Applicant:	**The Boeing Company**
File Number:	**0279-EX-CN-2022**
Correspondence Reference Number:	**69383**
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Responses to Additional V-Band Question

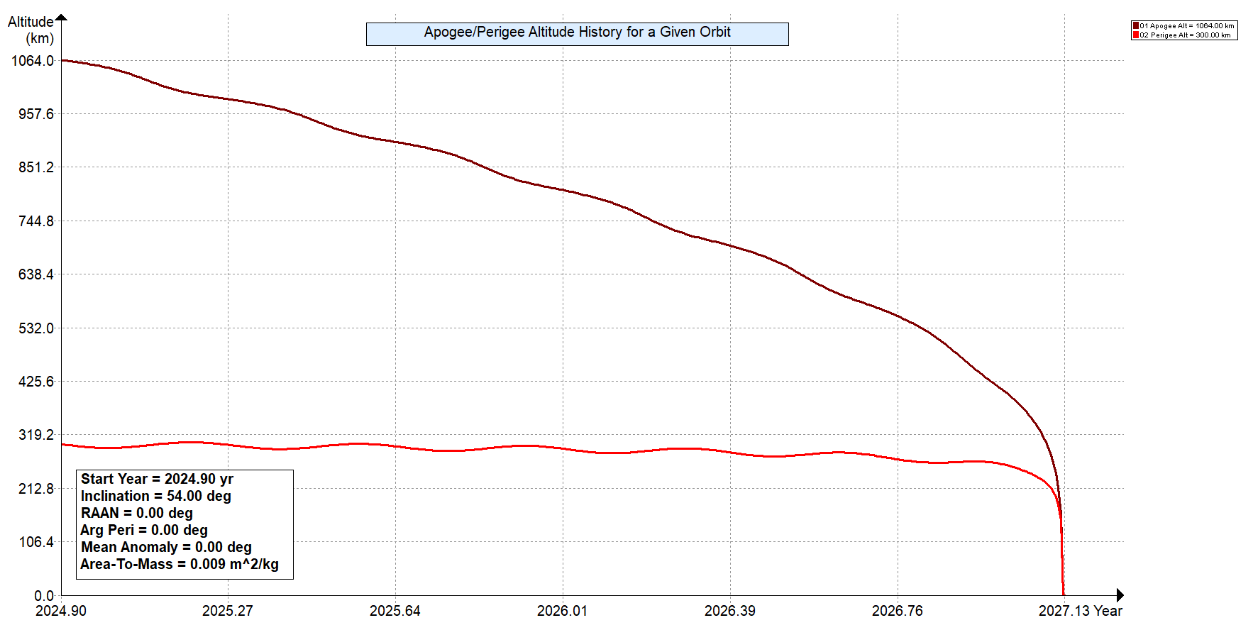
1) Please indicate why there are no V-Band frequencies being requested in the spacecap, or indicate the ITU filing that contains authority to use V-Band frequencies.

    - Consistent with our submitted response on April 18th to previous questions, the V-Band frequencies associated with VARUNA mission will be operated in accordance with the Boeing V-Band license (Call Sign S2993, IBFS File Nos. SAT-LOA-20170301-00028) and notified to the ITU as USASAT-NGSO-5 (PART II-S published in IFIC 2934, 24 Nov 2020). Thus, the operation of V-Band frequencies for this experimental filing have already been submitted to the FCC and notified at the ITU.

ODAR Questions

1) The area-to-mass figure given on page 14 for the spacecraft after it has expelled all propellant does not match the figure given in the graph on page 15. Please indicate what the correct A/M value is when the spacecraft has finished its orbit lowering, update the ODAR and any required calculations, and resubmit.

    - The correct A/M ratio based on latest as-designed/as-built information is .0089 m^2/kg. Corrected graph is shown below. Please note that the latest DAS output also incorporates the small expected orbital eccentricity, with perigee =1048 km and apogee = 1064 km, and the post-mission disposal orbit starting at 300 x 1064km.



2) The final mass figure on page 19 used in DAS calculations is 135 kg. All other instances of dry mass for the spacecraft are indicated to be 140 kg. Please provide an explanation for the discrepancy in the dry mass figures in the ODAR.

   - The discrepancy was due to an error. The correct value for final mass is 140 kg, and the DAS has been updated to reflect this.

3) In the DAS logs, on page 19 of the ODAR, the duration indicated is 5 years. This is indicated to be a 2 year mission before orbit lowering will occur. Please indicate why a duration of 5 years was chosen for this calculation.

   - The 5 year duration used in the original calculation was an error. The correct duration is 2 years, and the DAS has been updated to reflect this.

4) Please provide the total large object collision risk number for the spacecraft, to include both the mission timeframe at 1056 km circular altitude and the post-mission timeframe when the spacecraft is at 1056 km x 300 km.

   - The large object collision risk for the operational mission is 9.0688E-06. The large object collision risk for the post-mission disposal orbit is 6.6005E-06.
   - Please note that the latest DAS output also incorporates the small expected orbital eccentricity, with perigee =1048 km and apogee = 1064 km, and the post-mission disposal orbit starting at 300 x 1064km.

5) Please provide the orbital lifetime and large object collision risk in the case the spacecraft is unable to lower orbit from its mission altitude of 1056 km circular orbit.

   - Based on a DAS run, the expected orbital lifetime is greater than 100 years, and the large object collision risk is 3.4549E-04 for this scenario.
   - Note that for this scenario, it is assumed that the propellant allocated for the deorbit burn is not consumed, leaving the relevant spacecraft parameters as:
     - Spacecraft dry mass: 157 kg
     - Cross-sectional area: 1.246 m2
     - Area-to-mass: 0.0079 m2/kg
   - The DAS analysis indicates that after 100 years, the orbit will have degraded from an initial 1048 km x 1064 km orbit to a 1040 km x 1056 km orbit.
   - As described in the ODAR report, the likelihood of a failure in this orbit that would prevent deorbit is low over the mission duration. However, Boeing and Astro Digital are assessing the addition of a docking plate to provide the opportunity for active debris mitigation in the future.

6) The casualty risk numbers provided on page 12 of the Reentry Risk Assessment document are listed as 0.6x10^-4 and 0.4x10^-4, while the equations would indicate 0.6x10^-5 and 0.4x10^-5, respectively. Please indicate if the equations, or the results are in error.

- A review of the Aerospace Risk Assessment document indicates that the values shown and calculation is correct, though the change in exponent may be misleading. Restating the calculation for our planned orbital inclination:

  $$(3.32\ m^2) \times (1.76 \times 10^{-5}\ m^{-2}) = 5.84 \times 10^{-5}$$

  For the 97.7 degree inclination, which is not relevant for our mission:

  $$(3.32\ m^2) \times (1.19 \times 10^{-5}\ m^{-2}) = 3.95 \times 10^{-5}$$

7) Please provide any information concerning the steps taken to design for demise for the spacecraft that were considered and why the current design was chosen.

- The Varuna spacecraft is designed with demisability being a key consideration. Of the major components making up the spacecraft, the Command & Control System (CCS), the Payload Module, the RWA modules, Antennas, Solar Arrays, and Sherpa structure are made of materials that readily demise, as shown by the results from both DAS and the independent Aerospace analysis. Examples of material selections chosen for demisability are the aluminum rotors in the Reaction Wheel Assemblies, the aluminum chassis designs used for all electronics, and the iron torque rods. The combination of material selection and size/shape ensure that none of these components survive re-entry. The only two elements that don't fully incinerate during re-entry are the Titanium propellant tanks and the Niobium used in the propulsion engines.
- These are both common materials used in satellite propulsion systems. The selected propulsion system, from Benchmark systems, is composed of components that have all been space-proven, sized to work with the Sherpa structure, and so represented low risk both in terms of development, and in terms of on-orbit success. We considered that incorporating design changes would add significant risk, and with propulsion subsystems, the risk would be that a failure would generate significant in-orbit debris. So rather than asking Benchmark to substitute fully demisable materials, we first had a more sophisticated analysis performed by Aerospace. This analysis was submitted with Boeing's experimental license application and showed that, although these components do not fully incinerate during reentry, the area/volume is small enough that the risk of human casualty will be only in the range of 0.4×10^{-4} to 0.6×10^{-4}, depending on the inclination at reentry, which is below the specified risk tolerance of less than 1×10^{-4} for probability of human casualty. With this analysis result, we concluded that it was advisable to adhere to the existing

space-proven heritage for this initial spacecraft, as it represented the highest likelihood of mission success, and the lowest risk of a catastrophic failure. These design choices will be explored further, however, with respect to subsequent spacecraft launched in support of Boeing's V-band NGSO system.

8) Please provide a description of the process Boeing uses for responding to Conjunction Data Messages (CDMs), and more generally for collision avoidance. Please indicate whether there are any risk thresholds or lead time limits that inform whether and when an action is required, the sequence of events from when a CDM is received to the time a collision avoidance maneuver is executed, etc.

- Boeing's approach to collision avoidance has been developed using decades of experience operating geosynchronous satellites through initialization and transfer orbit, as well as our support of missions in low-earth orbit, including the International Space Station, Iridium and Iridium NEXT. Astro Digital, operating the satellite under the direction of Boeing, will be assuming the same process and thresholds for this mission.

  Boeing and Astro Digital will continually perform orbit determination (using onboard GPS) and be ready to respond to a CDM if received. Upon receiving a CDM, the orb ops team will verify the CDM using the latest ephemeris and assess against the criteria in the table below. Note that these are thresholds and the Mission Director and operations team may elect to take preparatory action.

Time of Closest Approach (TCA)	Probability of Collision (Pc)	Miss Distance (km)	Risk Level	Response
TCA – 48 hours	≥ 4.4e-4 (> 1 in 2273)	0.5	High	Action
TCA – 72 hours	1.0e-7 ≤ Pc < 4.4e-4 (btw 1 in 10 million & 1 in 2273)	5	Moderate	Prepare
TCA > 72 hours	< 1.0e-7 (1 in 10 million)	30	Low	Monitor

If the CDM indicates an event at the "Moderate" risk level, the ops team will notify the Mission Director (if not already notified) and begin working preparatory measures including requesting additional/updated ephemeris, coordination with the other operator (if possible), arranging for additional TT&C contacts (if needed) and performing initial burn studies to allow for quick updates at TCA-48 hours. If the "High" risk level is reached, action will be taken. This could include altering existing burn plans, creating a new burn plan, or flying through (if coordinated). The mitigation approach, including burn plans and contact plans (if applicable), is developed by the response team and approved by the Mission Director. Final action will be coordinated with CSpoC to ensure conjunction avoidance action will result in safe separation. For the chemical propulsion system on the Varuna mission, the burn must be executed no later than 6 hours before TCA.