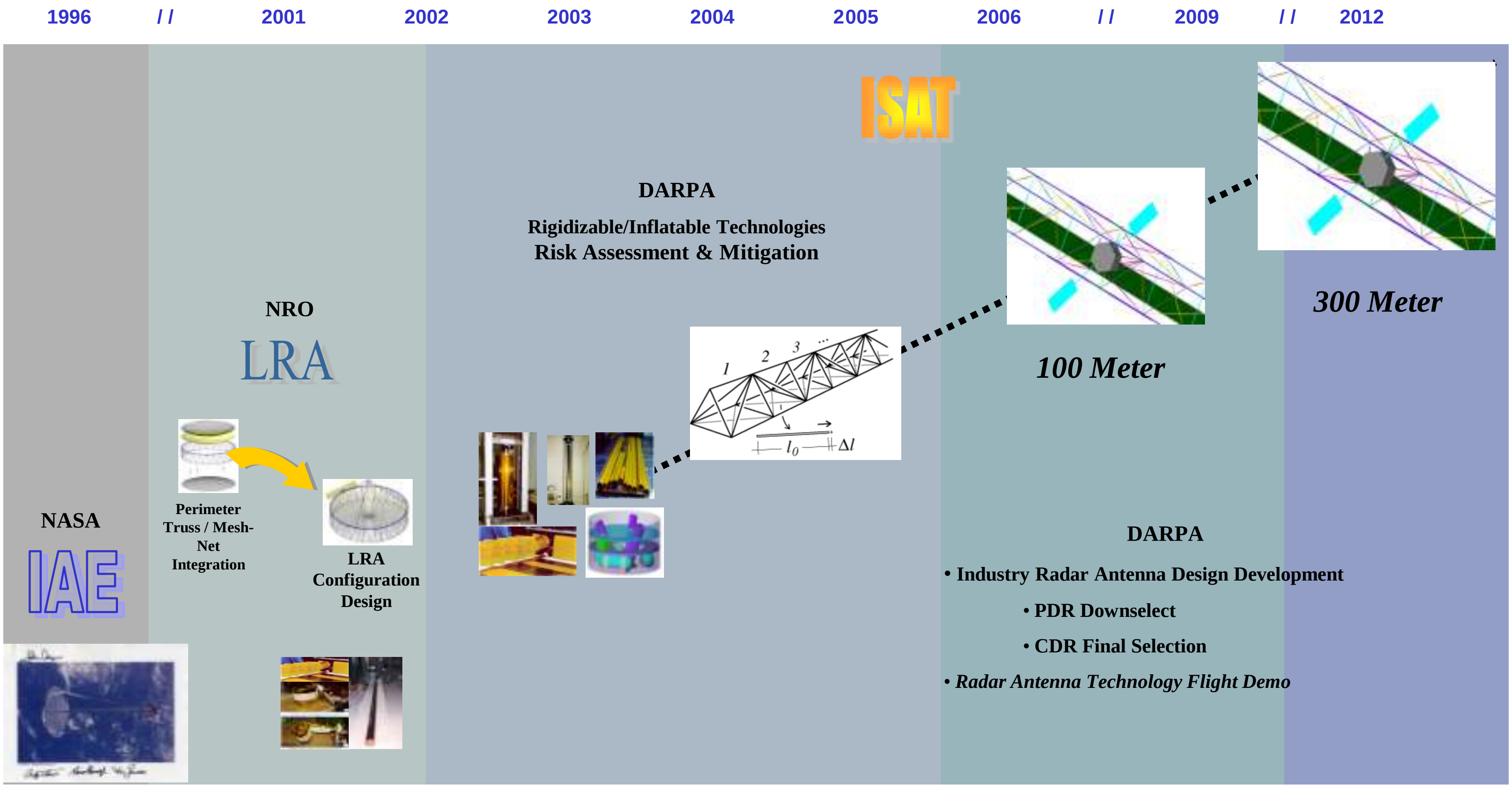
Performance Requirements:

- Baseline **Option:**
  - Truss Length ≥ 300 Meters
  - 10 GHz RF Operation
  - MEO Operation
  - Truss Bay Depth ≈ 3 Meters
  - Multiple Active RF Panels
  - Alignment Precision TBD Meters

Accomplishments:

- Early LRA developments led to significant enabling RI materials technologies
- Gov. baseline highly instrumental in calibrating and validating vendor radar antenna design performance
- Established one-of-a-kind statistical RI mechanical properties *test* database along with the corresponding constitutive correlations
- Hybridized analysis techniques developed
- Enabled NASA Technology Readiness Levels to establish RI Tech. Risk Assessment and Mitigation

DARPA/STO INNOVATIVE SPACE-BASED RADAR ANTENNA TECHNOLOGY (ISAT) PROGRAM PLAN



ISAT

Phase I	Phase II	Phase III	Phase IV
"Seedling" Tech. Studies	Industry Design Competition	Flight Demo System	Operational System Concept

INFLATABLE ANTENNA TECHNOLOGY MATURITY ISSUES

- The applicability of the R/I technology for specific mission types is a function of the maturity of the basic elements and their effective interactions.
- The maturity of each element is a function of the challenge of the specific mission application with the potential of a large range of maturity levels among the elements.
- In the last ten years there has been significant advancements in certain technology elements.
- Currently, the most significant issue (and potential "show-stopper") is the lack of workable concepts for simple and reliable *deployment control cages.*
  - A concerted design effort and investment is required to extensively modify and/or develop new basic technology elements.

BASIC INFLATABLE STRUCTURES TECHNOLOGY ELEMENTS

- Materials Rigidization Concepts
- Deployment Control Techniques
- Mechanical Packaging Techniques
- Ascent Venting Approaches
- Launch Restraint/Release Techniques
- Analytical Simulation/Deployment/Operational Performance
- Space Durable Flexible Materials
- Thin Film/Handling/Processing/Fabrication
- Manufacturing Quality Verification
- Assembly/Alignment/Verification
- Ground Based Deployment Test Techniques
- Ultra Light/On Orbit Gas Generation & Pressure Control

 Government sponsorship acknowledged.

Next Generation Technology

THE LIMITATIONS Of GROUND TESTING LARGE SPACE STRUCTURES

- “One-g” laboratory environment
  - Sag
  - Kinematic friction and lock-up due to mechanical loading
  - Poor repeatability and non-linear motions
  - Non-representative initial and boundary conditions
- Limited facilities large enough to test structure and its deployment
- Conventional structural and dynamic validation tests difficult to perform
- Thermal simulation and control issues
- Test/analysis correlation for on-orbit performance increasingly limited to structural sub-systems, components, and elements.

RISKS

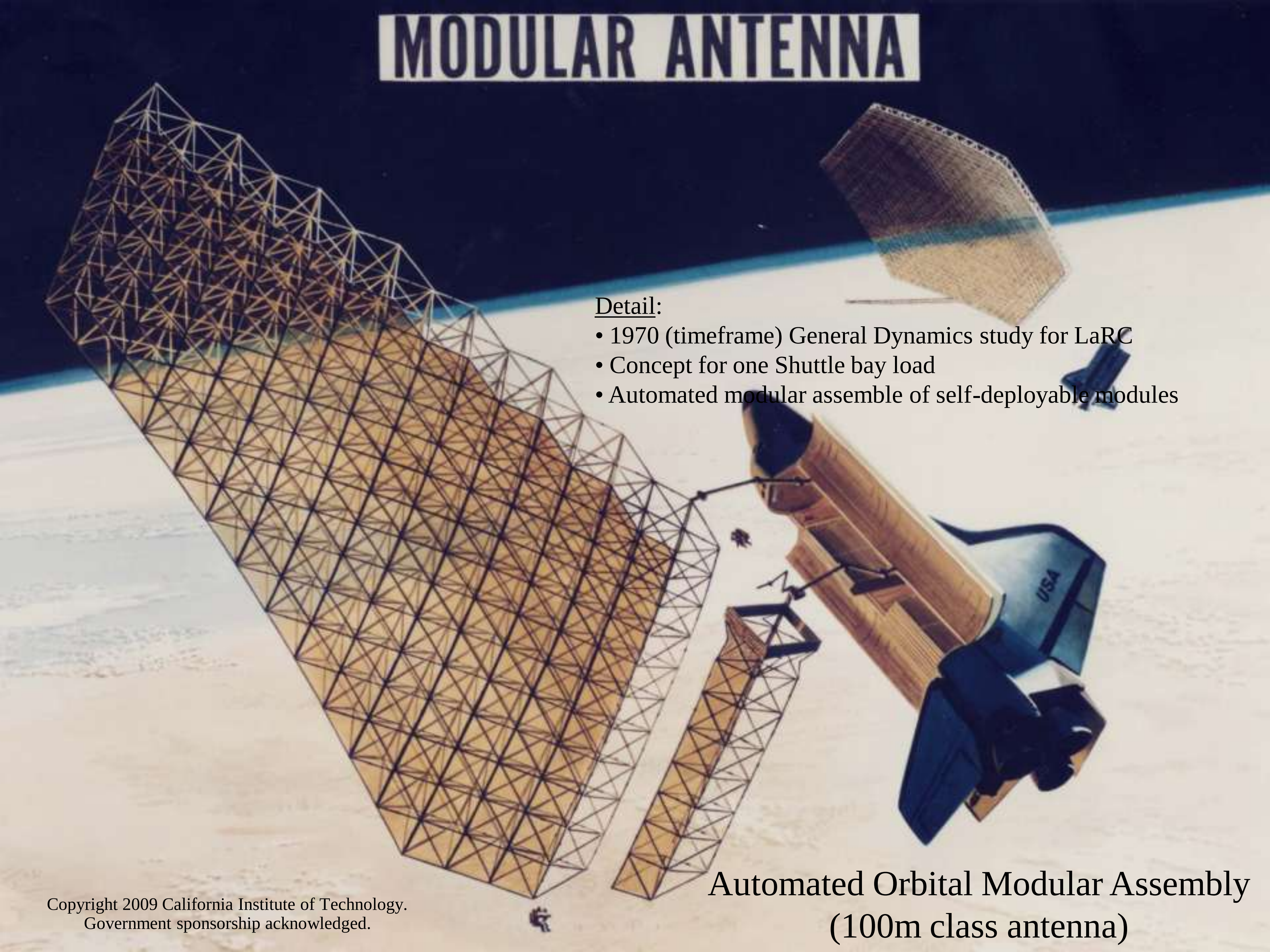
Risks associated with not performing adequate ground testing:

- ❑ Poor validation of on-orbit structural and deployment performance
- ❑ Limited demonstration of functional behavior
- ❑ Test/analysis correlation compromised

Conclusions for very large orbiting sensor structures…in general

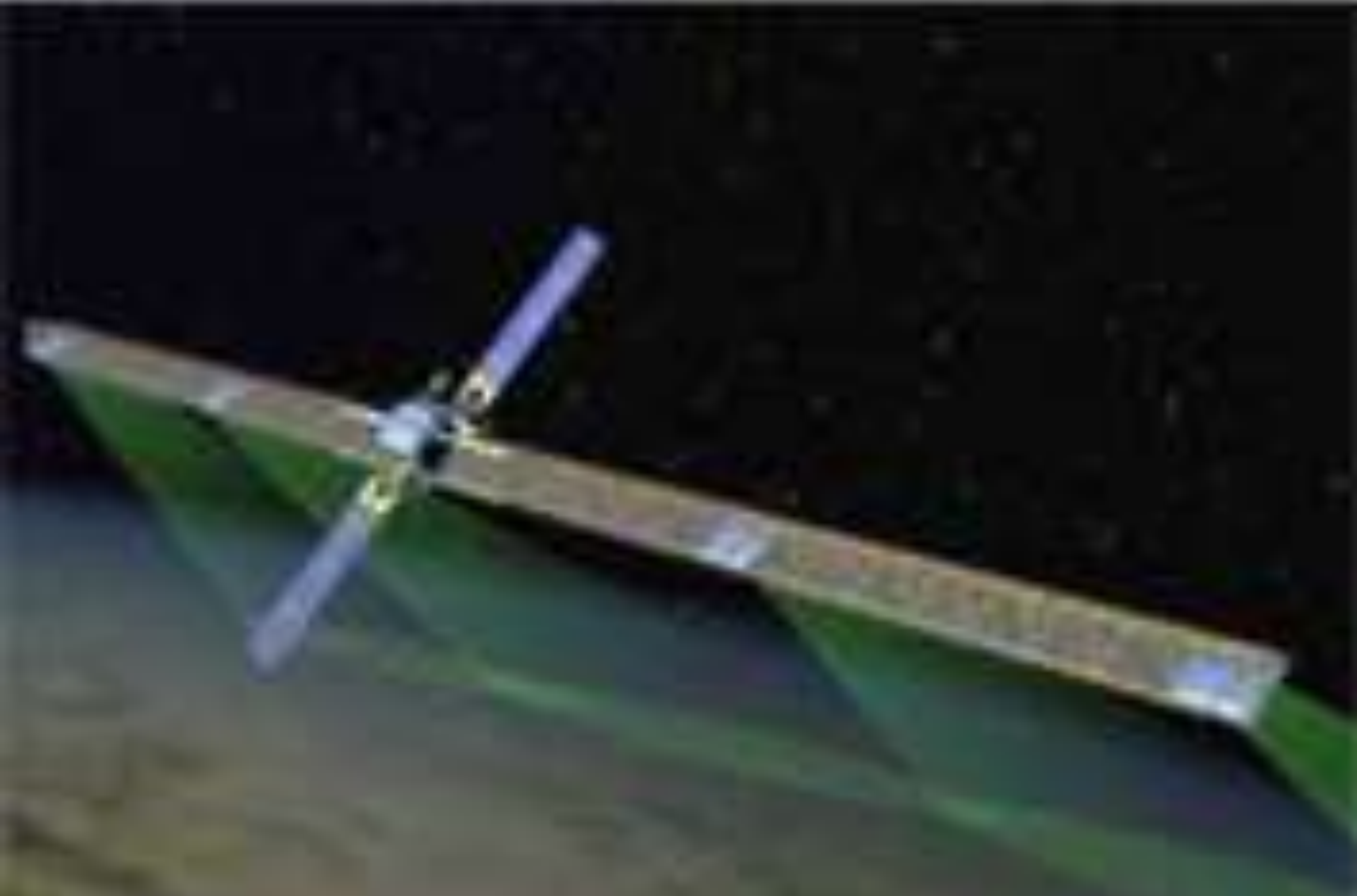
- Based on the current trends in requirements, the limitations of the state-of-the-art technologies, and the *high* potential of some of the early concepts, the application of old, current, and new technologies for future very large space structures is clearly suggested.
  - The potential of any combination of these technologies is proportional to the maturity of each and every element, and their compatibility with each other.
- A possible scenario based on such an approach would be the *automated orbital assembly* of a small number of flight proven *sub-systems* to achieve a substantial (large, high-precision) full-up *operational system*.
  - Example: self-deployable modules (80-100 meters) based on repeated segments that lend themselves to "simple" orbital assembly that could potentially create a structure in the 300-600 meter size range.

 Government sponsorship acknowledged.



Detail:
- 1970 (timeframe) General Dynamics study for LaRC
- Concept for one Shuttle bay load
- Automated modular assemble of self-deployable modules

Automated Orbital Modular Assembly
(100m class antenna)



ELECTRONICALY SCANNED PLANAR ARRAY ANTENNA

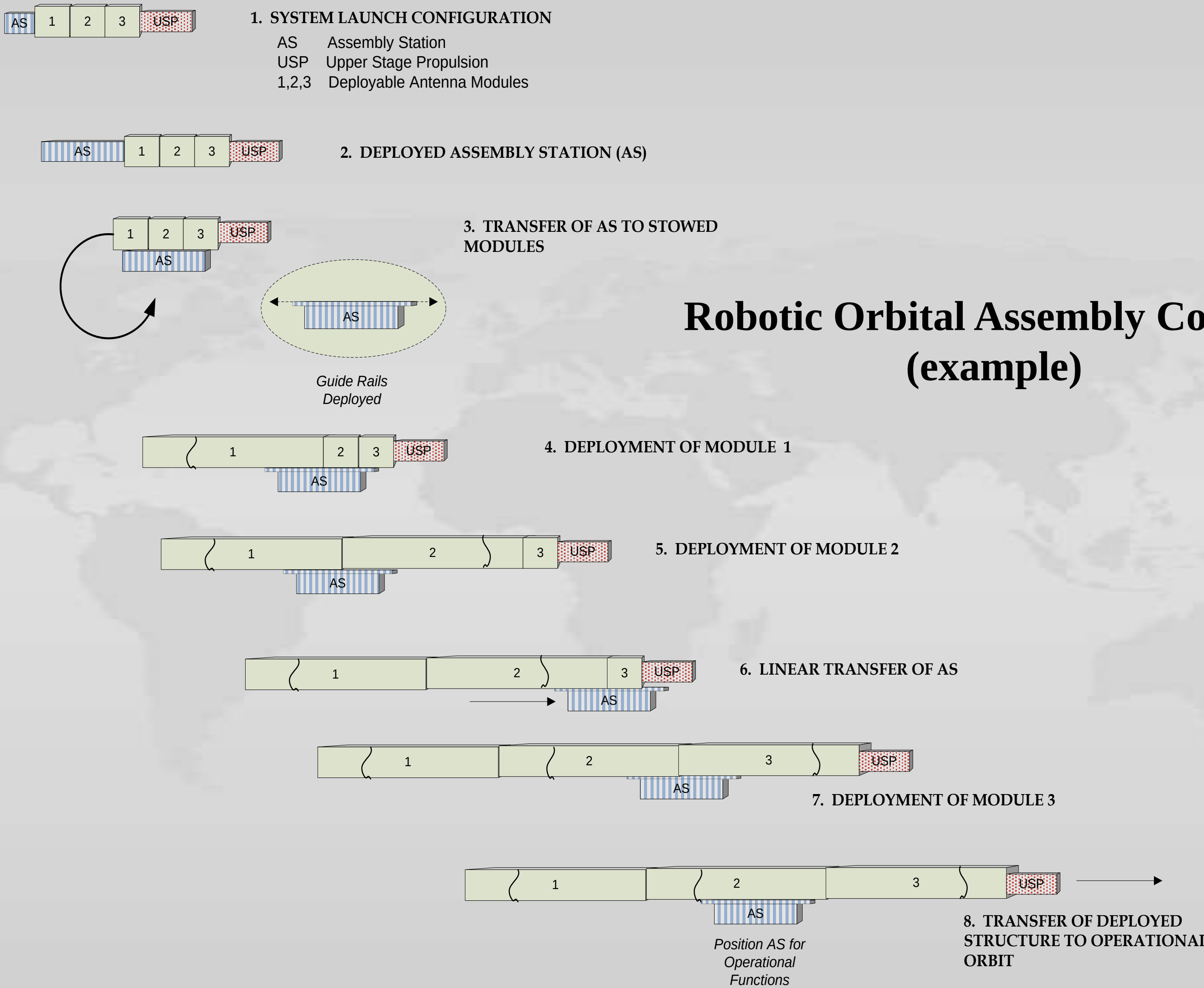
Back-UP Viewgraphs

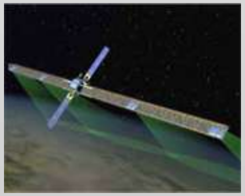
MODULAR ORBITAL ASSEMBLY CONCEPT

Self-deployable modules (10's of meters) combined as repeated segments that lend themselves to "simple" automated orbital assembly with the potential to create a structure in the 300-600 meter size range

This approach has the advantage of combining previously demonstrated large antenna structures into one long continuous antenna. The complexities of testing, packaging, and launching an enormous monolithic structure are mitigated, thus reducing risk, cost, and schedule.

Robotic Orbital Assembly Concept (example)





MODULAR ORBITAL ASSEMBLY
Risk, Cost and Schedule Advantages

- Potential Risk Reduction:
  - Ground testing limitations mitigated
  - Test/analysis correlation and “scaling” factors simplified
  - Orbital assembly risks smaller than those for launching and deploying a large monolithic structure
  - Modular ground test validation with higher maturity levels
  - Higher aperture precision due to less tolerance build-ups
  - Deployment simplified through isolation of cascading boundary conditions and single-point failures

MODULAR ORBITAL ASSEMBLY
Risk, Cost and Schedule Advantages (2)

- Cost Reduction:
  - Smaller sized modules have significantly less kinematic complexity and associated costs
  - Smaller scope ground testing with simplified and repeatable techniques
  - Less technology development required when using heritage hardware
- Schedule Reduction:
  - Early structural characterization and mathematical model verification for more realistic orbital performance predictions
  - The technology development planning, the contracting activities for hardware, specialized services, and long lead time items, will all benefit from simpler structures concept development.

ASTROPHYSICS ELECTROMAGNETIC SPECTRUM