Inflatable Antenna for CubeSat: Motivation for Development and Initial Trade Study

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Outline

- State of the Art in CubeSat Communication
- Benefits of Inflatable Antennas for CubeSat
  - Increased Data Rate for LEO and GEO
  - Enables Interplanetary Communication
- Previous works in Inflatable Antennas for CubeSat
- Trade Study
  - Option 1: Flat Membrane Reflectarray
  - Option 2: Parabolic Dish Reflector
  - Comparison and Selection of
- Risks and Mitigation
- Conclusions and Future Work
State of the Art in CubeSat Communication

- Antennas
- Orbits: LEO (between 200Km and 800Km)
- Data rate

Data from Klofas and Anderson (2008)
Benefits of Inflatable Antenna for CubeSat

1. Improve link data rates for a CubeSat in LEO or GEO that uses a small university ground station antenna.

2. Enable CubeSat exploration of deep space by developing technology to maintain a low power communication link over a long transmission path.
**Benefit 1: Increased Gain and Data Rate**

**Assumptions:**
- 1m dish
- OSAGS 2.3 m dish at the receiver

**Performance:**
Data rate increases of 5000%

Leo: 600 km
GEO: 35,786 km
Benefit 2: Enables Interplanetary Communication

Assumptions:
- 1m dish
- USN 13m dish at the receiver

Performance:
Parabolic dish allows communication from a location that is 7 times further than the same CubeSat equipped with a patch antenna.

Moon: 378,000 km
Earth-Sun L1/L2: 1,500,000 km
Previous Works in Inflatable Antennas

- **Spartan 207/Inflatable Antenna Experiment** *(Freeland et al., 1997)*
  - Flown on STS-77, May 1996
  - 14 m antenna, three 28 m struts built by L’Garde, Inc
  - Lenticular antenna structure supported by torus
  - Partial deployment achieved
    - Nominal deployment of torus and struts
    - Lenticular antenna structure failed to deploy due to malfunction of gas inflation system
    - Unexpected spacecraft dynamics during deployment due to residual air in structure

- **Inflatable Reflectarray by ILC Dover, Inc.** *(Cadogan et al., 1999)*
  - Not flown to date
  - 1 m antenna membrane assembly supported by inflatable torus
  - Designed for X-band radar applications
  - Not designed for compatibility with CubeSat form factor
Project Objective: design and test an Inflatable High Gain (IHG) antenna for CubeSat:
- Diameter between 0.5 m and 1 m.
- Stowed size of 1 U-2 U.

Comparison of two options:
- Option 1: Flat Membrane Reflectarray
- Option 2: Parabolic Dish Reflector

Performance metrics:
- Gain
- Mass
- Volume
Option 1: Flat Membrane Reflectarray

1. Circular reflective membrane (1 m, less than 1000 microstrip elements, 1.5 cm each)
2. Tubular inflatable support structure
3. Compressed gas cylinder
4. Microstrip patch feed
5. Container for stowing packaged assembly
Option 1: Flat Membrane Reflectarray

- Upper bound Gain of 33.7 dB (X-Band).
  - Measured for a 1 m Reflectarray prototype with ~1000 microstrip elements (Cadogan et al., 1999).
- Mass and Volume:

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass: [kg]</th>
<th>Volume: [Liters]</th>
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<tbody>
<tr>
<td>Reflective Membrane</td>
<td>0.597</td>
<td>0.397</td>
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<tr>
<td>Support Structure</td>
<td>0.896</td>
<td>0.622</td>
</tr>
<tr>
<td>Packing Inefficiency (200%)</td>
<td>N/A</td>
<td>2.038</td>
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<tr>
<td>Gas Cylinder and Plumbing</td>
<td>0.35</td>
<td>0.3</td>
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<tr>
<td>Feed</td>
<td>0.0595</td>
<td>0.022</td>
</tr>
<tr>
<td>Container</td>
<td>0.429</td>
<td>0.159</td>
</tr>
<tr>
<td>Actuators</td>
<td>0.224</td>
<td>0.112</td>
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<tr>
<td><strong>Subtotal</strong></td>
<td><strong>2.556</strong></td>
<td><strong>3.650</strong></td>
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<tr>
<td><strong>50% Margin:</strong></td>
<td><strong>1.278</strong></td>
<td><strong>1.825</strong></td>
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<td><strong>TOTAL:</strong></td>
<td><strong>3.833</strong></td>
<td><strong>5.475</strong></td>
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</table>
Option 2: Parabolic Dish Reflector

1. Parabolic reflective membrane (12 µm Mylar with a 0.2 µm layer of vapor deposited aluminum)
2. Parabolic RF transparent canopy
3. Memory metal wire hoop structure
4. Microstrip patch feed
5. Container for stowing packaged assembly
Option 2: Parabolic Dish Reflector

- Estimated Gain of 35.8 dB (X-Band).
- Mass and Volume:

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<tr>
<th>Component</th>
<th>Mass [kg]</th>
<th>Volume [Liters]</th>
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<tbody>
<tr>
<td>Reflective Membrane</td>
<td>0.0189</td>
<td>0.013</td>
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<tr>
<td>Transparent Canopy</td>
<td>0.0183</td>
<td>0.013</td>
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<tr>
<td>Sublimating Powder</td>
<td>0.000268</td>
<td>0.000211</td>
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<td>Packing Inefficiency (200%)</td>
<td>N/A</td>
<td>0.052</td>
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<td>Wire Hoop Structure</td>
<td>0.004</td>
<td>0.000617</td>
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<td>Feed</td>
<td>0.0595</td>
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<tr>
<td>Container</td>
<td>0.137</td>
<td>0.051</td>
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<tr>
<td>Actuators</td>
<td>0.224</td>
<td>0.112</td>
</tr>
<tr>
<td>Subtotal</td>
<td>0.462</td>
<td>0.264</td>
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<tr>
<td>50% Margin:</td>
<td>0.231</td>
<td>0.132</td>
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<td>TOTAL:</td>
<td>0.693</td>
<td>0.396</td>
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## Comparison and Selection

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<tbody>
<tr>
<td>Option 1</td>
<td>33.7</td>
<td>3.83</td>
<td>5.48</td>
<td>-Elements folding and spacing (radiation)</td>
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<td></td>
<td></td>
<td></td>
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<td>-Sequential and controlled deployment</td>
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<td>Option 2</td>
<td>35.8</td>
<td>0.69</td>
<td>0.40</td>
<td>-Packaging and release of the sublimating powder</td>
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<td></td>
<td></td>
<td></td>
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<td>-Radiation characterization</td>
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<td>Attitude Control</td>
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<td>Deployment dynamics</td>
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<td>Radiation characteristics</td>
<td>Anechoic chamber testing</td>
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<td>Micrometeoroid impact</td>
<td>Investigate UV and radiation hardened materials for inflation chamber membranes</td>
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</table>
Conclusions and Future Work

- Inflatable antenna for CubeSat will allow higher data rate links in LEO and GEO, and interplanetary communication.
- 2 Options have been compared
  - Option 1: Flat Membrane Reflectarray
  - Option 2: Parabolic Dish Reflector
- Option 2 selected as most promising design solution.
- Future work will include the design and test of the antenna.
  - Testing will ensure the correct deployment and inflation, and measure the radiation and the gain of the antenna on the different axes.
  - The radiation of the antenna will also be simulated to obtain a preliminary estimate of the expected radiation pattern.
Thank you!
Questions?
References

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