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Comment:

Anti-satellite weapon tests to disrupt large satellite constellations

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Russia's test of a direct-ascent (DA) anti-satellite (ASAT) weapon on 15 November 2021 has prompted renewed efforts in space arms control. A multilateral treaty banning all destructive ASAT weapon tests is urgently needed.

When Russia hit its own satellite Cosmos 1408 with a ground-based missile at an altitude of 480 km, it produced 1500 pieces of trackable debris that threatened the International Space Station (ISS) and China's Tiangong space station. "Conjunctions" (close distances between orbits) necessitated several collision-avoidance manoeuvres by the ISS. Having cosmonauts on board did not deter Russia.

Similar DA ASAT weapon tests have been conducted by other states, including the US in 1985, China in 2007, and India in 2019.

DA ASAT tests use a missile launched from the ground, sea, or air to destroy a satellite or rocket body owned by the testing state, using the tremendous kinetic energy of the collision. While DA ASAT tests have received substantial attention, there have also been destructive co-orbital tests,[1] where a killer satellite in orbit manoeuvres close to the target and, for example, detonates. Co-orbital tests have contributed roughly 10% of ASAT-related space debris in orbit today (Figure 1), spread over a wide range of orbits.

The debris from the 2021 test created complications for satellites at higher altitudes, including SpaceX's Starlink "megaconstellation". According to SpaceX, over 1700 of the 6873 collision-avoidance maneuvers performed by its satellites in the six months from 1 December 2021 to 31 May 2022 were due to Cosmos 1408 debris.[3]

This outcome raises the possibility that a state may conduct a "test" with the *intent* of disrupting space operations of another state. Such a "test-to-disrupt" may be attractive to some states because it offers a way to diminish another state's space capabilities without the action constituting an "armed attack", which would trigger the right of self-defence and allow a military response.

Feasibility

The top panel of Figure 2 shows the orbital density of Starlink satellites and debris two months after the 2021 test.

The injection of debris from the test created an immediate orbital hazard. Take Starlink as an example. SpaceX reports using a collision probability threshold of 1-in-100,000 for conducting collision-avoidance manoeuvres. While this does not cleanly correspond to a conjunction distance, it is reasonably consistent with a distance of 1 km or less between any Starlink satellite and trackable debris.

A rough estimate for the expected conjunction rate within 1 km is found by

$$\lambda = 4\pi \int_{shells} n_{deb}\, n_{sat} A v r^2 dr,$$

where *r* is the altitude of each shell, n_{deb} the number density of Cosmos 1408 debris in the local shell, n_{sat} the Starlink density, $A = \pi\,\mathrm{km}^2$, and $v = 4v_c/3.$ Here, v_c is the local circular orbital speed. For the 27 January 2022 data, $\lambda \approx 22\ \mathrm{d}^{-1}$. Thus, over 151 d, keeping λ fixed, we would expect about 3,300 conjunctions within 1 km. Of course, λ is time dependent, with the Cosmos 1408 debris decaying. This is somewhat offset by the increasing number of Starlink satellites.

This value is no more than a factor of two different from what SpaceX has disclosed. This difference is not a concern given the lack of a precise threshold for the conjunction distance and not knowing the exact number of collision-avoidance maneuvers performed by Starlink satellites.

Test-to-Disrupt

What if the testing state had used a satellite closer to the Starlink 550 km shell as the target, instead of one at 480 km?

To explore this situation, we generate debris fields using the NASA Standard Breakup Model for a catastrophic collision[4] between a small kinetic kill vehicle and a 1750 kg satellite (like Cosmos 1408).

This engineering model statistically samples debris distributions, including the velocity "kicks" that any given debris piece obtains from the collision. The breakup model does not depend on the energy of the impact insofar as the collision is catastrophic, causing complete fragmentation of the satellite. Thus, the delivery method of the weapon need not be specified.

The results for two altitudes are shown in the bottom panel of Figure 2, one a hypothetical ASAT test at 480 km for verification against the actual 2021 test, and another at 548 km, which explores the consequences of conducting a test near the peak Starlink density. Integrations over the distributions yield $\lambda = 24\ \mathrm{d}^{-1}$ and $240\ \mathrm{d}^{-1}$ for the lower and higher altitudes, respectively.

The lower altitude simulation results are similar to that determined using the known Cosmos 1408 distribution of 27 January 2022.

The results for the simulated 548 km test involve an order of magnitude more conjunctions. Indeed, projecting over 151 days, the expected number of conjunctions would be 36,000. Even if we had altitude decay of some debris, tens of thousands of conjunctions would still be expected. Adding to the concern, the number of Starlink satellites in orbit today is more than double that used for these calculations.

Discussion

We focus on Starlink because it has (1) on orbit over 4800 of its approximately 12,000 satellites that have been authorised so far, (2) been affected by an ASAT test, (3) been used extensively to support a foreign military (Ukraine) in an armed conflict with an ASAT-capable state, indeed, the same state that conducted the 2021 test.

That state has noticed the latter development. Speaking at the United Nations in September and October 2022, its ambassador said that the use of Western commercial satellites to support the Ukrainian military was “provocative” and “an extremely dangerous trend”[5] and that such “quasi-civilian infrastructure may be a legitimate target for a retaliatory strike”.[6]

In hindsight, the 2021 ASAT test could be viewed as a warning to Western states against the provision of satellite support to Ukrainian forces. At a minimum, it demonstrated that the testing state has the means and will to strike objects in orbit.

Still, one might assume that strikes against single satellites (or even tens of satellites) forming part of a megaconstellation would be ineffective, owing to the massive redundancy inherent in a large system. Indeed, a megaconstellation of 1000s of satellites will remain fully functional after the loss of a small number of satellites, with a small percentage of failures being normal. The appeal of such redundancy-by-shear-numbers is visible in statements by US military leaders.

Moreover, using an ASAT test to initiate a physically destructive collisional cascade of debris[7] offers no immediate military advantage due to the relatively long timescale between satellite-debris collisions.

The only way to disable a megaconstellation with a direct strike is to make a debris injection the central component of the weapon.[8] However, such an all-of-system attack could be traced straight back to the responsible state, and most importantly, the intent behind the attack would be clear. It is this combination of attributability and clarity of intent that constitutes a weakness in all direct attacks.

The most significant deterrent against direct strikes on megaconstellations is that such strikes could constitute “armed attacks” under the *jus ad bellum*, the international law governing the recourse to force. The criterion of “armed attack” acts as a tripwire; if an “armed attack” occurs, this triggers the right of self-defence, opening the door to a military response—either in space or in another domain, such as striking the attacking state’s launch facilities.[8]

Instead of being designed to physically damage satellites, the creation of fragments through a carefully crafted ASAT weapon test would disrupt a megaconstellation by requiring a greatly elevated number of collision avoidance manoeuvres. This would lead to increased fuel use, shorter satellite lifetimes, and possibly the degradation of services. A high frequency of manoeuvres also brings the possibility of errors or manoeuvre conflicts, and with this the real chance of collisions.

An established space power planning a test-to-disrupt will have no difficulty finding a “target”, owing to the large amount of its own abandoned rocket bodies and massive satellites in orbit.

Importantly, there would be no clarity of intent. The acting state could assert that it was only conducting a “test” and therefore acting legally. This assertion would make it difficult for the affected state to claim self-defence and respond with military force. Perhaps most importantly, the argument of “only a test” might create uncertainty for other states, thus diminishing international support for any forceful response and associated self-defence claim.

For while states are not entitled to do everything they wish, it is a fundamental principle of international law that restrictions on state freedom cannot be presumed.[9] Absent evidence of intent to disrupt another state’s satellites by forcing them to manoeuvre frequently to avoid destruction, a strike against one’s own satellite would *normally* not constitute an “armed attack” and trigger the right of self-defence.

We use the word “normally” to emphasize that calling an “armed attack” a “test” does not make it so. For instance, if the test involves choices that self-evidently will cause massive disruption to another state’s constellation, the basis for a claim of self-defence by the affected state might still be present. Ultimately, the affected state will have to consider political as well as legal factors when deciding how to respond.

It is also possible that *all* debris-creating kinetic ASAT tests are becoming illegal, under one or both of two different strands of international law. The first involves a reinterpretation of the “freedom for exploration and use” set out in Article I of the 1967 Outer Space Treaty (OST), the corollary of which is a duty of “due regard” set out in Article IX. [10] The precise content of these rules can only be determined by assessing state behaviour, notably the “subsequent practice” of the parties to the treaty. As states become more critical of kinetic ASAT testing, these treaty provisions could come into play.

For the second strand, it is possible that increased criticism of kinetic ASAT testing, along with efforts by states to avoid creating debris or at least deny that they have done so, is contributing to the development of "customary international law". Such a rule requires both "state practice" and "*opinio juris*", with the latter being at least an awareness, by the acting state, that its practice is legally relevant.

The US, Canada, New Zealand, Japan, Germany, South Korea, UK, Australia, Switzerland, France, Netherlands, Austria, and Italy have all made unilateral declarations not to conduct DA ASAT testing. These thirteen declarations could be considered subsequent practice for interpreting the OST, as well as state practice and evidence of *opinio juris* for customary international law. Along with these developments, in December 2022 the United Nations General Assembly (UNGA) adopted Resolution 77/41, which calls upon states "to commit not to conduct destructive [DA ASAT] missile tests."[11] UNGA resolutions are often cited as state practice and evidence of *opinio juris* for customary international law. While these are steps in the right direction, the unilateral declarations and the resolution are directed at DA ASAT testing only, and do not contribute to a general ban against destructive ASAT testing.

Treaty reinterpretation and the making of customary international law take time, and a faster, parallel path may be available: in December 2021 the UNGA created an Open-Ended Working Group (OEWG) on Reducing Space Threats through Norms, Rules and Principles of Responsible Behaviours,[12] thus providing an opportunity for states to address test-to-disrupt and other potentially destabilizing actions in space. After meeting in four sessions, and not yet adopting a final report, the mandate of the OEWG will now have to be renewed. If and when that happens, the OEWG should (1) consider the right of self-defence, which all states accept applies in space. It could usefully emphasize that calling an "armed attack" a "test" does not make it so, and that any action self-evidently designed to cause massive disruption to a constellation is already proscribed under international law.

The OEWG should also (2) recommend a ban on all destructive ASAT weapon testing, not just DA ASAT testing. Even if some states might not initially support a treaty, many states would, and this can have the effect of shifting normative expectations.

Consensus is difficult to achieve, even in the best of geopolitical circumstances, but there are many precedents for arms control during times of heightened tensions between superpowers. In space, the testing of nuclear weapons has been prohibited since 1963, when the United States and Soviet Union concluded the Limited Test Ban Treaty.[13] The ban was motivated, in part, by the disablement of satellites after the US military detonated a 1.4-megaton hydrogen bomb at an altitude of 400 km,[14] and the consequent realization of the shared interest in preserving safe access to orbit.

For six decades, no state has conducted a nuclear weapon test in space because the ban serves the interests of every advanced military and national space agency.

The authors declare no competing interests.

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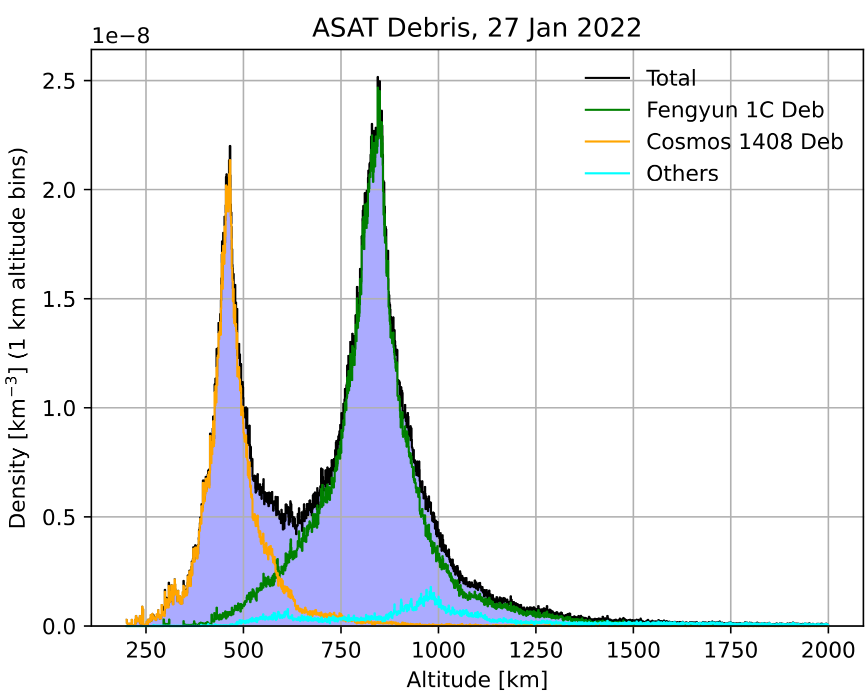

Figure 1: Catalogued debris from destructive ASAT weapon tests. Peaks are driven by Cosmos 1408 (2021 ASAT test) and Fengyun 1C (2007 China ASAT test). Soviet-era co-orbital tests are highlighted by "Others". About 1260 pieces make up the Cosmos 1408 debris distribution. Approximately 100 tracked Cosmos 1408 debris remain in orbit as of fall 2023. Data: USSPACECOM.[2]

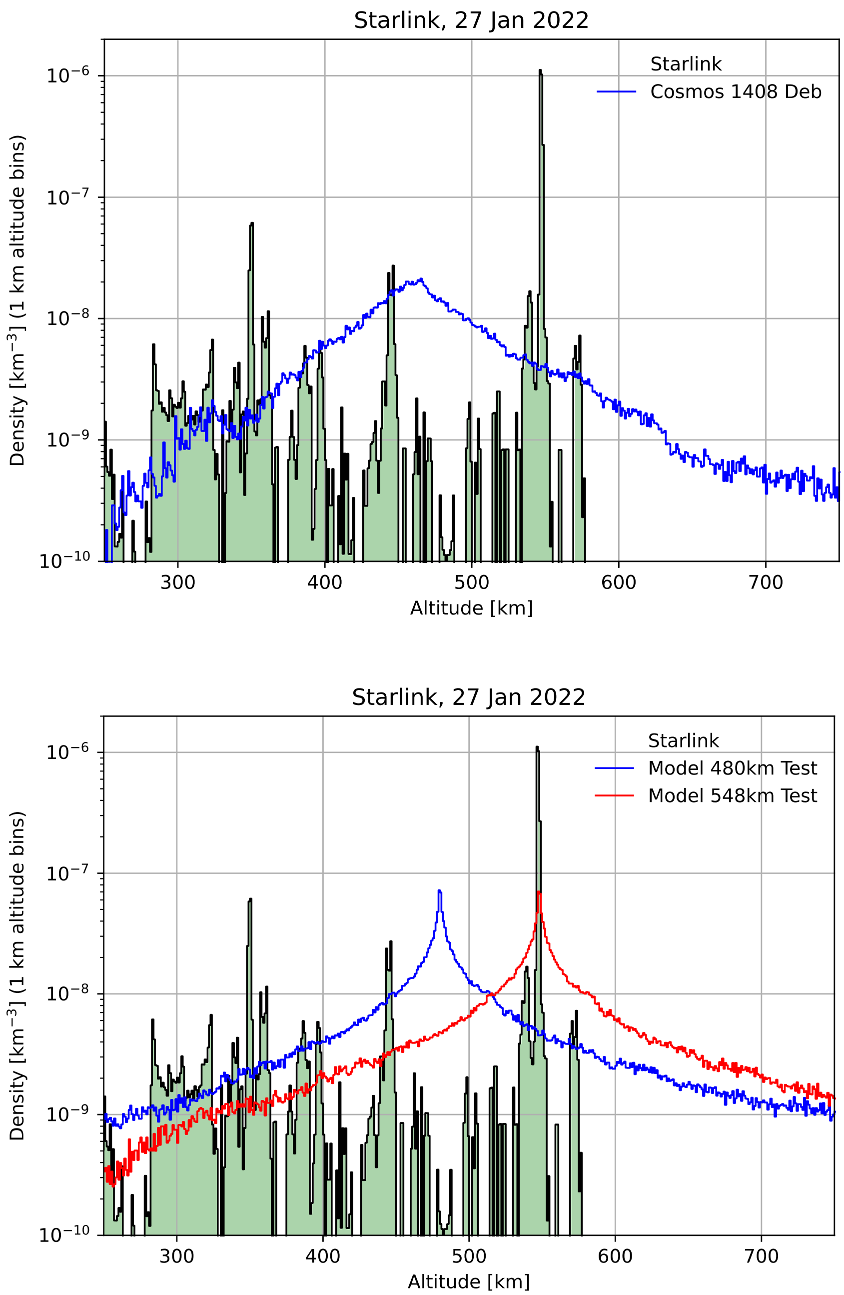

Figure 2: ASAT debris overlapping Starlink satellites. Top. The density distribution for almost 1900 Starlink satellites (green) and Cosmos 1408 debris (blue). Bottom. Similar to the top panel, but for two hypothetical 2021 ASAT test analogues. Note that the actual debris profile has been shaped by some orbital decay, while the model profiles have not. Data: USSPACECOM.[2]