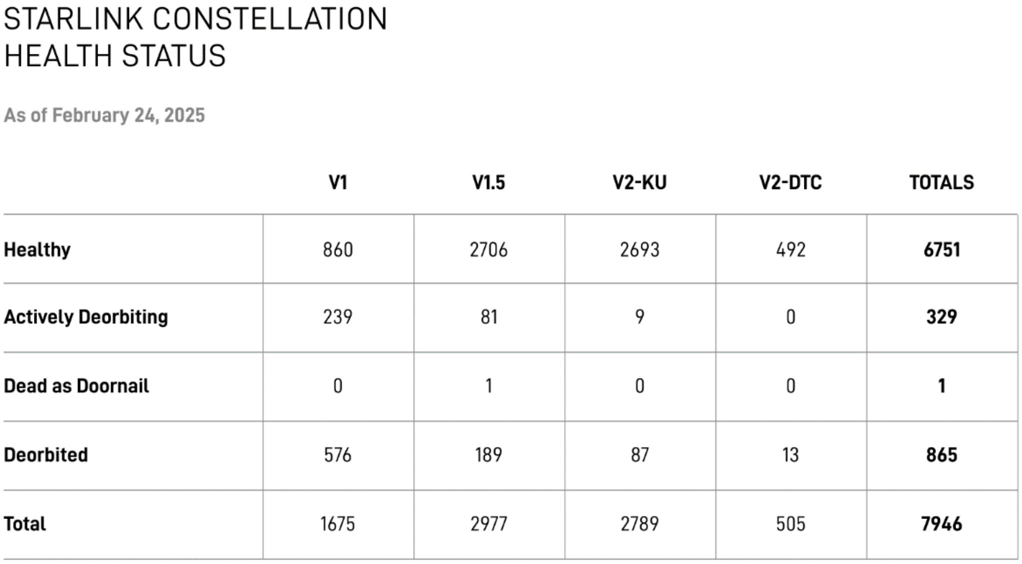
STARLINK SATELLITE DEMISABILITY

Starlink operates the world's largest satellite constellation, with more than 6,750 satellites currently in orbit, serving millions of active customers around the globe with high-speed, low-latency internet. As the world's largest satellite constellation operator, we are deeply committed to space safety. Starlink operates with the most conservative maneuver thresholds in the industry, publicly shares its high-precision ephemerides, and has introduced a space safety service to ease coordination with other satellite operators and launch service providers.

Starlink's Approach to Satellite Demisability

As part of our commitment to space safety, Starlink takes a conservative position on deorbit decisions based on the risk analysis of potential hardware failures. As detailed previously, Starlink began a proactive, large scale deorbit of early V1 satellites in 2024 after identifying a common issue in a small population of these satellites that could increase the probability of future failures. Many of these satellites were on-orbit for more than five years at the time of deorbit. Controlled, propulsive deorbit is much shorter and safer than a comparable uncontrolled, ballistic deorbit from an equivalent altitude and allows all Starlink satellites to maintain maneuverability and collision avoidance capabilities during the descent. Controlled, propulsive deorbit of Starlink satellites also allows SpaceX to continue sharing high-fidelity future position and uncertainty prediction information, multiple times a day, with other operators and launch providers. As a result of this conservative risk posture, Starlink only has a single failed satellite in orbit and expects this number to reduce to zero by the end of 2025.



STARLINK CONSTELLATION
HEALTH STATUS

As of February 24, 2025

	V1	V1.5	V2-KU	V2-DTC	TOTALS
Healthy	860	2706	2693	492	**6751**
Actively Deorbiting	239	81	9	0	**329**
Dead as Doornail	0	1	0	0	**1**
Deorbited	576	189	87	13	**865**
Total	1675	2977	2789	505	**7946**

In this update, we describe how Starlink approaches satellite demisability, referring to the process by which satellites are safely decommissioned and deorbited, leaving no debris in space. The Starlink approach ensures that deorbiting satellites result in no risk to humans on the ground, at sea, or in the air due to impact from satellite fragments.

Targeted Reentry for Deorbiting Satellites

Starlink takes a belt-and-suspenders approach, where we design for demisability but also mitigate risk by targeting deorbits in unpopulated regions. While we design with the intent to be confident that satellites demise with extremely low impact energy, we also retain the paranoia that we might be wrong. Thus, Starlink implements a targeted reentry approach to deorbit satellites over the open ocean, away from populated islands and heavily trafficked airline and maritime routes. This targeted reentry approach is the result of significant technical development and on-orbit testing by Starlink, going above and beyond regulatory requirements for safe reentry.

Successful targeted reentry requires maintaining attitude control down to very low altitudes (~125 km), far below the design requirement of these early Starlink vehicles. This control authority allows us to fly satellites along a reference trajectory, using variable drag (instead of propulsion) to remove energy from the orbit. As shown below, the solar arrays of a V1 satellite are modulated to induce drag. With this approach, we are able to track an atmospheric entry point to within approximately 10% of an orbit's ground track, or ~10 minutes, which is sufficient accuracy to successfully target reentry of the entire potential debris ellipse over the open ocean.

Although we have demonstrated successful targeted reentry numerous times in the past six months, we are still iterating on making this feature robust to attitude control system failures, atmospheric variability, and different vehicle configurations. The V2 Mini and V3 Starlink satellites have been designed with sufficient control authority that they too can be deorbited with targeted reentry over the open ocean.

Satellite Demisability Analysis

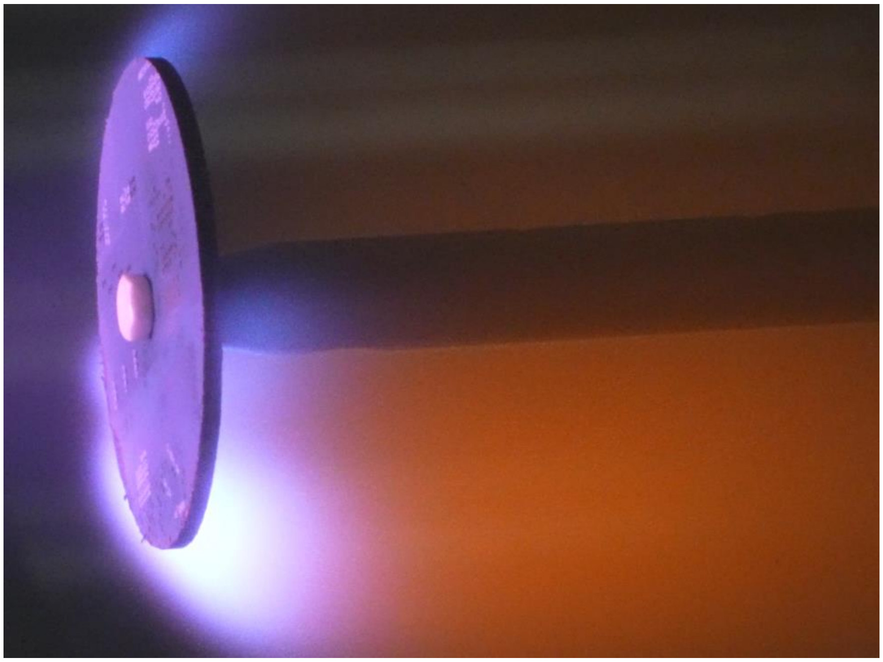
A critical aspect of sustainable satellite design is demisability, which ensures that satellites fully break up and burn up during atmospheric reentry. Any fragments that do not completely demise should have negligible impact energy. As part of the FCC licensing process for satellite constellations, operators must undertake a casualty risk assessment based on U.S. Government Orbital Debris Mitigation Standard Practices (ODMSP) and the NASA Standard that limits the risk of human casualty, anywhere in the world, from a single, uncontrolled reentering space structure, to 1 in 10,000. The human casualty risk assessment includes all objects that would have an impacting kinetic energy in excess of 15 Joules. For reference, 15 Joules of energy corresponds to roughly that of a 1.7" piece of hail.

Starlink takes a much more conservative design approach, targeting an impact energy of <3 Joules at the component level. Starlink's approach to minimizing reentry risk, based on aggressively limiting impact energy coupled with targeted reentry, means that a reentering V2-mini-optimized satellite (the latest iteration of the Starlink V2 satellite currently being launched on Falcon 9) represents a risk of human casualty of less than 1 in 100 million, significantly more conservative than the current industry standard. Our goal is to keep improving this figure (as well as our understanding of the demise physics) on all future designs. If a component is not predicted to fully demise, we ensure via analysis and experimentation that its impact energy falls well below the ODMSP standard of 15 Joules. Again, Starlink's design goal is to have no fragments that exceed a design target of <3 Joules. Therefore, if any fragments survive reentry, they have negligible impact energy.

Components with high melting temperatures, like ceramics, or with very low ballistic coefficients, are likely to survive reentry without fully melting. On the Starlink V2mini satellite, we predict that approximately 5% of the mass of the entire satellite could survive reentry. The biggest contributor (~90% of the surviving mass) is silicon from the solar cells, which has a high melting point and a very low ballistic coefficient, which could survive reentry in extremely small fragments with very low impact energy (<<1 Joule). Other components that do not fully demise include the core of inductors and transformers, which are made of ferrite. To reduce the impact energy of these parts, SpaceX is limiting the size and the mass of each inductor core, even at the cost of reducing their efficiency and increasing the complexity of the system design.

There are several publicly available tools commonly utilized for satellite demise analysis. NASA's Debris Analysis Software (DAS) and ESA's Debris Risk Assessment and Mitigation Analysis (DRAMA) tool can both be utilized to model the breakup, impact energy, and impact risk of reentering objects. However, as discussed below, these tools have inherent limitations and are only as good as their inputs.

To fully understand the demise characteristics of its designs, Starlink does experimental testing to ground its analysis. An example of our experiments studying printed circuit board (PCB) demise is shown below, where we evaluated the behavior of PCBs under reentry-like heating conditions in plasma chambers. These experiments are used to ensure that the predicted behavior from the models is accurate.



PCB at the start of a reentry-like heating test

PCB at the completion of a reentry-like heating test

How Good Are the Tools?

On July 11, 2024, the Falcon 9 launch vehicle launching the Starlink G9-3 mission experienced a second stage engine issue in orbit. After a planned relight of the second stage Merlin Vacuum engine to raise perigee – or the lowest point of orbit – Falcon's second stage engine experienced an anomaly and was unable to complete its second burn. The stage survived the anomaly and deployed the Starlink satellites, at vehicle rates exceeding worst case pre-flight predictions, despite the stage failing to successfully circularize its orbit. This left the satellites in an eccentric orbit with a very low perigee of 135 km, which was less than half the expected perigee altitude. Despite the anomalous deploy, Starlink teams worked to contact the satellites in order to send early orbit-raising burn commands, but the satellites were left in an enormously high-drag environment only 135 km above the Earth. At this level of drag, the maximum available thrust from each satellite was not enough to successfully orbit raise, and all of the satellites launched on the G9-3 mission reentered the atmosphere.

On August 20, 2024, a 2.5 kg piece of aluminum was found on the ground in a farm in Saskatchewan, Canada, and determined by SpaceX engineers to have come from a Starlink satellite that reentered following the erroneous Falcon G9-3 deploy. The debris was traced by SpaceX engineers to a specific satellite and part – a modem enclosure lid of the backhaul antenna on a Starlink direct-to-cell satellite. This part was predicted to fully demise by both the NASA and ESA tools and is the only known Starlink fragment to have not done so.

Given, the survival of this satellite component was not consistent with the analysis described in the previous section, the Starlink program is aggressively working to understand whether unique conditions of the anomalous G9-3 deploy could have contributed to how this component survived reentry. In short, our findings show that the government and industry tools are not accurate when predicting aerothermal loads and heating rates on smaller bodies attached to a larger structure – e.g., before components break away from large structures, like the satellite bus. The typical Starlink reentry approach includes tumbling satellites prior to reentry in order to facilitate and guarantee breakup. On the Falcon 9 G9-3 mission, several Starlink satellites never made contact as a result of the off-nominal deploy from Falcon 9's second stage and were able to maintain aerostability due to the orientation of the solar arrays, preventing tumbling. As a result, the actual breakup altitude was lower than that predicted by the analysis tools. After correcting for under-conservative assumptions in the analysis tools, Starlink was able to more accurately predict the reentry trajectory and survival of fragments, giving confidence to our understanding of the demise physics. All current and future Starlink satellite demise analyses correct the component heating rates in DRAMA, and these tools and model practices will be shared publicly to facilitate their use by other satellite operators. Learnings from this event were quickly incorporated into the design of the V2mini optimized satellite.

Summary

In addition to advancing technologies that are able to scale and provide gigabit connectivity to 100s of millions of people globally, Starlink is leading the way in responsible and sustainable large constellation operations. Starlink is fully committed to ensuring the safe and sustainable deorbit of its satellites, and that those reentering vehicles demise in predictable ways with no impact to humans on the ground. Developing ways to target entry over low population regions rather than allowing satellites to passively enter, and actively testing to improve demisability models are examples of Starlink's proactive approach to responsible and sustainable large constellation operation.