Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, DC 20554

In the Matter of	)	
	)	
Tyvak Nano-Satellite Systems Inc.	)	
	)	
Application for Authority for Ground	)	
Testing, Launch, and Operation of	)	File No. ____-EX-PL-2018
Experimental Non-Geostationary	)	
Low Earth Orbit Satellites	)	

NARRATIVE EXHIBIT

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Application for Authority for Ground Testing, Launch, and Operation of Experimental Non-Geostationary Low Earth Orbit Satellites	)	

NARRATIVE EXHIBIT

Tyvak Nano-Satellite Systems Inc. ("Tyvak") provides nano-satellite and CubeSat space vehicle products and services that target advanced state-of-the-art capabilities to support operationally and scientifically relevant missions. With this Application, Tyvak requests two-year authority for ground testing, launch, and operation of an experimental non-geostationary ("NGSO") low earth orbit ("LEO") CubeSat satellite, designated as PROPCUBE 2 – FAUNA, referred to as FAUNA from here on. FAUNA will consist of a single technology demonstration satellite. The FAUNA mission is owned by NRO Mission Integration Division (MID) and operated by the Naval Post-Graduate School (NPS). The RF communications links for the satellite will be two-way telemetry monitoring, and command ("T&C") transmissions in the 915 MHz UHF and 450 MHz UHF[1] for space-to-Earth downlink and Earth-to-space uplink transmissions respectively, and payload data space-to-Earth downlink at a center frequency of 2340 MHz S-Band and 400 MHz.

[1] Authority for the UHF transmission has been granted from the NTIA per the colonyii-m450-rfas. This application will transmit to stations listed in that NTIA authorization in addition to stations listed in this application

UHF T&C spectrum allocation has been already been granted to this mission from the NTIA, this application requests license for payload data for the S-Band and UHF transmission.

I. NARRATIVE INFORMATION REQUIRED BY FCC FORM 442

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

Through its technology demonstration satellites, Tyvak validates the technologies needed to support spacecraft communication systems, position information and the development of atmospheric sensors and methods for earth exploration satellite services ("EESS"). The program leverages the inherent relative low costs of CubeSat vehicle manufacture and launch capabilities to perform testing and demonstrations in real-world conditions, as well as flight training. Throughout the course of the FAUNA program, Tyvak will develop a single satellite to perform a technology demonstration of a beacon technology.

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

FAUNA 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. T&C for the satellites will be carried out by the Naval Post Graduate (NPS) school and Tyvak via a two-way link in the UHF band with uplink on 440 MHz - 450 MHz.and downlink on 902 MHz – 928 MHz range.

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

The primary purpose of the FAUNA program is to test and validate new satellite capabilities or subsystems. 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. Since this application is only requesting approval for payload data downlink within the S-Band frequency range, no associated ground station application is necessary due to no uplink via S-Band required.

Question 6C. Showing that Existing Communications Facilities are Inadequate

Not applicable for this submission.

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

FAUNA only has capabilities for UHF T&C and payload downlink data downlink via S-Band and UHF. T&C on FAUNA is carried out in the UHF band with uplink on 440 MHz - 450 MHz and downlink on 902 MHz – 928 MHz range. Payload data downlink is carried out on S-Band in the 2320 MHz – 2345 MHz range and 399.9 MHz – 400.05 MHz range. The following graphic provides an overview of the transmitting and receiving components of each element. The specific model numbers are subject to change based on product availability and system upgrades.

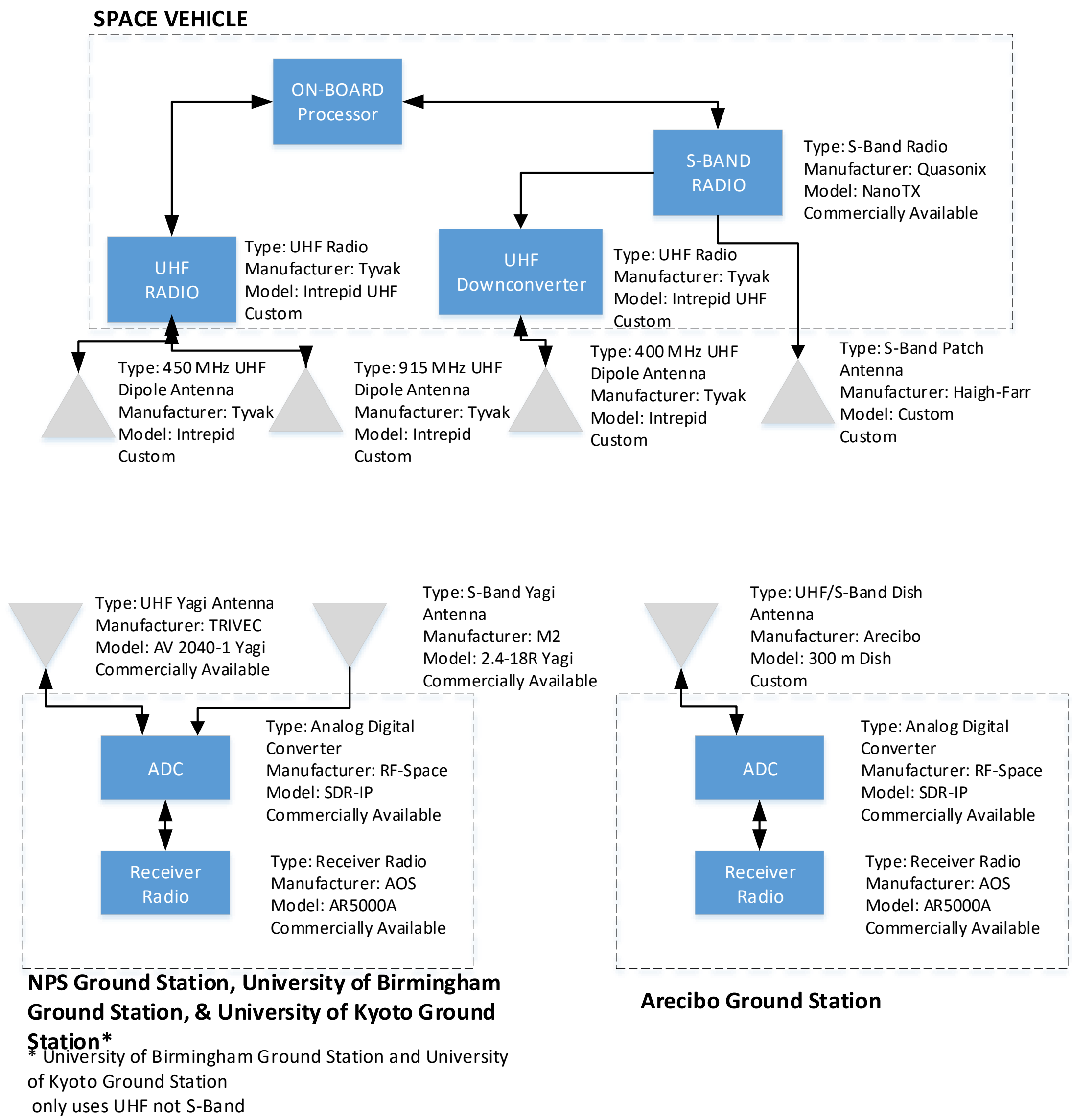


Figure 1: CubeSat System Communications Components

Station	Coordinates
NPS (Montery, CA)	36.3542° N, 121.5229° W
University of Birmingham (Birmingham, UK)	52.4862° N, 1.8904° W
University of Kyoto (Kyoto, Japan)	35.0262° N, 135.7808° E
Arecibo (Puerto Rico)	18.3464° N, 66.7528° W

Table 1: Ground Station Locations

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

The T&C communications system uses a Tyvak-developed UHF radio derived from commercially-available UHF communications systems. The radio operates at 9,600 baud using GMSK. The UHF system will use a custom designed half-wave dipole antenna. The S-Band transmitter is a commercially designed S-Band Transmitter (NanoTX) from Quasonix. The UHF component of the payload transmitter is a Tyvak designed downconverter for the signal. The radio operates at 1 Mbps baud using BPSK. The S-Band system will utilize a custom patch antenna from Haigh-Farr.

The T&C ground segment can address FAUNA individually through the use of different message destination addresses, authentication counts and/or encryption keys using the same frequency allocation. The transmitting component located at the NPS, University of Birmingham, and University of Kyoto Earth stations are controlled by dedicated Microsoft Windows workstations. The workstations are used for antenna pointing control, Doppler frequency shift corrections, and data processing for transmission. The antennas used (UHF manufacturer/model: TRIVEC / AV 2040-1 YAGI, S-Band manufacturer/model: M2 Antenna Systems, Inc. / 2.4-18R Yagi) and radio (manufacturer/model: AOS/AR5000A) are commercially available, off-the-shelf units, which will be modified with additional hardware to function at the requested frequencies. The University of Birmingham does not utilize the S-Band antenna, only UHF. The Arecibo Earth Station utilizes the same back end setup as the NPS, but has a custom 300 m dish for both UHF and S-Band.

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 at the end of each complete transmission. The station identification process is incorporated into the mission operations procedure. The space component will transmit the 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

FAUNA is a low earth orbit ("LEO") satellites 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 twelve minutes for each Earth station location. The UHF / S-Band Earth stations will use a computer-controlled tracking antenna to point the Earth station's antenna in the direction of the moving satellites. The UHF Trivec antenna has a maximum gain of 9 dBi along the bore-sight of the antenna and a half-power beam-width (*i.e.*, -3dB) of approximately 30 degrees. The S-Band M2 antenna has a maximum gain of 18 dBi along the bore-sight of the antenna and a half-power beam-width (*i.e.*, -3dB) of approximately 15 degrees. The Arecibo antenna is custom and has approximately 72 dB of gain and a half-power beam-width of less than 1 degree.

FAUNA is a NGSO satellite, thus the range of antenna azimuth and elevation will vary based on the relative motion of the satellites with respect to the ground station. It will also differ for each satellite pass. The Earth station will only transmit above a 10 degree elevation angle. Consequently, the range of antenna elevation angles for all satellite passes will be between 10 and 170 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.

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

Section 25.114(c)(4)(i) Radio Frequency Plan

UHF Communications System

The FAUNA UHF communications system will operate using half-duplex communications with uplink within 420 MHz - 450 MHz range designated for Amateur band and downlink within the 902 MHz – 928 MHz range designated for ISM Equipment. FAUNA has already received allocation for 12.5 kHz at 450 MHz center frequency and 115 kHz bandwidth at 915 MHz center frequency through the NTIA (Reference: colonyii-m450-rfas). The payload UHF system down converts the S-Band transmitter signal to 400 MHz for beacons.

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

FAUNA 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.

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 UHF satellite transmitter can be adjusted to provide up to two watts of power output when communicating with the Earth station. UHF Transmission power on the Earth station transmitter can be adjusted to provide up to 75 watts of power output. The UHF Payload transmissions are down converted from the NanoTX transmitter and can provide up to two watts of power output when beaconing to the Earth Station. 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	115KG1D
Service	Digital Data
Center Frequency	915 MHz
Requested Bandwidth (includes Doppler)	115 kHz
Modulation	GMSK
Data Rate	9,600 bps
Polarization	Linear
Antenna Type	Dipole
Antenna Gain	+2 dBi (Max)
RF Power Output	2W
Line/Misc Losses	-2dB
EIRP	3 dBW

Table 1: FAUNA UHF Telemetry Communication Space-to-Ground (Downlink) Parameters

CubeSat Communications Parameters	**Value**
Emission Designator	115KG1D
Service	Digital Data
Center Frequency	400 MHz
Requested Bandwidth (includes Doppler)	1.7 MHz
Modulation	BPSK
Data Rate	1 Mbps
Polarization	Linear
Antenna Type	Dipole
Antenna Gain	+2 dBi (Max)
RF Power Output	2W
Line/Misc Losses	-2dB
EIRP	3 dBW

Table 2: FAUNA UHF Payload Data Communication Space-to-Ground (Downlink) Parameters

Earth Station Communications Parameters	**Value**
Emission Designator	12K5G1D
Service	Digital Data
Center Frequency	450 MHz
Requested Bandwidth (includes Doppler)	12.5 kHz
Modulation	GMSK
Data Rate	9,600 bps
Polarization	Linear (H, V) or Circular
Antenna Type	Yagi array
Antenna Gain	+9 dBi (Max)
RF Power Output	75 W
Line Losses	-3dB
EIRP	24.75 dBW

Table 3: NPS, University of Bermingham, and University of Kyoto Station UHF Communications Earth-to-Space (Uplink) Parameters

Earth Station Communications Parameters	**Value**
Emission Designator	12K5G1D
Service	Digital Data
Center Frequency	450 MHz
Requested Bandwidth (includes Doppler)	12.5 kHz
Modulation	GMSK
Data Rate	9,600 bps
Polarization	Linear (H, V) or Circular
Antenna Type	Yagi array
Antenna Gain	+72 dBi (Max)
RF Power Output	75 W
Line Losses	-3dB
EIRP	87.75 dBW

Table 3: Arecibo UHF Communications Earth-to-Space (Uplink) Parameters

S-Band Communications System

The FAUNA S-Band communications system will operate only downlink operations within the 2320 – 2345 MHz range designated for Satellite Communications. FAUNA will utilize Approximately 1.7 MHz of bandwidth with a 2340 MHz center frequency. The S-Band system is capable of transmissions up to 1 Mbps digital but will not transmit the full data rate during operations.

Space-to-Earth S-Band Communications

FAUNA has been designed to include the same precautions used for UHF on S-Band as well, in order 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.

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

The S-Band satellite transmitter can be adjusted to provide up to two watts of power output when communicating with the Earth station. S-Band is only for downlink operations and thus there are no transmissions from the Earth station. The communications parameters for the S-Band downlink system for the space-to-Earth link are shown in the following tables:

CubeSat Communications Parameters	**Value**
Emission Designator	1M70G1D
Service	Digital Data
Center Frequency	2340 MHz

CubeSat Communications Parameters	**Value**
Requested Bandwidth (includes Doppler)	1.7 MHz
Modulation	BPSK
Data Rate	1 Mbps
Polarization	RHCP
Antenna Type	Patch
Antenna Gain	+5 dBi (Max)
RF Power Output	2W
Line/Misc Losses	-2dB
EIRP	6.0 dBW

Table 4: FAUNA S-Band Communications Space-to-Ground Parameters

Section 25.114(c)(5)(i) Orbital Locations

FAUNA is intended to operate in LEO with the orbit parameters shown in Table 6. Each 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	400 km (circular)
Inclination	deg	51.6 degrees

Table 5: CubeSat Orbit Parameters

Section 25.114(c)(10) Physical Characteristics of Satellites

FAUNA is a nano-class satellites (< 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. FAUNA is a 1U in size, which means each CubeSat will have the dimensions of approximately 10 x 10 x 10 centimeters. The CubeSat dispenser limits the total vehicle mass of a 1U CubeSat to less than 1.17kg respectively. The mass budget is identical for each satellite and is provided in the following table:

Component / Subsystem	**Mass [g] 6U**
Payload	250
Spacecraft (Subtotal)	916
Structure	200
Electrical Power System	200
ADCS	100
C&DH	100
Communication	216
TOTAL	1166

Table 6: CubeSat Mass Budget per Element

For power generation, FAUNA is equipped with body-mounted GaAs solar cells that generate approximately 4 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. For operations, the Payload is only powered for a portion of the total orbit. The EOL power budget is provided in the following table:

Component / Subsystem	**EOL Power [mW] Orbit Averaged (1U)**
Payload	1000
Spacecraft (Subtotal)	3000
ADCS	400
C&DH	600
Communication	2000
TOTAL	4000

Table 7: Power Budget for FAUNA

Section 25.114(c)(12) Schedule

The project timeline and major milestones for the launch and operation of the FAUNA are provided in the following table. FAUNA has already been launched and is currently in operation only for T&C, due to the NTIA authorization and lack of spectrum allocation for payload. The dates are approximate and contingent upon unforeseen events during on-orbit operations.

Milestone	**Date**	**Notes**
Launch	January 12, 2018	ToL + 0
Release from launch adapter	January 12, 2018	ToL + 0hr 30min
On-orbit check	January 19, 2018	ToL + 7 days
Decommissioning	January 2019	ToL + 12 months
Re-entry	November 2020	ToL + 2.8 year

Table 8: FAUNA System Major Milestones

Section 25.114(d)(1) General Description of Overall System Facilities, Operations and Services

FAUNA provides a platform for on-orbit testing of advanced 3-axis control software and hardware, sensor technologies, and beacon communication system. The onboard systems on FAUNA provide nominal attitude, electrical power, data storage, and command function for the communication payload. FAUNA communicates with the Earth stations through a low-rate (9.6 kbps) half-duplex communications link operating in the UHF band.

The FAUNA mission will be supported by a UHF Earth station at the at NPS Monterey, CA facility, the University of Bermingham facility, and the Arecibo, PR facility.

The primary responsibilities of the NPS Monterey, CA MOC facility 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.[2] 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.

Section 25.114(d)(3) 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.

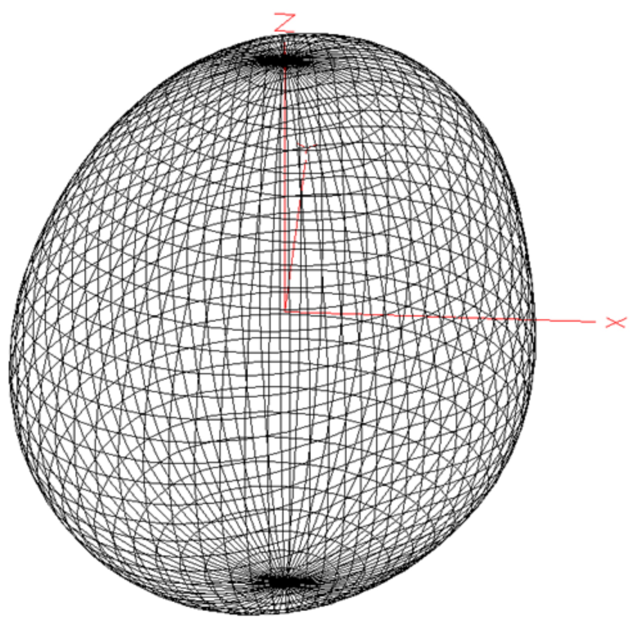
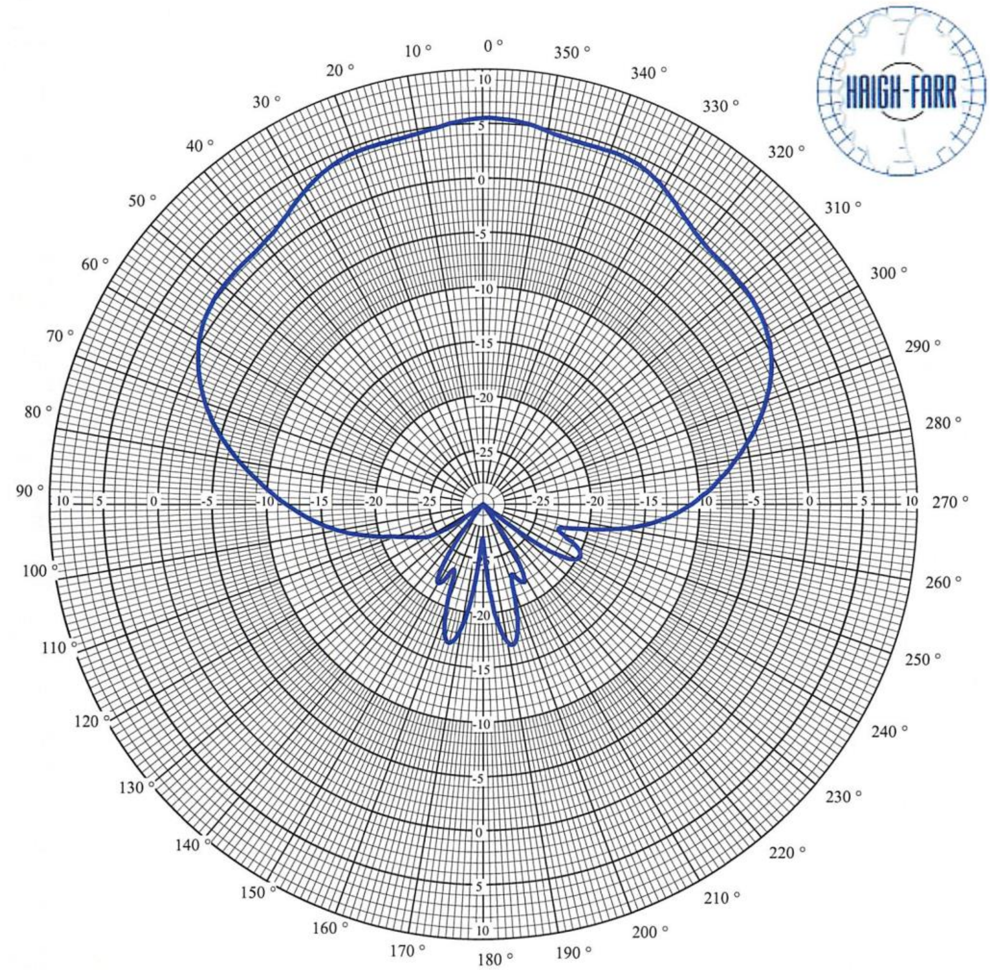


Figure 3: CubeSat L-Dipole UHF Antenna Gain Plot

The S-Band patch antenna used for downlink has the following gain pattern provided by Haigh-Farr:

[2] TT&C data will be received directly from the spacecraft via UHF link; payload data will be downlinked via S-band



Section 25.114(d)(14) Orbital Debris Mitigation

The CubeSat spacecraft will mitigate orbital debris by the following means:

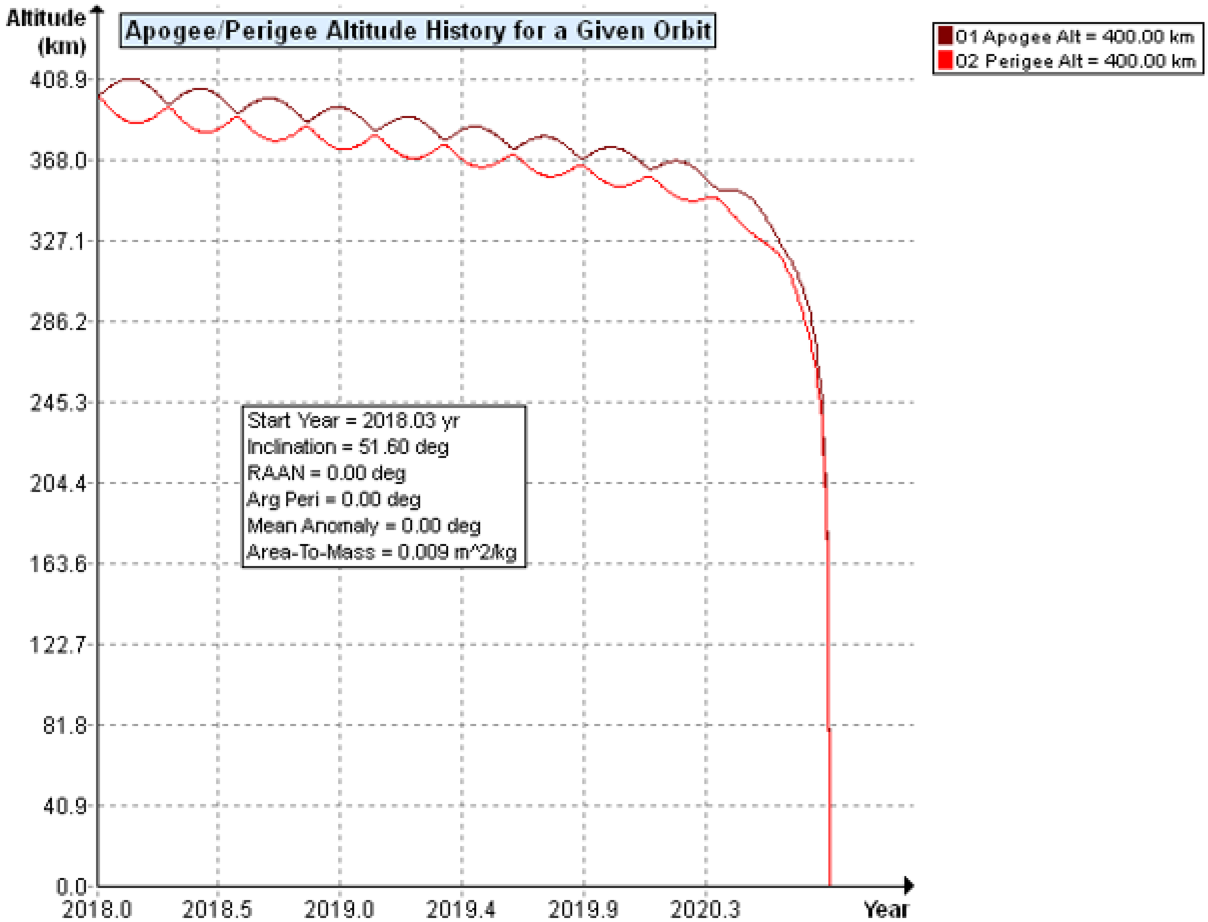
Section 25.114(d)(14)(i) Limiting the amount of debris released during normal operations and the probability of the satellite becoming a source of debris by collisions with small debris or meteoroids that could cause loss of control and prevent post-mission disposal

In order to limit the amount of debris generated during normal operations, FAUNA has been designed so that all parts will remain attached to the satellite during launch, ejection, and 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 of each FAUNA is a monolithic cubic structure (*i.e.*, 10cm x 10cm x 10cm). Based on an orbital debris model (ref. NASA DAS v2.1), 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 x 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 ~ 0.001 m^2) and the relatively short mission duration (*i.e.*, 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 400 km, the space vehicle is anticipated to re-enter the atmosphere within 2.75 year based on lifetime prediction simulations for the current mission epoch (*i.e.*, launch in Q12018).



Section 25.114(d)(14)(ii) Limiting the probability of accidental explosions during and after completion of the mission operations

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.

Section 25.114(d)(14)(iii) 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 CubeSats 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.

Section 25.114(d)(14)(iv) Post-mission disposal plans for the space station at end of life

The post-mission disposal plan for the CubeSats 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. Anticipated atmospheric re-entry of the satellites is within 20.75 years of mission completion based on its mission orbit, vehicle mass, geometry and mission epoch (*i.e.*, launch in CY2016). No active de-orbit maneuvers are required to meet the 25 year re-entry guidelines.

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 Ti 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 the FAUNA NGSO LEO satellite, which will permit Tyvak to demonstrate and validate advanced 3-axis stabilization hardware and software and communication beacon technology, adding valuable on-orbit performance data for future CubeSat Standard satellites. Tyvak's experiment will not cause harmful interference to any licensed service. Tyvak will conduct its experiment the 399.9-400.05 MHz UHF band and 2320 – 2345 MHz S-Band band whose allocations include Satellite Communications (25). 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.