Inflatable Space Structures

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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
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
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 its 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
- Aerimide 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

<table>
<thead>
<tr>
<th>Property</th>
<th>Kapton H (Dupont)</th>
<th>Kapton V (Dupont)</th>
<th>Kapton E (Dupont)</th>
<th>Aorimide (Triton)</th>
<th>PBO (Fort. Mfr.)</th>
<th>CP1&amp;2 (SRS)</th>
</tr>
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<tbody>
<tr>
<td>Coefficient of Thermal Expansion</td>
<td>PPM/C</td>
<td>20 @-14 to -38C</td>
<td>24 @-50 to -200C</td>
<td>12 @-75 to 200C</td>
<td>(Yellow, 70%) MD -7.6 TD +7.6</td>
<td>47 to 51</td>
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<tr>
<td>Shrinkage</td>
<td>%</td>
<td>0.17</td>
<td>0.03</td>
<td>0.03</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Coefficient of Hygroscopic Expansion</td>
<td>%HR</td>
<td>1.8 to 2.8</td>
<td>1.8 to 3</td>
<td>2.4</td>
<td>2 to 8</td>
<td>0.8</td>
</tr>
<tr>
<td>HDO Absorption</td>
<td>%</td>
<td>0.0065(100psci)</td>
<td>0.0055(1500psci)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Modulus</td>
<td>KPSI</td>
<td>370</td>
<td>400</td>
<td>750</td>
<td>450</td>
<td>315 to 420</td>
</tr>
<tr>
<td>Yield Strength TD MD</td>
<td>PSI</td>
<td>10000</td>
<td>10000</td>
<td>15000</td>
<td>8800 to 5600</td>
<td>27500</td>
</tr>
<tr>
<td>Creep (Total strain after 76 days)</td>
<td>% (applied stress)</td>
<td>NA</td>
<td>NA</td>
<td>0.0065(100psci)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Solvent Resistance</td>
<td>excellent</td>
<td>excellent</td>
<td>excellent</td>
<td>excellent</td>
<td>sol. in MEK MIBK, CHC13</td>
<td>NA</td>
</tr>
<tr>
<td>Uniformity (thickness), Mils</td>
<td>max.100</td>
<td>NA</td>
<td>NA</td>
<td>2.4 to 2.5</td>
<td>2.7 to 11.7</td>
<td>15.9</td>
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<tr>
<td>Space Env.: AO VUV/AO W V Ionizing Rad.</td>
<td>Re(AO)x10^-24</td>
<td>3</td>
<td>3</td>
<td>0.14</td>
<td>0.14</td>
<td>0.6</td>
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<tr>
<td>% Prop. Retained Rad.</td>
<td>3.07</td>
<td>3.07</td>
<td>0.17</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Rad Irradiation, %</td>
<td>5x10^-9</td>
<td>5x10^-9</td>
<td>5x10^-9</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Bonding</td>
<td>%</td>
<td>0.02</td>
<td>0.02</td>
<td>&lt;2</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Metallizability</td>
<td>%</td>
<td>0.77</td>
<td>0.77</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Inflatable Space Structures
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 its 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 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


10) http://www.estec.esa.nl/conferences/02C06/


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