INSTITUTE FOR DEFENSE ANALYSES

DATAWorks 2020: Characterizing the Orbital Debris Environment Using Satellite Perturbation Data

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Executive Summary

The attached poster was originally intended for DATAWorks 2020, but will now be presented at DATAWorks 2021 or some other venue. It reviews the issue of orbital debris as a risk to spacecraft, and explains how the orbital debris environment can be characterized using satellite perturbation data. It will be presented during the poster session.

Huge satellite constellations are being placed into altitudes where predicted orbital debris populations are high. The untracked orbital debris environment is the most serious predicted risk to spacecraft. There is no data for particle sizes between 1 mm and 3 mm, which is driving the risk of satellite loss, and there will be no more space shuttle data collected—ever.

However, it is possible to deduce the orbital debris environment using data on satellite perturbations (sudden orbital movements). A NASA study used an IDA-developed prediction technique to correlate impacts with orbital debris of various sizes to reported motions of low-earth orbit (LEO) satellites. When impacts occur, there is a momentum exchange between the orbital debris particle and the satellite (particle momentum multiplies by 2:1 to 3:1). An impact causes the satellite to lose orbital velocity and, averaged over an orbital period, orbit at lower altitude. The loss in average satellite altitude is proportional to the mass and velocity of the impacting particle, and depends as well on the design of the satellite body and the location of impact.

GPS positional changes can be correlated to orbital changes, which in turn can be translated into impactor size. Do to so, however, requires a perturbation database from commercial satellite operators to feed NASA's debris models. Following a recent IDA briefing, the Office of Space Commerce indicated strong interest in establishing IDA-recommended perturbation database. At least three large-constellation operators also stated their interest in sharing satellite perturbation data. The NASA Orbital Debris Program Office is willing to use the data, if provided, to update and validate orbital debris model.

Joel Williamsen, Daniel Pechkis, Asha Balakrishnan, Stephen Ouellette

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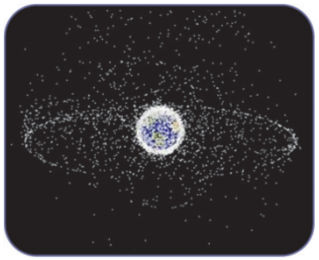
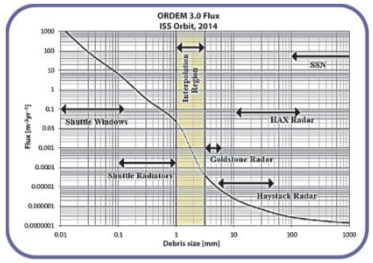
Untracked orbital debris environment is the most serious predicted risk to spacecraft





AL Sphere	Energy (j)	TNT (g)	AL Crater (mm)	Other Equivalents
1 mm (.0015 g)	192	0.045889	4.5	.22 bullet (178 j)
3 mm (.039g)	4992	1.193117	13.5	.30-06 bullet (4000 j)
1 cm (1.5g)	192000	45.8891	45	Mark 2 grenade (200,000 j)

No data for particle sizes between 1 mm and 3 mm; this is driving the risk of satellite loss.
And there will be NO MORE Shuttle data collected—ever.

Constellation growth: more debris sources equals more debris sensors

Operator	Number	Average Altitude (km)	Origin	Debris Impacts per Year (2029) Assuming 1 m^2 Satellite Body ≥ 1 mm	≥ 3 mm	≥ 1 cm
A - SpaceX Vband	7518	340	US	211	0.1	0.009
I - Hongyan	300	1100	China	321	0.4	0.020
K - SpaceX Starlink	4425	1200	US	2496	4.6	0.174
L - Boeing	2956	1200	US	1667	3.0	0.116
M - OneWeb	720	1200	ESA	406	0.7	0.028
N - Telesat LEO	117	1248	Canada	45	0.1	0.005
O - Astrome Tech	600	1400	India	804	0.9	0.020
P - Samsung	4600	1500	Korea	9476	7.1	0.141
			Predicted Totals per Year	16303	18	1

Huge satellite constellations are being placed into altitudes where predicted orbital debris populations are high.

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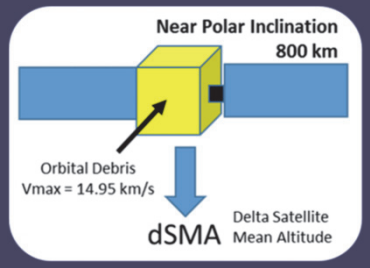
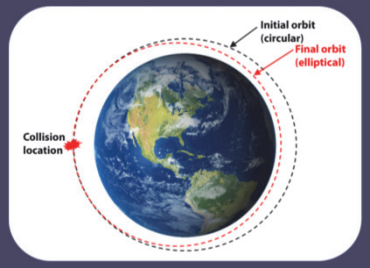
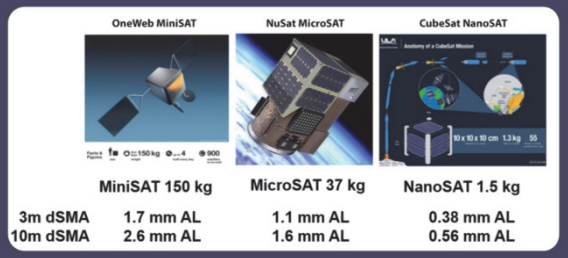
Orbital debris environment can be deduced from satellite perturbations (sudden orbital movements)



Collision lowers dSMA

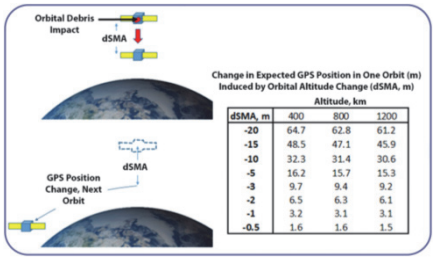


Changes orbit shape



Changes in orbit can be detected and translated into impactor size

GPS positional changes can be correlated to orbital changes and debris strikes



dSMA, m	400	800	1200
-20	64.7	62.8	61.2
-15	48.5	47.1	45.9
-10	32.3	31.4	30.6
-5	16.2	15.7	15.3
-3	9.7	9.4	9.2
-2	6.5	6.3	6.1
-1	3.2	3.1	3.1
-0.5	1.6	1.6	1.5

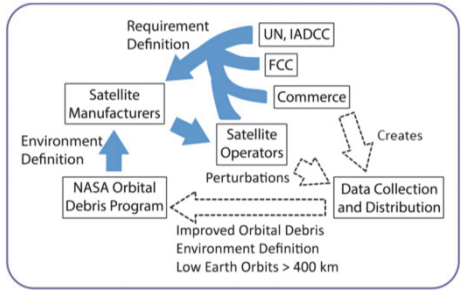
0.5 m change in altitude corresponds to
1.5 – 1.6 m position change along its track

Effects of orbital debris impacts on satellites

NASA study used an IDA-developed prediction technique to correlate impacts with orbital debris of various sizes to reported motions of low-earth orbit (LEO) satellites.

- When impacts occur, there is a momentum exchange between the orbital debris particle and the satellite (particle momentum multiplies by 2:1 to 3:1).
- An impact causes the satellite to lose orbital velocity and, averaged over an orbital period, orbit at lower altitude.
- The loss in average satellite altitude is proportional to the mass and velocity of the impacting particle, and depends as well on the design of the satellite body and the location of impact.

Need a perturbation database from commercial satellite operators to feed NASA debris models



Recent Developments

- Following IDA briefing, Office of Space Commerce (Mr. Kevin O'Connell) indicates strong interest in establishing IDA-recommended perturbation database.
- At least 3 large-constellation operators stated their interest in sharing satellite perturbation data: position change along track, mass, time of impact, etc.
  - Would prefer to avoid revealing failures.
- NASA Orbital Debris Program Office is willing to use data, if provided, to update and validate orbital debris model.
  - New model within 5 years; meets goals of SPD 3
- NASA Goddard would be willing to establish a government program given funding.
  - "Anomaly" is an avoided term – use "perturbation."

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14. ABSTRACT

The untracked orbital debris environment has been described as one of the most serious risks to the survivability of satellites in high-traffic low Earth orbits, where acute satellite population growth is taking place. This poster describes a method for correlating observed satellite orbital changes with orbital debris impacts, and demonstrates how populations of small debris (< 1 cm) can be characterized by directly examining the orbit and attitude changes of individual satellites within constellations. The poster also presents means for detecting unusual movements and other anomalies (e.g., communication losses) in individual satellites and satellite constellations using the Space Surveillance Network, other space surveillance sensors, and in situ methods. Finally, the poster discusses how an anomaly data archive and policy repository might be established, supporting an improved definition of the orbital debris environment in harmony with the President's Space Policy Directive 3.

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