Inflatable Antenna for CubeSats: X-band Design

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Interplanetary Small Satellite Conference
25th April 2016

Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Outline

- Introduction
- Inflatable Antenna Concept
- Structural design
- Manufacture
- Photogrammetry
- Anechoic Chamber Test
- Inflation and Rigidization
- Conclusion and future work

Introduction

- As CubeSats are becoming a way to explore deep space in a more affordable way than traditional spacecraft, new needs emerge: telecommunication systems must be able to sustain a severely increased path loss.

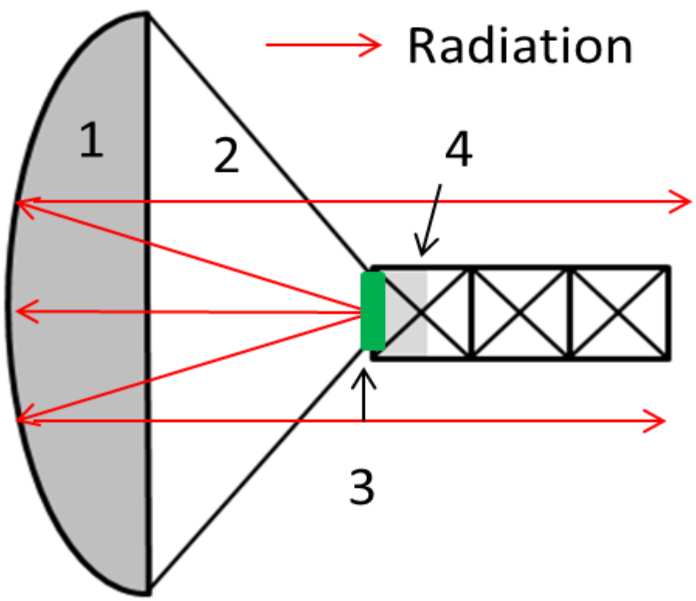
- Different communication technologies are in development to approach this problem and to support interplanetary exploration with CubeSats and small satellites. Examples are: the IRIS radio, reflectarray antennas, deployable antennas , CDMA techniques, optical communication, MSPA (Multiple Spacecraft Per Antenna), and the inflatable antenna.

- The first inflatable antenna for CubeSats was designed at the S-Band

- We are currently designing it at X-Band

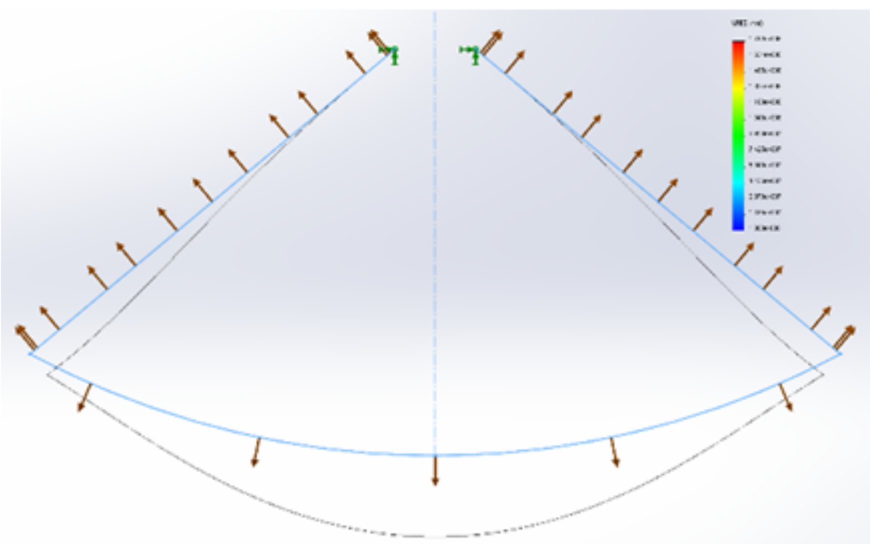
Inflatable Antenna Concept

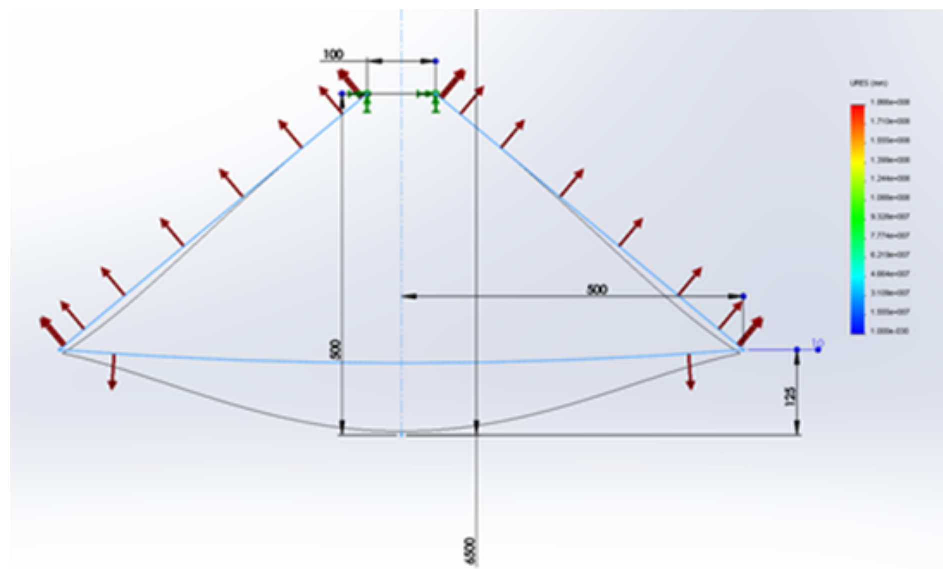
- The inflatable antenna is a parabolic dish reflector (1 m) made of one side metalized mylar, one side clear mylar, and with a patch antenna as the feed.
- Initial simulations (without considering deformations due to over inflation and wrinkles) indicate a peak gain of 34 dBi.
- The inflatable antenna is unique as it provides
  - extremely high stowing efficiency (20: 1)
  - low mass (<0.5 Kg)
  - Scalability
  - inflation with sublimating powder.



Inflatable antenna structural design

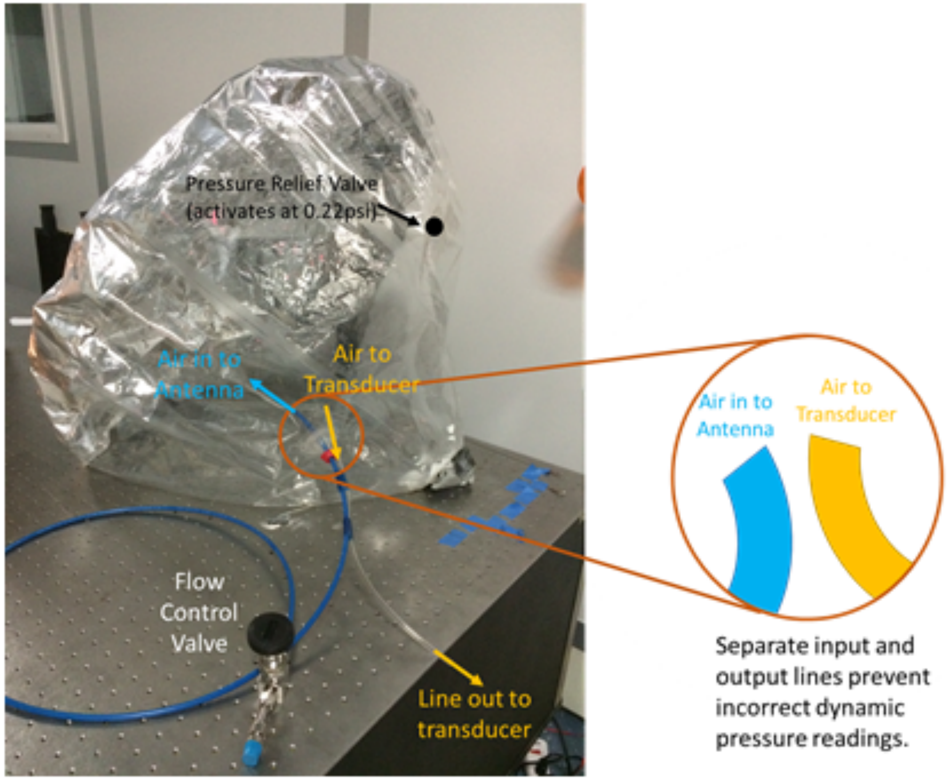
- The structural design is really challenging due to the non-linearity, the very thin membranes and the difficulty of models to characterize low pressure inflations
- Two initial designs were chosen for manufacturing from the simulation results.
- An undersized curved paraboloid surface→ after pressurization it would deform to the spherical shape which approximated a parabola.
- An entirely flat shape→ would be deformed by pressurization into a spherical surface which closed approximated a parabola. .





Antenna manufacturing

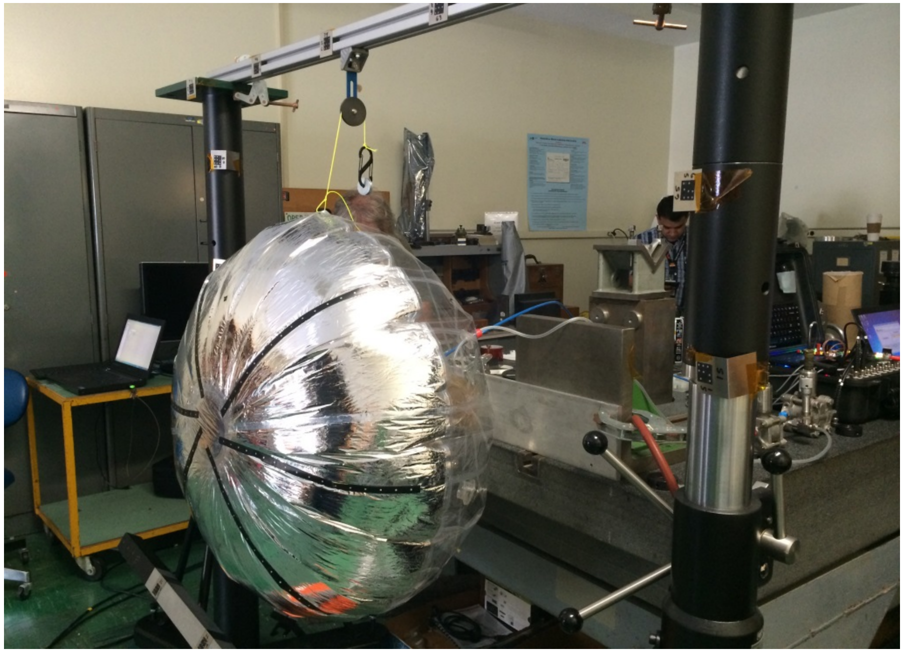
- The inflatable antenna membrane was manufactured by Meteorological Product Inc.
- A pressure input and pressure measurement couplings which connected to ¼" flex tubing were built into the antenna, along with a pressure relief valve to prevent over pressurizing the antenna.
- The pressure relief valve was designed to activate at 0.22 psi.



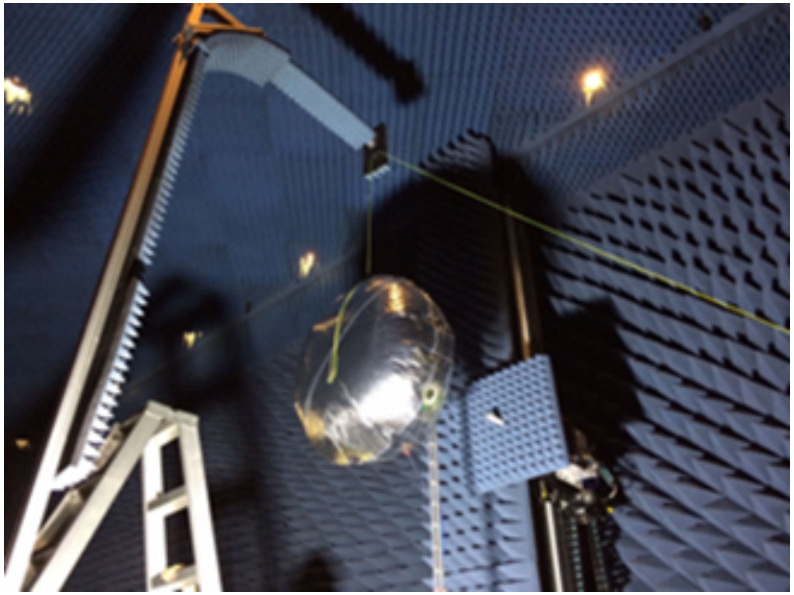
Separate input and output lines prevent incorrect dynamic pressure readings.

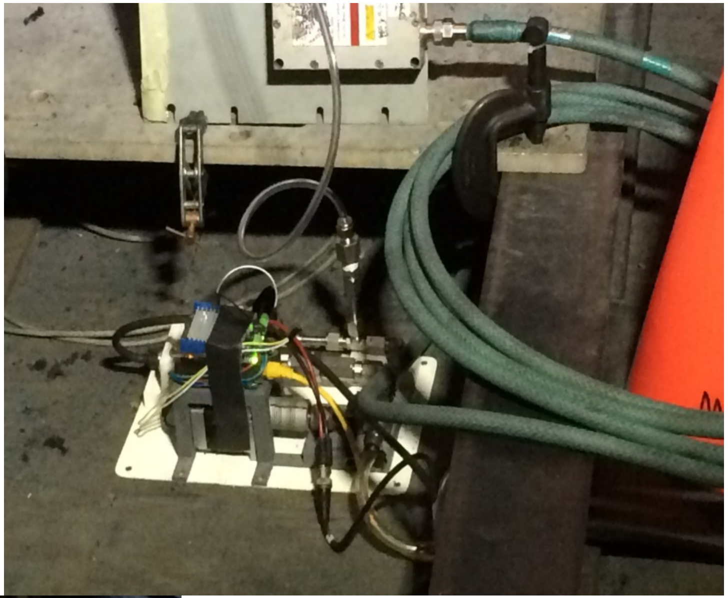
Photogrammetry

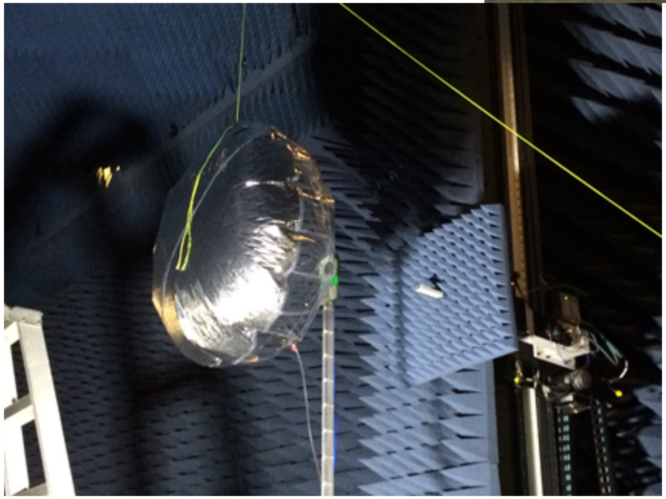
- The photogrammetry test was designed to test the impact of different pressure ranges on the curvature of the antenna.
- Pressure input was controlled manually, by a high sensitive valve, and pressure readings were made by using an Omega pressure transducer.
- A set of 3 photogrammetry cameras were used to determine the position of various photogrammetry targets, which were attached to the face of the reflector
- While the data was quite noisy, the flat antenna was found to have
  - the most predictable pressure vs. displacement curves
  - far less micro scale deformations (wrinkles) than the curved antenna.



Anechoic Chamber Test: Setup

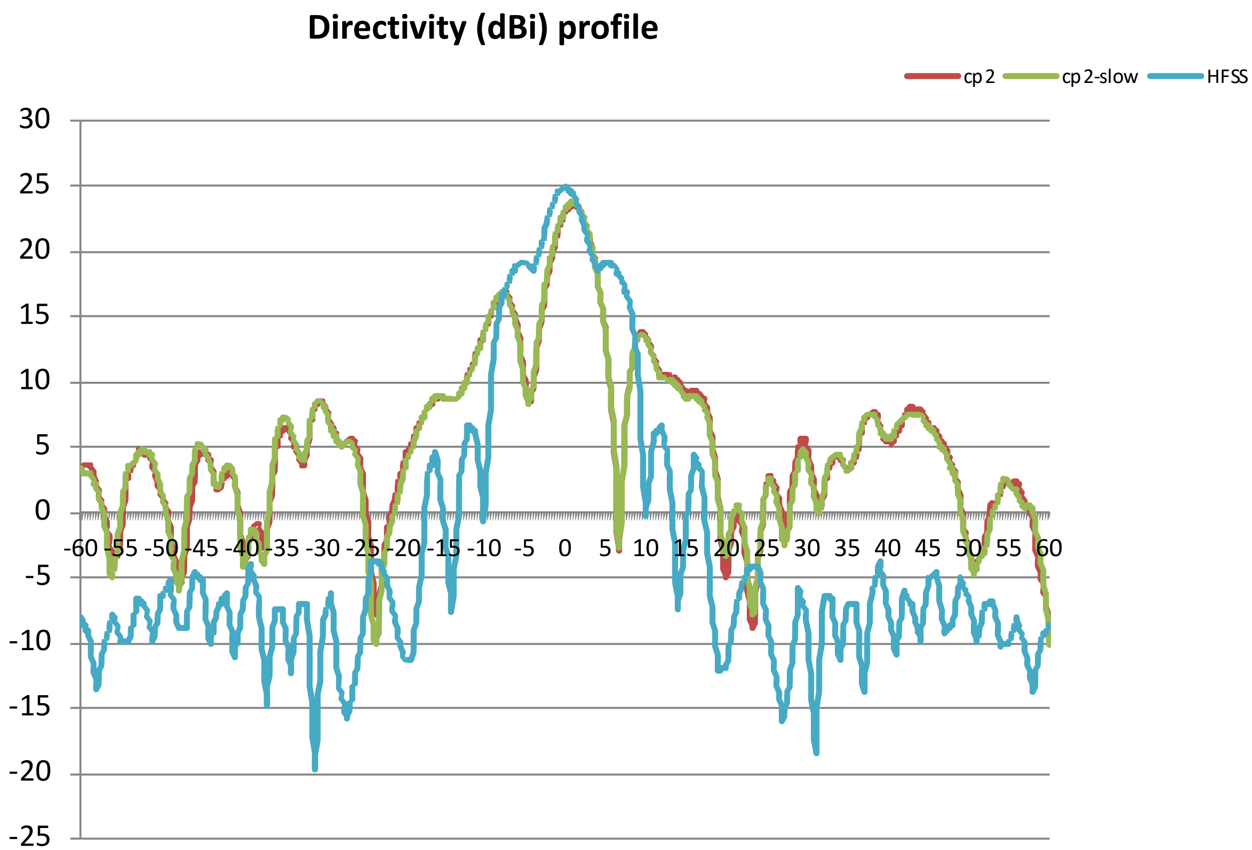






Anechoic Chamber Test: Results

- The scan were taken at 0.197 psi.
- The predicted peak directivity was 24.9
- The measured peak was 24.2 dBi

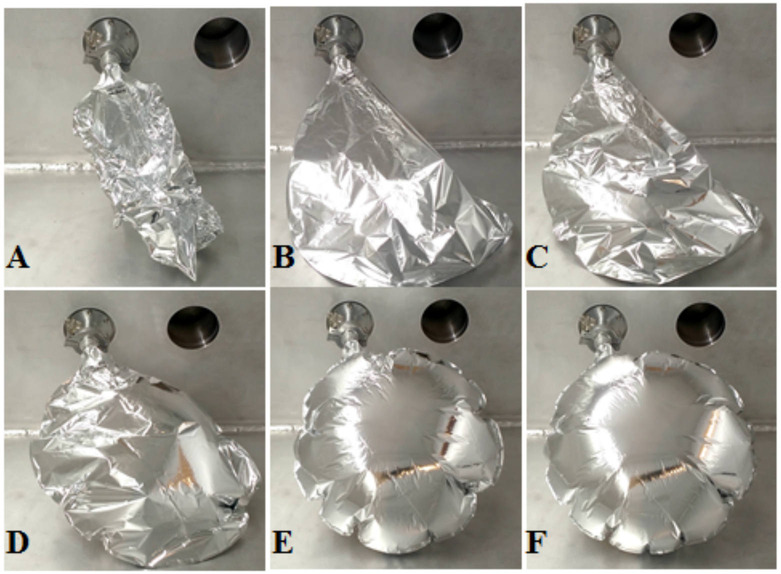


Inflation and Rigidization

- An initial study was performed to identify the best sublimating compound for the antenna
  - Benzoic acid (baseline) was confirmed to be a good choice for sublimates
- Tests in the vacuum chamber were performed to characterize the inflation
- UV rigidization was studied to allow for in-flight rigidization of the reflector

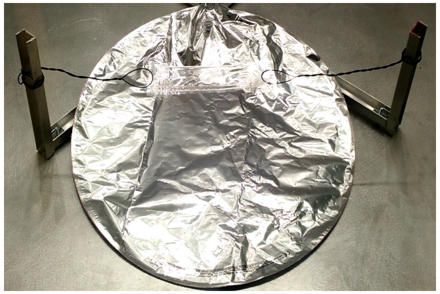
Vacuum Chamber Test

- Test steps:
  - The inflatable is evacuated of residual air at atmospheric pressure
  - The inflatable is sealed and the vacuum chamber is then evacuated
  - The chamber is held at a pressure of 10^{-5} torr.
- Phases:
  - A→ air evacuation
  - B→ peak due to redistribution of air locked pockets formed in Phase A
  - C→ progressively pressure lowering
  - D→ sublimation begins
  - E-F→ equilibrium is reached (0.0026 Torr)
- The test has shown that inflation is achievable with 1 g of sublimating powder. Additional powder does not damage the antenna and can be used to generate additional gas in case of micrometeoroid perforation.

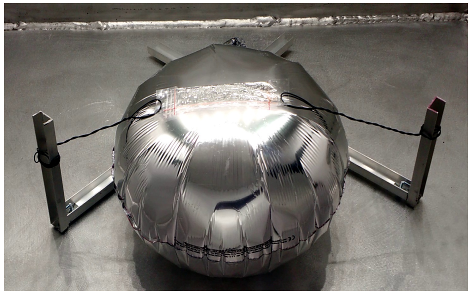


UV Rigidization

- Clear Mylar envelope (15 cm x 3cm) injected with UV resin P 600.
- The envelope was stretched and placed over a sublimate containing inflatable.
- Upon reaching vacuum and completing inflation, the envelope takes the curved shape and it is exposed to UV radiation.
- UV radiation takes up the induced curvature and forms a rigid glass like structure in approx. 2.5 hours.



Before inflation



After inflation

Before UV curing

After UV curing

An attempt to rigidize the entire shape

Conclusions and Future Work

- This paper describes the effort in developing an X-Band inflatable antenna for CubeSat.
- The structural analysis looked at the correlation between pressure and shape, discovering that only a very minimal pressure is necessary to inflate the antenna.
- The reflective part of the surface was designed as something less than parabolic.
- Two shapes were manufactured and tested at the photogrammetry laboratory
- The flat shape presented fewer wrinkles due to the differences in the manufacturing.
- The flat reflector was further tested in the anechoic chamber were a directivity of 24.1 dBi was measured (very close to the simulated value of 24.9 dBi).
- Regarding inflation, a review of the powders was performed to identify the most appropriate sublimate compound for the antenna and benzoic acid was chosen.
- Test in the vacuum showed that it is possible to inflate the antenna using sublimating powder and provided measurements of the pressure differential.
- The UV rigidization experiment is a preliminary effort in the process of rigidizing the antenna.
- Future work is focused on
  - Improving the EM characteristics of the antenna by trying to compensate for the lack of a perfect parabolic curvature on the reflector.
  - More studies and experiments on the rigidization process
  - A dynamic test to identify the effect of rotation and translation on the antenna structure

Thank you!