Appendix 2
Response of Global Western and Nevada Museum of Art to the Questions Distributed by Commission Staff

1. What version of DAS was used for preparation of the current ODAR?

   Response: DAS 2.1.1

2. Does inflation of the balloon instantaneously perturb the spacecraft orbit, under any scenario?

   Response: In this analysis, the spacecraft is considered to be a single unit that includes the mass of the cubesat, gas, and balloon. When viewed this way, no mass is released from the spacecraft upon balloon inflation. Accordingly, there is no net momentum change, and therefore no net angular momentum change upon balloon inflation. **Therefore, inflation of the balloon does not instantly perturb the spacecraft orbit under any scenario.** The center of gravity with respect to the satellite bus shifts slightly, but only along the velocity vector by 3.1 m. This was calculated using the following equations:

   moments = (distance_from_reference * mass)

   CG = Sum(moments)/Total_Mass

   Initial mass = 3300 grams (at 5 cm)

   Final balloon mass = 675 grams (at 1524 cm)
   Bus mass = 2625 grams (at 5 cm)

   Total moments = (675 g * 1524 cm) + (2625 g * 5 cm)
   = 1028700 g-cm + 13125 g-cm
   = 1041825 g-cm

   New CG = Total Moments / Mass
   = 1041825 g-cm / 3300 g
   = 315.7 cm

   CG Shift = 315 - 5 = 3.1 meters

   As a result of this slight change, the difference in the satellite's trajectory along the theoretical path prior to inflation and the trajectory of the cubesat after inflation is 0.0005 milliseconds.

   Time = distance/velocity = 3.1 m / 7,571 m/s = 0.0004 seconds

3. What is the upper limit of how much Delta V would be imparted as a result of a puncture of the balloon?

Response: The upper limit of ΔV imparted as a result of balloon puncture is 0.15 m/s.

To minimize the effect of puncture, the system incorporates "Zero Pressure Balloon" technology, which utilizes largely inelastic material (like Mylar), so that a puncture does not result in a high velocity jet of expelled gas, as would be the case in the more common latex balloon. At full inflation, the internal pressure in the balloon is 0.009 psig. The propellant is 25 g of CO_2 (molecular weight = 44 g/mol).

The specific impulse, Isp, is 2.1 seconds, and is found using the following equation:

$\gamma = c_p / c_v$

Taking $c_p = 34.342$ and $c_v = 26.028$

$\gamma = 1.319$, R = 106, T= 240 K

Characteristic Velocity is:

$$c* = \frac{\sqrt{\gamma RT}}{\gamma\sqrt{2/(\gamma+1)\wedge(\frac{(\gamma+1)}{(\gamma-1)}}}$$

Therefore c* = 20.58 m/sec

$I_{sp} = c^* / g_0 = 2.1$ seconds

Therefore, the ΔV is computed using the following equation:

$\Delta V = g_o * Isp * \ln(Mo/M_{final})$

Where $g_o = 9.81\ m/s^2$; Isp = 2.1 seconds; Mo = 3.3 kg, and M_{final} = 3.275 kg.

So, $\Delta V = g_o * Isp * \ln(Mo/M_{final}) = 9.8\ m/s^2 * 2.1$ seconds $* \ln(3.3\ kg / 3.275\ kg) = 0.15$ m/s

**Reference: Rocket Propulsion Elements, 7th edition, George P. Sutton, Oscar Biblarz equations 3-32, 3-18, 3-40, 4-36

4. Please provide an estimate of the number of conjunction warnings involving the spacecraft during its orbital lifetime, assuming balloon deployment at the 575 km altitude.

Response: In addition to coordinating with JSpOC/SPCS to ensure ORBITAL-REFLECTOR is cataloged in the Space-Track database, we attempted to work with JSpOC/SPCS to approximate the number of conjunction warnings for the ORBITAL-

REFLECTOR. Unfortunately, the SPCS stated that they only provide "real-time post-launch (on-orbit) services" and any pre-launch estimation services are only provided "for a specific timeframe, nothing beyond that." Since they were unable to estimate the number of conjunctions for the ORBITAL-REFLECTOR, we have approximated the number of warnings using a methodology previously accepted by the FCC. We have also used DAS 2.1.1 and ORDEM to run additional collision estimation calculations for large objects. This tool enables us to compute the number of impacts for meteoroids and orbital debris, but does not estimate the number of impacts for orbiting spacecraft.

1. Estimation of Conjunction Warnings for ORBITAL-REFLECTOR

Historical data presented to the FCC indicates that from 2010 - 2014, on average, a conjunction warning would be issued for a given satellite approximately once every four months. Since that time, the number of satellites in low earth orbit (LEO) has roughly doubled. Therefore, we assume that today, a warning would be issued approximately once every two months.

To estimate the number of conjunction warnings, we have considered the most conservative configuration submitted in our ODAR, which models the ORBITAL-REFLECTOR as a 30.48 m radius sphere.

In computing the probability of collision in its collision avoidance (CA) analysis, JSpOC represents the size of the objects as "screening volumes". For a basic LEO screening volume, which assumes perigee is less than 2000 km and eccentricity is less than 0.25, an additional 1 km is included radially in the object size to account for uncertainty.

If we assume that the ORBITAL-REFLECTOR is 10x the size in the largest direction of the average satellite orbiting from 2010-2014, the ratio of the screening volumes is approximately 1.08.

ORBITAL-REFLECTOR Screening Volume = (4/3) * pi * ((30.48m + 1000m)^3)
Original Screening Volume = (4/3)* pi *((3m + 1000m)^3)

Therefore, we assume the number of warnings, assumed to be once every two months on average, will be 1.08 conjunction warnings every two months.

2. Additional Collision Assessment for Large Objects (Meteoroids and Orbital Debris)

Figure 1 contains the Number of Impacts vs. the Diameter of the Impactor for altitudes in 50 km increments between 325 – 575 km considering the ORBITAL-REFLECTOR in a Fixed Orientation.

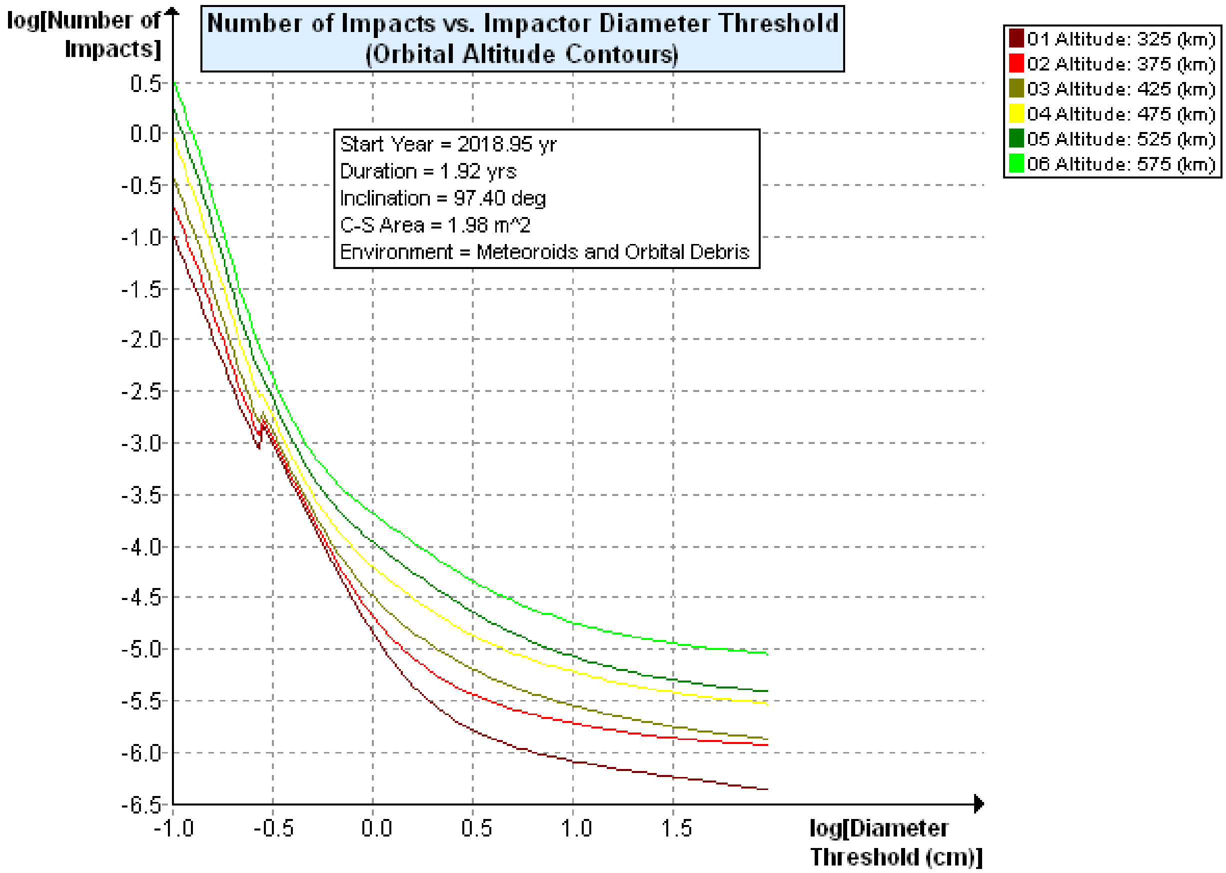

Figure 1. Number of Impacts vs. Diameter of Impactor for the ORBITAL-REFLECTOR in the Fixed Orientation

The results for the diameter threshold are cumulative, meaning that there are no more than three anticipated collisions of objects $\geq 10^{-1} = 0.1$ cm in diameter, and no more than 0.00002 anticipated collisions of objects $\geq 10^{1} = 10$ cm in diameter. JSpOC/SPCS issues warnings for potential collisions with debris ≥ 10 cm, therefore we do not anticipate many warnings issued for debris based collision.

Figure 2 contains the Number of Impacts vs. the Diameter of the Impactor for altitudes in 50 km increments, between 325 – 575 km, for the ORBITAL-REFLECTOR in a random tumbling orientation. The outputs for this simulation are nearly identical to the outputs for the ORBITAL-REFLECTOR in a fixed orientation.

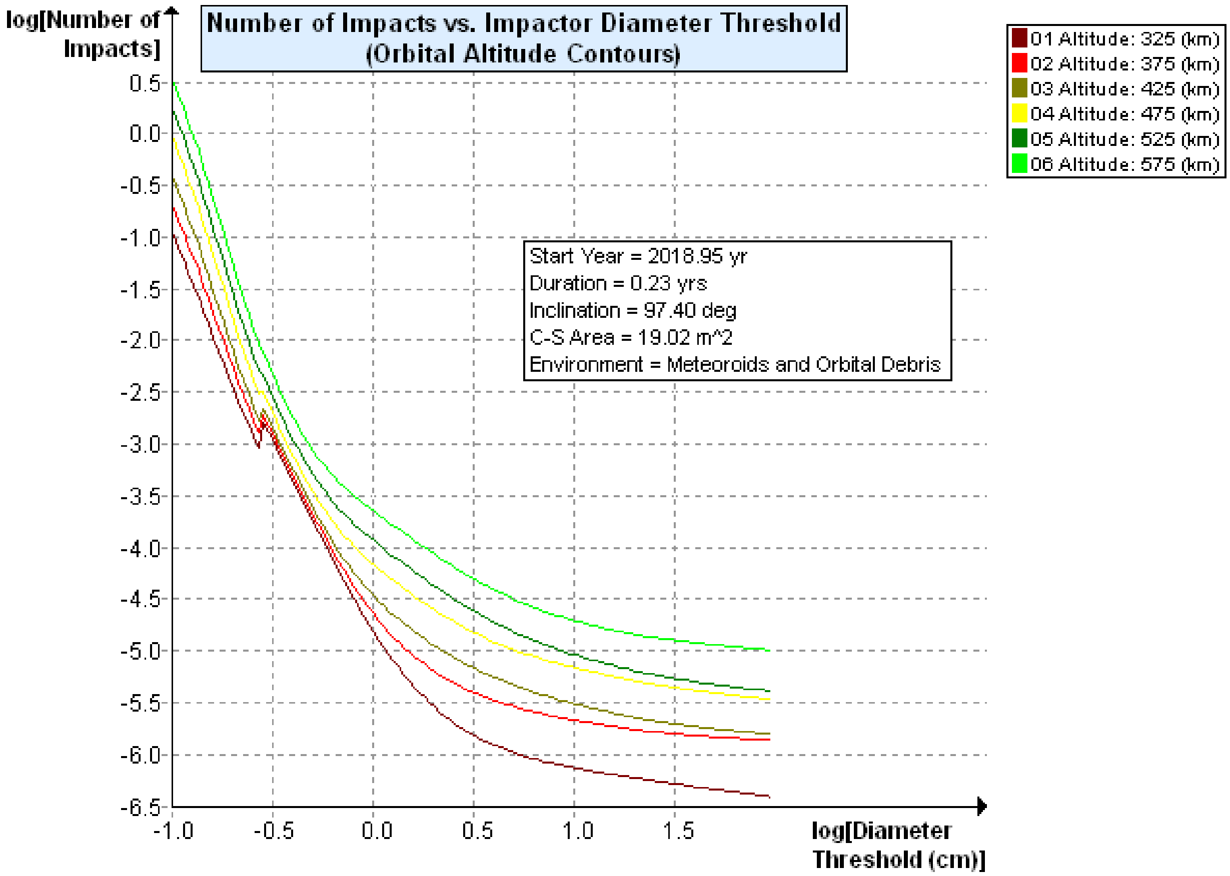

Figure 2. Number of Impacts vs. Diameter of Impactor for the ORBITAL-REFLECTOR in the Random Tumbling Orientation

5. Will there be any capability to assist other operators with position data for the satellite, either prior to deployment of the reflector, or after, for purposes of initial cataloguing or in the event of a conjunction warning?

   Response: We have worked with JSPOC and the 18th SPCS to ensure that we have taken all steps to be properly included in the Space-Track database, under the identification of ORBITAL-REFLECTOR. This will assist other operators in obtaining our position data once launched. We will also publish our spacecraft location, using the TLEs provided by JSpOC, to our website, orbitalreflector.org.

6. Assuming deployment at the 575 km altitude, please provide an estimate of the anticipated eccentricity growth of the satellite's orbit due to solar radiation pressure. Will the apogee exceed 575 km.?

Response: The apogee of the ORBITAL-REFLECTOR is not expected to substantially exceed 575 km. As presented in the ODAR, using NASA's DAS for a randomly tumbling orientation, the worst-case apogee growth is 595 km.

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