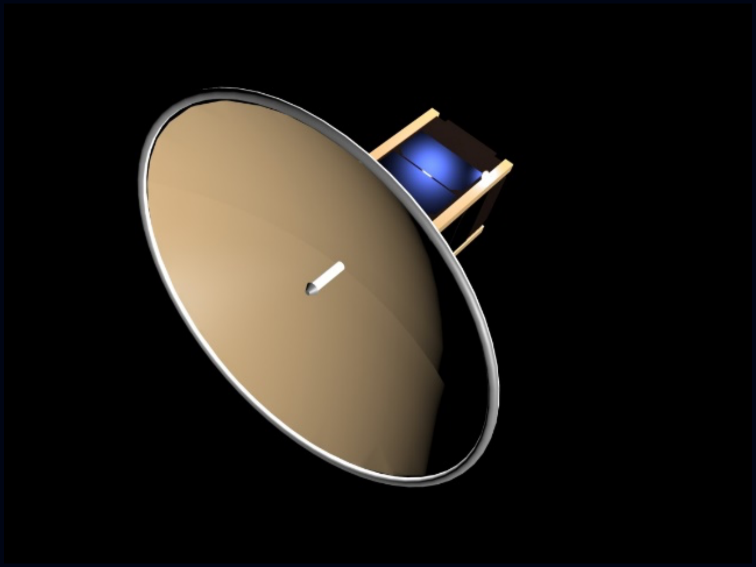
Development of an Inflatable Antenna Prototype for Interplanetary CubeSats



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Motivation

Communication Capability

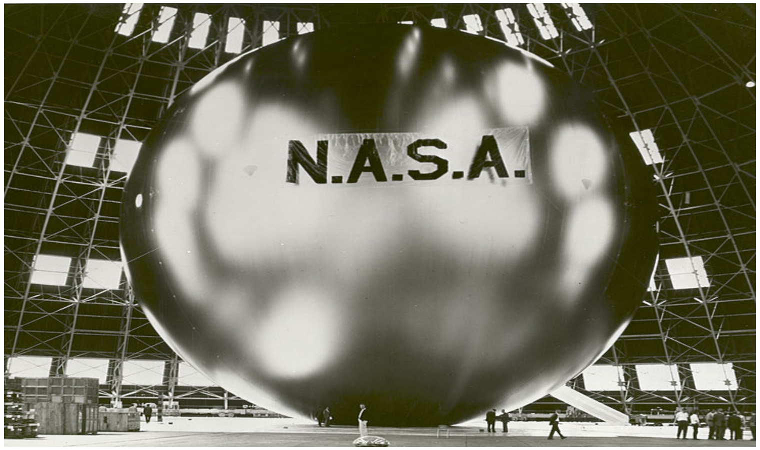
- At LEO or higher
- For Interplanetary missions
- Antenna requirements

Motivation

Inflatable offer a promising technology pathway for interplanetary CubeSat communication and tracking

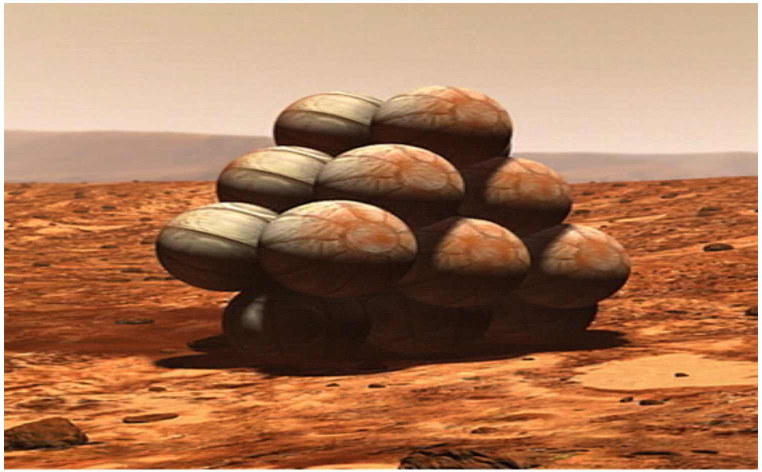
- Very high deployed volume
- Very low mass
- High-packing efficiency
- Quick deployment
- Relative simplicity

Inflatables

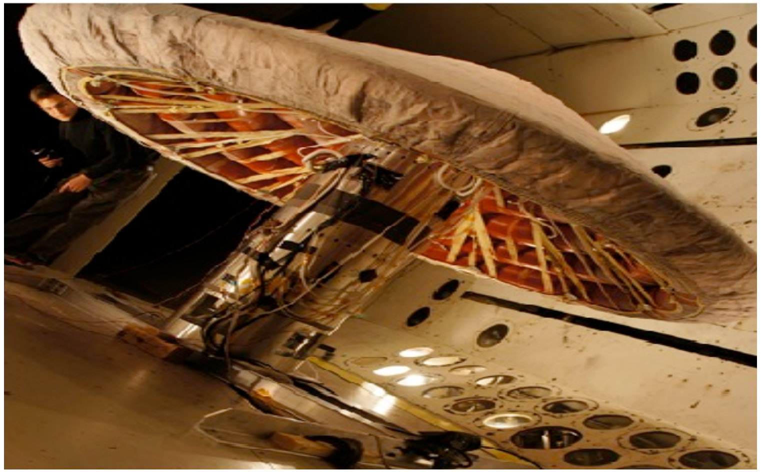


ECHO I MISSION

INFLATABLE HABITAT



MARS EXPLORER ROVER



INFLATABLE DECELERATOR

Challenges

Inflation System

- Optimum Inflation Pressure
- Passive Activation/Inflation
- Rigidization & Shape Conformance
- Micrometeorite Attack

Objective

Research inflation techniques and develop an inflation system for CubeSat platform

- Low mass, low cost system
- Passive activation
- Resistance to micrometeorite attacks
- Validate with physical models

Inflation Systems

ECHO I & II Satellite

- Sublimating Powder [Clemmons, 1964,Talentino,1966]

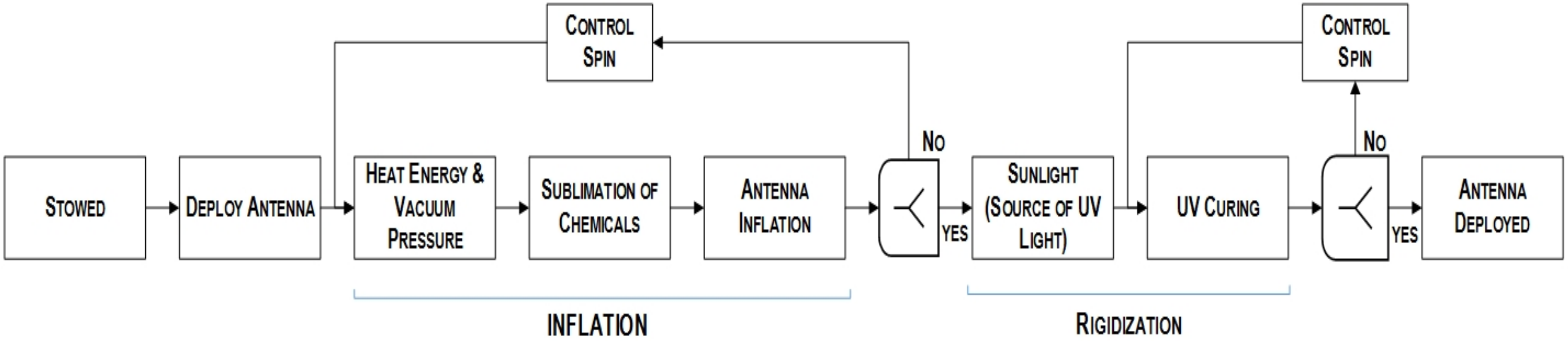
Mars Pathfinder

- Gas Generator [Cadogen et al., 2002]

Inflatable Aerodynamic Decelerators

- Gas Generator & Ram Air [Cruz et al., 2006, Hughes et al., 2011]

Proposed System



Stowed

Deploy Antenna

Heat Energy & Vacuum Pressure

Sublimation of Chemicals

Antenna Inflation

No

Control Spin

Yes

Sunlight (Source of UV Light)

UV Curing

No

Control Spin

Yes

Antenna Deployed

INFLATION

Rigidization

Sublimating Chemicals

Sublimation

- Phase transition from solid state to gaseous state without going through the liquid state

Features

- Chemicals: Powder or Crystalline form, less mass and easy packing
- Sublimate to release large volume of gas

Selection of Chemicals

Operating Temperature of Antenna [Babuscia et al., 2013]

Range: 369K – 377K

Average: 373K

Sublimation Enthalpy:

- Depends on operating temperature
- Helps Passive Activation

Selection of Chemicals

Vapor Pressure

Pressure exerted by the gas on the inflatable surface

- High Pressure: Rapid inflation and rupture
- Low Pressure: Insufficient internal pressure for inflation

[Clemmons, 1964,Talentino,1966]

Candidate Chemicals

From an extensive list of sublimating chemicals the following were shortlisted [Jones, A.H, 1960]

SUBLIMATING POWDERS	CHEMICAL FORMULA	MOLECULAR MASS (g)	MASS REQUIRED (mg)
Benzoic acid	C7H6O2	122.12	0.86
Butyramide	C4H9NO	87.12	0.62
Diformylhydrazine	C2H4N2O2	88.07	0.62
Hexachloroethane	C2Cl6	236.74	1.68
O-methoxybenzoic acid	C8H8O3	152.15	1.08
Oxalic acid (anhydrous)	H2C2O4	90.03	0.64
Pyrene	C16H10	202.25	1.43
Salicyclic acid	C7H6O3	138.12	0.98
Urea	CH4N2O	60.06	0.43

Rigidization Techniques

- UV setting resins [Keller et al., 1964]
- Thermosetting resins [Cadogen et al., 2001]
- Glass transition resins [Lichodziejewski et al., 2005]
- Gas cured resins [Bernasconi et al., 1990]
- Stretched metal laminates [James et al., 1964, Bahiman et al.,1965]
- Evaporation hardened rigidizing foams[Schnell et al., 2002]

Rigidization Techniques

Proposed Technique

- UV Curable Ink sprayed over the antenna surface
- Curing through rapid polymerization

Advantages

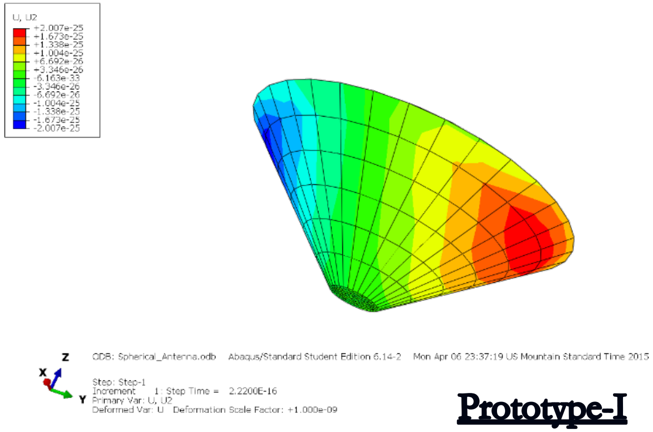
- Rapid Curing (<20s) [Chattopadhyay et al., 2005]
- Flexible coating post curing [Schwalm et al., 1997]
- No hazardous vapors [Chattopadhyay et al., 2005]
- Low UV Energy requirement [Chattopadhyay et al., 2005]
- Clear coating possible [Seubert et al.,2004]
- Strong mechanical property [Chattopadhyay et al., 2005]

Analysis

Verified structural integrity of 2 prototypes

Forces applied

- Centrifugal Force
- Radiation Force
- Internal Vapor Pressure



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Step: Step-1
Increment      1: Step Time =    2.2200E-16
Primary Var: U, U2
Deformed Var: U   Deformation Scale Factor: +1.000e-09
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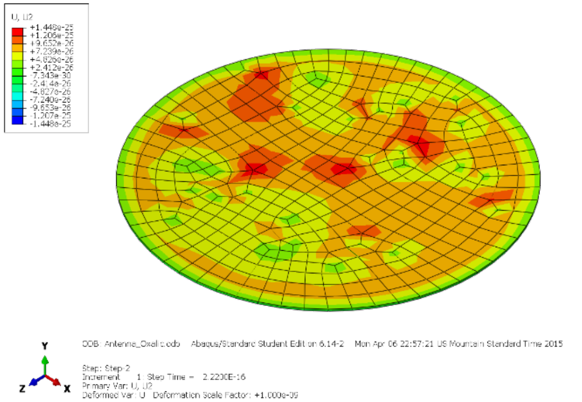
Prototype-I



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Step: Step-2
Increment      1: Step Time =    2.2200E-16
Primary Var: U, U2
Deformed Var: U   Deformation Scale Factor: +1.000e-09
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Prototype-II

Results

Max. Deformation of Mylar at Break

$5.226\text{x}10^{-25}$mm

SUBLIMATING CHEMICAL	VAPOR PRESSURE (Pa)	MAX DEFORMATION (mm)	
		Prototype-I	Prototype-II
Benzoic Acid	9.33E-02	1.19E-26	1.01E-25
Butyramide	5.21E-01	2.007E-25	5.66E-25
Diformylhydrazine	6.67E+01	3.01E-27	7.24E-27
Hexachloroethane	5.33E+01	1.69E-27	5.69E-27
Methoxybenzoic acid	2.00E-01	1.018E-26	2.17E-25
Oxaclic Acid	1.33E-01	5.04E-26	1.45E-25
Pyrene	6.00E-04	3.28E-28	6.51E-28
Salicylic Acid	1.09E-02	4.93E-27	1.19E-26
Urea	1.60E-03	3.49E-28	1.74E-27

Discussion

Structural Feasibility:

- No structural failure (except Butyramide)

UV Curable Rigidity:

- Curing increases mechanical strength as temperature [Chattopadhyay et al., 2005]

Future Work

Experimental Validation in Vacuum Chamber

Sublimating Chemicals:

- Validation Pressure & Temperature points for Sublimation
- Time taken for Inflating the model

UV Curable Ink:

- Observation of chemical reactions with Mylar sheet
- Rigidity achievable measured with FTIR method
- Transparency of coat to electromagnetic radiations

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