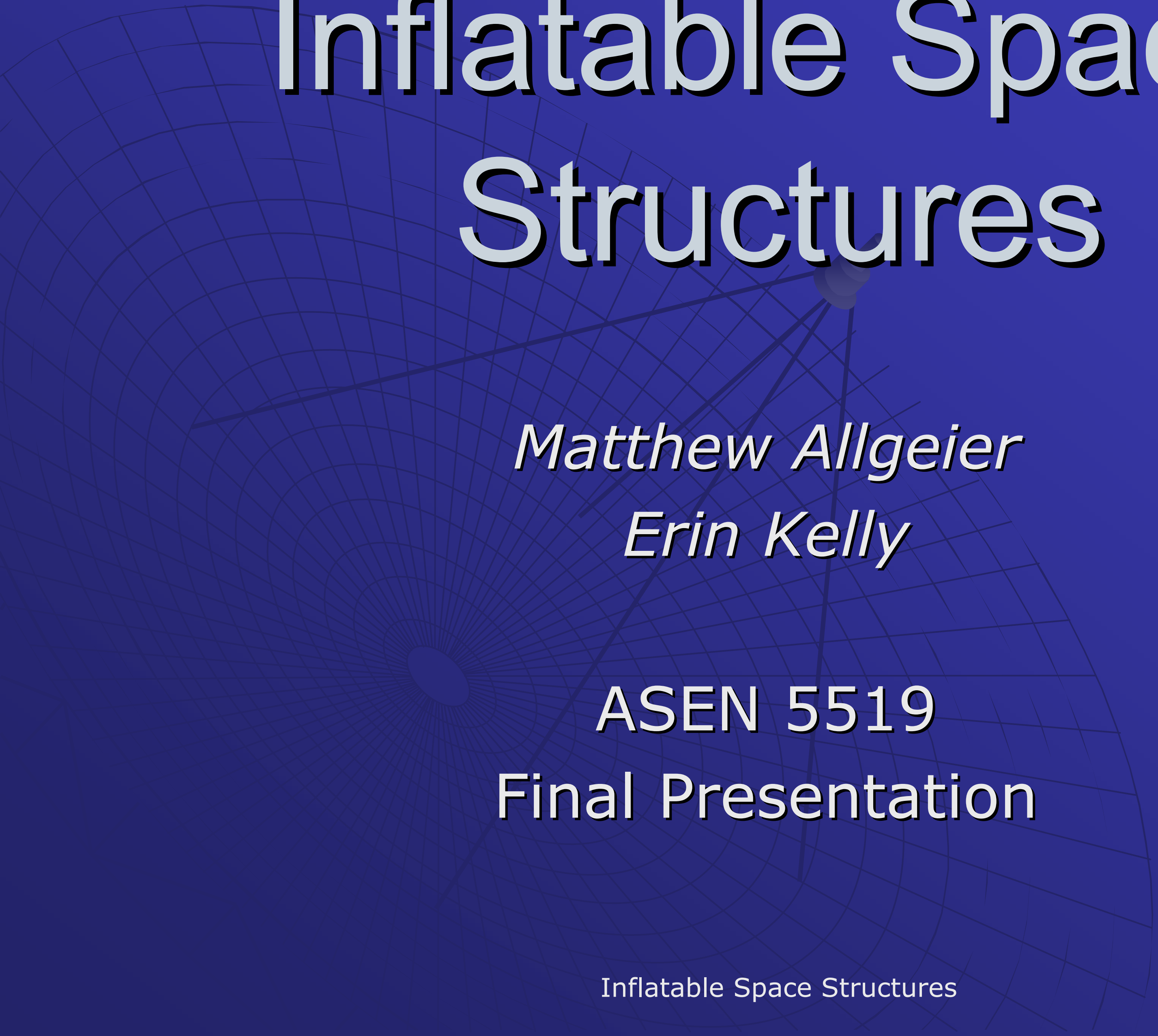


Inflatable Space Structures

Matthew Allgeier
Erin Kelly

ASEN 5519
Final Presentation

Presentation Overview

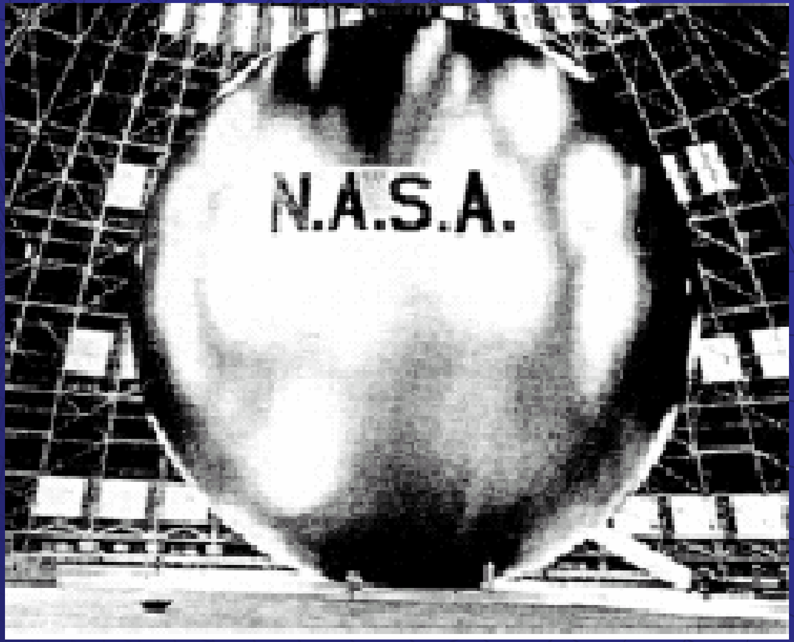
- Introduction
- Background
- Technical issues
- Applications
- Environmental interactions
- Material selection
- Assembly methods
- Deployment Techniques
- Sources of error
- Analysis/Verification
- Piezoelectric Deformation
- Future uses
    - Inflatable Antenna
    - Solar sail booms
    - Inflatable radiator
- Take Home Lessons

Introduction

- Interest in inflatable deployable space structures since 1950s.
- Potential for:
  - Low cost flight hardware
  - Exceptionally high mechanical packaging efficiency
  - Deployment reliability
  - Low weight

Background

- Early Inflatable Structures
- Contraves Inflatable Structures
- Inflatable Antenna Experiment

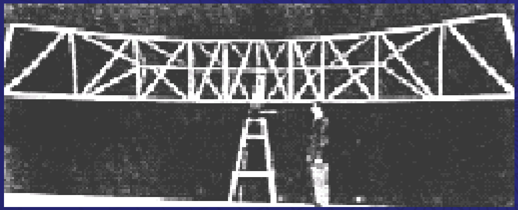
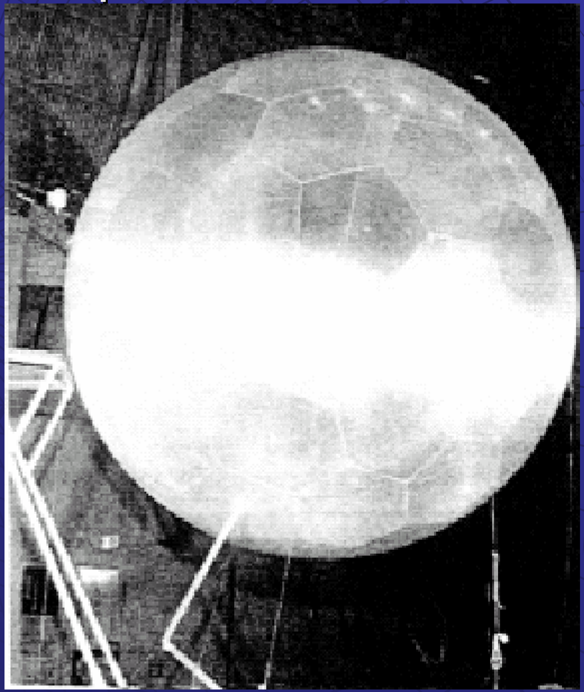


Early Inflatable Structures

- **Echo 1**
  - Launched Aug. 12, 1960
  - Diameter = 100 ft (30 m)
  - Frequencies = 960 and 2390 MHz
  - Weight 136 lbs
  - Lifetime = 8 years
  - Made of 12µm thick Mylar coated w/ 2000 angstroms of vapor-deposited aluminum
- **Echo 2**
  - Launched Jan. 25, 1964
  - Diameter = 135 ft. (40 m)
  - Orbit altitude = 1000 mi. (1600 km) also Echo 1
  - Lifetime = 5 yrs
  - Made of Mylar coated with Aluminum on the inside
  - Improved inflation system to improve smoothness and sphericity

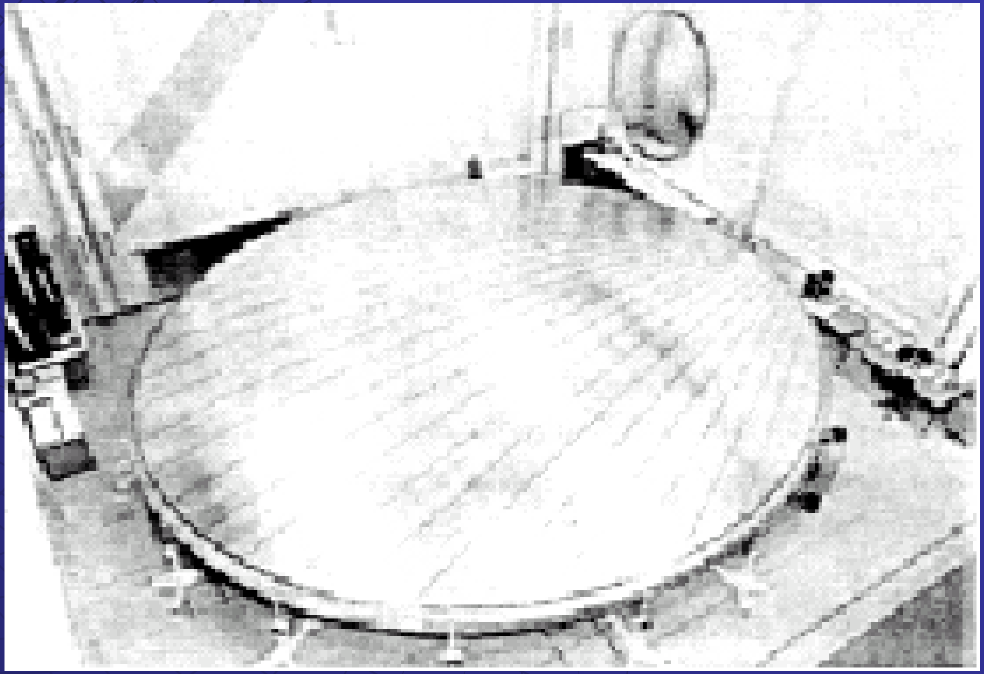
Early Inflatable Structures cont.

- Goodyear Inflatable Structures
  - From late 1950s to mid 1960s they developed:
    - Search radar antenna, Radar calibration sphere
    - Lenticular parabolic reflector


Contraves Inflatable Structures

- A 10 x 12 meter offset reflector antenna for land mobile communications at L-band was built and evaluated for surface precision and other mechanical characteristics

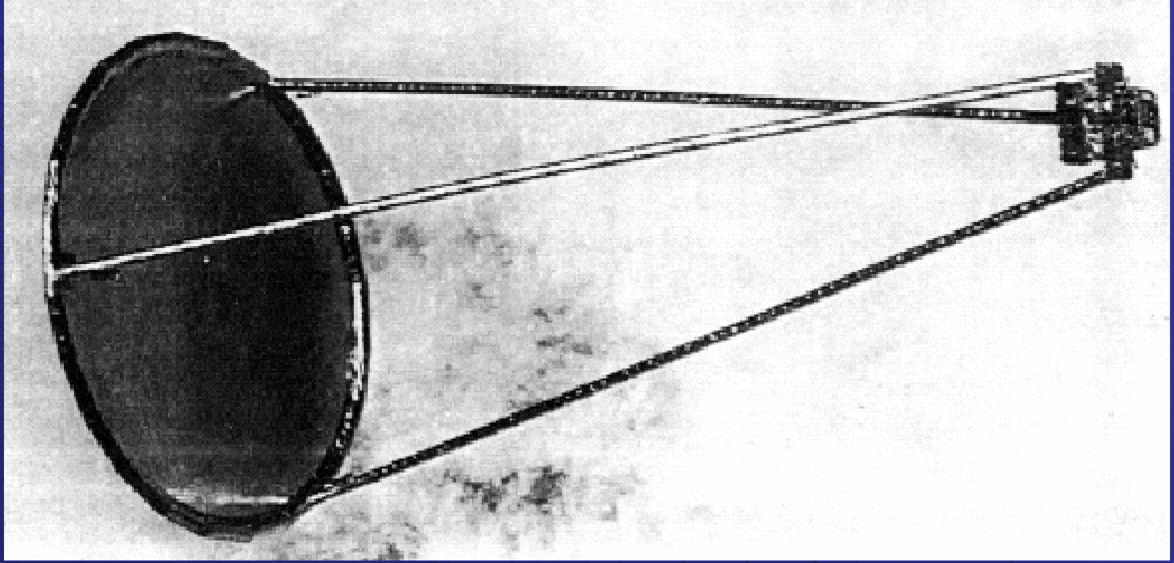


Inflatable Antenna Experiment

- NASA project
- Launched with STS-77 on May 29, 1996
- Experiment objectives:
  - Verify large structures can be built at low cost
  - Show high mechanical packaging efficiency of large inflatable structures
  - Demonstrate high deployment reliability
  - Verify manufacturing with high surface precision
  - Measure the reflector surface precision on orbit

IAE (cont.)

- 2 basic elements
  - Inflatable reflector assembly
  - Torus/strut supporting structure



Applications

- Current uses
  - IAE
  - NASA Shuttle Space Suit
  - MK 50 Torpedo Recovery System
  - Collapsible Hyperbaric Chamber

System Requirements

- Issues that must be overcome before ISS can be widely used
  - Lifetime
  - Deployment techniques
  - Structure/Environment interactions
  - Rigidization techniques
  - Membrane Shape Inaccuracies
  - Accurate pressure control
  - Withstand solar/space radiation

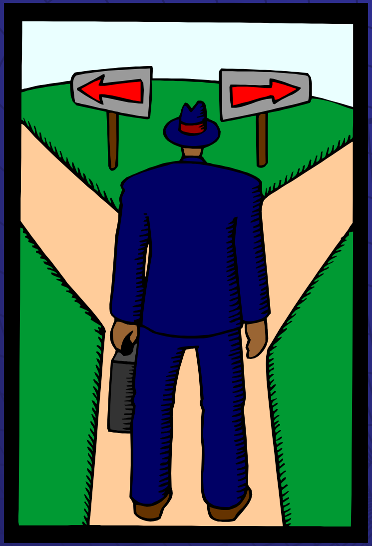
Environmental Interactions

- Inflatable structures have the most significant interaction with the space environment of all space structures
  - Resistance to solar radiation environment
    - Low thermal expansion
    - Low long term creep
  - Micrometeoroid penetration
    - Requirement to maintain pressure
  - Oxygen atoms in LEO
    - Some materials require hydrocarbon coatings
  - Thermal issues
    - Temp varies from -200F to 200F
    - Multilayer Insulation required

Material Characteristics

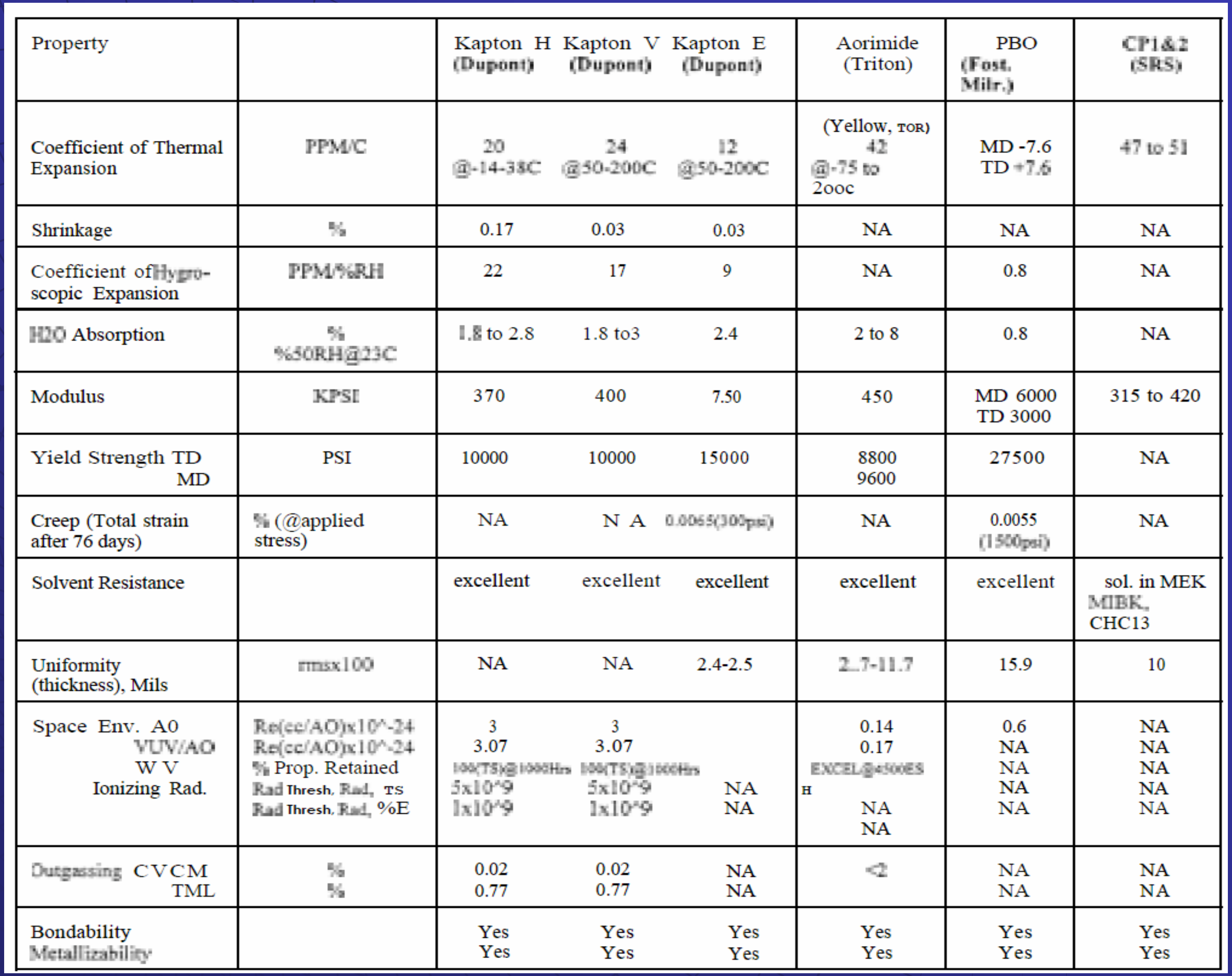
- It is desirable to have large elastic deformations due to pressure compared to fabrication errors
  - This will ensure that the reflector will achieve it's desired analytically predicted shape under load.
- It is desirable to have films with a very low modulus of elasticity
  - Current thin polymetric films have modulus on the order of 500,000 to 800,000 psi
  - Ideally, these materials should be an order of magnitude lower
- It is desirable to have thin materials
  - On the order of 0.5 to 1 mm depending on the operating stress level (usually 100 to 3000 psi)
  - Lower the stress level, the lighter the support structure and the lighter the gas weight.

Material Selection



- Polymides such as Kapton have proven very resistant to UV radiation
  - Kaptons are readily available in production quantities and desired thicknesses
- Aorimide and CP2 also exhibit excellent radiation resistance.
- Mylar may become brittle and opaque with extended exposure to UV radiation
- Polyurethanes
  - Can be used for Sub glass transition temperature (T_g) rigidizable structures.
  - Useful way to rigidize structures and increase their ability to bear loads

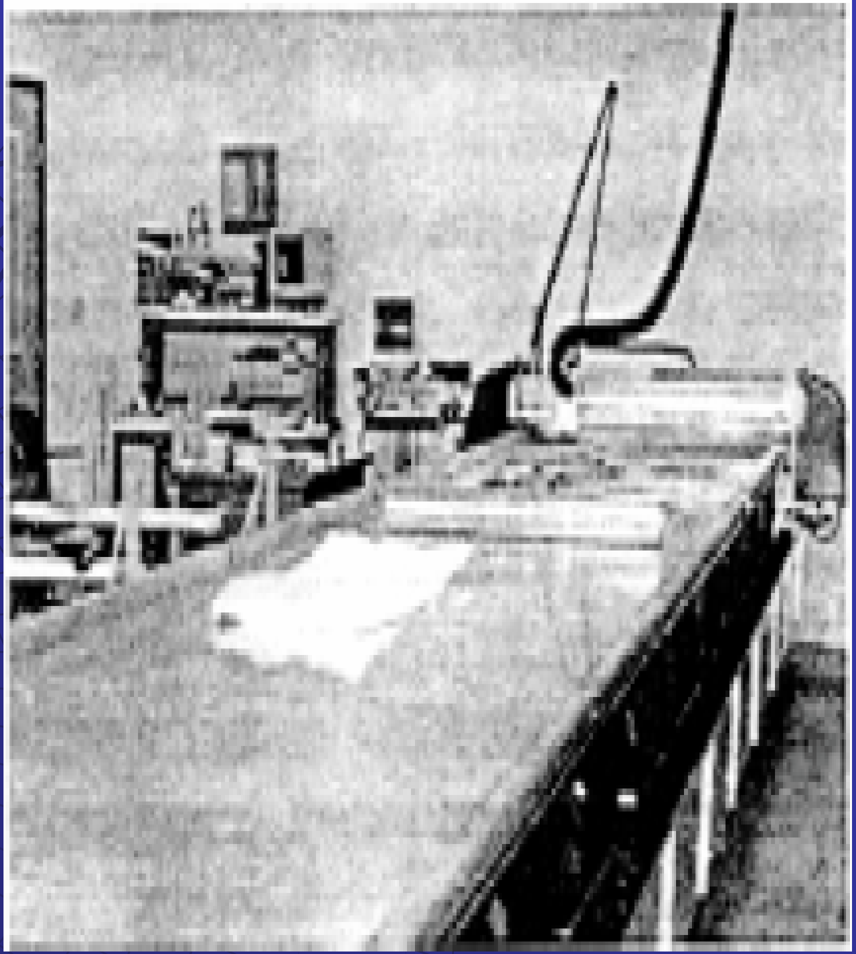
Material Comparison



Property		Kapton H (Dupont)	Kapton V (Dupont)	Kapton E (Dupont)	Aorimide (Triton)	PBO (Fost. Milr.)	CP1&2 (SRS)
Coefficient of Thermal Expansion	PPM/C	20 @-14-38C	24 @50-200C	12 @50-200C	(Yellow, TOR) 42 @-75 to 2ooc	MD -7.6 TD +7.6	47 to 51
Shrinkage	%	0.17	0.03	0.03	NA	NA	NA
Coefficient of Hygro-scopic Expansion	PPM/%RH	22	17	9	NA	0.8	NA
H2O Absorption	% %50RH@23C	1.8 to 2.8	1.8 to3	2.4	2 to 8	0.8	NA
Modulus	KPSI	370	400	7.50	450	MD 6000 TD 3000	315 to 420
Yield Strength TD MD	PSI	10000	10000	15000	8800 9600	27500	NA
Creep (Total strain after 76 days)	% (@applied stress)	NA	N A	0.0065(300psi)	NA	0.0055 (1500psi)	NA
Solvent Resistance		excellent	excellent	excellent	excellent	excellent	sol. in MEK MIBK, CHC13
Uniformity (thickness), Mils	rmsx100	NA	NA	2.4-2.5	2..7-11.7	15.9	10
Space Env. A0 VUV/AO W V Ionizing Rad.	Re(cc/AO)x10^-24 Re(cc/AO)x10^-24 % Prop. Retained Rad Thresh, Rad, TS Rad Thresh, Rad, %E	3 3.07 100(TS)@1000Hrs 5x10^9 1x10^9	3 3.07 100(TS)@1000Hrs 5x10^9 1x10^9	NA NA	0.14 0.17 EXCEL@4500ESH NA NA	0.6 NA NA NA NA	NA NA NA NA NA
Outgassing CVCM TML	% %	0.02 0.77	0.02 0.77	NA NA	<2	NA NA	NA NA
Bondability Metallizability		Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes	Yes Yes

Assembly Methods/ Manufacturing

- Unique manufacturing methods are required since thin, flexible materials are used.
- Currently fabricated using flat gores joined together at the seams
- Precision cutting of gores required
  - Use of gore templates
    - Expensive for large reflectors
  - Computer cutting gore system developed by L'Garde



Deployment - Inflation Methods

- Combining nitrogen gas and subliming powders
  - Used for the IAE
  - Subliming powder inserted into inflatable after orbit insertion
  - Powders sublime into a gas which increases vapor pressures
  - Temperature is controlled through proper thermal design
  - Provide pressure regulation by allowing excess power to sublimate as make-up gas
  - Low toxicity and low cost
- Hydrazine systems now being evaluated
  - Lower weight and volume
  - Handling, safety and cost issues

Deployment – Rigidization Methods

- Only practical applications of purely inflatable space structures are for reflector and concentrator structures
  - Most reflector and concentrator structures can be operated at low pressures to minimize pressure losses due to micrometeoroids
- Load bearing structures must operate at high pressures
  - Rigidization after deployment is necessary to minimize pressure losses due to micrometeoroids.
- Rigidization Techniques
  - Impregnating a fabric with resin so that it rigidizes when it is cooled below it's glass transition temperature
    - Polyurethanes are now being explored as a material option because their unique chemistry allows formulation of desired glass transition for any specific application over a wide range of temperatures.
    - Can be packaged very densely
  - Laminate of Aluminum foil and Kapton foil which rigidizes when aluminum is strained past it's yield point.
    - Not a reversible process

Reflector Error Sources

- Inflatable Structures require accuracy greater than that of customary tolerances in structural engineering

- Sources of error
    - Material stiffness property variation
    - Material thickness and area variation
    - Creep
    - Moisture effects
    - Material wrinkling and creasing
    - Fabrication
    - **Analytical shape prediction and correction**
    - Pressure level
    - Thermal distortion
    - Gravitational effects

Analysis – Reflector Shapes

- Shape Analysis
  - Membrane shape deformations can be diagnosed through the use of photogrammetric techniques and FEM analysis
- Shape Correction
  - Variation of inflation pressure
    - Enables adjustment of focal length
    - Will not correct asymmetric distortions
  - Shape distortions can be corrected through Piezoelectric deformations

Piezoelectric Deformations

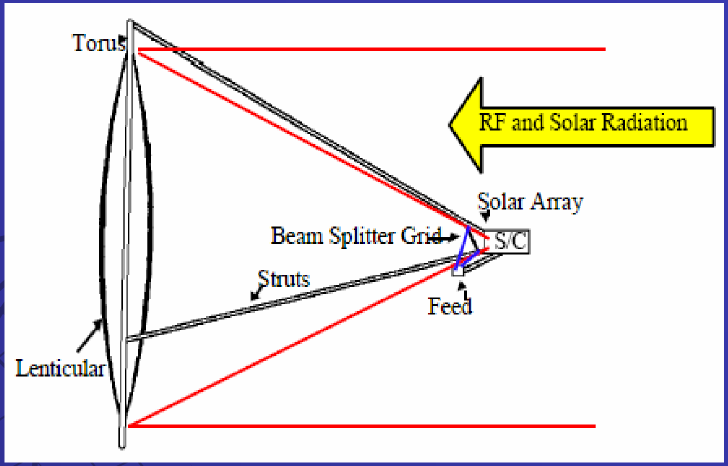
- Surface imperfections limit frequencies of antennas to 100 GHz.
  - Increasing frequency will require increased surface accuracy of reflectors
- Piezos can be used to induce deformations in order to improve surface accuracy.
    - Applying a static electric charge to certain regions of the membrane to make small local adjustments in the shape of the structure.
- Piezo system allows for on orbit adjustments.

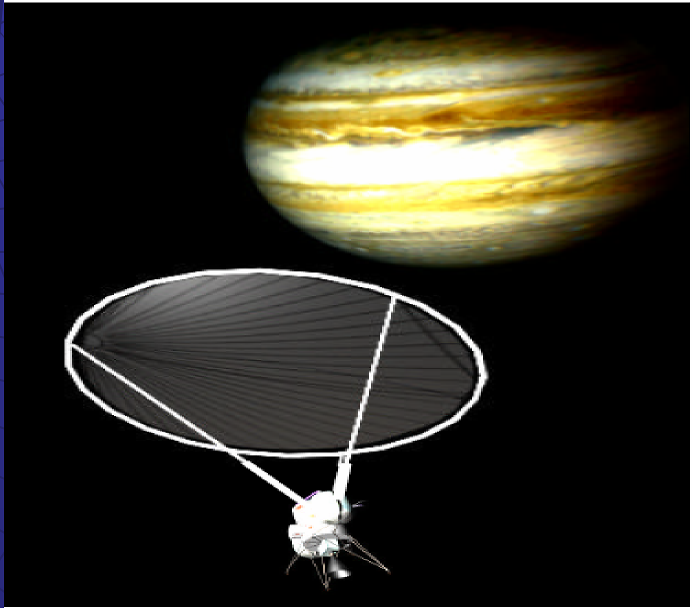
Future of Inflatable Space Structures

- Inflatable Power Antennae
- Solar Sail Booms
- Inflatable Radiator

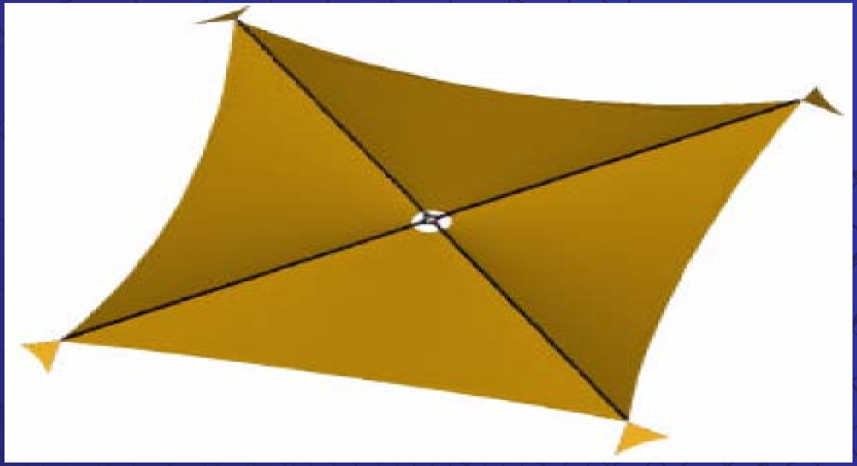
Inflatable Power Antennae

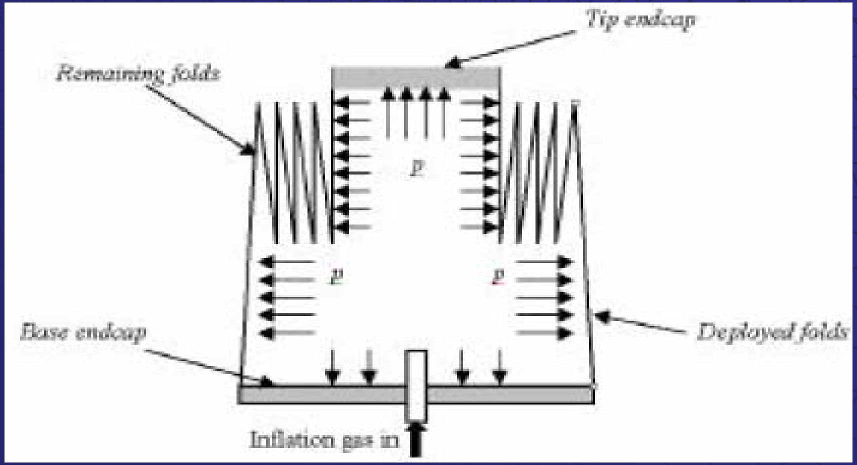
- Proposed under Gossamer Spacecraft Program / JPL.
- The Power Antennae utilizes an inflatable parabolic reflector.
    - Concentrate solar energy for space electrical power generation
    - Simultaneously acts as a large aperture antennae.
- Parabolic reflector acts as a solar concentrator and focuses energy onto a solar array.
- A beam splitter is mounted in front of the array to deflect RF onto a feed.
- The feed is used to separate optical from RF energy.
- Can be used for deep space power generation and high gain RF communications concurrently.





Solar Sail Boom





- Solar sails are devices that reflect photons from the sun and convert some energy into thrust
- Inflatable rigidizable booms can be used for support
- Inflation gas is introduced at the base
  - Deployment is smooth and predictable
- Utilizes the concept of glass transition rigidization
- Since tube is rigidized, it can withstand substantial loads after deployment

Inflatable Radiator

- High power generation on Space-based defense systems require large amounts of heat rejection
- Conventional radiators impractical
  - Weight
  - Significant Drag at LEO
  - Vulnerability to tracking
- Inflatable radiator can capture heat during short power generation periods and radiate into space over longer periods
  - During power generation phase, radiator is extended out of spacecraft while filled with waste heat
  - Steam is condensed gradually as heat is radiated into space.
  - Radiator is retracted during this period to maintain constant saturation pressure. This also keeps radiator protected from space debris

Technical Issues Revisited

- Possibility of Meteoroid Puncture
  - Meteoric flux is lower than originally predicted
  - Low inflation pressure systems can be up kept with reserve gas.
    - Reserve gas weight only a fraction of total system weight
  - Self-Rigidized systems in which inflation is used only for deployment

- Surface Shape Accuracies
  - Inflatable do not currently have the accuracy required for use as space telescopes
    - Material uniformity
    - Inadequate manufacturing procedures
    - Inadequate material properties

Take Home Lessons

- 2 types of inflatables
  - Purely inflatable
  - Deployed by inflation and rigidized
- Inflatables offer a low cost, low mass alternative to conventional space structures.
  - Possibility for Deep Space Solar power extraction and RF communications.
  - Rigidizable structures offer prospect of lightweight load bearing structures.
- However, significant technical issues must be overcome
  - Further development of assembly methods
  - Improved accuracy of structure shape prediction and correction

References

- 1) Cadogan, D. Stein, J. Grahne, M. Inflatable Composite Habitat Structures for Lunar and Mars Exploration. 49th International Astronautical Congress. Oct. 2, 1998.
- 2) Chittenden, D. High Power Inflatable Radiator for Thermal rejection from Space Power Systems. http://lgarde.com/people/papers/highpower.html
- 3) Freeland, R.E. Inflatable Deployable Space Structures Technology Summary. http://lgarde.com/people/papers/spacestructs.html
- 4) Lichodziejewski, David. Bringing an Effective Solar Sail Design Toward TRL 6. http://lgarde.com/people/papers/2003-4659/index.html
- 5) Lichodziejewski, David. Inflatable Power Antenna Technology. http://lgarde.com/people/papers/powant/index.html
- 6) Palisoc, A. Geometry attained by Pressurized Membranes. http://lgarde.com/people/papers/geometry.html
- 7) Salama, M. On Orbit Shape Correction of Inflatable Structures. http://lgarde.com/people/papers/correct.html
- 8) Thomas, Mitchell. Scaling Characteristics of Inflatable Paraboloid Concentrators. http://lgarde.com/people/papers/scaling.html

References

- 9) Thomas, Mitchell. Inflatable Space Structures: Redifining Aerospace Design Concepts Keeps Costs from Ballooning. http://lgarde.com/people/papers/structures.html
- 10) http://www.estec.esa.nl/conferences/02C06/
- 11) http://www.ilcdover.com/WebDocs/mech_99.pdf
- 12) http://science.howstuffworks.com/framed.htm?parent=solar-sail.htm&url=http://science.nasa.gov/headlines/y2000/ast28jun_1m.htm
- 13) http://spaceflightnow.com/news/n0006/26spaceinflate/
- 14) www.roland.lerc.nasa.gov/~dglover/sat/alltext

Questions?

Supplemental Slides

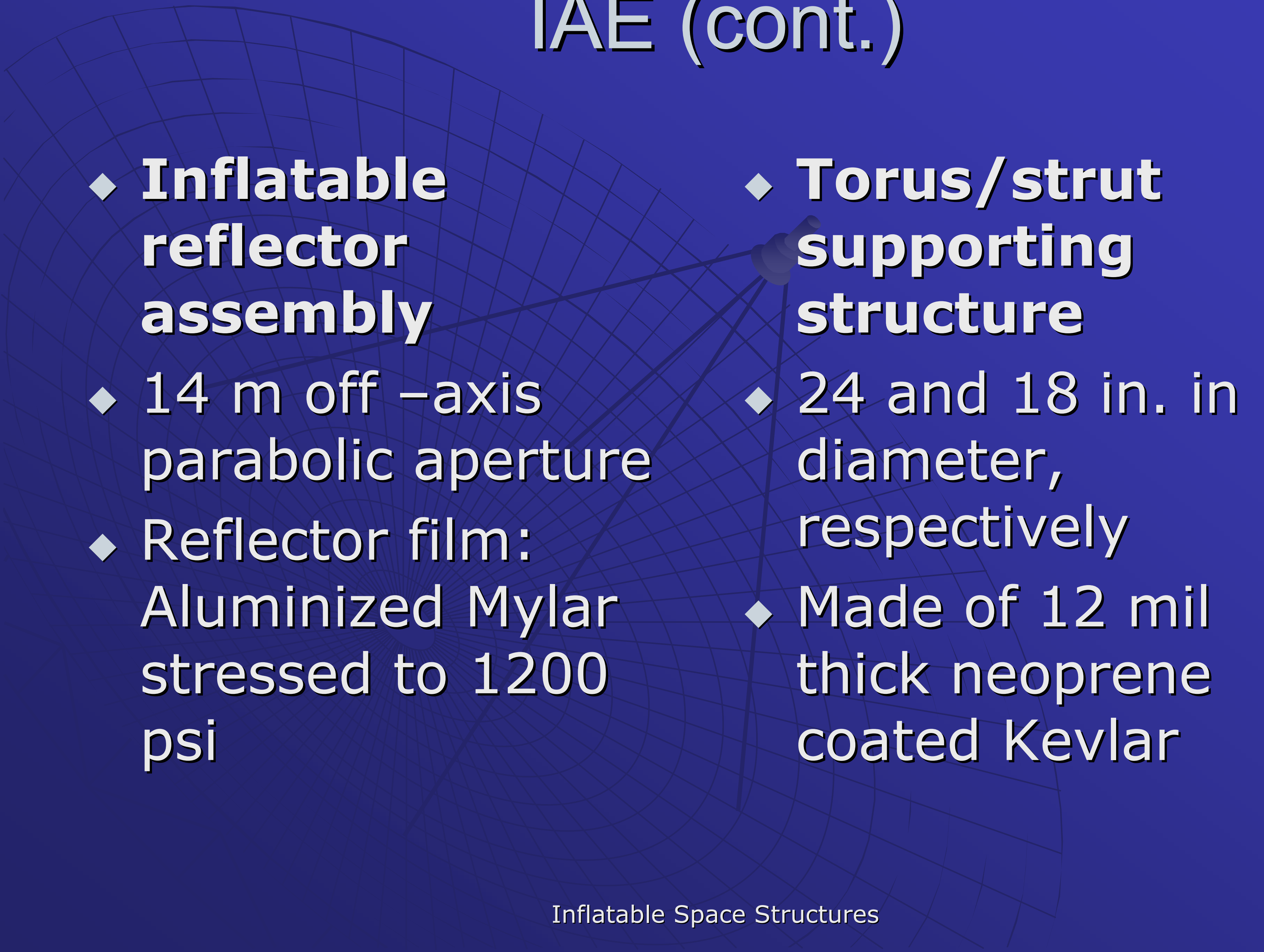
Early Inflatable Structures

- Echo 1 and 2
  - NASA's first communication satellite project
    - Developed by NASA Langley Space Vehicle group
  - Purpose: test feasibility of using satellites to relay communication signals
  - Passive satellites that reflected radio waves back to ground
  - After Echo series NASA abandoned passive communication systems in favor of the superior performance of active satellites

Contraves Inflatable Structures

- Developed by the European Space Agency
- Focus was for axisymmetric reflector antennas for Very Large Baseline Interferometry (VLBV)
- Construction based on 2 parabolic membranes
  - made from multiple gores (1 RF transparent, 1 metalized w/ Al.)
  - Load carrying fibers made of Kevlar and matrix material was designed to become rigid from solar heating on orbit

IAE (cont.)



- **Inflatable reflector assembly**
- 14 m off –axis parabolic aperture
- Reflector film: Aluminized Mylar stressed to 1200 psi

- **Torus/strut supporting structure**
- 24 and 18 in. in diameter, respectively
- Made of 12 mil thick neoprene coated Kevlar