Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, DC 20554

In the Matter of	)	
	)	
The Boeing Company	)	
	)	
Application for a Non-Geostationary Low Earth Orbit Satellite Experimental License	))	File No. ____-EX-PL-2022

NARRATIVE EXHIBIT

The Boeing Company ("Boeing") holds a Commission authorization to launch and operate a non-geostationary satellite orbit ("NGSO") system operating in the fixed-satellite service ("FSS") using frequencies in the V-band.[1] Boeing herein requests experimental authority to launch and operate the first of a series of demonstration satellites that would be used for a number of purposes in furtherance of the deployment of Boeing's authorized NGSO FSS V-band system. Boeing is requesting experimental authority for this initial demonstration satellite, mission name: Varuna, because the tracking, telecommand and control ("TT&C") frequencies that will be used for the Varuna satellite are different from the TT&C frequencies that were authorized in Boeing's NGSO FSS license. Boeing seeks authority to operate Varuna for a period of two years. Authority is also requested herein for the use of two earth stations in the United States for communication with Varuna.

Included below is the narrative information required by FCC Form 442 and the information required by Part 5 of the Commission's rules.

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[1] *See* The Boeing Company Application for Authority to Launch and Operate a Non-Geostationary Satellite Orbit System in the Fixed-Satellite Service, Call Sign, S2993, IBFS File Nos. SAT-LOA-20170301-00028, SAT-AMD-20170929-00137, SAT-AMD-20180131-00013 (Nov. 3, 2022).

I. NARRATIVE INFORMATION REQUIRED BY FCC FORM 442

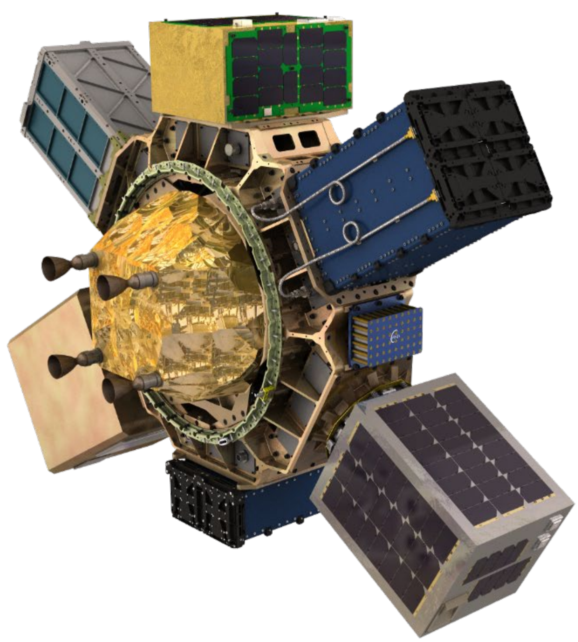
Question 7A. Description of the complete program of research and experimentation proposed including description of equipment and theory of operation.

Boeing is developing an NGSO FSS satellite system to provide broadband communications links to support individual, enterprise and government customers. Unlike previously launched NGSO FSS systems, Boeing's network has been authorized by the Commission to operate both service and feeder links using frequencies in the V-band. The unprecedented use of V-band frequencies for broadband communications services necessitates the development of new hardware (both on the ground and in space) and the verification of assumptions regarding the propagation characteristics of V-band spectrum. Prospective manufacturers of terminal equipment and other hardware that is compatible with Boeing's V-band NGSO FSS system seek an opportunity to demonstrate and confirm the capabilities of their equipment designs. In addition, prospective users of Boeing's broadband communications services (including both commercial and federal government users) desire the opportunity to evaluate the performance of V-band communications links and ascertain their attributes and acceptability for specific applications.

Certain activities that Boeing is proposing to undertake using the Varuna satellite may be completed pursuant to Cooperative Research and Development Agreements with federal agencies, although no such agreements have yet been finalized. Throughout this process, Boeing will ensure that all of the activities and operations that are conducted using the Varuna satellite are permissible under the Commission's experimental licensing rules. The specific program of experimentation is as follows:

1. **Configuration**

The major elements of Boeing's first demonstration satellite that Boeing seeks to be authorized with this experimental license application are (a) the Varuna satellite and (b) two U.S. based earth stations. The Varuna satellite will be manufactured under contract to Boeing by Astro Digital Inc. Varuna will consist of a Sherpa orbital transfer vehicle that is carrying two communications modules, a Command & Control System ("CCS") module operating in the UHF and S-band, and a separate V-band payload module. An illustration of a standard Sherpa configuration is provided below. For this mission, only two of the six available Sherpa slots will be populated.



The Sherpa transfer vehicle is a hexagonal solid shape with dimensions of 82 cm (Z) 142 cm (X) x 123 cm (Y). The Sherpa transfer vehicle includes its own chemical bi-propellant system, which will be used for orbital maneuvers including both initial insertion into the operational orbit, and the subsequent deorbit maneuvers at the end of the mission. For clarity, the Sherpa transfer vehicle constitutes the integrated spacecraft and the Sherpa transfer vehicle will not separate from the two communications modules, they will remain together as one vehicle throughout the mission life and disposal process.

At launch, the integrated spacecraft will have a total wet mass of approximately 180 kg with fuel. Of this total, 140 kg will be spacecraft inert mass and 40 kg will be consumable propellant. Of the total propellant, 10 kg will be reserved for deorbit operations, with another 6 kg held for margin.

The Sherpa transfer vehicle will be operated by sending commands from TT&C ground stations to the CCS module, which contains the flight computer and other bus electronics used to operate the vehicle. The payload module allows for direct V-band communications to and from the V-band ground station located outside the United States.

The Varuna satellite will communicate with two U.S.-based earth stations for TT&C purposes, both of which will operate in the UHF band. A backup TT&C earth station capability is also available for use outside the United States. Varuna will also communicate with experimental earth station terminals using frequencies in the V-band that will either be authorized by the FCC pursuant to separate experimental licenses or will operate outside the United States.

2. Mission sequence

After launch, the selected launch vehicle will deliver Varuna to a circular parking orbit at an altitude of 280 kilometers. Varuna will remain in a 280 km orbit for commissioning of the bus electronics. After bus commissioning is complete, a sequence of maneuvers will be performed to raise and circularize the orbit to the following parameters:

- Average Orbital Altitude: 1056 km
- Eccentricity of operational orbit: 0.001
- Inclination: 54º

After reaching this operational orbit, commissioning of the V-band payload will commence, with space-to-ground communications to the ground station located outside the United States. Once payload checkout and commissioning is complete, the Varuna satellite will conduct payload operations, for a period of up to 24 months total mission life. The Payload operations plan is described further in section 5 below.

After the Varuna satellite has demonstrated all relevant technologies and completed payload operations, it will perform a deorbit maneuver to lower the orbit perigee to 300 km. This will allow natural orbital decay due to drag, and enable the satellite to comply with deorbit regulations, further described below in the section on orbital debris mitigation and in the attached Orbital Debris Assessment Report ("ODAR").

4. Earth Station TT&C

The Varuna satellite will be monitored and controlled use two primary earth stations located in the United States:

1. Santa Clara, CA USA: Earth Station: Lat: 37.380000°, Long. -121.96111° Altitude: 23.3m (AMSL)
2. Littleton, Colorado USA: Earth Station Lat: 39.573201°, Long: -105.133683°, Altitude: 1773m (AMSL)

Primary telemetry and command data transmission to and from the spacecraft are proposed within the following frequencies:

Parameter	UHF-Band Uplink (Primary CMD)	UHF-Band Downlink (Primary TLM)
Max. Data Rate	38.4 Kbps	38.4 Kbps
Modulation	2-GFSK	2-GFSK
Frequency	402.9 MHz	400.5 MHz
Bandwidth	40 KHz	40 KHz
Transmit Power	19.8 dBW	6.0 dBW
EIRP	34.4 dBW	7.2 dBW
Encryption	AES-256	AES-256
Duty Cycle	20%	20%

In addition, there will be a backup TT&C ground capability outside the United States. Backup telemetry and command data transmissions to and from the Varuna spacecraft at a location outside the United States are proposed at the following frequencies:

Parameter	S-Band Uplink (Backup CMD)	UHF Downlink (Backup TLM)
Max. Data Rate	115.2 Mbps	38.4 Kbps
Modulation	2-GFSK	2-GFSK
Frequency	2050.0 MHz	400.5 MHz
Bandwidth	0.3 MHz	40 KHz
Transmit Power	46.5 W (18.1 dBW)	6.0 dBW
EIRP	+33.1 dBW	7.2 dBW
Encryption	AES-256	AES-256
Duty Cycle	20%	20%

A very steep skirted bandpass filter is used to limit output bandwidth to within the ranges specified.

Regarding UHF-band services, the primary U.S. government agency using the allocation between 400.15and 403 MHz is NOAA, which uses these frequencies for GOES DCS platforms and by NOAA radiosondes operating in the *Meteorological Aids* category of service. Boeing has contracted with Astro Digital to operate the TT&C ground facilities and carry out day-to-day tasks under Boeing's direction with respect to the monitoring and operations of the Varuna satellite. Astro Digital has previously coordinated satellites with NOAA on precisely the same frequencies (under both Part 5 and Part 25 of the Commission's rules). With this filing, Boeing and its contractor will, once again, ensure coordination with NOAA regarding this additional experimental use of the same frequencies for Earth-to-space transmission. The conditions for use are essentially identical to Astro Digital's previous operations within this band. We will, of course, keep the Commission apprised of our coordination efforts.

5. V-band Payload Operations

Once the Varuna satellite reaches its final orbit, the V-band payload operations will be conducted, as summarized below:

1) Atmospheric path loss characterization
    - Earth station loopback testing using multiple specific data points in the V-band frequency segment.
2) Dynamic loss change characterization
    - Loopback testing measuring received power on spacecraft and at earth station over a full pass.
3) Terminal Interference Modeling
    - Uplink of test tone from off-pointed terminal to determine potential interference effects.
4) Doppler Compensation Testing
    - Validation of capability of ground terminals to perform Doppler compensation for the orbits and frequencies under consideration.
5) Use case demonstrations

- Series of system-defined use cases (video transmission or data streaming) to validate quality of performance of terminal under test (track bit errors, bits lost, etc.).
- Initial evaluation service to customers and potential customers for the purpose of assessing and characterizing V-band commercial services.

Question 7B. The specific objectives sought to be accomplished.

During the demonstration and testing process, Boeing intends to obtain feedback and recommendations from prospective hardware suppliers, customers and potential customers on the performance and characteristics of the commercial V-band system and use that feedback to identify further tests that may be required and to optimize the performance of the final operational system. Boeing also seeks to demonstrate to hardware manufacturers and potential customers of its V-band satellite system the capabilities of an NGSO network using V-band frequencies for service links and its application to specific enterprise and government uses.

Question 7C. How the program of experimentation has a reasonable promise of contribution to the development, extension, expansion or utilization of the radio art, or is along line not already investigated.

Although theoretical models exist for performance of V-band systems under a variety of conditions, there has been very limited in-orbit validation of these models, particularly for LEO systems. With this satellite, Boeing intends to advance the radio art by collecting V-band link data on the following:

1) Link performance over a range of power levels, orbital geometry, and weather conditions, particularly in scenarios where the LEO satellite orbital motion causes the satellite to traverse through varying conditions on a single pass.

2) Link performance over a range of space-ground geometries, particularly when combined with LEO satellite orbital rates as the satellite moves through those geometries.

3) Required antenna pointing and antenna tracking accuracy for both ground and satellite antennas during satellite passes over a range of elevation angles and geometries.

4) V-band Doppler effects for systems operating in LEO orbit, over a range of elevation angles and geometries.

Using the collected data, Boeing seeks to demonstrate to hardware manufacturers and potential customers the capabilities of an NGSO network using V-band frequencies for service links and its application to specific enterprise and government uses.

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

To support the operational security of the Varuna satellite, neither the satellite nor the associated ground facilities are designed to transmit station identification signals for the spacecraft.

Question 4. Earth Station Transmitter Station Location and Operation

Santa Clara Earth Station

City	State	Latitude	Longitude	Mobile	Street or location	County	Radius of Operation
Santa Clara	CA	37° 22' 48"	-121° 57' 39.996"	No	3171 Jay St	Santa Clara	3,303.49km

Datum: NAD 83

Is a directional antenna (other than radar) used: Yes

Exhibit submitted: Yes

(a) Width of beam in degrees at the half-power point: 12 degrees

(b) Orientation in horizontal plane (degrees from True North): Not applicable. Rotor used to track spacecraft.

(c) Orientation in vertical plane (degrees from horizontal): Not applicable. Rotor used to track spacecraft.

(d) Will the antenna extend more than 6 meters above the ground, or if mounted on an existing building, will it extend more than 6 meters above the building, or will the proposed antenna be mounted on an existing structure other than a building? No

(a) Overall height above ground to tip of antenna in meters: 13.0m

(b) Elevation of ground at antenna site above mean sea level in meters: 23m

(c) Distance to nearest aircraft landing area in kilometers: 3.53km

(d) List any natural formations of existing man-made structures (hills, trees, water tanks, towers, etc.) which, in the opinion of the applicant, would tend to shield the antenna from aircraft: Building just to south**.**

Action	Frequency	Station Class	Output Power (W)/ ERP (kW)	Mean Peak	Frequency Tolerance (+/-)	Emission Designator	Modulating Signal
New	402.8800 – 402.9200 MHz	FX	64.5 W / 0.040 kW	Peak	40 KHz	40K0F1D	GFSK

Littleton Earth Station

City	State	Latitude	Longitude	Mobile	Street or location	County	Radius of Operation
Littleton	CO	39° 34' 23.523"	-105° 8' 1.2858"	No	7815 Shaffer Pkwy	Arapahoe	3,303.49km

Datum: NAD 83

Is a directional antenna (other than radar) used: Yes

Exhibit submitted: Yes

(a) Width of beam in degrees at the half-power point: 13.4 degrees

(b) Orientation in horizontal plane (degrees from True North): Not applicable. Rotor used to track spacecraft.

(c) Orientation in vertical plane (degrees from horizontal): Not applicable. Rotor used to track spacecraft.

(d) Will the antenna extend more than 6 meters above the ground, or if mounted on an existing building, will it extend more than 6 meters above the building, or will the proposed antenna be mounted on an existing structure other than a building? No

(a) Overall height above ground to tip of antenna in meters: 10.5m

(b) Elevation of ground at antenna site above mean sea level in meters: 1773m

(c) Distance to nearest aircraft landing area in kilometers: 5.43 km

(d) List any natural formations of existing man-made structures (hills, trees, water tanks, towers, etc.) which, in the opinion of the applicant, would tend to shield the antenna from aircraft: No

Action	Frequency	Station Class	Output Power (W)/ ERP (kW)	Mean Peak	Frequency Tolerance (+/-)	Emission Designator	Modulating Signal
New	402.8800 – 402.9200 MHz	FX	64.5 W / 0.040 kW	Peak	40 KHz	40K0F1D	GFSK

II. NARRATIVE INFORMATION REQUIRED BY PART 5

§ 5.64 Mitigation of Orbital Debris

§ 5.64(b)(1). Debris Released During Normal Operations.

Boeing will ensure safe operations and mitigate orbital debris for its Varuna satellite via a combination of satellite design and on-orbit monitoring, and if needed, on-orbit control. During on-station operations, we have no activities or events (such as deployments or use of release devices) that would generate debris larger than 5mm in any dimension. All exterior surfaces are designed to avoid production of debris due to space exposure. The satellite design is consistent with the United States Government ("USG") Orbital Debris Mitigation Standard Practices ("ODMSP"), initially established in 2001, and most recently updated in November 2019.

§ 5.64(b)(2). Minimizing Debris Generated by Collisions with Small Objects.

Boeing has worked with its satellite manufacturer to ensure that its Varuna satellite will not become a source of debris as a result of collisions with micrometeoroids or small debris (objects smaller than 1 cm) that would cause loss of control and prevent post-mission disposal. The spacecraft design uses blankets and exterior panels that prevent intrusion into the interior cavity of any objects large enough to cause damage to spacecraft electronics or propulsion system hardware. Analysis indicates that the probability that the satellite will become a source of debris by collision with small debris or meteoroids that would cause loss of control and prevent disposal is compliant with the <0.01 probability requirement, as calculated using the NASA Debris Assessment Software (DAS) version 3.2.

§ 5.64(b)(3). Minimizing Debris Generated by Accidental Explosions

Analysis indicates that the probability of accidental explosion to less than 0.001 (1 in 1,000) during deployment and full mission operations. Special attention is paid to energy sources on board the spacecraft which could potentially fragment and create debris that fragments the spacecraft. These onboard energy sources are as follows: pressurized fuel tank(s), fuel lines, reaction wheels, and batteries. The pressurized tanks are designed and operated with industry standard safety margins to avoid accidental explosions. The fuel line thruster valves will be left in a closed position (they are power-driven and therefore cannot be left open once the power is depleted). The post-mission disposal maneuver is intended to deplete all fuel remaining in the vehicle fuel tanks and leave the fuel lines unpressurized. The reaction wheels (spin rate) and batteries (state of charge) are operated well within their safe operating limits, again using industry standard safety margins, and will be depleted all stored energy after completion of the deorbit maneuver.

§ 5.64(b)(4). Minimizing Debris From Collisions with Large Objects.

§ 5.56(b)(4)(i)(A). Analysis indicates that the probability that the Varuna satellite could become a source of debris by collision with micrometeoroids or large objects (10 cm and larger) is:

- 3.0070×10^{-5} during the operational phase of the mission, at 1056 km circular orbit
- 5.2085×10^{-6} during the re-entry phase of the mission, starting at an elliptical orbit of 300 km perigee x 1056 km apogee.

These results are calculated using NASA's DAS 3.2.

In addition, the Varuna satellite will have propellant thruster capability, with an estimated 6 kg of unallocated propellant available for use. If a warning message is received from U.S. Space Force's Combined Space Operations Center ("CSpOC"), we will be able to perform maneuvers needed to effectively reduce the risk of a large-object collision to near-zero.

§ 5.56(b)(4)(i)(B). Our collision avoidance strategy identifies and assesses planned or operational satellite systems located in the vicinity of the proposed orbit of the demonstration satellite to determine whether they present an operational risk. The launch vehicle provider will plan its trajectory in a manner that avoids all existing satellites or systems already in orbit. This will be done using readily available data on in-orbit spacecraft, as well as data from CSpOC.

§ 5.56(b)(4)(i)(C). As noted previously in this application, the Varuna satellite will separate from the launch vehicle at a nominal orbit altitude of 280 km. After separation, we will perform an initial spacecraft checkout to verify proper performance of all the subsystems. Once this is completed, we will perform orbit-raising maneuvers in the form of a set of Hohmann-transfer burns. The first burn in the sequence will raise apogee to the target 1056 km altitude, with the second burn raising perigee to 1056 km in order to circularize the orbit. During the orbit raising operations, we will monitor data from CSpOC to ensure that we are able to avoid the International Space Station, all existing satellites and space systems already in orbit.

§ 5.56(b)(4)(i)(D). Upon final placement into operational orbit, the effects of Earth oblateness, residual orbit eccentricity, and other orbital effects will cause minor short-term and long-term variations in altitude, inclination, and right ascension. Variations in all of these parameters are small enough that they will not require ongoing active control. In particular, the apogee and perigee are set using a frozen eccentricity target, which ensures that those parameters will remain stable over the entire operational mission life. The accuracy with which orbital parameters will be maintained, including apogee, perigee, inclination, and the right ascension of the ascending node(s) (RAAN) are as follows:

- Apogee & Perigee Control 1056 km ± 9 km (no maintenance required, due to placement of satellite into an orbit with frozen eccentricity)
- Inclination Control: $54^{o} \pm 0.1^{o}$ (no maintenance required)
- RAAN: Selected at launch (no maintenance required)

§ 5.56(b)(4)(i)(E). Boeing hereby certifies that, upon receipt of such a space situational awareness conjunction warning, Boeing will review and take all possible steps to assess the collision risk, and will mitigate the collision risk if necessary, including, as appropriate, contacting the operator of any active spacecraft involved in such a warning; sharing ephemeris data and other appropriate operational information with any such operator; and/or modifying space station attitude and/or operations.

§ 5.64(b)(5). Trackability of the Satellite.

The Varuna satellite will be larger than 10 cm in each dimension, exclusive of deployable components and will be maintained in LEO. Therefore, the trackability of the satellite can be presumed. An onboard GPS receiver will be used to determine satellite orbital parameters and track its position and velocity. Due to our choice of initial orbital parameters for eccentricity and inclination, there are no orbit maintenance burns planned over the mission duration, making the satellite relatively easy to track over its operational life.

§ 5.64(b)(6). Proximity Operations.

Boeing will not perform any proximity operations with the Varuna satellite.

§ 5.64(b)(7). Post-Mission Disposal of Space Structures.

Boeing will actively decommission and maneuver Varuna to a final disposal orbit within one year of the end of the active mission lifetime. Following its active mission life, the Varuna satellite will lower satellite perigee to 300 km. The quantity of fuel that will be reserved for these deorbit maneuvers is 10 kg, with another 6 kg fuel held in unallocated reserve.

After the final 300 km x 1056 km orbit is achieved, de-energization of on-board systems will be performed, including depletion of all remaining propellant onboard the Varuna satellite, spin-down of the reaction wheels, and full discharge of the batteries. From this final orbit, the satellite will undergo passive reentry from atmospheric drag. During this reentry process, the satellite's location will continue to be tracked, but the atmospheric reentry process will be uncontrolled.

Boeing has analyzed its plans for the deorbit of its Varuna satellite and has determined that the probability of success in completing this chosen disposal method is 0.927, and is compliant with the requirement to be 0.9 or greater. This probability is calculated via a detailed reliability analysis of components used on the satellite and their operational in-orbit history.

The Varuna satellite is designed to employ demisable materials that limit the survivability of these materials upon reentry. An assessment has been completed as to whether portions of the satellite will survive atmospheric re-entry and impact the surface of the Earth with a kinetic energy in excess of 15 joules using the NASA Debris Assessment Software and Aerospace Corporation's AHaB (Atmospheric Heating and Breakup) tool, and has determined that the risk of human casualties is 1:17,100, and is thus compliant with the requirement to be below 0.0001 (1 in 10,000). With conservative projections for solar flare activity, our analysis indicates that reentry and demise will occur in a little more than two years, well within the 25 year duration specified in the ODMSP.