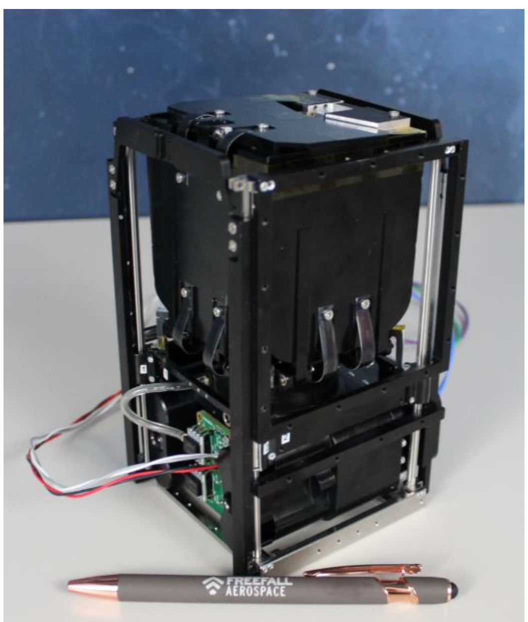
Inflatable Antenna System for Planetary Exploration

Introduction

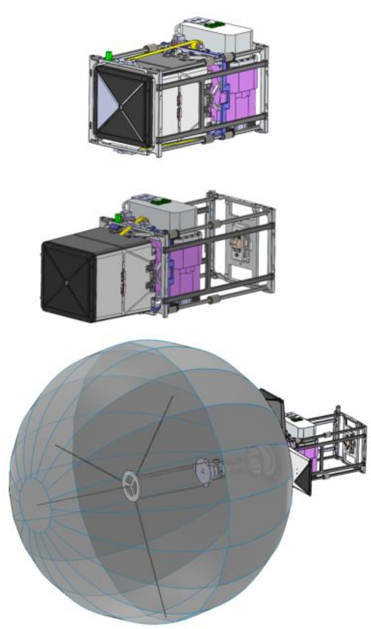
Maximizing data return while minimizing mass, volume, power, and operational complexity is one of the fundamental challenges facing all space missions. Planetary missions place particularly demanding requirements on communications, and the increasing emphasis on small low-cost spacecraft makes it imperative that future missions utilize new and innovative communications technologies. FreeFall Aerospace has developed and qualified a unique Inflatable Antenna System that can dramatically increase the data return capability of Cubesats and small spacecraft. This system has been delivered for flight on the CatSat mission, selected by the NASA Cubesat Launch Initiative with launch now expected in February 2023. The FreeFall antenna will enable the vision of “Big Data from Small Spacecraft” and has gained wide interest across the commercial, government, and scientific space ecosystem.

Description

The FreeFall Inflatable Antenna System (IAS) consists of a flexible membrane reflector with an internal RF feed, a compact deployment and inflation system, and a control unit. The entire system can be stowed and deployed from a 1.5U volume making it suitable for small satellites and CubeSats 6U and above. The current system deploys and maintains a 0.5 m inflatable spherical membrane reflector and line feed operating at X-band, and can be adapted to a variety of sizes and frequencies for future missions. The system is currently at TRL 8 and has passed all thermal vacuum, vibration, and system integration tests and has been delivered for spaceflight validation expected in February 2023.

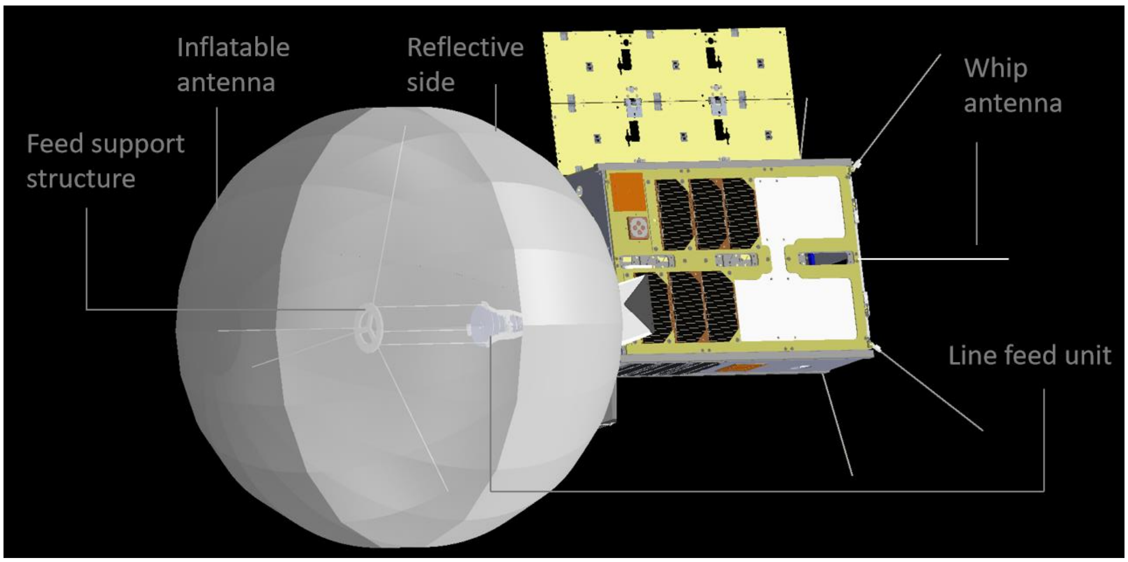


1.5 U Inflatable Antenna System Flight Unit

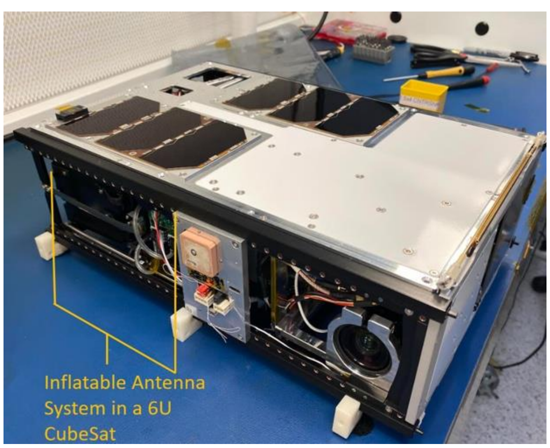


Inflatable Antenna System Deployment Sequence

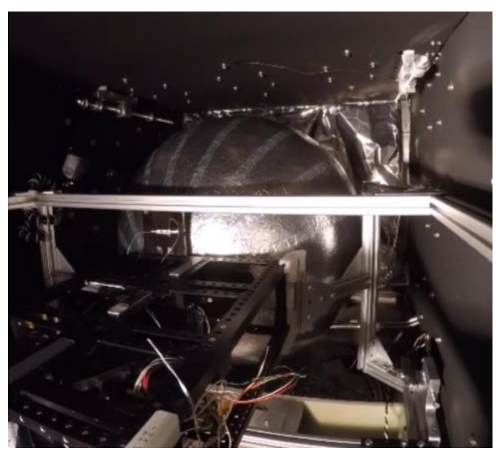
The spherical Mylar membrane reflector is half metallized and half transparent and is pressurized using a compressed gas mixture of nitrogen and helium. The autonomous deployment control system monitors and maintains desired pressure states during the mission to ensure proper antenna performance. One key advantage to the spherical reflector concept is that spherical geometries are relatively easy to attain using inflatable membrane structures, as opposed to parabolic surfaces or other more complex shapes. This dramatically reduces antenna deployment risk and ensures that the reflector surface will have the required shape and smoothness. In addition, the spherical reflector provides the widest possible field of view; this obviates the need for the extremely precise pointing required for parabolic dish antennas, historically one of the failure modes of deployed smallsat antennas.



Inflatable Antenna System – 6U CubeSat (CATSAT) Implementation



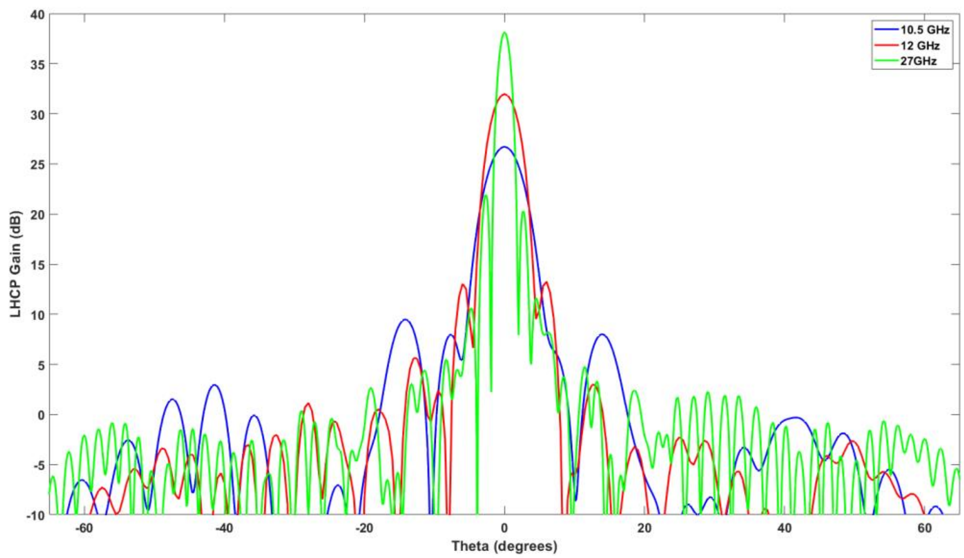
1.5 U Inflatable Antenna System – 6U CubeSat integration



Flight qualification TVAC tests

Operation and Performance

The lightweight feed is attached internal to the reflector and deploys to the proper focus position as the reflector inflates. The CatSat X-band feed is a “line feed” specially designed to correct spherical aberration and optimize reflector illumination. FreeFall has also designed a variety of feed systems to provide the frequency, polarization, and bandwidth required for different missions. Beam patterns and performance at a variety of frequencies are shown below for the 0.5 m inflatable reflector.



Far-field patterns (LHCP) for X, Ku and Ka-band

Frequency (GHz)	Peak gain (dB)	Beamwidth (degrees)	Sidelobe level (dB)
10.5	26.7	5	-17.3
12	32.0	4	-18.7
27	38.1	1.6	-16.3

Performance at X, Ku and Ka-band

Another key advantage to the IAS approach is its scalability. The same deployment system can be used with reflector sizes varying from 0.5 m to 3 m with feeds optimized for specific frequencies ranging from X-band to Ka-band. This makes the system compatible with a wide variety of mission types from LEO to deep space. Given the premium that planetary missions place on mass, volume, power, and data return, the IAS is the ideal solution for smallsat planetary missions such as those identified in the advanced mission abstracts. The table below shows a comparison of the FreeFall IAS with existing Cubesat antenna systems for roughly equivalent RF performance. The IAS provides a 25-40% reduction in stowed volume, 33-66% reduction in mass, and greatly reduced cost and risk and can thus be a key enabler for planetary smallsat missions.

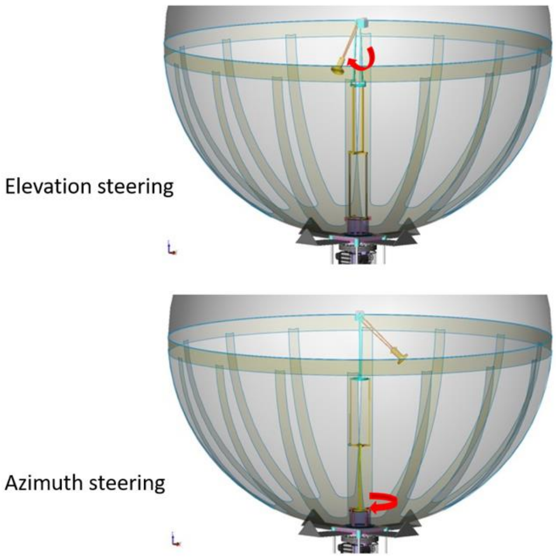
Comparison of High-Gain CubeSat Antenna Performance

	CubeSat High Gain Antenna technical demonstrations			
	MarCO	**RainCube**	**Omera (in development)**	**KaTENna (in development)**
Aperture Type	Reflectarray	Parabolic mesh reflector	Reflectarray	Parabolic mesh reflector
Aperture Size	0.6 m x 0.33 m	0.5 m diameter	1.05 m x 0.91 m	1 m diameter
Frequency (GHz)	8.4	32	35.75	35.75
Gain	29.2 dBi	42 dBi	47.4	48.4
Stowed Volume	2U	1.5 U	3U	~3-3.5U
Mass	1.2 kg	3 kg	5.5 kg	TBD
	Spherical Inflatable Antenna with equivalent performance			
Aperture Size	0.7 m	0.8 m	1.4 m	1.6 m
Stowed Volume	1.5 U	1.5 U	1.8 U	2 U
Mass	0.8 kg	1 kg	1.6 kg	1.8 kg
Feed	Cylindrical waveguide	Septum polarizer	Septum Polarizer	Septum Polarizer

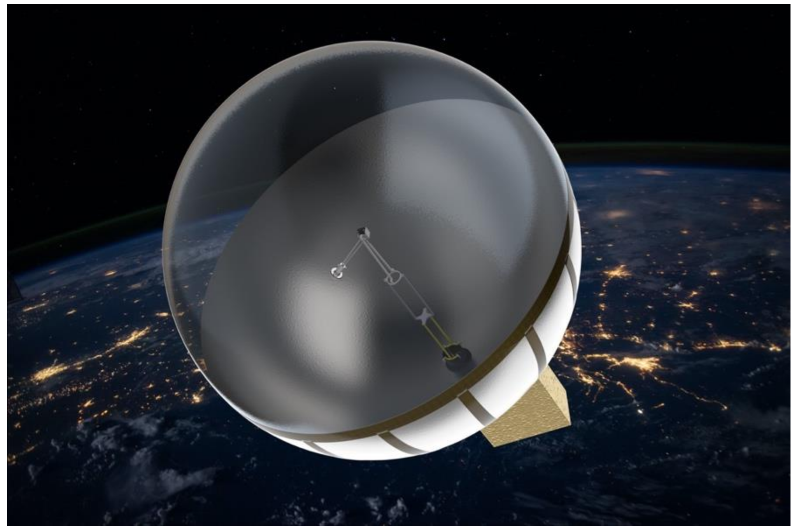
Advanced Development

With the first generation unit now delivered for flight validation in the coming months, FreeFall has begun work on additional capabilities to expand the utilization and improve performance of the IAS for planetary and other missions. One task is the incorporation of a resin-based rigidization system that can be incorporated into the reflector to rigidize on direct exposure to UV radiation. This can help to maintain reflector shape in the face of impacts by micrometeoroids or orbital debris, relieving the need to carry additional compressed gas for inflation maintenance. Lab research and experiments have proven the concept, including in thermal vacuum tests, and it can be introduced to the next generation systems where required. This is particularly important for missions to LEO where the orbital debris dominates the impact risk, but may also be useful for deep space.

Another key development is the implementation of a beam steering capability. This allows the IAS to take full advantage of the wide field of view of the spherical reflector. Beam steering can be implemented using small space-qualified motors to move the small feed in azimuth and elevation without requiring any articulation of the reflector itself or any spacecraft attitude changes. This is in direct contrast to parabolic dish antennas that must be physically pointed with high precision. The FreeFall approach greatly reduces mass, operational complexity, and overall system cost, and removes one of the major failure modes of typical high-gain antennas. The figures below show the mechanical beam steering concept as implemented on a 1m rigidizable spherical reflector antenna on a 12U Cubesat platform. Such a flight system can be an ideal template for future low-cost planetary missions.



Mechanical elevation and azimuth feed steering



1-meter sphere implementation on a 12U Cubesat

Relevance to Advanced Mission Concepts

Lunar Exploration Assessment Group

- **SelenITA mission:** Establishing a lunar communications relay on small satellites has been identified as a key challenge. Freefall's IAS is positioned well to serve high gain DTE links at low SWAP required for a small satellite communications relay. The steerable beam can further be used to maximize lunar coverage and provide greater Lunar orbit down-selection flexibility.

Mars Exploration Program Assessment Group

- **Mars Weather/ Comms Infrastructure:** The IAS being a low SWAP, high gain antenna is suitable to service DTE link requirements to support such an infrastructure. IAS's very low mass and packaged volume can make high delta v areo-stationary orbits feasible for small satellites. A steerable beam can be used to provide enhanced coverage needed for operations on landers and other surface assets.
- **Small Satellite Spectrometers:** IAS is designed to support DSN up/downlink frequencies from X-band to Ka-band and can deliver high data rates for science quality missions from deep space. Environmentally, deep space environments pose a lower risk to inflatable structures.
- **Key technology needs identified from KISS Report:** The KISS report calls for maximizing synergies between Lunar and Mars relay architectures. Small satellite/ CubeSat implementations are key to reduce the associated cost and risk. Further, the report identifies furthering small satellite technologies for deep space missions as major focus area. By

providing a very compact and lightweight communications aperture in excess of 1m^2 IAS address a fundamental technology gap for small satellites deployed in deep space.

Outer Planets Assessment Group

- **Titan Orbiter:** While this orbiter is not meant to be a small satellite implementation, aero-capture of the orbiter using Titan's atmosphere has been identified an important approach to conserve fuel. As a large, deployed surface, IAS exhibits significant drag performance. A large, deployed reflector can serve the dual purpose of aero-braking and temporary secondary communications during the aero-capture phase.
- **RideShare4OuterPlanets:** IAS with its beam steering capabilities can enable novel mission architectures for small satellites to support rideshare programs. The antenna's design uses simple electro-mechanical components and radiation hardened.
- **Shadow Chaser:** IAS is designed to support DSN up/down link frequencies from X-band to Ka-band with a focus on packaging and deployment from Cubesat and other smallsat systems. With large aperture sizes, it can deliver high data rates for science quality missions from deep space.
- **Prometheus:** The IAS system can be tuned to a wide range of frequencies and bandwidths. It enables deployment of reflector apertures in excess of 1 m^2 at low size, weight and power without changes in the design of the deployment system. IAS is positioned very well to enable deep space CubeSat/ Small Sat missions.

Summary of IAS Mission Relevance

Abstract	Small Satellite/ CubeSat Implementation	Large deployed aperture/ HGA	Beam Steering	Low SWAP	Aerocapture/ secondary comms
			LEAG		
SelenITA	✓	✓	✓	✓	
			MEPAG		
MSO	✓	✓		✓	
MSSS	✓	✓		✓	
SmallSat Spectrometers	✓	✓		✓	
KISS Report	✓	✓	✓	✓	
			OPAG		
Titan Orbiter			✓		✓
RideShare4OuterPlanets	✓	✓	✓	✓	
Shadow Chaser	✓	✓	✓	✓	
Prometheus	✓	✓	✓	✓	