Accidental Collision Risk Assessment

In response to FCC request dated 13 November, 2015

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Reference: SAT-MOD-20150802-00053, Callsign S2912

25 Nov, 2015

Excerpt of FCC request for information:

> Specifically, we ask Planet Labs to provide information regarding the aggregate risk of accidental collision with catalogued space objects from the proposed satellite constellation, both during operations and disposal. In particular, please provide a worst case scenario for the risk of accidental collisions, for example assuming all satellites are deployed in the longest-lived orbit, as well as any alternative scenarios that model anticipated realistic deployment patterns. Please also address whether variations in the solar cycle – particularly the possibility of lower than average sunspot activity in cycle 25 – would have any impact on the orbital lifetimes of the proposed constellation or on the aggregate risk of accidental collisions identified above.

Summary of Approach

Planet Labs utilizes NASA's Debris Assessment Software (DAS) to assess "Large Object Collision Risk" as the NASA approved method for completing collision risk assessments. In cases where a higher fidelity analysis is needed, AGI's STK Conjunction Analysis Toolkit is used. In this analysis we present 2 cases: 1) the realistic launch of our longest-lived orbit, and also 2) the orbital altitude where the majority of our satellites will be deployed.

1) Longest-Lived Orbit:

Planet labs has 56 Dove satellites ("Flock 2c") manifested on a Falcon 9 going to a 720 x 450 km, 98 deg inclination orbit. This launch is currently scheduled for late-Q1/early-Q2 2016. This represents the highest altitude launch planned, and therefore the expected highest collision probability on a per-satellite basis. For this orbit, the satellites are expected to remain in orbit for 13.4 years.

Simulating this scenario in DAS 2.0.2 gives a total large object collision probability of 1.12E-4 for the whole Flock over the whole orbit lifetime, which is compliant with NASA-STD 8719.14, section 4.5.2.1.

2) Most-Used Orbit:

The majority of Planet Labs satellites (>80%) will be launched to a 475 km SSO orbit over the duration of the requested license period. In this case, both DAS 2.0.2 and STK's Conjunction Analysis Toolkit (STK/CAT) were used to perform a close approach/conjunction analysis. The STK/CAT analysis compares the Flock members' orbit against the orbits of all of the objects in the US Space Catalog (debris, satellites and human space missions, including ISS), reporting all close approaches. We assumed that the orbits in the US space catalog have a covariance that results in a fixed threat volume ellipsoid defined as 20km tangential (along-track), 10km cross-track and 10km normal (radial) to the trajectory. The Flock satellites were assumed to have a covariance of 3km tangential (along-track), 0.5km cross-track and 0.5km normal (radial). To calculate collision probability, the Flock satellites are treated as hard spheres with cross-sectional area equal to the average cross sectional area of the satellites while tumbling. For catalog objects, radar cross section-derived radii are used (if no data exist, 1m is assumed). This allows estimation of the probability of collisions between any Flock satellite and any existing object in the catalog. It should be noted that this is extremely conservative. While individual collision probabilities are calculated statistically (using Patera's method), this analysis is deterministic rather than statistical and can be used as a point reference.

To keep the compute task reasonable, the analysis is performed over 1 year at the altitude of highest collision risk (i.e. the initial insertion altitude), in order to put an upper bound on each year's risk of a collision. This probability is then extrapolated for the lifetime of the Flock to determine a maximal total probability. It should be noted that this is an extremely conservative approach and will upper bound the total lifetime risk.

Lifetime analysis is performed using STK's lifetime tool and Schatten space weather predictions, which allows for investigation of uncertainty in space weather.

The scenario under consideration is 200 Planet labs satellites in a 475 x 475 km, 97.3 deg inclination (SSO) orbit. For this orbit, the satellites are expected to remain in orbit for 6.9 years. In this scenario, the probability of collision in the first year is 2.82E-5, so the total collision probability over the whole orbit lifetime is 1.95E-04.

The above analysis used Schatten space weather predictions assuming nominal solar flux values. However, if solar activity is lower than average during cycle 25, the satellites would remain in orbit for longer periods and the overall risk of collision would slightly increase. To assess the effect of lower than predicted solar activity, we ran simulations for the entire orbit lifetime assuming solar activity is consistently one standard deviation lower than nominal conditions (i.e. -1 sigma). Under low solar activity conditions, the total lifetime in orbit is 7.6 years and the total collision probability over the whole orbit lifetime is 2.15E-04.

By contrast, simulating this scenario in DAS 2.0.2 gives a total large object collision probability of less than 1.00E-5 for the whole Flock over the whole orbit lifetime.

Taking into account the most conservative estimation of low solar activity and STK/CAT analysis, the proposed mission is still compliant with NASA-STD 8719.14, section 4.5.2.1.

3) Aggregate Risk:

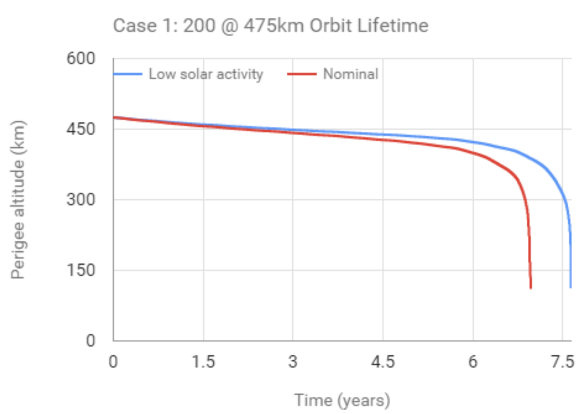
By combining the results from above, we can obtain the aggregate risk. Using the most conservative results, the total combined risk is 2.71E-4, which is compliant with NASA-STD 8719.14, section 4.5.2.1.

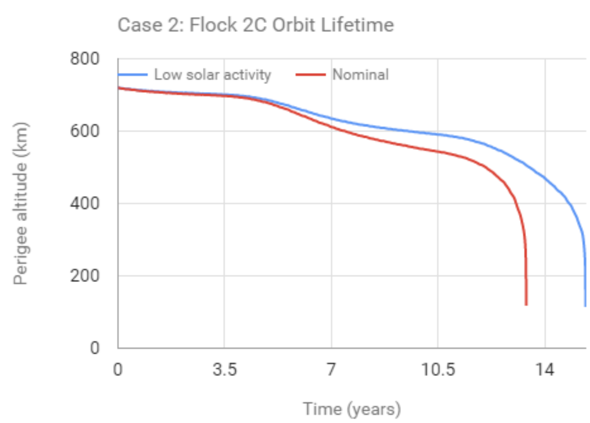
Solar Cycle Effects:

The orbit lifetimes are summarized below showing expected solar conditions and low solar conditions.

Case (Orbit)	Lifetime under expected solar conditions	Lifetime under low solar activity
Case 1: 475 km, SSO	6.9 years	7.6 years
Case 2: 720x450 km, 98 deg	13.4 years	15.3 years

Plots of the nominal and low solar activity orbit lifetime cases are shown below:





Conclusions

The analysis approach taken here is intended to find the worst case estimations, both in terms of using the orbit's initial altitude for calculating collision risk (being the densest region, and therefore highest risk), and also in considering an abnormally low solar activity period throughout solar cycle 25. It has been found that for the longest-lived orbit, the most-used orbit, and the combined aggregate based on realistic launch scenarios are all found to be compliant with NASA standards for debris mitigation.