December 2021

Self-Cleaning Orbit Myth

Introduction

There have been recurring misrepresentations that low Earth orbits between 500 km and 600 km in altitude are intrinsically "self-cleaning", and that collisions among maneuverable or non-maneuverable (derelict) satellites in such orbits are therefore inconsequential. That is incorrect, LEO satellite collisions at these altitudes have consequences that persist for decades because of the time it takes fragments from those collisions to decay.

In other words, the time required for intact derelict satellites to passively deorbit is being conflated with the time it takes fragments from a collision involving those satellites, whether maneuverable or non-maneuverable, to decay. The following figure shows the worst-case decay time (over the 11-year solar cycle)[1] of intact derelict satellites[2] in the nominal Starlink orbits[3]. The derelict satellites naturally deorbit within 6 years.

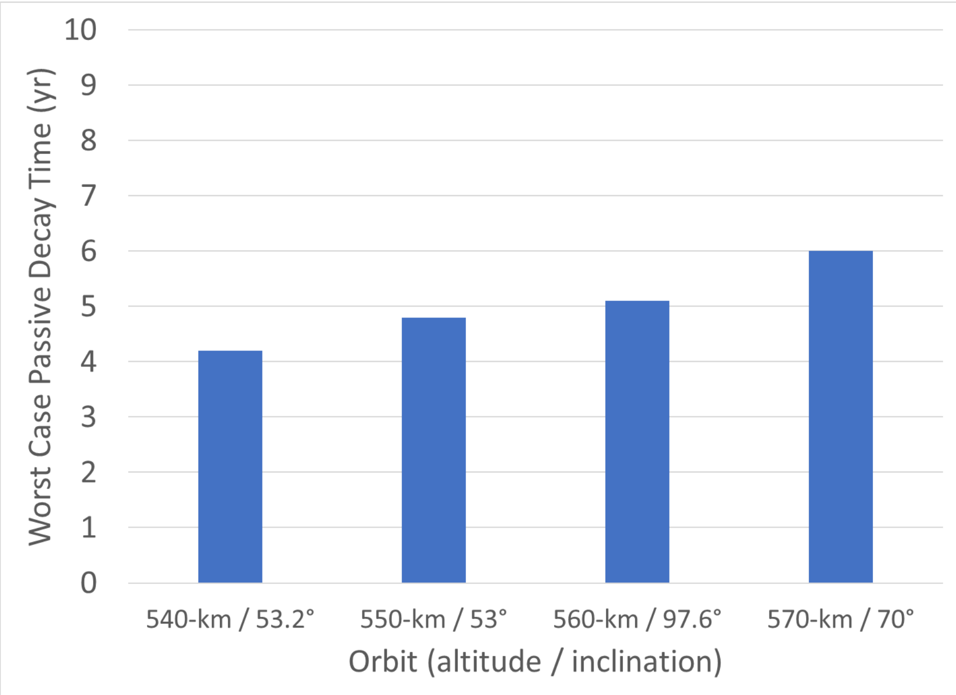

Figure 1 – Worst Case Passive Decay Time for an Intact Derelict Satellite

Unlike intact derelict satellites, fragments resulting from catastrophic collisions involving one of those satellites remain in orbit for decades. The debris field from such a collision consists of large numbers of lethal trackable (LT) fragments[4] and an even larger number of lethal non-

[1] Decay time depends on the atmospheric drag and the satellite's area-to-mass ratio. The height of the Earth's atmosphere changes based on the 11-year solar cycle. The larger the area-to-mass ratio, the more rapidly the satellite will decay.

[2] The derelict satellite is modeled using the physical parameters of the Starlink v1.0.

[3] SpaceX is licensed by the US FCC to operate 4,408 satellites in orbits with nominal altitudes of 540, 550, 560, and 570-km, and tolerances that allow the orbits to vary as much as +/- 30 km in altitude.

[4] Fragments larger than 10 cm are typically observable by ground-based radars and telescopes, and hence are trackable. They are also massive enough to fragment any satellite they collide with. These are the lethal trackable (LT) fragments.

trackable (LNT) fragments[5] all dispersed across the LEO altitudes. A collision with any one of these fragments will be catastrophic, fragmenting the satellite it collides with. The altitude dispersion means that these fragments will continue to pose a threat to all LEO satellites, the ISS, and other space systems for over a century.

Satellite Collisions at Any LEO Altitude Disperse Fragments Across All LEO Altitudes

The NASA Breakup Model[6] is used to model post collision fragment distributions. The following Gabbard diagrams[7] show the modeled fragments from a collision at 550-km between a Starlink satellite[8] and a debris fragment small enough to hold in the palm of your hand. Both the LT and LNT fragments are spread to altitudes across LEO space, from 200 km to 2,000 km.

Lethal Trackable (LT) Fragments	Lethal Non-Trackable (LNT) Fragments

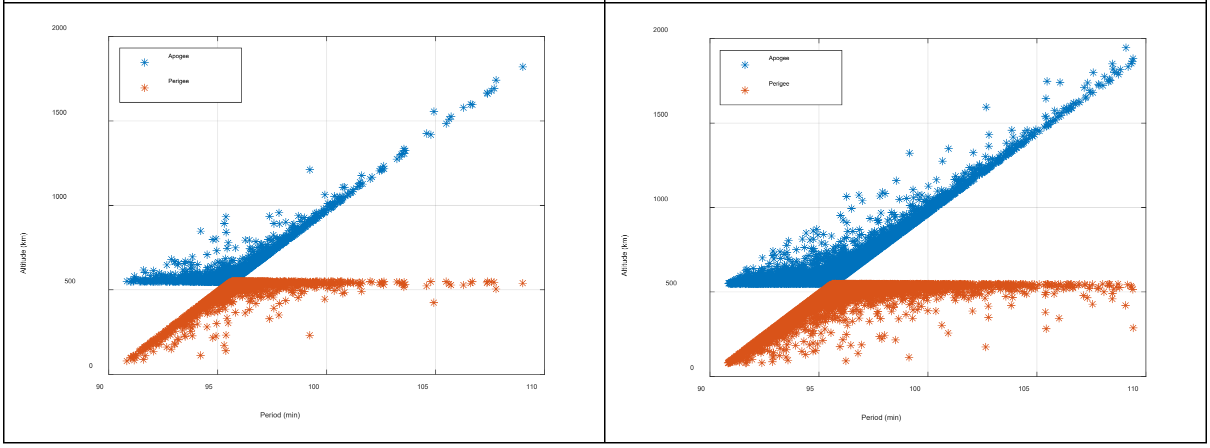

Figure 2 – Modeled LT and LNT Fragments from a Catastrophic Starlink Collision at 550-km

Consequences from LEO Satellite Collisions Persist for Decades

The following figure shows the decay times for various fractions of the LT and LNT fragments from a catastrophic collision for each of the Starlink orbits. The curves show the time required for 90%, 99%, and 99.9% of the fragments to "clean-out". Collisions in these orbits are seen to have consequences for decades.

[5] Fragments in the 1 cm to 10 cm range are not trackable but still have sufficient mass to fragment satellites they collide with. These are the lethal non-trackable (LNT) fragments.

[6] N. L. Johnson, P. H. Krisko, J.-C. Lieu, and P. D. Am-Meador, NASA'S NEW BREAKUP MODEL OF EVOLVE 4.0, *Adv. Space Res*. Vol. 28, No. 9, pp. 1377-1384, 2001.

[7] The Gabbard diagram is the standard for fragmentation analysis. Developed by John Gabbard in 1981, it is a scatter plot of apogee and perigee heights versus period. It allows rapid identification of the fragment's orbit types, and the direction and intensity of the fragment's spread.

[8] Starlinks are used for illustration, as they are the most numerous of the large LEO constellation satellites with 1,842 already launched, and a 15-year license from the FCC to maintain 4,408 operating satellites plus an unlimited additional number that could be undergoing orbit raising or deorbiting at any given time. Very simplistically, given the numbers, if a satellite were to collide with a lethal debris object, it would more likely than not be a Starlink.

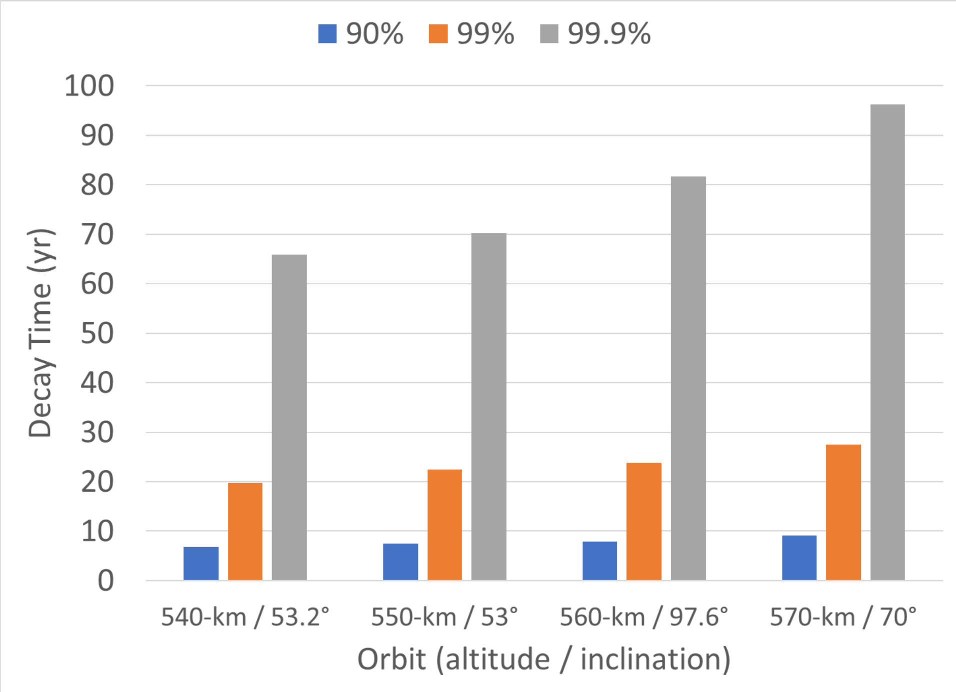

Figure 3 – Decay Time for Various Fractions of Debris vs. Orbit

The NASA Breakup model estimates that 17,000 lethal fragments will result from a catastrophic Starlink collision[9], only a small fraction of which are trackable (i.e., avoidable). Even with 90% "cleaned out", there will still be 1,700 lethal fragments in orbit; with 99%, 170 lethal fragments; and with 99.9%, 17 lethal fragments. Any one of these fragments can destroy other LEO satellites resulting in further catastrophic fragmentations and leading to a collision cascade (an exponential growth in the number of fragments resulting in a Kessler Syndrome). The following table shows the number of lethal fragments from a single catastrophic collision involving a Starlink satellite remaining in orbit 25 years later.

Table 1 – Number of Lethal Fragments Still in Orbit 25 Years Later

Collision Altitude	Number of Lethal Fragments Remaining 25 Years Later
540 km	92
550 km	114
560 km	145
570 km	199

Conclusion

Satellite collisions in the nominal Starlink orbits generate lethal debris fields that span LEO space. A portion of these fragments will continue to pose a threat to all LEO satellites, the ISS, and other space systems for decades. Unlike intact satellites, these fragments simply do not "clean out" in a few years.

[9] This estimate is based on the v1.0 physical parameters. SpaceX has recently suggested that v2.0 Starlink satellites will be more massive. That would increase the number of lethal fragments. The larger the satellite, the more significant the consequences of it being involved in a fragmenting collision.