Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
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Tyvak Nano-Satellite Systems Inc.	)	
	)	
Application for Authority Operation of	)	
Experimental Non-Geostationary	)	File No. 0281-EX-PL-2018
Low Earth Orbit Satellites	)	
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NARRATIVE EXHIBIT

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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 a 6 month Special Temporary Authority (STA) for operation of an experimental non-geostationary ("NGSO") low earth orbit ("LEO") CubeSat satellite, designated as PROPCUBE – FAUNA, referred to as FAUNA from here on. FAUNA will consist of a single technology demonstration satellite. The FAUNA mission is owned by the National Reconnaissance Office (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 914 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 2370 MHz S-Band and 390 MHz. UHF T&C spectrum allocation has

[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

been already been granted to this mission from the NTIA, this application requests license for payload S-Band and UHF transmission.

I. NARRATIVE INFORMATION REQUIRED BY FCC FORM 442

Question 4: Antenna Registration Form; Operation of Directional Antenna

FAUNA is a low earth orbit ("LEO") satellite in a 450 km circular orbit with an orbital 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 position of the satellites with respect to the ground station. It will also differ for each satellite pass. The antenna station software will be used to predict satellite contact times and antenna pointing angles to support Earth station planning and operations.

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 developed a single satellite to perform a demonstration of a beacon technology.

FAUNA adheres to a design specification co-developed by California State University, San Luis Obispo and Stanford University 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 was fabricated, tested, and delivered for launch by Tyvak. T&C for the satellites is being carried out by the Naval Postgraduate School (NPS), and Tyvak, as required, via a two-way link in the UHF band with uplink at 450 MHz, and downlink at 914 MHz.

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

FAUNA uses a CubeSat platform to collect critical data for improving communication systems. Both Earth- and space-based communications systems use the outer electrical field of the Earth's atmosphere to transmit, bend or bounce message signals. FAUNA performs high-resolution measurements on the exact position, density and potential vibration of this field to transmit signals in a more effective manner. FAUNA performs dual-frequency ionospheric calibration measurements of ionospheric electron density and irregularities to help reduce errors and delays introduced into radio signals passing through the ionosphere. 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

(2370 MHz) and UHF (390 MHz) frequency range, no associated ground station application is necessary due to no uplink via these S-Band or UHF frequencies.

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 data downlink via S-Band and UHF. T&C on FAUNA is carried out in the UHF band with uplink at 450 MHz and downlink at 914 MHz. Payload data downlink is carried out on a center frequency of 2370 MHz S-Band and 390 MHz. UHF. The payload has the ability to tune to anywhere in S-Band in the 2360 MHz – 2380 MHz range and UHF in the 380 MHz – 400 MHz range. Figure 1 provides an overview of the transmitting and receiving components of each element. Payload beacon receive location coordinates are shown in Table 1.

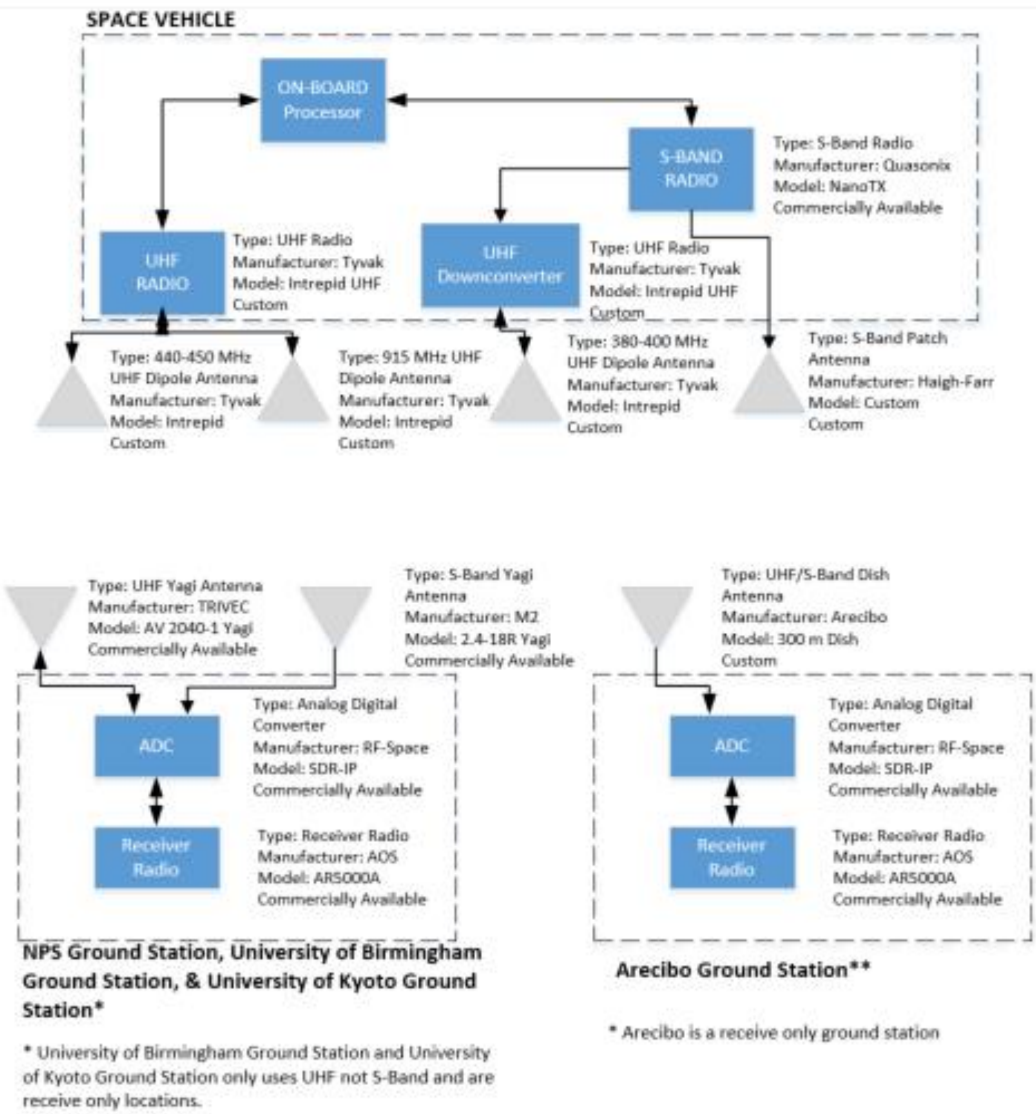

Figure 1: CubeSat System Communications Components

Station	**Coordinates**
NPS (Monterey, 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**: Payload Beacon Receive 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 T&C and an S-Band and UHF TX for payload data beaconing.

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 S-Band signal. The payload radios operate at 1 Mbps baud using BPSK. The S-Band system will utilize a custom patch antenna from Haigh-Farr.

The T&C ground segment communicates with FAUNA using a unique message destination address, authentication counts, and/or encrypted data. The receiving components located at the Earth stations are controlled by dedicated workstations. The workstations are used for antenna pointing control, Doppler frequency shift corrections, and data processing for received transmissions. 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 and University of Kyoto do 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 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.

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 T&C communications system operates using half-duplex communications with uplink at 450 MHz, and downlink at 914 MHz. FAUNA has already received an NTIA RFA for the T&C frequencies (Reference: colonyii-m450-rfas). This application only requests an STA for the payload UHF and S-Band beacon frequencies. The payload UHF beaconing system down converts the S-Band transmitter signal to 390 MHz. The payload UHF system has the ability to tune between 380 MHz – 400 MHz range.

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, space-to-Earth satellite transmissions will be controlled from the Earth station and the spacecraft will not transmit until it receives a command from the Earth 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 payload transmission operations in a timely manner, if required.

The UHF satellite transmitter outputs two watts of power 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 one watt 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 shown in Table 2 - Table 4.

CubeSat Communications Parameters	**Value**
Emission Designator	115KG1D
Service	Digital Data
Center Frequency	914 MHz
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 2: FAUNA UHF T&C Space-to-Ground Parameters

Earth Station Communications Parameters	**Value**
Emission Designator	12K5G1D
Service	Digital Data
Center Frequency	450 MHz
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 UHF T&C Earth-to-Space Parameters

CubeSat Communications Parameters	**Value**
Emission Designator	1M70G1D
Service	Digital Data
Center Frequency	390 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	1W
Line/Misc Losses	-2dB
EIRP	3 dBW

Table 4: FAUNA Payload Beacon UHF Space-to-Ground Parameters

S-Band Communications System

The FAUNA S-Band communications system will operate only downlink operations within the 2360 – 2380 MHz range designated for Satellite Communications. FAUNA will utilize approximately 1.7 MHz of bandwidth with a 2370 MHz center frequency. The S-Band system is capable of transmissions up to 1 Mbps.

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 command from the Earth 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 outputs one watt of power when communicating with the Earth station. S-Band is only for downlink operations and thus there are no S-Band transmissions from the Earth station. The communications parameters for the S-Band downlink system for the space-to-Earth link are shown in Table 5.

CubeSat Communications Parameters	**Value**
Emission Designator	1M70G1D
Service	Digital Data
Center Frequency	2370 MHz
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	1W
Line/Misc Losses	-2dB
EIRP	6.0 dBW

Table 5: FAUNA Payload Beacon S-Band Space-to-Ground Parameters

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

FAUNA is operating 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 twelve minutes per pass. The orbit parameters are presented in Table 6.

Parameter	**Units**	**Value**
Orbit Period	hrs	1.6 hrs
Orbit Altitude	km	450 km (circular)
Inclination	deg	51.6 degrees

Table 6: CubeSat Orbit Parameters

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

FAUNA 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. 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 1.33 kg. The mass budget is provided in Table 7.

Component / Subsystem	Mass [g] 1U
Payload	250
Spacecraft (Subtotal)	916
Structure	300
Electrical Power System	300
C&DH	100
Communication	216
TOTAL	1166

Table 7: CubeSat Mass Budget per Element

For power generation, FAUNA is equipped with body-mounted GaAs solar cells that generate approximately 4 watts of power. Because of the short operational lifetime of the satellite (*i.e.*, ~3 years), 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 Table 8.

Component / Subsystem	EOL Power [mW] Orbit Averaged (1U)
Payload	<1
Spacecraft (Subtotal)	4000
C&DH	3400
Communication	600
TOTAL	4000

Table 8: 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 Table 9. FAUNA has already been launched and is currently in operation only for T&C, due to the prior NTIA authorization and lack of S-Band and UHF spectrum allocation for the payload. The dates are approximate and contingent upon unforeseen events during on-orbit operations.

Milestone	Date	Notes
Launch	November 12, 2017	ToL + 0
Release from launch adapter	December 6, 2017	ToL + 25 days
On-orbit check (T&C only. Awaiting STA for UHF and S-Band Beacon Frequencies)	January 19, 2018	ToL + 32 days
De-commissioning and Expected Re-entry	May 2021	ToL + 3.6 years

Table 9: FAUNA System Major Milestones

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

FAUNA provides a platform for an on-orbit beacon communication system. The onboard systems on FAUNA provide 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 T&C will be supported by a UHF Earth station at the NPS Monterey, CA facility. The S-Band and UHF beacons will be received at the University of Birmingham, Arecibo, University of Kyoto, and NPS facilities.

The primary responsibilities of the NPS Monterey, CA Mission Operations Center (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 two UHF yagi antenna arrays 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 payload 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 2.

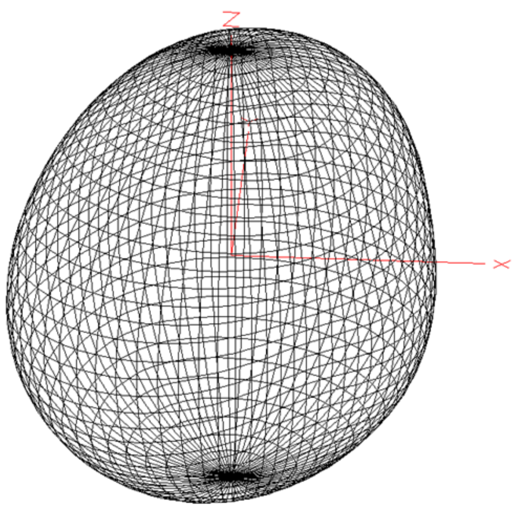

Figure 2: CubeSat Payload L-Dipole UHF Antenna Gain Plot

The spacecraft payload S-Band patch antenna used for downlink has the following gain pattern provided by Haigh-Farr is shown in Figure 3.

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

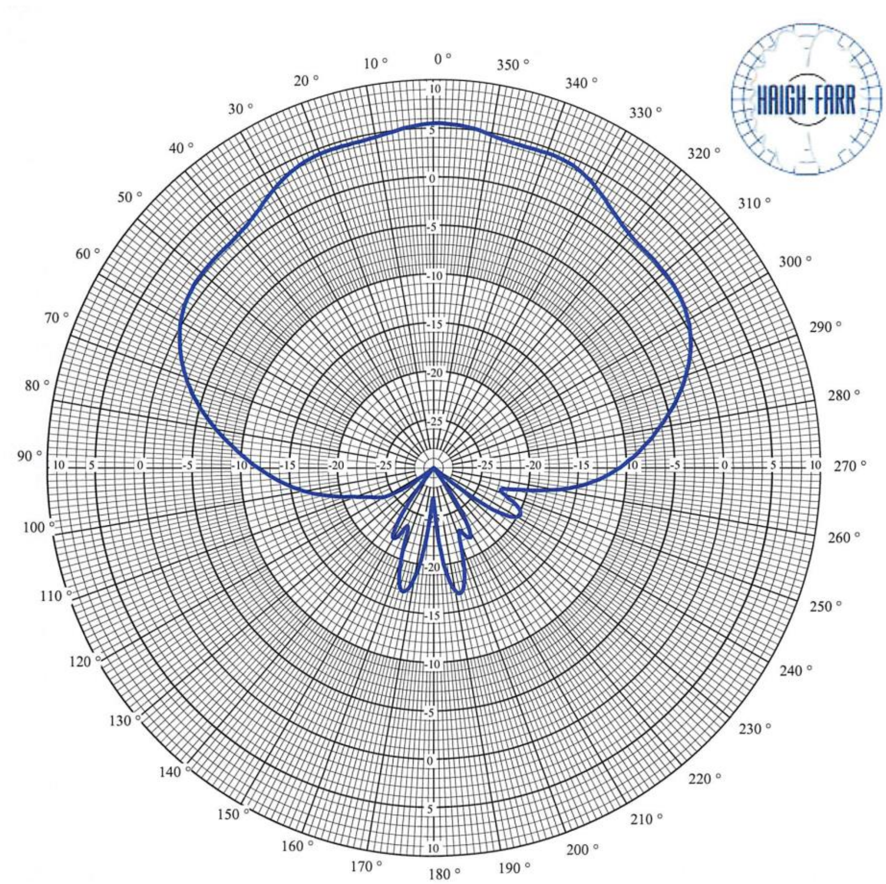

Figure 3: Haigh-Farr Payload S-Band Antenna Gain Pattern

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 NanoRacks deployer 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).

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 450 km, the space vehicle is anticipated to re-enter the atmosphere within 3.6 years based on lifetime prediction simulations for the current mission epoch (*i.e.*, launch in Q4 2017). See Figure 4 for details.

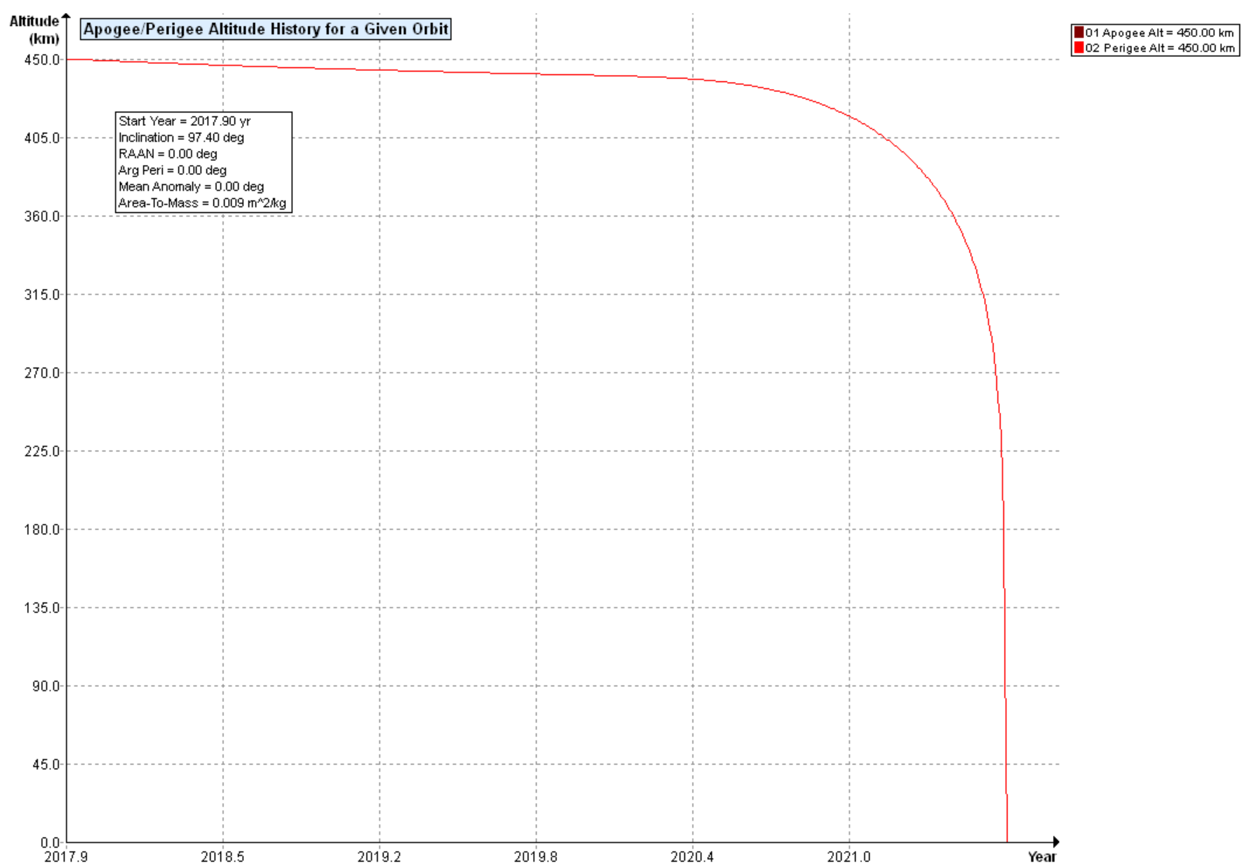

Figure 4: FAUNA Orbital Lifetime Prediction Plot

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

The vehicle possesses energy storage devices (*i.e.*, Li-ion batteries), which will be left in as discharged a state as possible 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 v2.1), 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 3.6 years of orbit insertion based on its mission orbit, vehicle mass, geometry and mission epoch (*i.e.*, launch in Q4 2017). 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 Titanium or stainless steel, and are not expected to survive reentry.

III. CONCLUSION

Tyvak requests the Experimental Licensing Branch to grant the application for a 6 month STA to operate the FAUNA NGSO LEO satellite, which will permit the stakeholders to collect critical data for improving communication systems. The FAUNA experiment benefits the satellite community at-large by providing a more detailed understanding of the medium through which space to ground communications occur. Better constraints on the physical parameters of this medium can inform the design of next generation downlinking systems and other satellite technologies. This experiment is not expected to cause harmful interference to any licensed service. The experiment will be conducted in the 380-400 MHz UHF band and 2360 – 2380 MHz S-Band. Further, this program will meet the Commission's orbital debris mitigation requirements. Therefore, we request that this STA application be granted at the soonest practicable time.