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Aggregate Orbital Debris Assessment Report
for the Flock Constellation

This report by Planet Labs Inc. (Planet) provides information concerning the difference in the risk of in-orbit collision for Planet's 200 satellite constellation at two different orbit altitudes, 500 km vs. 550 km. Planet requested a Modification[1] to its Authorization[2] for its Flock satellite system (FCC call sign S2912), to increase to 550 km the limit of its orbit deployment altitude applicable to 80% of its authorized satellites. The Modification request presented an orbital debris assessment report (ODAR)[3] showing the risk for any individual satellite operating at an orbit of 550 km. The Commission has requested more information about the total risk of collision for a 200 satellite constellation operating at 550 km. Further, the Commission asked for a comparison of the risks of a 200 satellite constellation operating at 500 km and at 550 km. This report presents that information, and progresses through the following parts:

1. Summary of Single Satellite Case
2. Summary of the 200 Satellite Case
3. Additional Perspectives on Risk

1. Summary of Single Satellite Case

As previously provided to the Commission, Table 1 below provides information on calculated collision risks and orbital lifetime for Dove Satellites at 500 km and 550 km altitude. Results are shown for an individual satellite at either altitude, using NASA's Debris Assessment Software (DAS) 2.0.2 software as well as STK's Conjunction Analysis Toolkit (CAT).

[1] *See* Modification Application, File No., IBFS File No. SAT-MOD-20170713-00103 (filed July 13, 2017) ("Modification"). Planet is currently authorized to deploy 600 satellites over the term of its FCC license with no more than 200 operational satellites at any one time. Eighty percent of the constellation (or 480 satellites) must be deployed at an orbital altitude no higher than 500 km, and up to twenty percent of the constellation (or 120 satellites) may be deployed at an orbital altitude between 500 km and 660 km.

[2] *See* Stamp Grant, Application, File No. SAT-MOD-20150802-00053 (granted Sep. 15, 2016) ("Planet Authorization").

[3] See "Attachment ODAR", section "Dove vs US Space Catalog", to Modification Application, File No., IBFS File No. SAT-MOD-20170713-00103 (filed July 13, 2017).

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	Orbital Lifetime NASA DAS	Orbital Lifetime STK CAT	Collision Risk via NASA DAS	Collision Risk via STK CAT
Single Dove @ 500 km	3.7 years	5.6 years	<1E-06[4]	7.44E-05
Single Dove @ 550 km	4.9 years	8.3 years	1E-06	2.88E-04

Table 1: Collision Risk of Single Dove at a given altitude, assessed against the space object catalogue.

2. Summary of the 200 Satellite Case

The general case assessment for the aggregate risk extends the single satellite case by the number of satellites in the constellation (assuming all satellites are in the same orbit and are statistically independent):

$$P_A = 1 - (1 - P_1)^N$$

where P_A is the aggregate collision probability, P_1 is the lifetime collision probability of one satellite, and N is the number of satellites. Table 2 below shows the lifetime risk of collision for 200 satellites at 500 km and 550 km orbit based on NASA DAS and STK CAT results above[5].

	Collision Risk via NASA DAS	Collision Risk via STK CAT
200 Doves @ 500 km	<2E-04[6]	1.489E-02
200 Doves @ 550 km	2E-04	5.598E-02

Table 2: Collision Risk of 200 Doves at a given altitude, assessed against the space object catalogue.

[4] NASA DAS results limit precision to 1E-6.
[5] The results between the tools differ because of their underlying model of the space objects. NASA DAS uses analytical statistical models for the satellite orbit and other orbiting objects. STK CAT takes a user input initial condition of the satellite and propagates it through a snapshot of the current space catalog, making the results highly dependent on the initial conditions.
[6] NASA DAS results limit precision to 1E-6 which limits the precision of the aggregate calculation.

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Planet believes the modification requested for the majority of its satellites to operate at 550 km altitude or lower does not represent a significant increase in risk for its operations as compared to the Commission's previously granted licensed operations, where the majority of satellites were to operate at 500 km altitude or lower. The STK CAT analysis shows the same order-of-magnitude results for risk at either altitude for both the single satellite and 200 satellite case. For the NASA DAS analysis Planet is within NASA's standard for compliance for the 200 satellite case.

3. Additional Risk Mitigation Considerations

Neither the NASA DAS or STK CAT model accounts for actions that Planet currently employs to actively control Doves while in orbit, which reduce the risk of collision during a Dove's lifetime.

- First, Planet can orient the satellite attitude such that its minimum-size profile is facing the relative velocity vector of the object of a potential collision reducing the surface profile of a Dove by a factor of four compared to the above referenced collision risk analysis. The full measurable effectiveness of this minimum area maneuver depends on the size of the other object, as the collision probability is a function of the combined size of the two objects involved in the conjunction.
- Second, Planet is developing the same differential drag techniques it uses for satellite orbit phasing in support of collision avoidance. Planet has previously reviewed this technique with the Commission, and will further describe it in an upcoming peer-reviewed journal article[7]. Planet has been studying the efficacy of this technique for collision avoidance maneuvers and expects it to have a significant effect on lifetime collision risk.
- Third, in support of Planets in-orbit actions, Planet: (a) works closely and routinely with Joint Space Operations Center (JSPoC) for space situational awareness (SSA), including discussions in advance of satellite deployments and other activities; (b) has a SSA Sharing Agreement with USSTRATCOM, which results in expanded screening volumes for any JSpOC warnings;[8] and (c) actively participates in the Space Data Association[9] (SDA), which assesses all conjunction warnings from the JSpOC for satellites belonging to member organizations. These proactive efforts to share information[10] facilitate the ability of others to assess potential conjunctions and further minimize collision risk.

[7] Foster, C., Mason, J., Vittaldev, V., et. al., Constellation Phasing with Differential Drag on Planet Labs Satellites, Journal of Spacecraft and Rockets, Manuscript ID 2017-03-A33927.R1, Accepted September 2017
[8] https://www.space-track.org/documents/JSpOC_Spaceflight_Safety_Handbook_For_Operators.pdf
[9] http://www.space-data.org/
[10] Including publicly available up to date precision ephemerides, http://ephemerides.planet-labs.com/

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TECHNICAL CERTIFICATE

I, Craig Scheffler, hereby certify, under penalty of perjury, that I am the technically qualified person responsible for the preparation of the engineering information contained in the technical portions of the foregoing report, that I am familiar with Part 25 of the Commission's rules, and that the technical information is complete and accurate to the best of my knowledge and belief.

Craig Scheffler
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Planet Labs Inc.