Deployable Helical Antenna for Nano-Satellites

Daniel Ochoa
Northrop Grumman Aerospace Systems, Astro Aerospace
6384 Via Real, Carpinteria CA 93013; 805-566-1784
daniel.ochoa@ngc.com

Kenny Hummer, Mike Ciffone
Northrop Grumman Aerospace Systems
1 Space Park, Redondo Beach CA 90278; 310-814-6031
kenneth.hummer@ngc.com, michael.ciffone@ngc.com

ABSTRACT

The purpose of this paper is to describe the development of a deployable helical UHF antenna which is able to stow in a 4-in x 4-in x 2-in package and deploy to 54" tall x 14"-in diameter which has been designed, prototyped, and tested. The novel structure is composed of S-2 Fiberglass/PEEK thermoplastic composite strips assembled in a precise configuration and collapsed such that the stowed package integrates within a 0.5U CubeSat. Deployment is achieved on orbit using only stored strain energy. Deployment testing at 1g and RF testing has been completed and results will be presented.

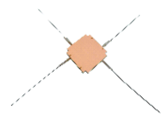
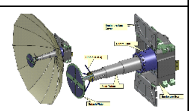
BACKGROUND

Low cost nano, micro, and small satellites (nanosats, microsats) have enabled unprecedented access to space for smaller institutions and organizations. As the benefits of low cost, small satellites have been realized by more entities there has been an increase in demand for higher performing small satellite systems. For most small satellite form factors available power is limited. This is especially true for systems utilizing the CubeSat form factor in a 1U to 3U configuration. For RF missions that hope to leverage CubeSats to enable scalable missions at low cost and in short time frames, the only way to achieve sufficient RF performance is to utilize a relatively large deployable antenna. This paper discusses the design and testing of a high gain deployable UHF helix antenna capable of stowing within a 5 cm x 10 cm x 10 cm volume or a 0.5U CubeSat unit.

State-of-the-Art

Currently small satellite, high gain, deployable antenna options are limited to a relatively few number of proven designs. Table 1 provides several examples of currently available small spacecraft deployable antennae.

Table 1: Current Deployable Antennae for Small Satellites[1]

Type	Description	Developer	Figures
Deployable UHF/VHF	CubeSat antenna. Deploys 4 monopole antennae Max Power: 2W Mass: 0.10 kg	Innovative Solutions in Space, Netherlands	
Deployable High Gain Antenna	CubeSat Parabolic antenna Max gain: 18 dBi Mass: 1.0 kg	BDS Phantomworks (USA)	
Deployable High Gain Antenna	CubeSat Parabolic antenna Max gain: 15 dBi Half Angle: 1.1° Mass: 1.0 kg	USC Space Engineering Research Center (SERC), USA	

MECHANICAL DESIGN

The helical structure was developed in response to the a requirement for a high gain UHF antenna capable of deploying from a stowed package of approximately 0.5U or half the size of a 10cm CubeSat volume.

Deployed Structural Configuration

As shown in Figure 1 the deployed structure utilizes a framework of fiberglass/thermoplastic pultruded tape strips ultrasonically welded together at each joint intersection. The material is a PEEK matrix and S2 fiber. The tape is approximately 0.005 inches thick. This material provides the desired deployed stiffness and flexibility to allow for a small stowed volume and the necessary strain energy to return the structure to the proper deployed shape.

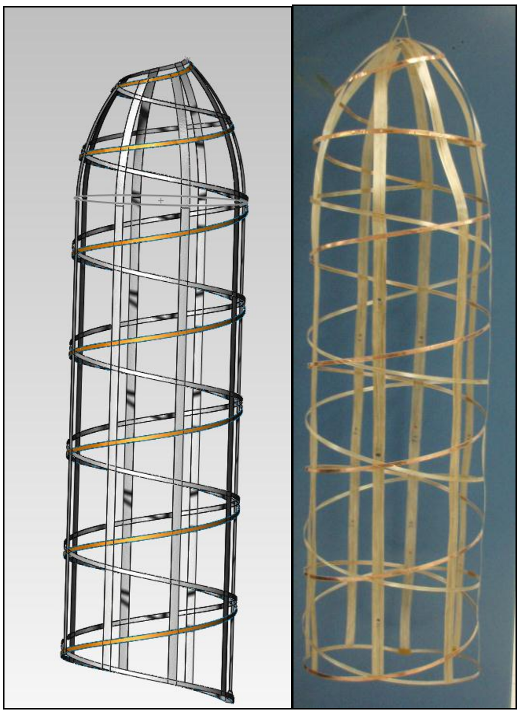


Figure 1: Deployed Helix as Designed and Constructed

The structure utilizes two opposing helical elements wound clockwise and counterclockwise relative to each other to form a column. The column is reinforced by eight vertical stiffeners circumferentially disposed around the column and equally spaced to provide axial stiffness. The conductive element is made of a .0035 inch thick copper adhesive tape that is continuously attached to one of the helical elements. See Figure 2. The structure is designed to have five coils at a 12° pitch so that the length of the column is 54.33 inches and the diameter is approximately 14.5 inches. The top of the helical column is terminated with a conical neck down. This shape was incorporated for better RF performance as will be discussed in following paragraphs. The helical element structures are 1/4 inch wide while the vertical stiffener element structures are 5/8 of an inch wide.

The helical structure is attached to a baseplate by a flexible beryllium copper strip formed into a semi-circle for stiffness. The aluminum baseplate forms the interface for the containment door mechanisms, the spacecraft interface and the deployable 24 inch by 24 inch ground plane.

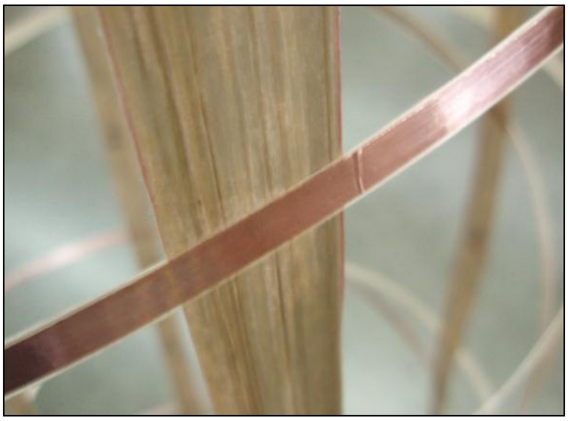


Figure 2: Copper Conductor Element Attached to A Single Helical Element

The ground plane is composed of a single layer of aluminized Kapton film stiffened by four 0.032 inch diameter fiberglass epoxy pultruded rods. The ground plane structure is stowed by spiral wrapping the rods around a center core. The rods provide sufficient strain energy to ensure a reliable deployment upon restraint release. Figure 3 shows the deployed ground plane structure and Figure 4 shows the stowed form.

Figure 3: Deployed Ground Plane

The deployed system conceptual design with helix, baseplate, ground plane and container is shown in Figure 5.

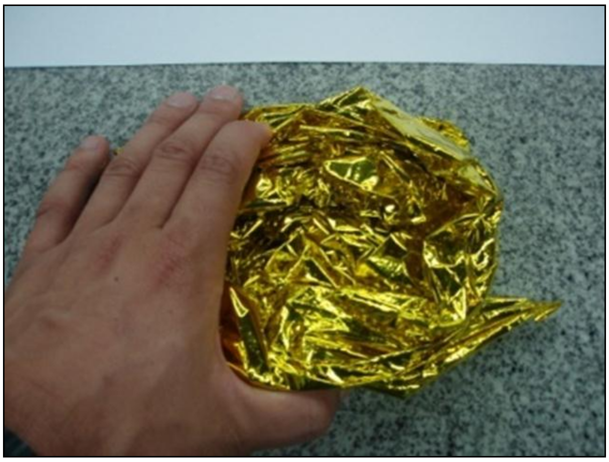


Figure 4: Stowed Ground Plane

The innovative design is ultra-compact. The deployed volume to stowed volume ratio is about 300:1 making it an extremely efficient deployable structure that can be scaled for many nano, micro, and small satellite form factors. The entire system including ground plane and simple stow box has a mass of 0.67 lbs.

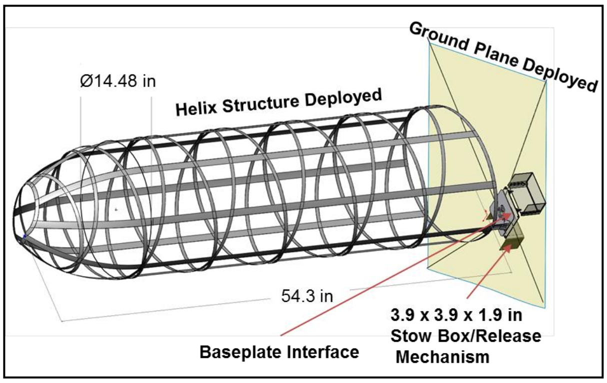


Figure 5: Deployed Antenna System

Stowed Configuration and Deployment

The helical structure is stowed by folding and rolling the flexible structure in a precise manner. The first step is to fold the structure along the long axis such that the eight vertical members are oriented on top of each other along the length of the column. When the vertical stiffeners are placed in this orientation, the helical elements are drawn together and extended away from the confined vertical stiffeners in a "rats nest" type orientation. Figure 6 shows the structure in the flattened orientation.

From this position the flattened antenna is rolled up on itself to form the final "ball" configuration which is then captured within the stowage container. The rolling is done starting at the tapered end so that upon release the antenna unrolls starting at the baseplate attachment point. **Figure 7** shows the stowed helical antenna.

Figure 6: Helix Mid Stow

Figure 7: Stowed Helix

Deployment is achieved by releasing the stored strain energy in the rolled helical structure at 0-g. Gravity negation ground support equipment has not been developed to facilitate ground deployments due to feasibility constraints for this type of very light weight deployable structure[2] however, allowing the helix to unfurl in the direction of gravity allows the structure to approximate on orbit deployment characteristics. Screen grabs from a high speed video of a simple hand released ground deployment at room temperature are shown in Figure 8 at 250 frames/second.

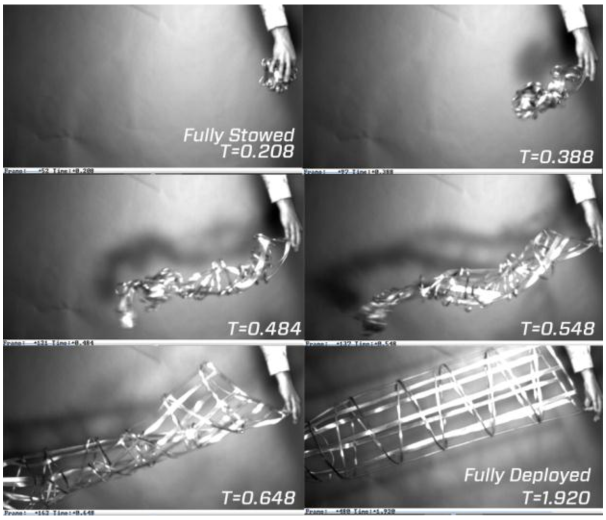


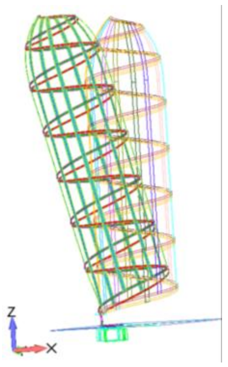
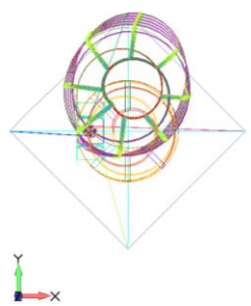
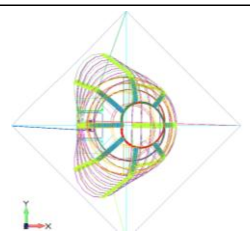
Figure 8: High Speed Video Deployment

Deployments at cold and hot temperature extremes have not been performed but at LEO the temperatures are not expected to pose problems. The glass transition temperature (T_g) of the helical structure is 143°C indicating that the material will remain stable with little loss in strain energy. Additionally material creep performance has not yet been evaluated. It is possible that the helix might need to remain packaged in the stow configuration for an extended period of time and may be subjected to creep forces[2] but again, this is not expected to negatively affect performance.

Modal Analysis

A deployed modal analysis has been performed on the helical antenna structure using Femap with Nastran. Table 2 presents the fundamental mode frequencies in the baseline configuration without additional stiffener elements.

Table 2: Helix Modes

Mode	Frequency (Hz)	Figure
1st	0.1839	
2nd	0.2593	
3rd	1.3334	

At the first mode the structure begins to buckle about the vertical stiffener acting at the single point root attachment to the baseplate. This is shown in Table 2 below as rotation about the Y-axis. At the second mode the structure twists around this same vertical stiffener. This is shown in Table 2 as rotation about the Z-axis. At the third mode the structure expands and contracts in a pumping motion about the Z-axis shown in Table 2.

The copper conductor element also has an effect on the modal performance of the structure. The added density on the single helical element, which acts as the attachment for the copper conductor, lowers the modal frequencies of the structure. A simple trade was performed and is presented in Table 3. The copper conductor as tested represents an approximate 10% increase in density on the helical element.

Table 3: Trade Study on Impact of Copper Conductor Density

Density Increase	Mode 1 (Hz)	Mode 2 (Hz)	Mode 3 (Hz)
0%	0.1857	0.262018	1.348104
10%	0.1839	0.25932	1.333423
20%	0.182095	0.256704	1.319212
30%	0.180341	0.254165	1.305445
40%	0.178636	0.251701	1.2921
50%	0.17698	0.249307	1.279156

RF DESIGN

Because high gain was required, a helix design was ultimately chosen as it provided the gain required and a deployable version capable of the 0.5U stowed volume was deemed feasible early in the process. Table 4 below shows key performance indicators for the various small satellite antennas investigated during the pre-design phase.

Table 4: Antenna Trade

	Helix	Cup Dipole	Spiral	Dipoles
Peak Gain	8-13 dB	5-7 dBi	7 dB with ground plane	2 to 4 dBi without ground plane
Polar-ization	Circular by design	Dual Linear; Circular, beamformer	Dual Linear; Circular, beamformer	Dual Linear; Circular, beamformer
Pattern Shape	Uni-directiona l	Uni-directional	Bi-directional without ground plane	Bi-directional without ground plane
Bandwidth	≤ 1 octave	≤50%	Multi octave	≤50%

RF Performance and Testing

A 5 turn helix was designed to provide the desired gain and beam width. A two turn taper was added to the helix to improve the axial ratio. The antenna was fabricated and a representative ground plane was attached. A wooden support with foam rings was used to support the antenna for testing in a 1G environment. A printed circuit matching network was fabricated to impedance to match the helix to 50 ohms. The Voltage Standing Wave Ratio (VSWR where VSWR = 1.0:1 is ideal) shows a VSWR ≤ 1.5:1 from about 230 MHz to 400 MHz. Figure 9 shows the VSWR of the antenna as tested.

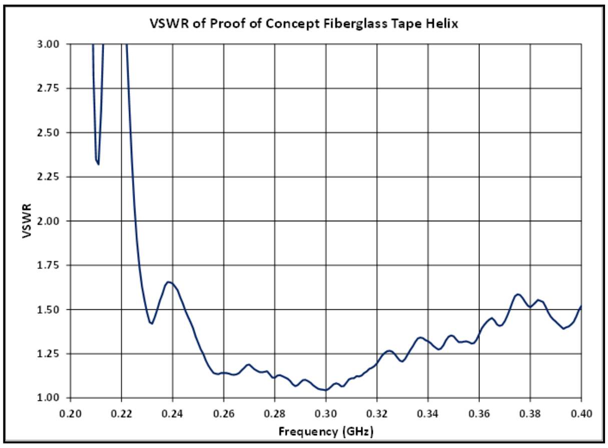


Figure 9: VSWR of the Deployable Helix

The antenna was placed in a 40 foot anechoic chamber for radiation pattern testing. Figure 10 shows the antenna under test in the anechoic chamber. A full contour was measured every 1 MHz from 200 MHz to 500 MHz. The contour was measured out to 140 degrees in θ in 1 degree steps and every 15 degrees in ϕ to determine pattern shape, directivity, and axial ratio.

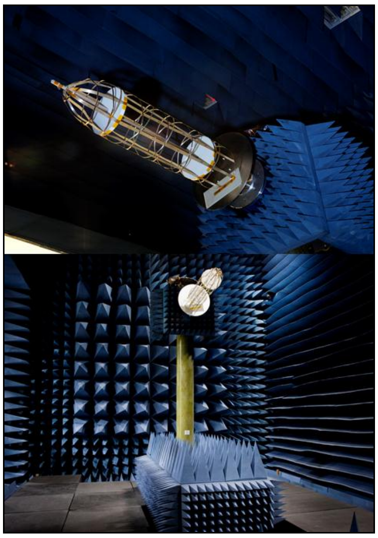


Figure 10: Deployable Helix Under Test

Figure 11 shows the radiation pattern at several frequencies and the desired beam width for the antenna.

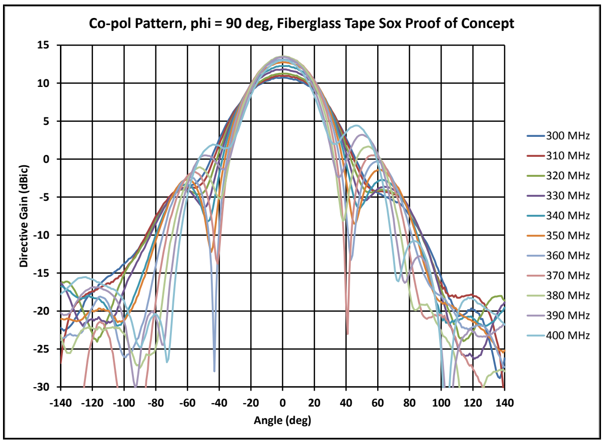


Figure 11: Co-polar Radiation pattern of the Deployable Helix at Multiple Frequencies

The side lobes are somewhat high at the higher frequencies, but this was acceptable for the application. The antenna demonstrates excellent axial ratio ≤ 2.0 dB from 250 MHz to 470 MHz (Figure 12). A bore sight gain measurement was conducted using the comparison method. Figure 13 shows the gain and directivity of the antenna. The resulting loss is less that -1.5 dB from 260 MHz to 400 MHz.

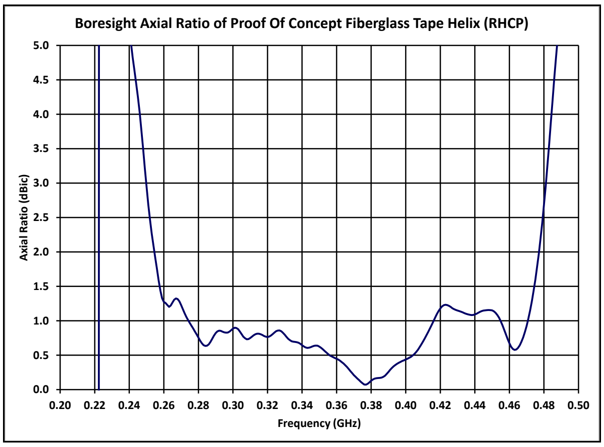


Figure 12: Axial Ratio of the Deployable Helix

The high loss at the low end of the bandwidth is mainly due to the radiation from the matching network. In a real application at these frequencies, a lumped element matching network will be used due to size and low loss.

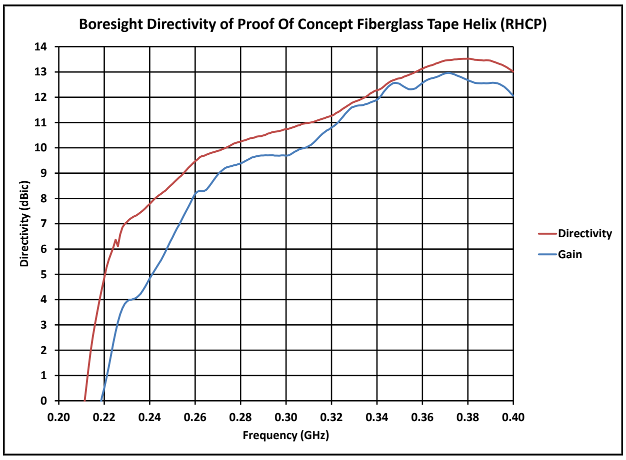


Figure 13: Deployable Helix Gain and Directivity Relative to an Ideal Circular Polarized Incident

AN EXAMPLE SYSTEM ARCHITECTURE

The potential of nanosats to provide beyond line of sight (BLOS) data communications for services such as tactical SMS, preformatted combat messages, graphics, etc. as well as for exfiltration of data from unattended ground sensors (UGS) was evaluated. To be militarily relevant, the services must be compatible with the needs of the forward tactical edge warfighter operating in remote areas who do not have dedicated UHF satellite communication (UHF SATCOM) support.

Technology Implementation

While satellite communication (SATCOM) is a mature technology, implementing this capability in a nanosatellite form factor in Low Earth Orbit (LEO) presents a number of unique technology challenges and opportunities. RF propagation impairments at UHF frequencies, such as multipath and ionospheric scintillation are not well characterized to LEO spacecraft and are anticipated to be more severe than for geosynchronous spacecraft. The communications link is further challenged by the fact that user radios must be portable and therefore rely on omni-directional antennas and the payload transmitter power is constrained by the very limited power and mass available in a nanosatellite. Collectively, these constraints required that we investigate solutions for a simple lightweight deployable antenna structure to provide the maximum gain possible within the challenging volume constraints imposed by the nanosatellite form factor.

UHF Amateur radio is used on the overwhelming majority of nanosatellite projects for command, telemetry, and mission data communication. However, link rates have been limited to the 100Kbps range by the 0dBi gain tape-spring antennas typically used (Figure 14). With this 10dBi antenna, >1Mbps data-links in the UHF ISM bands are feasible using a standard nanosatellite ground station (bandwidth allocation dependent).

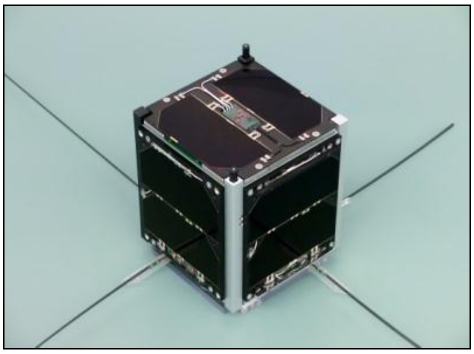


Figure 14: Standard 0dBi Tape Spring Antenna

As shown in Figure 15 below, a 0.5U stowed antenna solution allows for a full 1U allocation within a standard 3U CubeSat for mission-unique payload electronics (assuming a typical 1.5U CubeSat bus). A 1U payload allocation is more than sufficient to fit many existing software defined radio solutions developed for CubeSat applications, most of which require only a 1/2U[3].

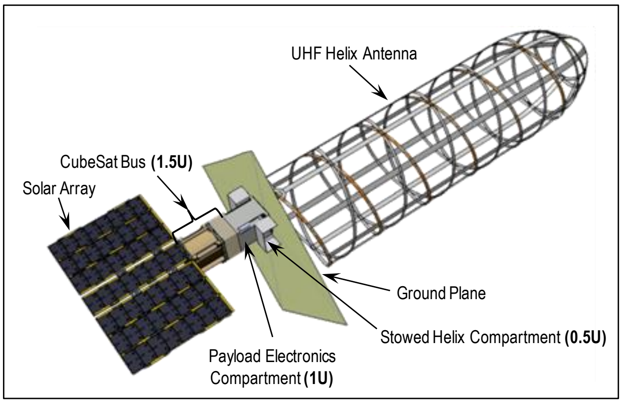


Figure 15: Conceptual Cubesat Using the Deployable UHF Antenna System

CONCLUSION

The deployable UHF helical antenna has been proven to perform well under test. The structure as designed provides approximately 13 dBi of gain at 400 MHz allowing > 1 Mbps data links, can stow within an extremely small volume, and it has sufficient deployed stiffness for a small satellite mission. Future work in developing the stow containment box and release device is not foreseen to present any new significant design challenges or any state-of-the-art leaps.

Acknowledgments

The authors would like to acknowledge Nathan Gates (NGAS Astro Aerospace) for Femap modal analysis support; Geoff Marks (NGAS Astro Aerospace) as a co-inventor of the technology; David Rohweller (NGAS Astro Aerospace) as a co-inventor of the technology; Dr. Mehran Mobrem for technical guidance (NGAS Astro Aerospace), and James Barazza (NGAS Astro Aerosapce) for high speed video support.

Notes

At least a portion of the technology which is discussed in this paper is the subject of one or more pending patent applications, including but not limited to US Application No. 13/564,393, EU Application No. 13003752.6-1812.

References

1. C. Frost. And E. Agasid et al, “Small Spacecraft Technology Sate of the Art,” NASA/TP-2014-216648, Ames Research Center, Moffett Field, CA, January 2014.
2. M. Mobrem and D. S. Adams, “Deployment Analysis of Lenticular Jointed Antennas Onboard the Mars Express Spacecraft” Journal of Spacecraft and Rockets, vol. 46, No. 2, March 2009.
3. B. Klofas, “CubeSat Communications Survey Update,” 2011 Summer Developers Workshop, Utah State University, August 2011.