Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
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Tyvak Nano-Satellite Systems LLC	)	
	)	
Application for Authority for Ground	)	
Testing, Launch, and Operation of an	)	File No. ____-EX-PL-2016
Experimental Non-Geostationary	)	
Low Earth Orbit Satellite	)	

NARRATIVE EXHIBIT

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NARRATIVE EXHIBIT

Tyvak Nano-Satellite Systems LLC ("Tyvak") uses nano-satellite and CubeSat space vehicle to conduct tests of satellite components and for other scientific missions. With this Application, Tyvak requests two-year authority for ground testing, launch, and operation of a single experimental non-geostationary ("NGSO") low earth orbit ("LEO") CubeSat satellite. Telemetry monitoring, tracking, and command ("TT&C") transmissions and payload data downlink will be carried out in the 400 MHz UHF range.[1]

I. NARRATIVE INFORMATION REQUIRED BY FCC FORM 442

Question 6A. Description of the Nature of the Research Project Being Conducted

Tyvak is internally funding a small nanosatellite attitude control experiment. This mission validates technologies needed to support precise near- and far-field optical imaging, precise

[1] Tyvak will also file an application for experimental authority to operate an associated UHF Earth station. Authority for additional associated UHF Earth stations may be sought by Tyvak affiliates in separate applications, as explained below.

propulsive maneuvering and bulk data transfer while leveraging the inherent relative low costs of their vehicle manufacture and launch capabilities.

The proposed satellite will adhere to a design specification co-developed by Stanford University ("Stanford") and California State University, San Luis Obispo ("Cal Poly") referred to as the CubeSat Standard. Additional information regarding the CubeSat Standard can be found at the CubeSat Community website, http://www.CubeSat.org/.

The spacecraft will be fabricated, tested, launched, and operated by Tyvak using its Mission Operations Center ("MOC") in Irvine, California, and using affiliated Earth Stations in other locations, the authorizations for which will be secured under a separate application.[2] TT&C and payload data downlink for the satellite will be carried out by Tyvak via a two-way link in the UHF band between 399.9-400.05 MHz. Prior to launch, Tyvak will conduct developmental testing of satellite components, including its transmitters and receivers, at its Irvine, California facilities. Post launch, the satellite on-orbit operations are expected to take 9 to 12 months, which will permit adequate time to demonstrate the optics, maneuvering, and attitude control systems under investigation.

Question 6B. Showing that the Communications Facilities Requested are Necessary for the Research Project

The primary purpose of this mission is to perform a technology demonstration of the optical system, propulsion system, and attitude control platform. On-orbit operation is the only effective way of collecting functional and performance data in the relevant operational environment, and cannot be adequately substituted by ground testing or computer simulation.

[2] References to Earth stations in this application are included to provide a comprehensive system overview, but are solely advisory.

With the proliferation of the CubeSat Standard and the availability of low-cost space access for those adhering to that standard, the cost to test miniature components on-orbit has become relatively inexpensive compared to equivalent ground testing and simulation. This is largely due to the availability of low-cost secondary payload launch options and cost sharing among multiple CubeSat developers.

In addition, on-orbit data provides confidence that future systems will operate successfully on-orbit through maneuvers. The evaluation of hardware and software in an environment similar to that found in space is not easily replicated on Earth. On-orbit component failures are often attributed to unforeseen conditions or coupling of effects that cannot be tested adequately until on-orbit. Consequently, the use of an on-orbit test bed provides significant direct and indirect financial benefits, as well as risk reduction for future satellite programs.

Question 6C. Showing that Existing Communications Facilities are Inadequate

Currently, there are no comparable communications facilities to support the operation of the CubeSat system for any of the three required operations.

For the TT&C and payload downlink in the 399.9-400.05 MHz UHF band, as discussed in a later section of this Application, Tyvak is unaware of any currently authorized use of the UHF band between 399.9-400.05 MHz in the United States or other countries. Thus, there are no suitable existing facilities.

Question 10. Transmitting Equipment to be Installed, Including Manufacturer, Model Number and Whether the Equipment is Experimental in Nature

The satellite has one transmitting element for which authority is being sought from the Commission: a TT&C and payload data transceiver that operates in the UHF band between 399.9-400.05 MHz. The following graphic provides an overview of the transmitting and receiving components. The specific model numbers are subject to change based on product availability and system upgrades.

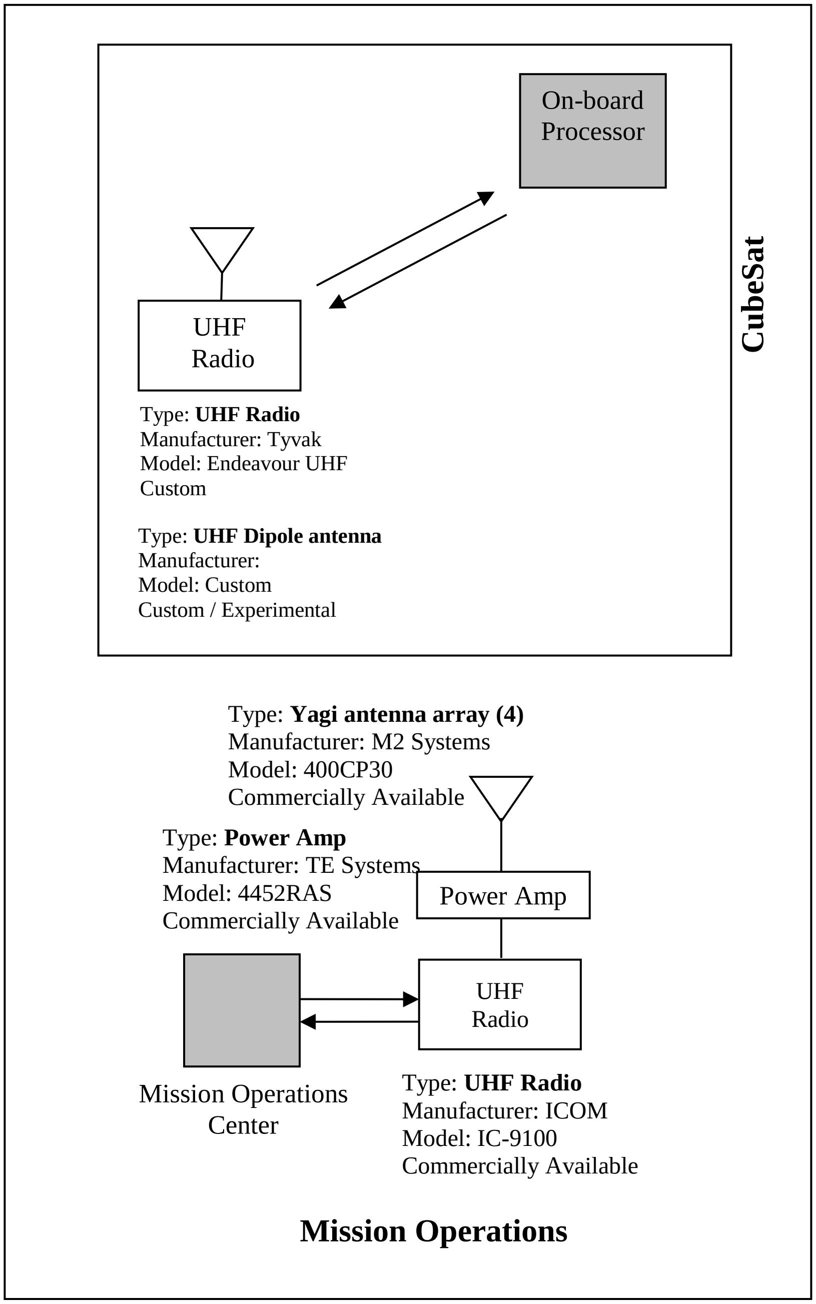

Figure 1: CubeSat System Communications Components

The transmitting components aboard the CubeSat are controlled by a dedicated on-board processor, which processes data for transmission, sends and receives data from the modem, and activates the appropriate radio systems depending on the state of operations. The satellite possesses a UHF system for vehicle command and telemetry retrieval and payload data download.

The TT&C UHF system uses a Tyvak-developed UHF radio derived from commercially-available UHF communications systems. The radio operates at 9,600 baud to 19,200 baud using GMSK. The UHF system will use a custom designed half-wave dipole antenna.

The TT&C ground segment will address the satellite through the use of specific message destination address, authentication counts and/or encryption keys using the same frequency allocation. The transmitting component located at the Irvine Earth station is controlled by dedicated Microsoft Windows workstations. The workstations are used for antenna pointing control, Doppler frequency shift corrections, and data processing for transmission. The antenna (manufacturer/model: M2 Antenna Systems, Inc./400CP30) and radio (manufacturer/model: ICOM/IC-9100) are commercially available, off-the-shelf units, which will be modified with additional hardware to function at the requested frequencies.

Question 11A. Is the Equipment Listed in Item 10 Capable of Station Identification Pursuant to Section 5.115

Each transmitting component of the system is capable of station identification, and the satellite will transmit its call sign in every packet transmitted as part of its frame header. The frame header is not encoded or encrypted.

Question 4: Antenna Registration Form; Operation of Directional Antenna

The satellite will be a low earth orbit (“LEO”) satellite in a sun-synchronous orbital with an orbit period of approximately 1.6 hours. The satellite will pass over the Earth station roughly one to twelve times per day depending on its location with an average access time of five to seven minutes for each Earth station location. The UHF Earth station will use a computer-controlled tracking antenna to point the Earth station's antenna in the direction of the moving satellite. The antenna has a maximum gain of +16.2dBi along the bore-sight of the antenna and a half-power beam-width (*i.e.*, -3dB) of approximately 30 degrees. The antenna array uses four off-the-shelf, yagi-type antenna developed by M2 Antenna Systems, Inc.

The spacecraft is an NGSO satellite, thus the range of antenna azimuth and elevation will vary based on the relative motion of the satellite with respect to the ground station. It will also differ for each satellite pass. The Earth station will only transmit above a 5 degree elevation angle. Consequently, the range of antenna elevation angles for all satellite passes will be between 5 and 175 degrees. The azimuth can vary between 0 degrees and 360 degrees. Earth station software will be used to control the antenna azimuth and elevation rotors for antenna pointing and limit the range of permissible elevation angles. In addition, the software will be used to predict satellite contact times and antenna pointing angles to support Earth station planning and operations.

In addition to on-orbit operations, the satellite components will undergo occasional ground test up until launch. Testing for the UHF TT&C link will be conducted in carrier current (*i.e.*, closed-loop) configuration and will not produce any measurable emissions.

II. RELEVANT INFORMATION ADDRESSED IN SECTION 25.114 OF THE COMMISSION'S RULES

A. Radio Frequency Plan

UHF Communications System

The satellite's UHF communications system will operate using half-duplex communications within the 399.9-400.05 MHz frequency band for telecommand (*i.e.*, earth-to-space) and telemetry (*i.e.*, space-to-earth). Although the satellite requires only 16.5 kHz of spectrum bandwidth, Tyvak requests herein authority to operate within the entire 399.9-400.05 MHz frequency band for the mission to facilitate design flexibility.

The following diagram shows the proposed spectrum use of the CubeSats and ground stations and also shows authorized spectrum uses in adjacent bands, such as the use by the Orbcomm Little LEO MSS network of the 400.075-400.125 MHz band as a beacon frequency. As explained below, the 399.9-400.05 MHz frequency band does not appear to be used by any authorized government or non-government operator in the United States. Tyvak acknowledges that the Commission has proposed to authorize operation of a federal Mobile Satellite System in the 399.99-400.05 MHz portion of this fallow band, however, any Tyvak transmissions related to this mission will be completed well before any Federal operations in the band commence.[3] Therefore, Tyvak's proposed operation of its experimental satellite in 50 kHz of the 399.9-400.05 MHz frequency band will not cause harmful interference to any authorized spectrum user.

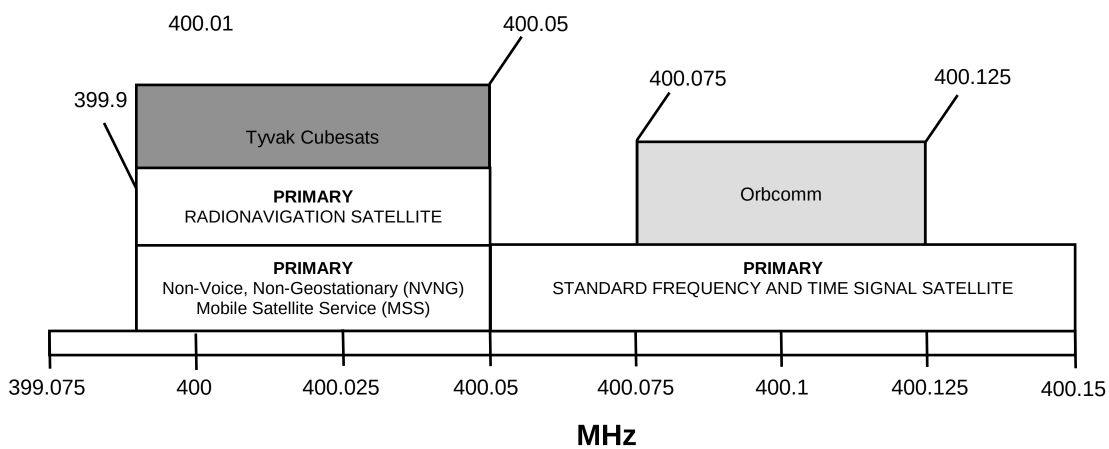

Figure 2: CubeSat Spectrum Diagram **(UHF)**

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[3] *See Federal Space Station Use of the 399.0-400.05 MHz Band, ET Docket No. 13-115,* Notice of Proposed Rulemaking, FCC 13-65, ¶ 63 (2013).

The 399.9-400.05 MHz frequency band is allocated internationally on a primary basis to the Mobile Satellite Service ("MSS") (earth-to-space). The 399.9-400.05 MHz frequency band is also allocated internationally on a primary basis to the Radionavigation Satellite Service ("RNSS") until January 1, 2015.[4] In the United States, the 399.9-400.05 MHz frequency band is allocated to the MSS and RNSS services for both government and non-government use.

During the 1995 World Radiocommunication Conference ("WRC-95"), the International Telecommunication Union ("ITU") allocated the 399.9-400.05 MHz band for the Little LEO MSS service. The Commission subsequently designated the 399.9-400.05 MHz band as available for use by Little LEO MSS networks.[5] None of the applicants for Little LEO MSS licenses in the United States, however, requested authority to operate in the 399.9-400.05 MHz band.[6] Therefore, the Commission refrained from adopting service rules for Little LEO MSS networks operating in the 399.9-400.05 MHz band and did not issue any licenses to Little LEO MSS networks authorizing them to operate in the band.[7] Tyvak is unaware of any Little LEO MSS network

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[4] *See* 47 C.F.R. § 2.106 n.5.224B.

[5] *See Amendment of Section 2.106 of the Commission's Rules to Allocate Spectrum to the Fixed-Satellite Service and the Mobile-Satellite Service for Low-Earth Orbit Satellites*, Report and Order, 8 FCC Rcd 1812 (1993); 47 C.F.R. §§ 2.106 n.US320 & 25.202(a)(3). Although the Commission originally included the 399.9-400.05 MHz band in footnote US320, reference to the 399.9-400.05 MHz band was inadvertently deleted from US320 during a Commission effort to consolidate footnotes. The Commission corrected the error, reincorporating the reference to the 399.9-400.05 MHz band in footnote US320. *See Amendment of Parts 2, 25, and 73 of the Commission's Rules to Implement Decisions from the World Radiocommunication Conference (Geneva, 2003) (WRC-03) Concerning Frequency Bands Between 5900 kHz and 27.5 GHz and to Otherwise Update the Rules in this Frequency Range*, Report and Order, 20 FCC Rcd 6570, 6625 (2005).

[6] *See Amendment of Part 25 of the Commission's Rules to Establish Rules and Policies Pertaining to the Second Processing Round of the Non-Voice, Non-Geostationary Mobile Satellite Service*, Report and Order, 13 FCC Rcd 9111, 9120-21 (1997).

[7] *See id.* at 9121.

operating anywhere in the world (and particularly not in the United States) that uses the 399.9-400.05 MHz band.

The 399.9-400.05 MHz frequency band is also allocated internationally on a primary basis to RNSS until January 1, 2015. The 399.9-400.05 MHz frequency band was previously used by the U.S. Department of Defense for its TRANSIT-SAT RNSS system, which was a polar orbiting satellite network that was primarily used for commercial and government maritime navigation. The TRANSIT-SAT network, however, was decommissioned in December 1996.[8]

It does not appear that the United States government or commercial operators are using the 399.9-400.05 MHz frequency band for any other RNSS service. As a consequence, the 399.9-400.05 MHz frequency band appears to be fallow of any authorized use in the United States. Therefore, the short term operation of Tyvak's experimental CubeSats will not result in harmful interference to any authorized spectrum user.

Space-to-Earth and Earth-to-Space UHF Communications

Despite the absence of any authorized spectrum users in the 399.9-400.05 MHz band, the satellite has been designed to include several precautions to prevent harmful interference to other services from space-to-Earth transmissions. First, as noted above, space-to-Earth satellite transmissions will be controlled from the Earth station and the spacecraft will not transmit until it receives a request from the Earth station or has on-board GPS confirmation that it is above the designated ground station.

Second, the satellite uplink and downlink will use the same 50 kHz bandwidth in half-duplex mode to send digital data using standard GMSK modulation with maximum data rates up

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[8] *See Federal Long-Range Spectrum Plan*, Working Group 7 of the NTIA Spectrum Planning Subcommittee (Sept. 2000), available at http://www.ntia.doc.gov/osmhome/LRSP/LRSP5a.htm.

to 9,600 baud. The spacecraft transceiver uses a packet-based (non-continuous) communications, which allows command reception between transmissions of packets to provide the ability to command the satellite to cease space-to-Earth transmission operations in a timely manner, if required.

The satellite transmitter can be adjusted to provide up to two watts of power output when communicating with the Earth station. Transmission power on the Earth station transmitter can be adjusted to provide up to 200 watts of power output. The communications parameters for the UHF communications system for the space-to-Earth and Earth-to-space links are show in the following tables.

CubeSat Communications Parameters	**Value**
Emission Designator	16K5G1D
Service	Digital Data
Center Frequency	399.96 MHz
Requested Bandwidth (includes Doppler)	50 kHz
Modulation	GMSK
Data Rate	9,600 bps
Polarization	Indirect Circular
Antenna Type	Dipole
Antenna Gain	+2 dBi (Max)
RF Power Output	2W
Line/Misc Losses	-2dB
EIRP	1.0 dBW

Table 1: Tyvak CubeSat UHF Communications Space-to-Ground Parameters

Earth Station Communications Parameters	**Value**
Emission Designator	16.5KG1D
Service	Digital Data
Center Frequency	399.96 MHz
Requested Bandwidth (includes Doppler)	50 kHz
Modulation	GMSK
Data Rate	9,600 bps

Earth Station Communications Parameters	**Value**
Polarization	Linear (H, V) or Circular
Antenna Type	Yagi array
Antenna Gain	+16.2 dBi (Max)
RF Power Output	180 W
Line Losses	-1dB
EIRP	7161.4 W

Table 2: Tyvak Earth Station UHF Communications Parameters

B. Orbital Locations

The CubeSat system comprises a single space vehicle operating in NGSO. The spacecraft is intended to operate in LEO with the orbit parameters shown in Table 6. The satellite will have an orbit period of roughly 1.6 hours with typical ground access times of five to seven minutes per pass. The orbit parameters are presented in the following table:

Parameter	**Units**	**Value**
Orbit Period	[hrs]	1.6 hrs
Orbit Altitude	[km]	610 km (circular)
Inclination	[deg]	97.-6 – 97.9 degrees

Table 4: CubeSat Orbit Parameters

C. Physical Characteristics of the Satellite

The space vehicle is a Nano-class satellite (< 10 kg), in which each element conforms to the CubeSat Standard. CubeSats can be designed in different sizes as long as they are multiples of the basic CubeSat standard unit, which is 10×10×10 centimeters, generally referred to as a 1U CubeSat, meaning one unit in size. The satellite will consist of a single 3U CubeSats, resulting in dimensions of approximately 30×10×10 centimeters. The CubeSat dispenser limits the total vehicle mass of a 3U CubeSat to less than 6 kilograms. The mass budget is provided in the following table:

Component / Subsystem	Mass [g]
Payload	1400
Spacecraft (Subtotal)	4300
Structure	300
Electrical Power System	1500
Propulsion System	1400
ADCS	400
C&DH	100
Communication	500
Thermal	100
TOTAL	5700

Table 5: CubeSat Mass Budget per Element

For propulsion, the satellite is equipped with eight miniature cold gas thrusters. Each thruster is fed from a common gas storage vessel with propellant capacity of 400 grams and an initial pressurization of 83 psi (at 20degC). The thrusters are not mechanical and propulsion uses common refrigerant (R236fa) involving no combustion. The thrusters are highly integrated with the sensors to provide for precision maneuvering.

For power generation, the satellite is equipped with body-mounted and deployed GaAs solar cells that generate approximately 16 watts of power during a typical orbit. Because of the short operational lifetime of the satellite (*i.e.*, less than a year), the difference between the beginning-of-life ("BOL") and end-of-life ("EOL") power generation is negligible. To permit operations during eclipse, energy is stored on-board using Li-ion batteries, with power being distributed to subsystems and components through the electrical power subsystem circuitry. The EOL power budget is provided in the following table:

Component / Subsystem	EOL Power [mW] Orbit Averaged
Payload	3500
Spacecraft (Subtotal)	10000
Propulsion System	140
ADCS	5000
C&DH	600

Communication	3500
Thermal	400
TOTAL	13500

Table 6: Power Budget per Space Vehicle

D. Schedule

The project timeline and major milestones for the launch and operation of the CubeSat system are provided in the following table. The dates are approximate and contingent upon the exact launch date ("Time of Launch" or "ToL"), orbit parameters, and unforeseen events during on-orbit operations.

Milestone	**Date**	**Notes**
Fabrication and RF closed loop testing	March 2014-July 2015	ToL - 28 months
Delivery for Launch Integration	July 2016	ToL - 3 months
Pre-launch testing of transmitting components	Aug 2016	ToL - 2 months
Launch	Oct 2016	ToL + 0
Release from launch adapter	Oct 2016	ToL + 0hr 30min
On-orbit check	Oct 2016	ToL + 24 hours
Start of experiments	Oct 2016	ToL + 4 weeks
Decommissioning	July 2017	ToL + 9 months
Re-entry	Oct 2031	ToL + 13 year

Table 7: CubeSat System Major Milestones

E. General Description of Overall System Facilities, Operations and Services

The satellite provides a platform for on-orbit testing of advanced maneuvering and optical imaging technologies. The onboard systems on each space vehicle provide nominal attitude, electrical power, data storage, and command function for a set of mission payloads. The space vehicle communicates with the Earth stations through a low-rate (9.6 kbps) half-duplex communications link operating in the UHF band.

The satellite will be supported by a UHF Earth station at the Irvine MOC and several additional Earth stations operated by Tyvak affiliates at sites in North Pole, Alaska; Bozeman, Montana; and Columbia, Maryland. Tyvak affiliates will seek authorization for each of the UHF Earth stations in separate applications.

The primary responsibilities of the Irvine MOC will be to command the space vehicle to initiate the experiments, recover spacecraft engineering telemetry, and manage the function of the spacecraft. The Earth station equipment comprises a UHF yagi antenna array and UHF transceiver. The MOC will also have vehicle control workstations and a mission data archive server.[9] The workstations will serve as the primary interface with the ground controllers and will be used for data processing, antenna/radio control, and engineering analysis. The mission data archive server will archive command and telemetry data to support mission operations, status, troubleshooting, and post-mission assessment.

F. Predicted Spacecraft Antenna Gain Contours

The spacecraft UHF antenna is a half wavelength L-dipole antenna, which is essentially omni-directional when mounted on the corner of a CubeSat structure. A simulation of the antenna design is shown in Figure 3.

[9] TT&C data and payload data will be received directly from the spacecraft via UHF link.

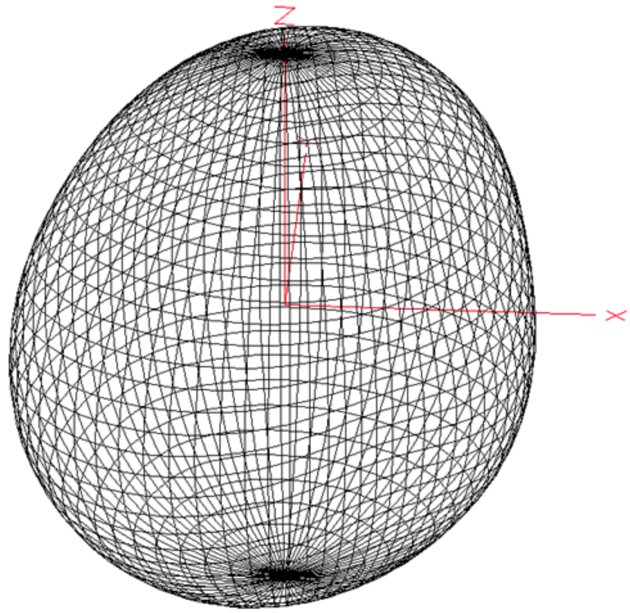

Figure 3: CubeSat L-Dipole UHF Antenna Gain Plot

G. Orbital Debris Mitigation

Because the CubeSat mission includes electro-optical imaging capabilities, Tyvak will apply to the National Oceanic and Atmospheric Administration ("NOAA") for a license to operate a private remote sensing space system. Pursuant to Section 960.11 of NOAA's rules, NOAA is responsible for evaluating the orbital debris mitigation plans of applicants for NOAA licenses.[10] Thus, the following discussion and the orbital debris assessment report ("ODAR") included as an attachment to this application are for informational purposes only.

1. *Limiting the amount of debris released and the probability of the satellite becoming a source of debris by collisions with small debris*

In order to limit the amount of debris generated during normal operations, the satellite has been designed so that all parts will remain attached to the satellite during launch, ejection, and

[10] 15 C.F.R § 960.11 (b)(12).

normal operations. This requirement is intrinsic to all satellites conforming to the CubeSat Standard and compliance is required for launch using the Poly-Picosatellite Orbital Deployer ("P-POD") system.

The basic geometry the two satellite is a monolithic cubic structure (*i.e.*, 30cm x 10cm x 10cm) with two pairs of 30cm x 10cm deployable panels. Based on an orbital debris model (ref. NASA DAS v2), the probability of a single particle impact with a size of 1 millimeter or larger over the mission lifetime is very low (*i.e.*, roughly 1.3×10^{-3}). This low probability of impact for the mission is a result of the small effective area of the space vehicle (*i.e.*, effective area ~ $0.15\ m^2$) and the relatively short mission duration (*i.e.*, operational mission life less than one year).

Catastrophic system failure due to orbital debris or micrometeoroid impact will not affect the vehicle's ability to de-orbit within the guidelines for vehicles operating in LEO (*i.e.*, less than 25 years). Based on the mission orbit of 600 km, the space vehicle is anticipated to re-enter the atmosphere within 13 year based on lifetime prediction simulations for the current mission epoch (*i.e.*, launch in CY2016).

2. Limiting the probability of accidental explosions during and after completion of the mission operations

Experimentation with technologies for maneuvering and optical imaging are primary mission objectives for the satellite. Thus, the satellite is equipped with small cold-gas propulsion systems employing low specific impulse, low-pressure gas. The pressure vessel is made from aluminum, has a volume of 400 ml and an initial pressurization of 83 psi (at 20degC). The vessel has been designed to an ultimate safety factor of 2.5 times the operating pressure at maximum storage temperature. These vessels will be fully depressurized as a part of the deorbit maneuver process.

In addition, the vehicles possess energy storage devices (*i.e.*, Li-ion batteries), which will be left in a nearly discharged state as part of the decommissioning procedure.

3. Limiting the probability of the satellite becoming a source of debris by collisions with large debris or other operational space stations

Based on a simple orbital debris model (ref. NASA DAS v2), the probability of the CubeSat colliding with large debris or other space systems of sizes one centimeter or greater at the mission orbit altitude and inclination is negligible (*i.e.*, roughly $4x10^{-6}$).

The launch provider has instituted deployment procedures in order to place the co-manifested satellites in the launch vehicle into slightly different orbits in order to reduce the risk of collision. One of these procedures is to stagger deployment times.

4. Post-mission disposal plans for the space station at end of life

The post-mission disposal plan for the CubeSat includes the transition of all vehicle systems to a dormant state, which includes the cessation of all radio operations (*i.e.*, transmit and receive). Energy storage devices will be held at a minimal charge state at the end of the life of the vehicles. All propellant remaining at end of life will be expended to initiate deorbit, resulting in anticipated atmospheric re-entry of the satellite within 13 years of mission completion based on its mission orbit, vehicle mass, geometry and mission epoch (*i.e.*, launch in CY2016). Although no active de-orbit maneuvers are required to meet the 25 year re-entry guidelines, Tyvak anticipates accelerating de-orbit using the measures described above.

Re-entry debris and probability of human casualty will be negligible. The materials used on the vehicle include aluminum and PCB material, which have a relatively low melting temperature as compared to other materials such as titanium or stainless steel, and are not expected to survive reentry.

III. CONCLUSION

The Experimental Licensing Branch should grant Tyvak's application for two-year experimental authority to launch and operate a single NGSO LEO satellite, which will permit Tyvak to demonstrate and evaluate advanced maneuvering and optical imaging technologies.. Tyvak's experiment will not cause harmful interference to any licensed service. Tyvak will conduct its experiment using low-power transmissions in the vacant 399.9-400.05 MHz UHF band. Further, the Tyvak operation will meet the Commission's orbital debris mitigation requirements. Therefore, Tyvak's application should be granted at the soonest practicable time.