**TON618 Capital**

THEMATIC RESEARCH · SPACE ECONOMY

# Twenty Times Cheaper — Ten Catalysts That Decide Whether It Happens

*TON618 Capital · Research Note · 2026-08-21*

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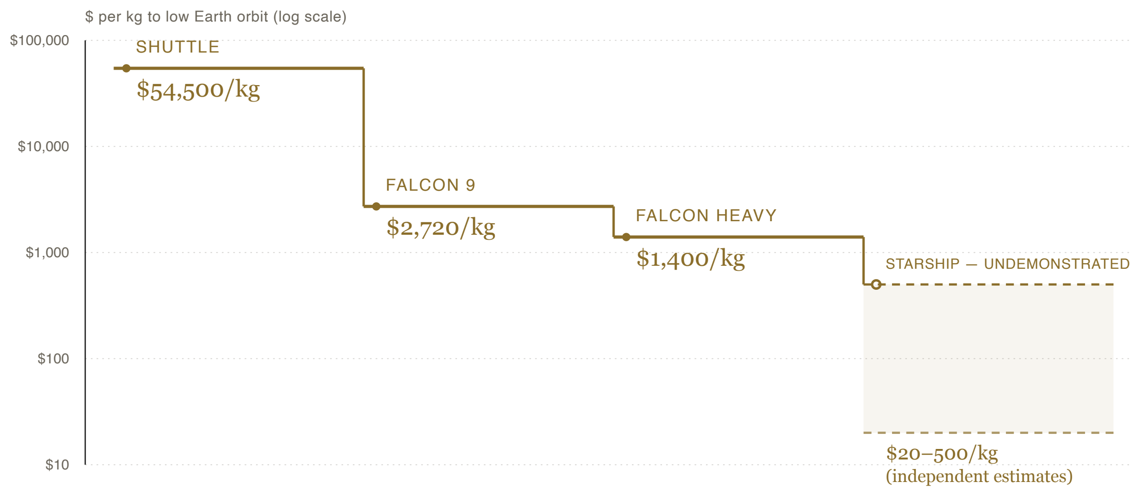


THE THRESHOLD

## Two calls from the same canyon

*A scene, not a forecast [OPINION]. The full version, with both worlds told in their own strongest terms, is §8a.*

It is 2036, and a woman is driving the hundred and twenty-odd miles of Interstate 80 between Winnemucca and Elko, Nevada, through a canyon where no phone has ever worked. Her daughter calls.

In one version of that year, the call connects. It is not fast — the speed of a decent 2015 connection — but it holds through the whole canyon, because the satellite overhead is carrying an antenna the size of a tennis court and her carrier has leased it the spectrum it wasn't using. She pays eight dollars a month for this and thinks of it the way she thinks of the seatbelt. Above her, a Starship launched that Tuesday that nobody in the industry wrote about, because it was the third that week and the tanker it was meeting had been in orbit since Sunday. Three hundred kilometres higher, a satellite with a seventy-metre wingspan is radiating heat from a panel the size of a large house's roof — one of a few thousand that together make a little under a gigawatt of computing, one-hundredth of what was projected a decade earlier, and a real business. And on the rim of Shackleton crater, at the Moon's south pole, four Americans have been living for eight years in a base that began on schedule in 2028, fuelled in Earth orbit by eleven tankers in nineteen days; when a Chinese crew landed forty kilometres away two years later, the base was already there to watch them. It is funded on a continuing resolution. It exists anyway. Launch is a utility nobody writes about. That is what the space economy is.

In the other version, the call drops where it always has. Her carrier offers satellite texting, which works, and "satellite broadband," which is a menu item that delivers three megabits when the beam is not busy. Starship flew twelve times that year, each flight an event, each carrying something irreplaceable; the word *refurbishment* has quietly returned to the industry's vocabulary. There has been no American in orbit for twenty-six months. On the rim of Shackleton crater, a Chinese crew has walked the ice-bearing ground that two American administrations named as the destination; the American landing came eighteen months later, on a rocket that flies once every two years because its statute says it must, and the photograph that mattered — the one that will be shown in every hearing for a decade — is of someone else's flag. Starlink is a very good business. That is what the space economy is.

The same companies, the same budgets and the same physics are at work in both versions. What separates them is a short list of events — a propellant transfer between two ships, a measured payload, a reflown ship, a budget line, a radiator specification — that either happen or do not within a few years of this note. This note is about that list: what has to be true for space to become an industry rather than a program, and how much of it is true today.

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TREAD 1

## Executive Summary

ONE PROFITABLE BUSINESS

**Verdict.** Space is one profitable business and an ecosystem that depends on it. The cost step that already happened — roughly 20× from Shuttle to Falcon 9 — built Starlink, the only large space enterprise that has ever earned money, and a launch cadence (100 Falcon 9 flights by 18 August 2026) the rest of the industry cannot approach. It did not build an industry: three-quarters of that cadence carries the company's own satellites, the Space segment that flies them lost $657 million in 2025, and every second-source rocket failed in 2026. The promised second step — Starship at a few hundred dollars a kilogram — rests on three milestones, none of which has produced a data point: propellant transfer between ships (more than ten tanker flights per lunar mission, per NASA's Inspector General, none flown), reuse of a ship without Shuttle-style refurbishment, and a measured payload to a stable orbit [NASA OIG IG-26-004, 2026-03-10; Jones 2018, 48th International Conference on Environmental Systems, ICES-2018-81].

**The program side.** Artemis is where the two ways of buying spaceflight run side by side, and the record is asymmetric. Fixed-price contracting has controlled cost — the lander contracts grew 6% and under 1% against a $3.47 billion overrun on the cost-plus capsule — but not schedule: NASA's Inspector General calls the lander not ready for its original date, and the agency's safety panel judged the original landing mission "high risk" and a landing-capable Starship in time "probably not achievable" (written before Flights 12–13). The first crewed landing is now Artemis IV in 2028, against China's 2030 target. The expensive half has been written into statute — reconciliation law floors SLS at $1.025 billion and Gateway at $750 million a year — and the administration's attempt to pause Gateway sits in a legal vacuum no one has tested [NASA OIG IG-26-004; OBBBA §40005].

**The demand side.** The only demand story large enough to justify daily heavy-lift flights is compute in orbit. The numbers behind it are the launch provider's own — an IPO prospectus that names orbital compute a strategic pillar, a 150 kW satellite design and a stated one-gigawatt-a-year plan — and the most widely circulated quantification of them, which attributes itself to those statements, contains no thermal input. Rejecting 100 gigawatts of heat in vacuum needs on the order of 110 square kilometres of radiator and, with the best radiator panel NASA has ever tested, about 163,000 tonnes of it: roughly ten times everything now in orbit, before any computer, solar array, or structure is counted [TON618 thermal model, 2026-08-20 (method in §10)]. That is not impossibility; it is a bill that has not been priced — and every tonne of it is also launch demand.

**The public market** prices these names as separate bets, not one trade (pure-play EV/sales from 3.2× to 288.8×), has wiped out five of thirteen SPAC-era entrants and rewarded the two with defense and connectivity revenue, and carries SpaceX at $136.30 against the house's fair value of $78.51 [`spcx-first-print-scored`, scored 2026-08-05; TON618 comps spread, FINRA SI settlement 2026-07-31 / EDGAR XBRL, 2026-08-21]. Short interest across the group is structural — convertibles and a new listing — not a sentiment read.

**What the note commits to.** Ten dated, observable tripwires (Section 8): the propellant-transfer demo; a measured Starship payload above 50 tonnes; a reflown ship with disclosed turnaround; the Artemis III/IV dates; the FY27 SLS and Gateway appropriations language; second-source flight counts; a commercial station before the ISS deorbits; measured direct-to-cell throughput at subscriber density; a debris event in a populated shell; any flown radiator specification above a megawatt. Each has a reading if it lands and a reading if it stays silent. The case for and the case against are stated in their own strongest terms before any of them is tested.

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TREAD 1B

## The business, in plain terms

**One number sets the boundary for everything else.** Every dollar figure in this note — a satellite company's stock multiple, the size of a government contract, whether a lunar lander flies on schedule — traces back to what it costs to move one kilogram of mass from the ground into low Earth orbit, the number this note calls $/kg to LEO. That number has already fallen by roughly 20× once: from about $54,500/kg on the Space Shuttle to about $2,720/kg on Falcon 9, achieved not by a new fuel or a new engine but by reuse — recovering and re-flying a rocket's first stage instead of throwing it away after a single flight [Jones 2018]. A steep drop in the cost of reaching orbit works the way a steep drop in ocean-shipping cost once did: it does not just make the missions people were already flying cheaper, it makes missions nobody could previously afford worth attempting. That is why $/kg functions as the industry's master variable. It does not describe the launch business alone — it sets the ceiling on every business built on top of launch, including ones, like orbital data centers, that do not exist yet.

**Three ways to make money — and only one of them has.** The industry earns revenue three distinct ways. The first is selling the launch itself: charging a satellite operator or a government agency to put a payload on a rocket. The second is selling a service that only exists because launch got cheap enough to build it — Starlink's broadband connectivity, and the newer direct-to-cell (D2C) business that beams a cell signal from orbit straight to an ordinary phone. The third is selling hardware and missions to governments: NASA's human-landing-system contracts under Artemis, and defense-agency programs like the Space Development Agency's missile-tracking satellites and the Space Force's launch-services contracts. Of the three, only the second has shown up as profitable in the numbers this note carries. SpaceX's Connectivity segment generated $11.387 billion of FY2025 revenue — 61% of the company's total — and was the only segment with a GAAP operating profit, at $4.42 billion. Space, the segment that actually does the launching (it also includes satellite manufacturing), lost $657 million in FY2025 and another $662 million in the first quarter of 2026 [SpaceX Form 424B4, SEC EDGAR; Form 10-Q]. The government-contracts leg is sized in this note by contract value, not by a disclosed profit margin: the Space Development Agency's $3.5 billion Tranche 3 award and the Space Force's $13.7 billion NSSL Lane 2 award (§3) are commitments to spend, not evidence either the government or its contractors turns a profit on the work.

**Who pays matters more than what's technically possible.** Three kinds of customer show up in this note: the launch company launching its own payloads, governments buying missions and capacity, and a small set of commercial operators buying launch or connectivity from someone else. That distinction matters because it is easy to confuse "this could theoretically work" with "someone is paying for it." Starlink's share of Falcon 9's own launch schedule rose from 54% in 2020 to roughly 79% in 2026, while external-customer revenue stayed roughly flat — cadence growth that looks like a thriving market is substantially one company launching its own satellites (§3). Orbital compute makes the same point from the other direction: 100 gigawatts of orbital data-center capacity is not physically impossible — Section 4's model finds a specific, large area and mass, not a wall — but almost none of the demand numbers behind it trace to an actual buyer's contract. They trace to the launch provider's own public statements — its prospectus, its satellite design, its stated build rate — and to third-party quantifications that cite those statements as their source (§4, T4). This note also keeps three government-money words apart for the same reason: a number that is merely requested (asked for, not voted on) is not the same claim as one that is appropriated (enacted into law) or obligated (contracted against money that exists) — see §3.

**What "reuse" actually requires.** Reuse means recovering a rocket stage and flying it again instead of discarding it; refurbishment is the inspection and repair work a reused vehicle needs before its next flight. Whether a reusable rocket is actually cheap comes down to three numbers, not one. The first is refurbishment cost: the Space Shuttle's fastest turnaround between flights, in thirty years of the program, was reportedly 54 days (a secondary figure; see T2), and it was never repeated; no Starship ship has yet been recovered, refurbished, and reflown to produce a comparable number of its own (§4, T2). The second is flight rate: NASA's Inspector General states that a single crewed Moon landing requires "more than 10" Starship tanker flights, roughly one every six days, to move enough propellant — a rate nobody has yet flown (§4, T1). The third is payload mass: how much cargo a rocket can actually deliver to a stable orbit, as opposed to the tonnage a company targets. As of this note, no Starship V3 flight has delivered a measured payload to a stable orbit; the one flight that deployed operational satellites did so on a suborbital trajectory (§4, T3). A rocket can be reusable and still be expensive if any one of these three numbers is bad.

**How the industry gets measured.** A handful of recurring figures do most of the work in this note. Mass to orbit — the tonnage a provider actually delivers, not just how often it launches — is the cleanest measure of who is doing the work: SpaceX delivered roughly 2,213 metric tons in 2025, about 80% of the global total [BryceTech, FY2025 report]. Launch cadence — the count of launches in a period — measures how fast a cost advantage turns into flown missions; Falcon 9 reached its 100th launch of 2026 on 18 August. Manifest share — the percentage of a provider's own schedule filled with its own payloads — separates real outside demand from internal use, which is why Starlink's rise to roughly 79% of the Falcon 9 manifest matters more than the raw launch count. Backlog — the dollar value of signed work not yet flown — is not disclosed as a single audited figure anywhere in this note's sourcing, so contract-award totals like the $3.5 billion SDA award and the $13.7 billion NSSL award stand in as the closest proxy for how much future revenue is already committed. Segment revenue and operating loss — what a business unit earns and what it costs to run — is how this note finds that Space loses money while Connectivity earns it. And EV/sales — enterprise value divided by revenue, used because most of these companies do not yet have positive earnings to value against — is how the public market prices the group: the pure-play names span 3.2× to 288.8× [TON618 comps spread] (§6).

**How the rest of this note is built.** Section 2 lays out the cost curve itself — what already fell, and what a second fall would require. Section 3 asks what that cost step unlocks in demand, and for whom. Section 4 tests the physics standing between today's numbers and tomorrow's promises, one unsolved problem at a time. Section 5 uses Artemis, NASA's Moon program, as the one place a government-funded structure and a commercial company are buying the same outcome side by side, so their track records can be compared directly. Section 6 maps who else is in the business and how the public market prices them. Section 7 covers the politics — budgets, treaties, regulation — that decide which version of this future actually gets funded. Section 8 closes with ten dated, checkable events that will move this read one way or the other over the next year or two.

TREAD 1A

## The case for and the case against — stated before the test

**The case that space becomes an industry, 2026–2036.** The $/kg curve already broke once, empirically: Shuttle at $54,500/kg to Falcon 9 at $2,720/kg is a ~20× reduction already in the historical record, not a projection [Jones 2018]. Falcon 9 hit its 100th launch of 2026 on 18 August — two months faster than the equivalent 2024 milestone — guiding to 140–145 for the year, up from 25 in 2020. The downstream business the cheap launch enabled is already profitable, not merely promised: Connectivity generated $11.387B of FY2025 revenue (61% of total) and a GAAP operating profit of $4.42B — the pattern a large e-commerce company followed with its own cloud platform, where a capital-intensive platform runs thin while a downstream business it enables becomes the profit engine and funds the next generation. Starship's flight record shows a program converging, not stalling: Flight 12's booster-relight failure was exactly the kind of failure a flight-test program exists to surface, and Flight 13 succeeded nine weeks later, the ship surviving splashdown intact for the first time. Government demand stepped up an order of magnitude in one budget cycle, backed by contracts already signed: SDA's $3.5B award and NSSL's $13.7B Lane 2 award describe a buyer deliberately building redundancy into its own supply chain. D2C moved from spectrum fight to a demonstrated link inside one year (AST SpaceMobile's 98.9 Mbps, disclosed under securities law). Reuse generalized beyond one company: China's Long March 10B completed a maiden flight with a net-captured recovery — if reuse is a generalizable method rather than a SpaceX-specific trick, the global cost curve has room to keep falling. Capital agrees, independent of any single print: Rocket Lab and AST SpaceMobile are up 630% and 551% from their SPAC reference prices; Blue Origin's first-ever outside round priced it at a ~$130B pre-money valuation.

**The case that the sector disappoints or is mispriced.** The market's own most cost-advantaged, highest-cadence launch operator disclosed, under securities law, that its Space segment lost $657M on $4.086B of FY2025 revenue, and lost another $662M in Q1 2026 — a second consecutive negative quarter with no dated capex peak disclosed. The cadence growth that looks like demand elasticity is mostly one company launching its own satellites: Starlink's manifest share rose to roughly 75–79% while external revenue stayed roughly flat. The vehicle meant to extend the cost curve has not demonstrated its own load-bearing claim: ship-to-ship propellant transfer has never been demonstrated by anyone, and Raptor 3, marketed as the reliability fix, failed on its debut. The "second source" story is collapsing: New Glenn flew once and failed to reach orbit, then a second vehicle exploded on the pad; Neutron has not flown. Orbital compute — the strand carrying the most speculative multiple — rests on the company's own statements with no independent thermal input: this note's smoke test finds 100 GW needs 163,000–1.13 million tonnes of radiator mass, 10×–70× everything in Earth orbit, even using the best NASA-tested prototype. D2C shows the identical marketing-versus-measurement gap: AST's 98.9 Mbps is a single disclosed peak, while the only independently measured figure anywhere — Starlink D2C's crowdsourced dataset — found a median of ~3.1 Mbps, two orders of magnitude below. Human-spaceflight infrastructure is sliding when it needs to hold: Artemis IV now targets 2028 after Artemis III was demoted to an Earth-orbit demo, and NASA's safety panel called a flight-ready Starship "probably not achievable." The capital-markets record argues for selection risk, not a rising tide: 5 of 13 SPAC-era names are down more than 90% or wiped out, and the sector's own ETF is only ~34% arguably-pure-space, having had to rename itself and broaden its mandate to stay investable.

**What this note's own framework tests, and what it cannot.** The tripwires in Section 8 (SE-1 through SE-10) test the propellant-transfer, payload-fraction, reuse/refurbishment, Artemis schedule, appropriations-vs-request, second-source cadence, commercial-station, D2C throughput, debris-cascade, and orbital-compute claims — the load-bearing empirical claims on both sides. What this framework **cannot** test, because no observable exists yet or the mechanism is legal/political rather than physical: whether the

Gateway Impoundment Control Act question is ever formally litigated; whether the Musk-government relationship's durability holds absent an actual contract clawback; whether China's 2030 target converges or slips, given thin CMSA reporting; and whether RKLB/ASTS represent genuine second-wave validation or two-name survivorship, undistinguishable before a third SPAC-era cohort exists to test against. These are flagged, not resolved, and are not converted into tripwires because they lack a bounded, dated observable.

TREAD 2

## The Cost Curve

*This section answers: what has launch actually cost, in real historical numbers, and what does it cost today? It follows directly from §1b, which named $/kg to LEO as the master variable without yet supplying the figures behind it. The takeaway to carry forward: one real, documented ~20× cost drop has already happened; a second drop, the one Starship is meant to deliver, is still a wide range built on undemonstrated flights, not a settled fact.*

Every claim in this note about space "becoming an industry" traces to one number: the dollar cost of putting one kilogram of mass into **low Earth orbit (LEO — roughly 160–2,000 km above Earth, where nearly all satellite constellations and crewed spaceflight to date have operated)**. The standard reference is Jones (2018), *"The Recent Large Reduction in Space Launch Cost"* (48th International Conference on Environmental Systems, ICES-2018-81, NASA CASI-indexed). In 2018 dollars, the Space Shuttle delivered mass to LEO at roughly **$54,500 per kilogram ($/kg)**; Falcon 9, expendable-equivalent, at **$2,720/kg**; Falcon Heavy at roughly **$1,400/kg** [Jones 2018]. That is a **~20× reduction**, achieved by **reuse** — recovering and re-flying a first stage rather than discarding it — and the **refurbishment** discipline (inspection and repair between flights) reuse demands. No new propellant chemistry did this; a business model did. 2026 pricing has not moved the headline number much: Falcon 9's list price runs roughly $74 million per launch, carried forward from essentially the same arithmetic Jones used. One estimate argues Falcon 9's true marginal cost is closer to $300/lb (~$660/kg) — roughly 25% of what customers pay [nextbigfuture.com, 2026-02] — an estimate, not an audited disclosure, but one that matters: if correct, part of the "cost reduction" story is SpaceX's own margin choice, not a hard floor.

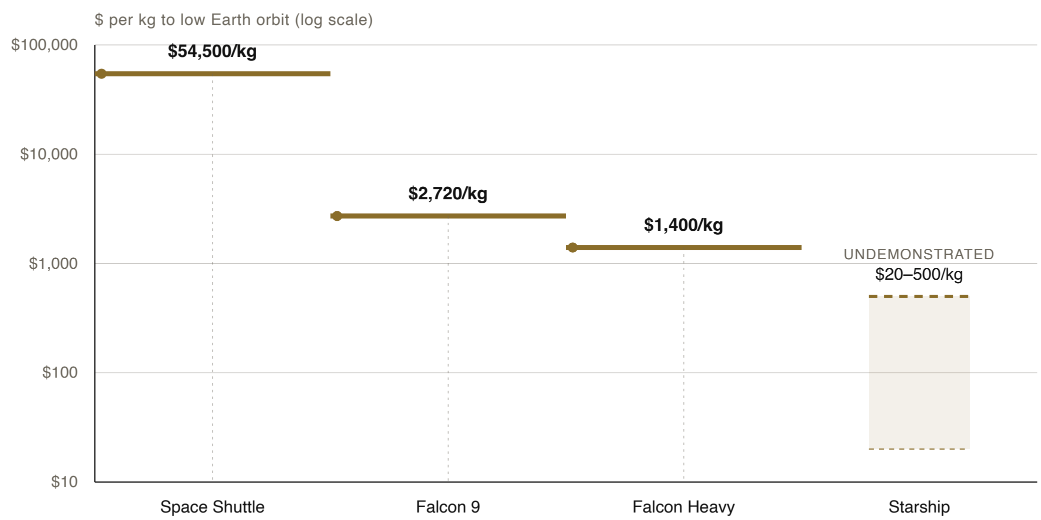
**The segment-level correction.** SpaceX does not report a "launch segment." Its Form 424B4 (2026-06-12) and 10-Q (period ended 2026-06-30, filed 2026-08-04) report three segments: **Space** (Falcon 9, Falcon Heavy, Starship, Starlink satellite manufacturing — broader than launch alone), **Connectivity** (Starlink service revenue), and **AI** (a broader, xAI-linked segment). For FY2025, Space generated **$4,086 million of revenue, an operating loss of $(657) million, and Adjusted EBITDA of $653 million**; the loss deepened in Q1 2026 to $(662) million on $619 million of revenue. In Q2 2026: Space $962M (12.3%), Connectivity $4,291M (54.9%), AI $2,561M, total $7,814M. **The company whose reusability broke the cost curve does not, on its own segment accounting, make money launching rockets.** Connectivity generated $11.387 billion of FY2025 revenue — 61% of total — and was the only segment with a GAAP operating profit, at $4.42 billion. The $/kg story and the "who profits from cheap launch" story are different claims, not conflated here.

**Cadence, concentrated.** SpaceX flew 21 times in 2018, rising to 167 in 2025. Falcon 9 reached its **100th launch of 2026 on 18 August** — two months faster than the equivalent 2024 milestone — guiding to ~140–145 for the year [SpaceDaily, 2026-08-18, secondary]. Starlink's share of the Falcon 9 **manifest** rose from 54% (2020) to roughly 79% (2026) [press reporting, Aug 2026]. The cadence that makes the cost curve look "used" is disproportionately SpaceX launching its own satellites — not proof a broad external market responded elastically.

**The promised second step.** Starship is built to extend the curve roughly another order of magnitude. Independent $/kg estimates span an unusually wide range: **$20–35/kg** in older optimistic projections, a more recent **~$100/kg** built on ~100 ships/year [Handmer], to Payload Research's estimate of Starship's *current*, expendable-V1 cost at roughly **$500/kg**. This note treats Starship's $/kg as a range — roughly **$20–500/kg** — not a point: every number at the low end assumes zero flight-demonstrated outcomes: (1) reuse without refurbishment (T2); (2) a measured payload — Flight 13 (2026-07-24) deployed 20 V3 Starlinks, but suborbital (T3); (3) the propellant-transfer flight rate HLS requires. NASA's OIG (IG-26-004, p.5) states SpaceX's plan requires **"more than 10" tanker flights** per HLS mission, one every ~6 days; ASAP corroborates, citing "at least a dozen V3s." The test is **"more than 10 tanker flights, undemonstrated," not a numeric dispute.**

The flight record so far, as SpaceX's own S-1 counted it at Flight 12 (2026-05-22): **12 integrated flights — 7 successful, 5 RUD** ("rapid unscheduled disassembly", the company's phrase for a vehicle lost in flight). Flight 12, the Block 3/Raptor 3 debut, was a partial failure: booster B19 suffered engine issues, forcing a hard ocean impact. Flight 13 (2026-07-24) succeeded — 20 V3 Starlinks deployed, soft splashdown off Western Australia; Booster 20's landing burn failed, destroying the booster. Flight 14, the first genuine orbital-profile attempt with a planned tower-catch, is targeted NET late August 2026 (unconfirmed). The step that already happened built the only large, profitable business ever constructed around orbit access — though that profit sits in Connectivity, not the Space segment whose cadence created the "$/kg fell" story. The promised second step remains a range, not a point.

**EXHIBIT 1** The 20× that already happened — $/kg to LEO (log scale)




**TREAD 3**

## What Each Threshold Unlocks (Demand)

*This section answers: now that launch is roughly 20× cheaper than it was, what does that actually unlock, and who is buying it? It follows from §2's cost history the way a price cut naturally raises the next question — what does the lower price make possible. The takeaway to carry forward: real demand did show up, but it is heavily concentrated in one buyer using its own cheap launch, and of the outside demand strands that could be next, only one is large enough to matter — and it is also the least proven.*

The ~20× cost step created demand — but predominantly SpaceX's own. The manifest figures in §2 (Starlink from 54% to roughly 79% of Falcon 9's schedule) sit alongside external-customer Space-segment revenue that was roughly flat through 2025 even as total launch count grew [press reporting, Aug 2026]. That fact supports two readings the record does not resolve: the strand *worked as designed* — internal demand for cheap launch monetized downstream, the pattern a large e-commerce company followed with its own cloud platform — or the demand is *internal only*. What resolves it: the trend in external revenue over further quarters, and whether a second launch provider sees comparable order growth at similar prices.

Three words are kept deliberately distinct: **requested** (a budget ask, not voted on), **appropriated** (funds Congress has enacted into law), and **obligated** (a contract signed against appropriated funds). Conflating any two overstates a strand's certainty. In order of current, sourced size: defense proliferation, direct-to-cell connectivity, stations/manufacturing, lunar logistics, and orbital compute — the smallest strand in committed dollars today, but the only one whose theoretical scale justifies *daily* Starship-class flight rates.

**Defense proliferation.** The Space Force's enacted FY26 topline is **$31.9 billion**. Its **FY27 request is $71.3 billion** (+123%), of which $12.1 billion is contingent on an unpassed reconciliation bill — *requested*, not appropriated [SatNews; SpacePolicyOnline, 2026-08-06]. Already *obligated*: SDA's Tranche 3 Tracking Layer put **$3.5 billion across four vendors** (Lockheed Martin $1.1B, L3Harris $843M, Rocket Lab $805M, Northrop Grumman $784M) for 72 satellites, awarded 2025-12-19 as **Other Transaction Agreements (OTAs — a vehicle under 10 U.S.C. §4022 letting an agency move faster and admit non-traditional vendors)**. NSSL Phase 3 Lane 2 committed **$13.7 billion** in April 2025 (SpaceX $5.92B/28 missions, ULA $5.37B/19, Blue Origin $2.39B/7); Lane 1's ceiling tripled to **$17B** in July 2026, bringing combined NSSL to roughly $30 billion across seven vendors.

Golden Dome — the largest headline figure — illustrates why the three words cannot be used interchangeably. Total program cost is estimated at **$185 billion** (a competing, unconfirmed press figure of $175 billion also circulates — Section 9). The **FY27-specific ask is $17.9 billion** ($17.1B reconciliation-contingent); the House Appropriations mark to date provides only **$397.9 million — a ~45× gap**. What has actually been *obligated*: SpaceX won **$6.45 billion across two Golden-Dome-related contracts within a four-day span in May 2026** — data/communications-layer work, not interceptors. In plain terms: roughly $30 billion of launch work and $3.5 billion of satellites are signed; $71 billion is asked for; $185 billion is a headline. The case for a durable strand: signed contracts describe a buyer deliberately building redundancy. The case against: most of the FY27 ask is contingent on one unpassed bill, and requests are routinely cut in conference. What resolves it: FY27 enacted appropriations.

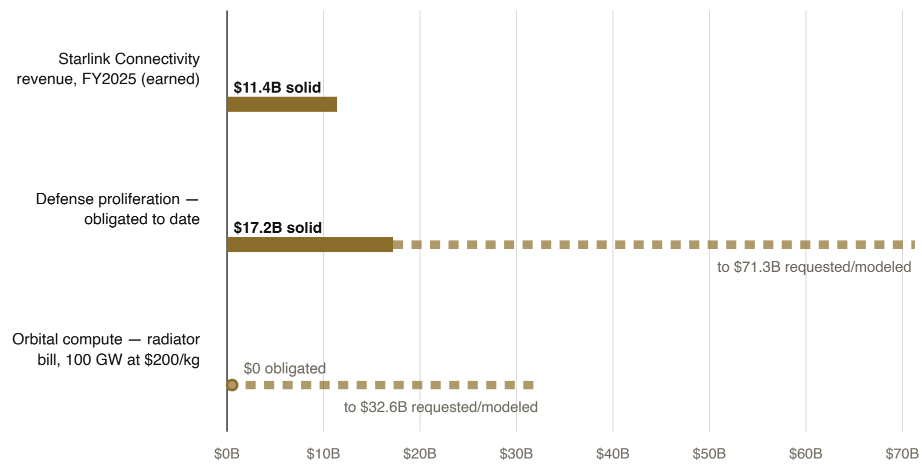
**Direct-to-cell (D2C).** D2C is a satellite constellation broadcasting a cellular signal directly to an unmodified smartphone. FCC Order DA 26-391 (2026-04-21) authorized AST SpaceMobile to operate up to 248 satellites providing **Supplemental Coverage from Space (SCS — leasing a terrestrial carrier's spectrum to fill coverage gaps, "strictly non-interference, unprotected")** on AT&T/Verizon spectrum. AST's 10-Q discloses a **peak 98.9 Mbps** to a standard smartphone — a demonstrated peak, not a network-typical rate. The only independently measured, at-scale figure anywhere in the record is a crowdsourced Starlink D2C dataset showing a **median per-beam throughput of ~3.1 Mbps** — two orders of magnitude below AST's peak [arXiv 2506.00283]. A D2C cell of roughly 1–4 km², carrying 20–150 Mbps shared, sits **1–3 orders of magnitude below** a terrestrial macro cell's ~1 Gbps/km² capacity. This note sizes D2C as a coverage-gap strand, not competitive with terrestrial broadband — Section 4 (T5) tests the physics.

**Stations and in-space manufacturing.** NASA's CLD program has **not** awarded Phase 2; **award is now planned for Spring 2027**, not the "early 2026" originally scheduled. Axiom targets 2027; Vast's Haven-1 has slipped to NET Q1 2027; Starlab targets ~2028; Orbital Reef's most recent milestone is a June 2025 SDR, furthest behind. The ISS is committed through 2030, deorbit late 2030/early 2031 — realized size depends on a commercial successor operating with paying crew before then (Section 8, SE-7).

**Lunar logistics.** Not an independent market — a function of NASA's Artemis schedule. Every crewed HLS mission requires the "more than 10" tanker flights above, plus a storage-depot launch. On CLPS: Astrobotic's Griffin-1 has slipped to Q4 2026; IM-3 to Q1 2027; Draper's CP-12 was cancelled in July 2026.

**Orbital compute — the strand large enough to matter, and untested.** The claim originates with the launch provider: SpaceX's IPO prospectus discloses "orbital compute" as a strategic pillar and a "Terafab" chip partnership; trade-press reporting (no primary source located) describes an "AI1" satellite — 150 kW peak, ~70-meter wingspan — and a plan of roughly one gigawatt of orbital compute a year by late 2027. Starcloud, the venture-funded operator that flew the first H100 in orbit, publishes a 5 GW-class concept. The most widely circulated quantification of the opportunity — roughly **25% less expensive** than terrestrial compute below $100/kg, driving a **60×** increase in reusable-rocket demand to satisfy **100 GW** — appears in ARK Invest's "Big Ideas 2026" (2026-01-21), which attributes it to "SpaceX public statements"; neither that quantification nor any public model the house could locate carries a $/kg, W/kg, or radiator-mass input [TON618 thermal model, 2026-08-20 (method in §10)]. Orbital compute is, by its proponents' own framing, the one strand whose realized scale would require daily cadence to make a second $/kg step matter — and the strand whose physics carries the largest untested assumption in this note. Section 4 (T4) tests it in full: 100 GW requires 163,000–1.13 million tonnes of radiator mass alone, 10×–70× all mass currently in Earth orbit.

**EXHIBIT 2** Solid tread, dashed tread — obligated vs. requested/modeled demand ($B)




TREAD 4

## The Six Technical Problems

*This section answers: before treating any of §3's demand strands as real, does the physics and flight record actually support them? It follows from §3 because naming a demand strand — orbital compute, direct-to-cell, lunar logistics — is not the same as showing the hardware behind it works; this section checks the hardware. The takeaway to carry forward: every load-bearing technical claim in this note — propellant transfer, heat-shield reuse, payload mass, orbital compute's thermal bill, direct-to-cell throughput, debris control — has a plausible physical case and, so far, zero flight-demonstrated data confirming it.*

Six load-bearing unsolved problems gate the demand strands above; eleven smaller ones follow in a compact box. Each of the six closes with the same three-line standard: **the claim being sold / the physics or flight data that tests it / the observable that settles it.** The framing throughout is "here is the frontier where it becomes possible," never "impossible." Stefan-Boltzmann forbids nothing; it sets an area.

### T1 Orbital cryogenic propellant transfer

**Boil-off** is cryogenic propellant absorbing heat and vaporizing; **settling** is using low-thrust propulsion to force propellant to a tank outlet in near-zero gravity; **transfer loss** is propellant vented or boiled off rather than usefully delivered between vehicles.

**Why this matters to the money.** The tanker-flight count below is not a technical curiosity — it is the multiplier behind two dollar figures already in this note. Every crewed Artemis landing needs a storage-depot launch plus the "more than 10" tanker flights described below before the mission itself can fly, and NASA's $4.3 billion Appendix H value for the HLS award (§5) prices a mission built on that flight count actually working. It is also the flight-rate assumption behind the cheapest published Starship $/kg estimates in §2 — the low end of the ~$20–500/kg range assumes a cadence this section's physics has not yet been demonstrated at.

NASA's Office of Inspector General, in IG-26-004 (2026-03-10, p.5), states — drawn from SpaceX's own mission plan — that ahead of Artemis III and IV, SpaceX will launch a storage depot to LEO followed by **"more than 10 Starship tankers,"** targeting one launch every ~6 days. ASAP's 2025 Annual Report independently corroborates the low end, citing **"at least a dozen V3s"** [ASAP 2025 Annual Report, p.22, 2026-02-25]. OIG, ASAP, and SpaceX's own public "~10" figure converge in the same range; none has flight data behind the number, because the demonstration that would produce it has not happened.

Ship-to-ship cryogenic propellant transfer has never been demonstrated by anyone. The only flight data is Starship's Flight 3 (March 2024), which moved roughly 5 tonnes of LOX from a header tank to the main tank on a **single ship** — no docking, no second vehicle. A 2024 review in *npj Microgravity* catalogues settling, slosh, and vapor-liquid separation as active research areas, not solved problems with an agreed coefficient [nature.com/articles/s41526-024-00377-5]. The actual ship-to-ship demonstration is planned no earlier than late 2026 and has not flown.

**The claim being sold:** more than 10 (OIG/SpaceX) to "at least a dozen" (ASAP) Starship tanker flights, launched roughly every 6 days, aggregate enough propellant to fuel one HLS mission. **The physics or flight data that tests it:** ship-to-ship transfer has never been flown by anyone; the only flight data is a single-ship, ~5-tonne intra-vehicle transfer; the settling and boil-off physics that would set a real loss rate remain open research topics. **The observable that settles it (SE-1):** the actual ship-to-ship propellant-transfer demonstration flying, with quantity transferred and loss percentage disclosed.

## T2 Reusable heat shield

**TPS (Thermal Protection System)** is the outer layer of a reentry vehicle that absorbs or rejects atmospheric-friction heat; **refurbishment** is the inspection, repair, and replacement work required before a reused vehicle flies again.

**Why this matters to the money.** Reuse only lowers cost if refurbishment between flights is fast and cheap; if it is not, the ~20× reduction §2 documents does not extend further, and the low end of Starship's $20–500/kg range becomes unreachable even if every other piece works. Falcon 9's own $2,720/kg figure already reflects a real, working refurbishment discipline [Jones 2018] — the comparator below tests whether Starship can match it or instead reverts toward the Shuttle's far more expensive pattern.

The comparator is the Space Shuttle: roughly 20,000-plus individually unique, hand-bonded tiles, averaging about 50 replaced per mission; the single fastest turnaround in the 30-year program — Atlantis, 1985 — was **54 days** [secondary, unconfirmed], never repeated [NASA CASI TPS refurbishment study; americaspace.com]. Starship carries roughly 18,000 hexagonal tiles. Flight 13 (2026-07-24) was deliberately flown at higher dynamic pressure specifically to stress-test tile adhesion and reportedly lost only a handful — a genuinely favorable data point. But no Starship *ship* (as distinct from the booster) has yet been caught, refurbished, and reflown to produce an actual turnaround-time number; only two boosters have been reflown, and the booster does not carry the reentry tiles. There is a live, unresolved disagreement: skeptics argue the tile system is "inspection-bound by design" regardless of loss rate, while SpaceX's position is that the ablative sub-layer and gap-fillers mean a single lost tile rarely threatens the vehicle, changing the *required* inspection standard rather than the loss rate [techtimes.com vs. nextbigfuture.com]. Both positions are consistent with the same Flight 13 data; the disagreement is about what a low loss rate implies for turnaround time, not what was observed.

**The claim being sold:** near-zero-refurbishment reuse, avoiding Shuttle's months-long, labor-intensive turnaround cycle. **The physics or flight data that tests it:** Shuttle's 54-day turnaround floor, never repeated and handinspection-bound, versus Starship's favorable early tile-loss data and the absence, as of this draft, of any reflown-*ship* turnaround-time comparator. **The observable that settles it (SE-3):** a reflown Starship ship with turnaround under 30 days and tile-replacement count disclosed.

## T3 Payload mass fraction

**Payload mass fraction** is the tonnage a vehicle can actually deliver to a stated orbit, as distinct from the tonnage targeted; **dry mass** is vehicle structure alone, excluding propellant and payload.

**Why this matters to the money.** $/kg is a fraction — dollars spent divided by kilograms actually delivered — so the denominator matters as much as the price tag in the numerator. Every Starship $/kg estimate in §2, from the optimistic ~$20–35/kg figures to Payload Research's ~$500/kg estimate, assumes a specific tonnage reaching orbit; if the delivered payload comes in lower than targeted, the same launch cost divides into a smaller number and every figure in that range moves higher, regardless of what the rocket costs to fly.

SpaceX's V3 Starship is targeted at roughly 100–200 tonnes to LEO fully reusable, up to ~400 tonnes expendable — figures that vary across the company's own public statements, itself indicating design targets rather than a fixed specification [satnews.com; payloadspace.com]. As of this note, **no V3 flight has delivered a measured payload to a stable orbit.** Flight 12 (2026-05-22), the first integrated V3/Raptor 3 flight, was a partial failure with a hard ocean impact on the booster. Flight 13 (2026-07-24) deployed 20 operational V3 Starlink satellites — the first Starship flight to deploy operational satellites at all — but on a **suborbital** trajectory, not a full orbital deployment [space.com]. That is the precise test: a suborbital deployment of 20 satellites demonstrates deployment mechanics, not payload-to-orbit capacity. Flight 14, pending, is reported as the mission intended to reach a genuine orbital profile. The predecessor V2 vehicle supports treating these as targets under revision: V2 never reached orbit and, per secondary reporting not yet confirmed against a primary figure, carried roughly 16 tonnes on its best suborbital flight — a wide underperformance against its own target, flagged as needing primary confirmation before being treated as load-bearing [americaspace.com, secondary — see Section 9].

**The claim being sold:** V3 Starship reaches 100–200 tonnes to LEO reusable (up to ~400t expendable). **The physics or flight data that tests it:** no V3 flight has delivered a measured payload to a stable orbit; Flight 13's 20-satellite deployment was suborbital; the predecessor vehicle underperformed its own target on secondary sourcing still needing primary confirmation. **The observable that settles it (SE-2):** the first Starship flight with a measured payload greater than 50 tonnes delivered to a stable orbit.

## T4 The Radiator Problem, rad-hard compute, and downlink

**Radiator** — a deployed panel rejecting waste heat by thermal radiation, since there is no air in orbit to carry heat away by convection. **Stefan-Boltzmann law** — radiated power per unit area = $\varepsilon \cdot \sigma \cdot T^4$; the $T^4$ term means a small rise in operating temperature buys a large rise in heat-rejection capacity per unit area. **TID (total ionizing dose)** — cumulative radiation exposure, measured in krad(Si); **SEU (single-event upset)** — a transient error from a single particle strike. **HBM/TPU** — high-bandwidth memory stacked on modern AI accelerators; Google's custom AI chip.

**Why this matters to the money.** Of the five demand strands §3 sizes, orbital compute is the only one whose claimed scale — 100 gigawatts — is large enough to justify daily Starship-class flight rates, which is exactly why it carries the industry's most speculative narrative weight. The case its proponents make is that sub-$100/kg launch makes orbital compute economic and drives a 60× increase in reusable-rocket demand — a launch-demand multiplier larger than every other strand in §3 combined (§3). Whether that math holds depends entirely on the thermal-mass bill this section prices for the first time.

The claim under test is the launch provider's: SpaceX's prospectus names orbital compute a strategic pillar, its AI1 design and ~1 GW/year plan (benchmarked below) state the build rate, and Starcloud's 5 GW concept states the scale. The quantification most readers have seen — that at sub-$100/kg launch costs "space-based compute could prove **25% less expensive than terrestrial compute**," driving a **60×** increase in reusable-rocket demand to satisfy **100 GW** — is ARK Invest's [Big Ideas 2026, pp.33–37, 2026-01-21], and ARK attributes it to **"SpaceX**

**public statements"**. What matters for this section is not whose number it is but what it omits: an audit of the only public, code-level model behind it found worksheets for Earth, Earth-Bandwidth-TAM, and Mars, and **no orbital-data-center worksheet and no $/kg, W/kg, or radiator-mass input anywhere** [TON618 thermal model, 2026-08-20 (method in §10)]. The house found no public model from any party that prices thermal mass.

A stdlib Python model applies Stefan-Boltzmann directly to a hypothetical 100 GW fleet, two-sided panels at ε=0.85 [TON618 thermal model, run 2026-08-20 (method in §10)]:

| REJECT TEMP (K) | ENVIRONMENT | NET FLUX (W/M²) | AREA (KM²) |
|---|---|---|---|
| 300 | LEO | 223.0 | 448.5 |
| 350 | LEO | 888.7 | 112.5 |
| 400 | LEO | 1,909.9 | 52.4 |
| 300 | GEO/deep-space | 780.8 | 128.1 |
| 350 | GEO/deep-space | 1,446.5 | 69.1 |
| 400 | GEO/deep-space | 2,467.7 | 40.5 |

Reject temperature, not orbit choice, dominates: moving from 300 K to 400 K collapses the LEO area requirement from 448.5 to 52.4 km² — an 8.6× reduction from the $T^4$ term alone. Converting area to mass at four areal-density figures, spanning flown hardware to the best NASA-tested prototype:

| HARDWARE | KG/M² |
|---|---|
| ISS PVR (flown, 1995-era) | 7.8 |
| Conventional metal radiator (GEO comsat heritage) | 10.0 |
| NASA advanced lightweight target (unflown) | 3.0 |
| Best credible advanced (tested prototype) | 1.45 |

At the LEO, 350 K case — **the middle case** between the 300 K flown-ISS-heritage floor and the 400 K frontier below, and the one this note's headline figures use because it is the temperature at which flown spacecraft thermal-control hardware actually operates — conventional flown-heritage hardware requires **~1,125,254 tonnes** of radiator mass alone — **~70× all mass currently in Earth orbit combined** (16,185 tonnes at end-2025, McDowell 2025). The single best NASA-tested prototype in the literature reduces the figure only to **~163,162 tonnes, still ~10× everything now in orbit** [TON618 thermal model, 2026-08-20 (method in §10)].

At 400 K — the other side's best case, and the frontier this model tests — the same best-credible-advanced hardware falls further still, to **~75,921 tonnes, ~4.7× everything now in orbit, or roughly 507 Starship flights at 150 t/flight** [TON618 thermal model, 2026-08-20 (method in §10)]. That case is shown, not buried, and it is not the headline for a stated reason: no flown thermal-control loop rejects heat at 400 K, because the hardware it is cooling has to run hotter still. Commercial silicon, including the high-bandwidth memory (HBM) that the radiation discussion below identifies as the most sensitive subsystem, carries junction-temperature limits clustered in the 350–360 K range [OPINION — standard silicon-datasheet limits, not a flown-hardware citation for this specific figure], and a radiator has to reject heat *above* the chip temperature it serves; a coolant loop's own ΔT and pumping-efficiency losses eat further into that margin before the panel ever sees 400 K. The one way around that ceiling is an active heat pump — thermoacoustic devices, which move heat along a tube of pressurised gas using a sound wave and no moving parts, are the variant now being pushed toward commercial use [pv magazine, 2026-

04-23] — lifting the radiator above the chip temperature it serves; but a heat pump consumes electrical power that becomes further waste heat for the same radiator, and one funded orbital-compute developer, Sophia Space, chose passive heat spreading precisely to avoid that tax, claiming 92% of generated power reaches the compute against 66–72% for active heat-pump designs [TechCrunch, 2026-02-26; Via Satellite, 2026-06-23]. A heat pump, in other words, buys the 400 K row at the price of a larger power and radiator budget; it does not remove the area. SE-10 — a flown radiator spec above 1 MW — is the observable that would test whether this ceiling is real or merely undemonstrated.

**$/kg × t/MW → $/MW — thermal subsystem only, LEO, 350 K reject**

| HARDWARE | T/MW | $1,000/KG | $200/KG | $50/KG | $10/KG |
|---|---|---|---|---|---|
| ISS PVR (flown) | 8.78 | $8,776,984 | $1,755,397 | $438,849 | $87,770 |
| Conventional (10 kg/m²) | 11.25 | $11,252,544 | $2,250,509 | $562,627 | $112,525 |
| NASA advanced target | 3.38 | $3,375,763 | $675,153 | $168,788 | $33,758 |
| **Best credible advanced** | **1.63** | **$1,631,619** | **$326,324** | **$81,581** | **$16,316** |

At the sub-$100/kg crossover the claim itself specifies, using the best-credible-advanced hardware line, the thermal subsystem alone still costs $16,000–$82,000 per MW to loft (the $50/kg and $10/kg columns), before compute hardware, solar arrays, or shielding; at the $200/kg price point — above that crossover — the same hardware line costs roughly $326,000/MW. **The extrapolation weakness, stated openly:** the ISS's Active Thermal Control System rejects roughly 70 kW via six radiator arrays — the flight heritage behind every areal-density figure above. A 100 GW fleet is ~1,430,000× larger. Area and mass scale defensibly under Stefan-Boltzmann; cost and on-orbit assembly logistics at that scale carry no flight precedent.

**Rad-hard compute and downlink.** Heat is the first of three mass bills an orbital data center has to pay, and the radiator is only the part of the spacecraft that disposes of it. The second bill is radiation: outside the atmosphere and much of the magnetosphere, charged particles corrupt and degrade ordinary silicon, so the compute either uses slower radiation-hardened parts or is wrapped in shielding — and shielding is mass that must be launched and, because it traps heat, adds to the load the radiator must reject. The third bill is the link to the ground. Each is sized here from the proponents' own figures. Starcloud's whitepaper states "$1.2m @ 1kg of shielding per kW of compute" — an unverified company claim. At that ratio, 100 GW requires roughly **100,000 tonnes of shielding**, the same order of magnitude as the best-case radiator mass above. Google's Suncatcher preprint found a V6e Trillium TPU shows **no hard failures up to 15 krad(Si)** (20× the mission's requirement), but **HBM — the most sensitive subsystem — shows irregularities at just 2 krad(Si)**, only ~2.7× the requirement [Google, arXiv:2511.19468]. Purpose-built radiation-hardened silicon buys SEU-rate reductions "up to six orders of magnitude" at a compute-density cost of roughly three orders of magnitude versus a modern GPU — why every serious proposal flies commercial-off-the-shelf accelerators with added shielding instead. NASA's TBIRD demonstrated **200 Gbps** LEO-to-ground downlink in 2023 — two orders of magnitude below Suncatcher's demonstrated inter-satellite link (800 Gbps/1.6 Tbps) — and Google's paper concludes existing commercial optical links, "including Starlink's," "**do not meet the multi-Terabit... requirements**" for tightly-coupled clusters, directly contradicting Starcloud's proposal to piggyback on them.

**Benchmark: SpaceX's AI1.** SpaceX has disclosed a design, "AI1" — 150 kW peak/~120 kW average, ~70-meter wingspan, no primary source located. **100,000,000 kW ÷ 150 kW ≈ 667,000 satellites** to reach 100 GW (833,333 at the 120 kW average) — a satellite-count stress test complementing the smoke test's tonnage-based one, both orders of magnitude beyond anything flown. AI1's roadmap of ~1 GW/year by late 2027 implies roughly a century to reach 100 GW.

**The launch-tonnage twist.** Every input that makes orbital compute *worse* for the compute buyer — heavier radiators, shielding, a lower reject temperature — makes it *better* for the launch provider, because all that mass has to be launched. A radiator fleet at conventional hardware requires roughly 7,500–11,300 Starship flights at 350 K; even best-case hardware requires over a thousand — none visible in the "25% cheaper" framing. **T4's own arithmetic argues against orbital compute clearing on unit economics, and simultaneously argues for the same 60× reusable-rocket-demand multiplier the claim cites — for a different reason than its stated one.**

**The claim being sold:** orbital data centers deliver compute at ~25% below terrestrial cost once launch reaches sub-$100/kg, made by the launch provider (prospectus pillar, AI1 design, ~1 GW/year plan) and by Starcloud (5 GW concept), and quantified most widely by ARK Invest, which attributes the figures to SpaceX's public statements. **The physics or flight data that tests it:** Stefan-Boltzmann arithmetic applied to flown/tested hardware requires 40.5–448.5 km² of radiator for 100 GW and, at the middle case (350 K) reject temperature with conventional flown hardware, roughly 1.13 million tonnes of radiator mass alone (~70× everything now in orbit), falling only to ~163,000 tonnes (~10×) with the best NASA-tested prototype; shielding adds a comparable additional mass line; HBM shows irregularities near the mission's own dose requirement; ground downlink sits two orders of magnitude below demonstrated inter-satellite capacity. **The observable that settles it (SE-10):** any orbital-compute operator publishing a flown radiator specification or kg/MW figure at greater than 1 MW of actual operating capacity.

**163,000 t**

Radiator mass for 100 GW of orbital compute, at the single best NASA-tested prototype in the literature — roughly 10× everything now in Earth orbit combined.

### T5 Direct-to-cell link budget

**Link budget** — the full accounting of gain and loss a radio signal experiences transmitter-to-receiver. **EIRP** — the power a transmitter would need to radiate equally in all directions to produce the achieved signal strength. **Aperture** — the physical or effective area of an antenna. **PFD** — power per unit area a signal delivers at distance, the regulatory quantity the FCC caps.

**Why this matters to the money.** AST SpaceMobile trades at 288.8× EV/sales, the highest multiple of any name in this note's comps universe (§6), and that multiple is a bet on the D2C link budget closing at commercial scale, not merely on the peak speed already disclosed. The physics below tests exactly the claim the market is pricing: whether AST's 98.9 Mbps peak generalizes into a real service, or whether the only independently measured D2C figure anywhere — Starlink's ~3.1 Mbps median — is the more representative number.

AST SpaceMobile's Form 10-Q states the company has "achieved **98.9 Mbps peak data speeds directly to a standard unmodified smartphone**" — a tested peak, not a commercial-network throughput. Both AST and Starlink face the same fixed constraint: the 3GPP Power Class 3 standard caps a smartphone's transmit output at 23 dBm (~200 mW), forcing the link-budget burden onto the satellite's receive aperture. AST's answer is aperture: Block 1 satellites carry ~64 m² arrays; Block 2 carry ~223 m². Starlink's answer is constellation scale: a roughly 6 m² antenna per satellite, substituting hundreds of satellites for aperture [AST SpaceMobile 10-Q; secondary reporting on the Starlink antenna comparison]. FCC Order DA 26-391 caps the service via aggregate power-flux-density and elevation-angle-dependent dynamic EIRP, not an explicit Mbps number — throughput is geometry-dependent, and 98.9 Mbps is most plausibly a best-case result; SCS itself operates on an "unserved area," "strictly non-interference, unprotected" basis.

The only independently measured, at-scale figure for either company is the same Starlink D2C crowdsourced dataset cited in Section 3: **median per-beam throughput of ~3.1 Mbps** [arXiv 2506.00283, Oct 2024–Jul 2025 dataset], two orders of magnitude below AST's peak — not apples-to-apples, but the closest anchor for real-world delivery. The same study attributes that median to Starlink's current 2×5 MHz spectrum allocation and projects roughly 18.6 Mbps per beam on the 2×30 MHz aggregate SpaceX is acquiring from EchoStar (Section 7) — the measured figure is as much a spectrum cap as an architecture cap. A modeled terrestrial LTE deployment delivers roughly 1 Gbps/km² of aggregate capacity, median user throughput 7.9–34 Mbps. AST's own claimed cell (1–4 km², 20–150 Mbps shared) sits **1–3 orders of magnitude below** that benchmark.

**The claim being sold:** AST SpaceMobile's 98.9 Mbps peak, positioned as broadband-class direct-to-cell service. **The physics or flight data that tests it:** the only independently measured, at-scale figure for any D2C service — Starlink's crowdsourced dataset — sits roughly two orders of magnitude below the AST headline figure; the FCC's own structure caps the service via geometry-dependent EIRP rather than a fixed rate; areal capacity places satellite D2C 1–3 orders of magnitude below terrestrial guided infrastructure. **The observable that settles it (SE-8):** independently measured throughput per cell at meaningful subscriber density from a live commercial service — not a test call, not a company-disclosed peak.

## T6 Kessler syndrome / debris cascade

**Conjunction** — a predicted close approach between tracked objects. **Kessler syndrome** — a hypothesized self-sustaining collision-debris chain reaction. **Deorbit compliance** — the share of satellites or rocket bodies leaving orbit within a stated guideline after mission end.

**Why this matters to the money.** Every dollar this note attributes to a working space business ultimately depends on satellites in a populated shell staying intact. Connectivity — the only GAAP-profitable segment in this note, at $11.387 billion of FY2025 revenue (§2) — is carried on the largest single constellation exposed to the collision risk this section tests. A debris cascade in a heavily used shell would not be an abstract environmental event; it would be a direct threat to the one part of the space economy that already makes money, which is why the weak enforcement record below matters as much as the physics.

"Automated avoidance handles it" is the operative industry claim. SpaceX's semi-annual Starlink collision-avoidance report is reported, via multiple matching secondary sources, to disclose **207,152 maneuvers** for December 2025–May 2026, up from **148,696** the prior period — the underlying FCC filing could not be located and is treated as secondary [secondary reporting — AIAA/Aerospace America, space.com; see Section 9]. SpaceX maneuvers at a threshold roughly 300× stricter than the industry-standard trigger. The count's deceleration (from roughly doubling every six months in 2022–23 to ~50% annual growth by 2024–25) is confounded by that ~300-fold tightening — a meaningful share of the growth reflects a more conservative policy, not purely rising true risk.

Maneuver counts, by construction, only capture *predicted* conjunctions; they say nothing about spontaneous self-fragmentation. Two Starlink satellites broke apart in the populated shell within roughly three months: satellite 35956 around 2025-12-19 at 418 km, attributed by SpaceX to an "internal energetic source," corroborated by LeoLabs [The Register, 2025-12-23]; satellite 34343 around 2026-03-29 at ~560 km (weaker sourcing). Neither is collision-attributed, but two events within three months is inconsistent with a "zero fragmentation" framing.

Deorbit compliance sits in a wide range, not a point estimate, per ESA's 2026 Space Environment Report (Issue 10.0, 2026-05-01, data through end-2025): **44,964** tracked objects; rocket-body compliance with the 25-year LEO guideline **60–90%**, the tighter 5-year standard **30–80%**; payload compliance **40–90%** and **5–65%** respectively [ESA Space Debris Office, Table 3.1]. A previously circulating "≥95% compliance threshold" attributed to ESA was searched directly against the full report text and **is not present anywhere** — dropped entirely. No binding international enforcement mechanism exists: the FCC's 5-year rule (Order 22-74) is US-only, its only enforcement precedent (a $150,000 fine) falling under the *old* 25-year rule; the IADC's 2002 guidelines, adopted by UN COPUOS in 2007, remain explicitly voluntary, with no penalty authority anywhere.

**The claim being sold:** automated collision avoidance, evidenced by a rising and decelerating maneuver count, adequately manages collision risk at current and projected constellation scale. **The physics or flight data that tests it:** the deceleration is confounded by a ~300× tightening of SpaceX's own trigger threshold; maneuvers address only predicted conjunctions and did not prevent two self-fragmentation events within roughly three months; deorbit compliance sits in wide ranges (60–90%/30–80% rocket bodies, 40–90%/5–65% payloads), not the point estimates or 95% threshold previously misattributed to ESA; no binding international enforcement mechanism exists. **The observable that settles it (SE-9):** an ESA/NASA ODPO quarterly conjunction or fragmentation-event report in a populated shell, independent of SpaceX's self-reported count.

### T7–T17 Also unsolved — T7 through T17

**T7 Engine reliability at cadence.** Flight 12's Raptor 3 debut saw 5 of 33 booster engines fail to relight — an FAA-declared mishap; near-daily cadence requires this rate to fall substantially, with no post-Flight-12 sample large enough yet for a new baseline. **T8 Cislunar boil-off in NRHO.** The Artemis-baseline halo orbit offers near-continuous solar exposure, thermally harder on propellant than LEO; secondary-sourced NRHO tanker estimates range "four to over ten," lower-confidence than T1's figures. **T9 Orion Avcoat char loss.** Artemis I's heat shield lost material during skip-entry; NASA modified the trajectory rather than rebuild the shield, and Artemis II (April 2026) flew it successfully — one flight validating the workaround, not an independent fix. **T10 Lunar dust and PSR thermal extremes.** No primary source quantifies lunar-dust adhesion or shadowed-region hardware qualification; flagged as an evidentiary gap. **T11 GCR/SPE shielding mass.** NASA Langley's guideline targets 20 g/cm² of hydrogen-rich shielding; counter-intuitively, non-hydrogenous shielding beyond that can *increase* dose via secondary-particle production. **T12 Laser downlink.** Folded fully into T4 above. **T13 Space-based solar power.** Faces the identical Stefan-Boltzmann economics as T4's waste-heat problem, plus transmission/rectenna infrastructure on top; no primary source located — an inference from T4's physics. **T14 ISRU water-ice extraction.** No extraction process demonstrated at flight scale; NASA cancelled the VIPER prospecting rover in 2024, its payload reassigned to a repeatedly-delayed CLPS mission. **T15 Closed-loop life-support beyond ~98%.** No primary source quantifying current recovery rates was located; flagged as a gap. **T16 On-orbit servicing and refueling.** No primary source beyond the T1 material was located; flagged as a gap. **T17 Human-risk tail.** NASA's Inspector General: "NASA does not currently have the capability to rescue a stranded crew from space or the lunar surface." Starship's crew elevator sits ~115 feet up with no alternate entry if it fails — a "top risk" HLS itself tracks, alongside the sector's already-realized tail risk this decade (Boeing's Starliner, Section 5), not yet realized for Starship.

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TREAD 5

## Artemis — The Test Case

*This section answers: how do the unsolved problems in §4 actually play out inside one real program, where a bill has to be paid and a date has to be hit? It follows from §4 because Artemis is where several of those open technical questions — propellant transfer, payload mass, reusable heat shields — stop being abstract and become a specific mission with a customer and a deadline. It is also the one place a fixed-price commercial contract and a traditional cost-plus government contract are buying the same outcome side by side, which makes it a natural comparison. The takeaway to carry forward: the fixed-price, commercial half of Artemis has controlled cost but not schedule; the cost-plus, legacy half has controlled neither, and is protected by law regardless.*

Science and national prestige never competed with industrial profitability while the state paid for both — Apollo's spacecraft, launch vehicles, and science payloads were one federal bill. What has changed is that the profit side of the space economy now has its own engine: SpaceX's Connectivity segment is GAAP-profitable and does not need the Moon to keep growing. Artemis is the one program where a cost-plus legacy structure (SLS, Orion, and — until March 2026 — Gateway) and a fixed-price commercial structure (**HLS**, the Human Landing System) run side by side. **Cost-plus** contracting reimburses allowable costs plus a fee, so a schedule slip adds directly to the government's bill; **fixed-price** pays a set milestone price, so a slip is absorbed by the contractor. **OBBBA** (P.L. 119-21, 2025-07-04) is a different statute from **P.L. 119-74**, the FY2026 CJS appropriations act (2026-01-23) — frequently conflated in secondary reporting, kept separate here.

**Cost record.** SpaceX's HLS award grew from Option A ($2.89B, 2021-04-16) through Option B (~$1B) to a total Appendix H value of $4.3B; per OIG's text, that value had grown **6% — roughly $253 million** — through December 2025. Blue Origin's Appendix P award, originally **"approximately $3.1 billion,"** had grown **less than 1% — $13 million** [NASA OIG IG-26-004, p.18]. By contrast, Orion's life-cycle cost baseline grew from **$11.28B (April 2023) to $14.76B (April 2026)** — a **$3.47 billion overrun, 73% of NASA's entire 53-project major-projects portfolio overrun** [GAO-26-108556]. OIG's synthesis: "NASA's acquisition approach for the lunar landers has been effective in controlling contract costs... This approach contrasts with development efforts using cost-plus contracts, where schedule delays typically result in contract cost increases." The defensible reading is narrow: fixed-price has controlled NASA's budget exposure; it says nothing about whether the vehicle flies on time.

**Schedule record.** The same OIG report documents the fixed-price half is behind: **"SpaceX's lander will not be ready for a June 2027 lunar landing"** [p.4]. ASAP is sharper: **"the Panel deems Artemis III a high risk"** and, on Starship, **"appears daunting and, to the Panel, probably not achievable"** [ASAP 2025 Annual Report, p.21–22]. Two further OIG findings: **"NASA does not currently have the capability to rescue a stranded crew from space or the lunar surface,"** and Starship's crew elevator, roughly 115 feet up, has "no other method for the crew to enter the vehicle... in the event of an elevator failure" — a "top risk" HLS itself tracks [p.4, p.25, p.29]. Blue Origin: an ~11-month CDR delay pushes that milestone to July 2026, and Artemis V has moved to **NET March 2030**.

**The statutory floor.** OBBBA §40005 requires: not less than **$750,000,000** obligated for Gateway each FY2026–2028; not less than **$1,025,000,000** for SLS each FY2026–2029; $20,000,000 for Orion in FY2026. P.L. 119-74 contains **zero occurrences of "Gateway," "SLS," or "commercial alternative"** in direct text — the widely cited reallocation language is committee-report text attached to that statute, not OBBBA's. NASA's FY2027 Budget Request shows a 23.0% topline cut and states Gateway "will be transitioned to support development of a lunar base camp... no discretionary funding is requested for Gateway." Congress pushed back: the House CJS markup (H.R. 8845, 2026-05-15) holds NASA flat at $24.4B, increases SLS to $2.6B, and restates the reallocation bar with an added human-rating certification requirement. The Senate CJS subcommittee had not released an FY27 bill as of 2026-08-21; the government is on a continuing resolution.

**The Gateway pause and the legal vacuum.** NASA's "Ignition Day" release (2026-03-24) states: **"the agency intends to pause Gateway in its current form and shift focus to infrastructure that enables sustained surface operations."** Administrator Isaacman issued a stop-work order to Northrop Grumman on the HALO module (~$1.9B contract) in April 2026, citing 0% schedule confidence and structural corrosion; funds have been redirected into "Lunar Infrastructure Demos," not against "Gateway" as named in statute. **No GAO decision and no formal Impoundment Control Act challenge were found.** Whether this is lawful program-management discretion or an unlitigated impoundment is a live, unforced question.

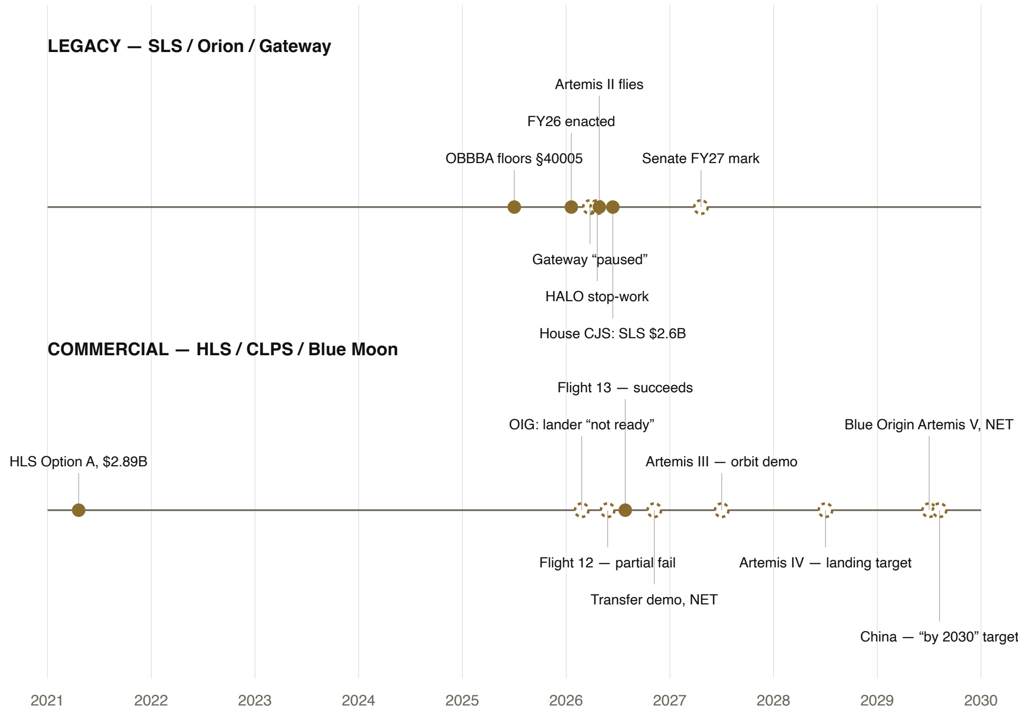
**Starliner vs. Dragon.** Both were contracted under the same fixed-price vehicle, same customer, same 2014 award round. NASA OIG found Starliner's per-seat cost at ~$90M vs. Dragon's ~$55M, and that NASA paid Boeing an "unnecessary" $287.2 million [NASA OIG IG-20-005]. Boeing's 10-K discloses cumulative Starliner charges exceeding **$2 billion**, including a **$523 million single-year charge in 2024** — the year of its crewed thruster failures and uncrewed return; Dragon has operated at cost since 2020. **Fixed-price transfers financial risk to the contractor; it does not, on the Starliner evidence, guarantee execution quality.**

**China as the coalition glue.** "Beat China" holds the SLS/Orion/Gateway coalition together (Senate hearing "There's a Bad Moon on the Rise," 2025-09-03). China's target remains "by 2030"; the **Long March 10B's** maiden flight (2026-07-10), net-captured off Hainan, is the world's first such recovery besides SpaceX. One flight is not a cadence, and China's timeline still trails Artemis IV's 2028 target — but it is the fact giving "beat China" its remaining force. A live complication: the identical rationale now both *saves* SLS/Orion/Gateway as a bundle and justifies *killing Gateway's original design*.

**What each model has and has not delivered.** Fixed-price (HLS) has delivered cost control (+6% SpaceX, +<1% Blue Origin) but not a lander ready on schedule, a demonstrated propellant transfer, or a resolved manual-control certification. Cost-plus (SLS/Orion) has delivered a flown, crewed Orion (Artemis II, April 2026) and a funding floor that has outlasted the executive's stated intent to retire the hardware, but not cost discipline, and — on Gateway —

not the station Congress funded. Neither model has delivered Artemis III as originally defined. **The correct statement is not that the commercial model wins.** Fixed-price has controlled what NASA pays. Cost-plus has controlled what gets built, because its enforcement mechanism is Congress rather than a milestone schedule. Neither structure has solved schedule risk. And the political durability of cost-plus funding has, so far, outlasted the executive's intent to retire the hardware it pays for.

**EXHIBIT 3** Artemis, 2021–2030 — legacy and commercial tracks




TREAD 6

## Landscape

*This section answers: who else is actually in this business besides the one company §2 through §5 have mostly been describing, and how does the public stock market price them? It follows from §5's government test case by turning to the commercial competitors and the public companies an investor can actually buy shares in. The takeaway to carry forward: one company still dominates by an overwhelming margin, every near-term "second source" launch provider stumbled in 2026, and the public names trade as differentiated, individually priced bets rather than one basket that rises or falls together.*

One company accounts for roughly 80% of global mass delivered to orbit and reached its 100th launch of calendar 2026 on 18 August; every other actor is defined, in some form, by its relationship to that company. BryceTech's full-year-2025 report — the most recent complete annual dataset — puts the global 2025 total at **325 orbital launches and 4,544 spacecraft deployed**. SpaceX flew **165 orbital launches (~51%)** and delivered roughly **2,213 metric tons (~80%+ of 2025 global mass-to-orbit)**; China's CASC flew 68 launches and delivered an estimated ~262 tons — roughly 12% of SpaceX's total [BryceTech, FY2025 report, published ~April 2026].

**Second sources — all delayed or failed in 2026.** New Glenn (Blue Origin) flew once — a failure in which the upper stage did not reach orbit — before a second vehicle **exploded during a pre-launch static-fire test on 28 May 2026**, destroying the pad; repair is estimated at over a year. Vulcan Centaur (ULA) flew once successfully despite a solid-rocket-booster anomaly, after which the Space Force paused all Vulcan NSSL missions (~25 February 2026); resumption status is **unverified** as of this writing. Neutron (Rocket Lab) has not yet flown; the target is Q4 2026 after a January 2026 propellant-tank failure. Ariane 6 completed 3 launches in 2026, targeting "as many as eight" for the year. A launch market with one high-cadence, reliable provider and every near-term Western second source delayed, failed, or missing its own pad is not, on 2026's record, a competitive industry — though each program retains a stated near-term flight path, what Section 8's SE-6 tripwire tests.

**China — the only other working reuse demonstration.** China's crewed lunar-landing target remains "by 2030." Its **Long March 10B (reusable variant) completed its maiden flight on 10 July 2026**, its first-stage booster recovered via net-capture — the world's first such recovery besides SpaceX. One recovery is a demonstration, not a cadence, but it is the first evidence reuse is not necessarily a SpaceX-specific trick.

**The public capital-markets universe — differentiated, not one trade.** Among the eight pure-play names (RKLB, ASTS, LUNR, RDW, BKSY, KTOS, IRDM, VSAT; PL excluded from the median for a data gap), **EV/Sales spans 3.2× (VSAT) to 288.8× (ASTS)** and revenue growth spans **-9.2% (LUNR) to +413.0% (ASTS)** [TON618 comps spread, FINRA SI settlement 2026-07-31 / EDGAR XBRL, 2026-08-21]. The pure-play median EV/Sales is **10.7×**; the full 13-name blended median (7.8×) is pulled down by conglomerates (NOC, LMT, BA, 2.0–2.5×) not comparable to the pure-plays. ASTS and RKLB are priced on a pre-revenue-scale, optionality basis; VSAT (+$1,592M TTM operating cash flow) and IRDM (+34.4% FCF margin, +22.0% ROE) actually generate free cash flow yet trade at the bottom of the multiple range; LUNR, RDW, BKSY, and PL cluster at 8×–14× with double-digit stock-comp drag and deeply negative operating margins.

**The SPAC-era base rate.** Of 13 names public via SPAC merger in 2020–22, **five are down more than 90% or wiped out** — Astra, Virgin Orbit (Chapter 11, 2023), Momentus, Virgin Galactic (SPCE $3.08, 2026-08-20, down ~98.5% pre-split-equivalent), and Terran Orbital (acquired by Lockheed at $0.25/share). One is down a moderate ~47% (Satellogic, SATL $5.30). **Seven are flat-to-up**, led by **Rocket Lab (RKLB $72.95, +630% from its $10 SPAC reference) and AST SpaceMobile (ASTS $65.06, +551%)** [2026-08-20 close]. The dispersion is closer to a system where the two standouts share the clearest defense-revenue and connectivity-demand stories, and picking correctly between those two — not owning the cohort — was the return driver.

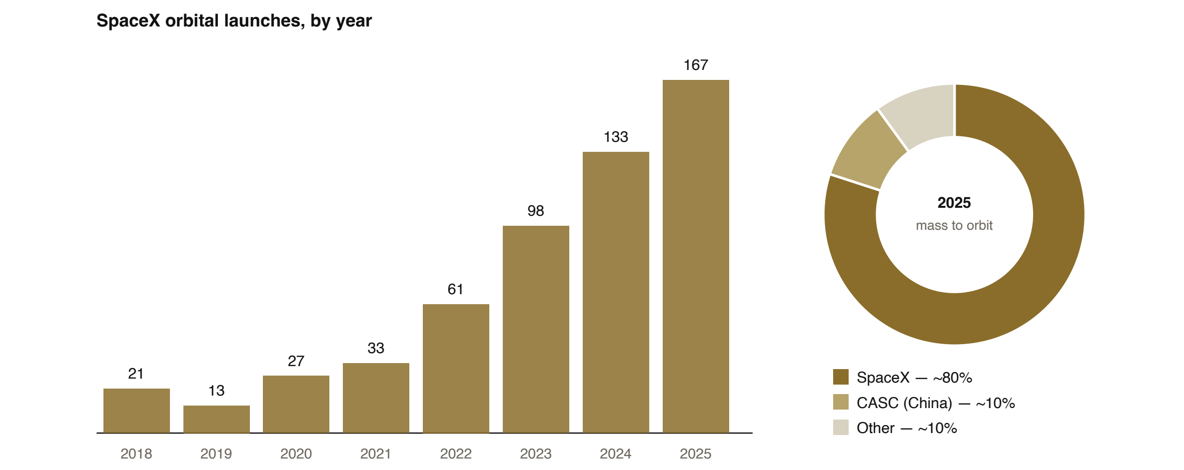
**ARKX and UFO — neither builds a pure-space basket.** ARKX (renamed "ARK Space & Defense Innovation ETF," Nov 2025) held, as of 2026-08-11, a top-15 led by SPCX (9.00%), KTOS (7.41%), LHX (7.00%), RKLB (5.51%), AVAV (5.11%) plus Deere, Amazon, AMD, Alphabet, Archer, Nvidia, and Palantir — summing arguably-pure-space names to only **34.0%** of top-15 weight. UFO leans heavily on legacy satcom predating the "new space" cohort entirely.

**Positioning — structural, not sentiment.** The house's positioning gate (settlement 2026-07-31) trips for **13 of 14 names**; LMT is the one clean "checked, unremarkable" name. Most trips are structural: `convertibles_outstanding` on ASTS, RKLB, LUNR, RDW, PL, BKSY, BA; SPCX's is a new-listing artifact; KTOS and VSAT trip on level alone but sit low in their own ranges; IRDM, LHX, and NOC trip on movement alone off small bases. A footnote: a raw USAspending pull shows Rocket Lab at effectively **$0** in DoD prime awards — a methodology blind spot (Rocket Lab's SDA awards are OTAs the standard filter misses), not a finding about actual defense revenue.

**Private markets.** Blue Origin closed its first-ever outside funding round in July 2026 — up to **$10 billion at a ~$130 billion pre-money valuation**. Stoke Space was raising toward **$1 billion at a ~$9 billion valuation**. Starcloud closed a $170 million Series A at a **$1.1 billion valuation**.

**SPCX — cited, not re-valued.** SpaceX is cited from the house's standing scored valuation and is **not re-valued in this note**: the house maintains an **AVOID** rating with a fair value of **$78.51** (scored 2026-08-05), against a price of **$136.30** (2026-08-21 pre-market). That call was driven by the AI segment, not launch or Starlink.

**EXHIBIT 4** SpaceX launch cadence, 2018–2025, and the 2025 mass-to-orbit split




**Before the table: what each column measures.** *Price (date)* is the last trade at the timestamp shown — dated deliberately, because these are thinly covered, volatile names where a two-week-old quote is already stale. *EV/Sales* is enterprise value — market capitalization (share price times shares outstanding) plus debt, minus cash — divided by trailing revenue; it is the valuation shorthand used throughout this note precisely because most of these companies do not have positive earnings, so a price-to-earnings multiple has nothing to divide into. *TTM revenue* (trailing twelve months) is the actual sales figure EV/Sales is divided against, shown alongside the multiple so a reader can see whether a high multiple is being paid against a small revenue base, as with ASTS's $115.3M, or a large one, as with VSAT's $4,625.8M (both below). The *Positioning gate* column condenses a screen this note runs on every name: whether current short interest sits unusually high against that name's own two-year history (the "level" read) and whether it has been rising or falling lately (the "movement" read) — both drawn from FINRA's short-interest settlement data already cited in this note [TON618 comps spread, FINRA SI settlement 2026-07-31], including the days-to-cover figure implicit in that data, how many trading days it would take short sellers to buy back their position at average volume. A name trips the gate if either read comes back live. Most trips below are marked structural rather than sentiment-driven — tied to convertible debt outstanding, a recent new listing, or a multi-class share structure — because a short position built to hedge a convertible bond (buying the bond, selling the stock short to isolate the bond's value from the stock's) is not a bet the stock will fall; that is why 13 of the 14 names trip the gate on structural grounds and only LMT reads clean.

**Table — the 14-name universe:**

| TICKER | PRICE (DATE) | EV/SALES | TTM REVENUE (OR SEGMENT) | POSITIONING GATE |
|---|---:|---:|---:|---|
| SPCX | $136.30 (2026-08-21 pre-mkt) | n/c — see standing valuation | $23.0B company-wide | TRIP — new listing |
| RKLB | $73.02 (2026-08-21) | 71.2× | $769.1M | TRIP — convertibles outstanding |
| ASTS | $68.70 (2026-08-21) | 288.8× | $115.3M | TRIP — convertibles, multi-class |
| LUNR | $18.40 (2026-08-21) | 14.2× | $481.3M | TRIP — convertibles, share-count growth |

| TICKER | PRICE (DATE) | EV/SALES | TTM REVENUE (OR SEGMENT) | POSITIONING GATE |
|---|---|---|---|---|
| RDW | $12.05 (2026-08-21) | 8.9× | $426.3M | TRIP — convertibles, share-count growth |
| PL | $22.40 (2026-08-21) | n/c (debt tags unresolved) | $335.6M | TRIP — convertibles, multi-class |
| BKSY | $28.40 (2026-08-21) | 12.4× | $108.9M | TRIP — convertibles, share-count growth |
| KTOS | $57.25 (2026-08-21) | 7.6× | $1,522.5M | TRIP — level only |
| IRDM | $48.87 (2026-08-21) | 7.8× | $884.2M | TRIP — movement only |
| VSAT | $75.31 (2026-08-21) | 3.2× | $4,625.8M | TRIP — level only |
| LHX* | $267.11 (2026-08-21) | n/c (debt tags unresolved) | Space & Airborne Systems $6.9B FY25 | TRIP — movement only |
| NOC* | $551.77 (2026-08-21) | 2.1× (whole-company) | Space Systems $10.8B FY25 (-8% YoY) | TRIP — movement only |
| LMT* | $564.00 (2026-08-21) | 2.0× (whole-company) | Space segment $13.03B FY25 (+4% YoY) | **No trip** — clean |
| BA* | $214.13 (2026-08-21) | 2.5× (whole-company) | No discrete space segment | TRIP — convertibles (structural only) |

*Conglomerate — whole-company multiple and revenue shown for scale context only; excluded from pure-play medians.

TREAD 7

## Political Layer & Governance

*This section answers: setting the technology and the stock prices aside, what politics actually decides how much of this future gets built and paid for? It follows from §6 because the market prices these companies today on assumptions about budgets, treaties, and regulatory approvals that the market itself does not control — this section covers who does. The takeaway to carry forward: five separate political threads bear on the outcome, none is resolved as of this note's date, and each has exactly one binding legal or budgetary constraint and one dated event still to come.*

Five political threads gate the transition from program to industry, each with one binding constraint and one dated next event. None is resolved as of 2026-08-21.

| # | THREAD | BINDING CONSTRAINT | CURRENT STATE | NEXT DATED EVENT |
|---|---|---|---|---|
| 1 | SLS geography | OBBBA §40005 floors ($1.025B/yr SLS FY26–29; $750M/yr Gateway FY26–28) | House CJS increased SLS to $2.6B and restated the "commercial alternative" reallocation bar (H.R. 8845, 2026-05-15) | Senate CJS FY27 mark (not yet released; FY27 on a continuing resolution) |
| 2 | Executive posture | Statutory Gateway floor vs. administrative stop-work/pause | HALO stop-work order (April 2026); funds redirected to Lunar Infrastructure Demos, not "Gateway" as named in statute | Any GAO Office of General Counsel decision or formal Impoundment Control Act challenge — none exists as of 2026-08-21 |
| 3 | Accords vs. ILRS | Soft-law coordination (Artemis Accords "safety zones") vs. a rival framework with no shared dispute-resolution mechanism | Accords: 70 signatories (Mauritius, 70th, 2026-07-17); ILRS: 13 sovereign-state signatories; a live overlapping-site dispute at the Shackleton crater rim | Landing-site selection by China's Chang'e-7 (targeted H2 2026) or a NASA Artemis III/HLS asset in the same region |
| 4 | Regulatory capacity | FAA Part 450 licensing; FCC D2C authorizations; NEPA review | Part 450 legacy-to-new-license transition completed 2026-03-10 without the promised substantive rewrite; a new NEPA suit over Starbase land-exchange approval is unresolved | Starship Flight 14's FAA license sign-off (NET late August 2026, unconfirmed) |
| 5 | Militarization | Golden Dome request ($17.9B FY27) vs. what appropriations has actually moved ($397.9M House mark) | SpaceX holds $6.45B+ in Golden Dome-linked awards across overlapping, unreconciled headline figures; the Musk-government rupture (June 2025) produced no contract cancellations | FY27 defense appropriations and the fate of the $17.1B reconciliation-contingent Golden Dome tranche |

**SLS geography.** Boeing, Lockheed Martin, Northrop Grumman, and Aerojet Rocketdyne/L3Harris are the primes across Michoud, Marshall, and Stennis. Neither House CJS chair Hal Rogers (R-KY) nor Senate CJS chair Jerry Moran (R-KS) represents an SLS-producing state — the program's defense runs through appropriators outside the geography. Two authorization vehicles (distinct from appropriations, neither passed a floor vote) move in parallel: Senate S.933 authorizes $24.7B FY26/$25.3B FY27 while ending the Block 1B upgrade mandate; House H.R. 7273 includes a "Reaffirmation of the Space Launch System" section.

**Accords vs. ILRS.** The Artemis Accords are US-led, non-binding political commitments establishing lunar-activity norms, including controversial "safety zones." The Outer Space Treaty's Article II bars national appropriation "by claim of sovereignty, by means of use or occupation, or by any other means"; the 2015 Commercial Space Launch Competitiveness Act asserts a US citizen's right to extracted space resources — the treaty text does not clearly address extraction short of a territorial claim, and legal scholarship reads it both ways. Safety zones are treated as soft law — "intend to" rather than "shall" language, with no dispute-resolution mechanism.

**Regulatory capacity.** An August 2025 executive order directed the FAA to "reevaluate, amend or rescind" Part 450; the license transition completed in March 2026, but no substantive rule reform had been published — rules changed procedurally without the promised rewrite. FCC Order DA 26-391 and SpaceX's purchase of 65 MHz of EchoStar spectrum ($2.4B escrow, full transfer not expected until ~2027-11-30) sit in this thread too.

**Militarization.** The Missile Defense Agency approved 340 additional vendors in January 2026, bringing a Tranche 3 pool to 2,440 of 2,463 applicants — deliberately broad, mostly uncommitted. SpaceX's Golden-Dome award figures do not cleanly reconcile: $3.2B (April), $6.45B (May), and $2.29B (27 May) all appear within one six-week window with no single primary DoD release reconciling them. The Musk-government rupture peaked June 2025; the only documented adverse action — the October 2025 HLS re-competition — is characterized by every source as schedule/performance-driven, not political; Falcon 9/Heavy cadence, Dragon, and the May 2026 awards proceeded uninterrupted through it.

**Debris governance sits outside the five threads but belongs here** as the clearest voluntary regime governing a rapidly scaling activity. FCC Order 22-74 is binding but US-only, its enforcement never tested; the ITU covers spectrum, not debris; UN COPUOS's 2007 adoption of the IADC's 2002 guidelines is explicitly voluntary, with no penalty authority anywhere.

**SE-1** Propellant-transfer demo

**SE-2** Payload >50t measured

**SE-3** Reflown ship, <30-day turnaround

**SE-4** Artemis III/IV dates hold

**SE-5** FY27 appropriations enacted

**SE-6** Second-source sustained cadence

**SE-7** Commercial station, pre-deorbit

**SE-8** D2C throughput measured at scale

**SE-9** Debris event, populated shell

**SE-10** Flown radiator spec >1MW

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TREAD 8

## Open Questions & Tripwires

*This section answers: given everything above — the cost curve, the demand, the unsolved physics, Artemis, the competitive landscape, and the politics — what specific, dated things would actually change this note's mind? It follows from §7 because politics was the last unresolved lever; this section turns every open lever in the note into a checkable event with a stated answer on both sides. The takeaway to carry forward: this is not a forecast of what will happen — it is a list of ten dated, observable events, each with a reading if it lands and a different reading if it stays silent.*

*The case for space becoming an industry, and the case that it disappoints, are stated in full — in their own strongest terms, before any test — in Section 1a.*

**The conflict ledger — the same fact, read two ways.**

| # | THE FACT | THE CASE FOR | THE CASE AGAINST | WHAT RESOLVES IT |
|---|---|---|---|---|
| 1 | Starlink is 75–79% of the Falcon 9 manifest | Genuine internal demand, monetized downstream | No elasticity response from outside customers; external revenue roughly flat in 2025 | Trend in external Space-segment revenue |
| 2 | Space-segment operating loss, –$657M FY2025 / –$662M Q1'26 | Temporary, by-design cross-subsidy | Cheap-launch and profitable-launch may be permanently separate claims | Further quarters of segment EBITDA trend |
| 3 | Tanker count — OIG "more than 10," ASAP "at least a dozen" | A pre-flight-data range that still pencils against HLS award value | Every figure converges near 10–12, but none has flight data behind it | The ship-to-ship transfer demo (SE-1) |
| 4 | Raptor 3's Flight 12 mishap (5/33 engines failed to relight) | Exactly what a flight-test program is for; Flight 13 succeeded nine weeks later | The "reliability fix" produced a multi-engine failure on debut | Raptor 3 failure rate over the next 5–10 flights |
| 5 | Space Force FY26 $31.9B → FY27 request $71.3B, +123% | A structural step-change, the strongest secular tailwind here | $12.1B contingent on an unpassed bill; Golden Dome's mark is ~45× below its ask | FY27 enacted appropriations |
| 6 | China's Long March 10B net-capture recovery, 10 July 2026 | Reuse is a generalizable method, not SpaceX-specific | One recovery is not a cadence; says nothing about turnaround or cost | LM-10B reflight with disclosed turnaround |
| 7 | Radiator mass for 100 GW of orbital compute: 163,000–1.13M tonnes | A second-order lever vs. reject temperature and $/kg — at 400 K with the best NASA-tested panel the bill falls to ~75,921 t (~4.7× current orbit mass, ~507 flights) | Even the best NASA-tested prototype needs ~10× everything in orbit; no public model from any party prices thermal mass | SE-10 — a flown radiator spec at >1MW |
| 8 | D2C: ASTS 98.9 Mbps peak vs. Starlink's independently measured 3.1 Mbps median | The demonstrated peak proves the physics closes | The only measured figure is two orders of magnitude below the headline | Independent measurement of ASTS at subscriber density |
| 9 | 207,152 avoidance maneuvers in six months (secondary-sourced) | Proof avoidance is working at scale; growth is decelerating | Maneuvers miss self-fragmentation; two events occurred in the same window | Fragmentation frequency, third-party confirmed |
| 10 | SPAC cohort: RKLB +630%, ASTS +551% vs. 5 of 13 wiped out | The market rewards genuine execution | The relevant base rate is the 5-of-13 wipeout; both winners share one trait | Whether the next cohort narrows dispersion |

**The tripwire table.**

| ID | OBSERVABLE | DIRECTION IF IT LANDS | DIRECTION IF SILENT/SLIPS |
| --- | --- | --- | --- |
| SE-1 | Ship-to-ship propellant-transfer demo, quantity and loss % disclosed | Validates T1; cost curve, HLS, demand strands all move | Downstream dates slip further; HLS concentration risk realized |
| SE-2 | First measured Starship payload >50t to orbit | T3 settles; $/kg denominator becomes flight-demonstrated | $/kg denominator stays aspirational |
| SE-3 | Reflown Starship ship, turnaround <30 days, tile count disclosed | T2 settles; refurbishment approaches near-zero as marketed | Shuttle-pattern refurbishment burden persists |
| SE-4 | Artemis III flies; crewed-landing date holds or moves | Legacy/commercial split becomes measurable | Program slips further past China's ~2030 target |
| SE-5 | FY27 enacted appropriations: SLS/Gateway language survives | Defines which model Congress has chosen in law | Congressional geography holds, on a continuing resolution |
| SE-6 | New Glenn/Vulcan/Neutron reach a sustained rolling-12-month flight count | Concentration risk falls; a genuine second source exists | Two-horse race (SpaceX/China) persists |
| SE-7 | CLD Phase 2 award plus a first paying-crew free-flyer, before ISS deorbit | LEO gap closed | Loss of continuous US LEO presence |
| SE-8 | Independently measured commercial D2C throughput/cell published | T5 settles on real network data | D2C thesis stays a link-budget argument |
| SE-9 | ESA/ODPO quarterly conjunction or fragmentation event, independently confirmed | T6 moves from model to observed event | (Event-detection tripwire — no silent branch) |
| SE-10 | Orbital-compute operator publishes a flown kg/MW radiator spec at >1 MW | T4 re-scored against real hardware | Stays a physics note, not a demand strand with a data point |

The verdict above is conditional on the tripwires; here is what reverses it. This note carries ten dated, bounded observables that are symmetric by design — each has both a "lands" and a "silent/slips" branch. The read would move **toward "genuinely becoming an industry"** if, over the next 12–18 months: a ship-to-ship transfer demo flies with a disclosed loss percentage near the range sources converge on (SE-1); a measured >50t payload or sub-30-day reflown-ship turnaround lands (SE-2/SE-3); external, non-Starlink Space-segment revenue begins growing as a share of SpaceX's total; at least one of New Glenn, Vulcan, or Neutron reaches a sustained double-digit rolling-12-month cadence (SE-6); and FY27 appropriations enact figures materially above FY26 levels, converting the current step-change in requests into a step-change in spending (SE-5). The read would move **toward "still fundamentally a program, not yet an industry"** if: SE-1 slips again or lands with a loss rate materially above the ~10–12 range now converged upon; the Space segment's operating loss widens with no dated peak; a third credible US second-source provider fails to reach flight in 2027 as New Glenn and Vulcan struggled to in 2026; FY27 appropriations land on another continuing resolution, leaving Golden Dome's ~45× gap largely unclosed; or the ISS deorbits with no commercial successor hosting paying crew (SE-7). Each condition is specific, dated, and checkable — not a sentiment call.

TREAD 8A

## Two 2036s — what the tripwires would mean for a person on the ground

*This section is scenario, not forecast [OPINION throughout]. It takes the ten tripwires in §8 and asks what ordinary life looks like a decade out in the two worlds they separate: one where they land, one where they stay silent. Every scene is pinned to the tripwire that would produce it, so the reader can check which world is arriving by watching the same events the house watches. Neither world is the house's expectation; the note's verdict is conditional on the tripwires, and this section shows what the condition is worth. Both are written in their own strongest terms.*

**The world where the tripwires land.**

A Starship lifts off from Boca Chica on a Tuesday and nobody in the industry writes about it, because it is the third that week and the tanker it is meeting has been in orbit since Sunday (SE-1, SE-3). The ship that flew on Friday is being hosed down and inspected by a crew of nine; it flies again inside the month, and the tile count is a line in a maintenance log, not a press release (SE-3). The number that matters to the company is not the flight but the manifest — and for the first time since 2020, less than half of it is the company's own satellites (SE-6's mirror: external demand broadened).

A woman driving the hundred and twenty-odd miles of Interstate 80 between Winnemucca and Elko takes a video call from her daughter with no tower in sight. The call is not fast. It is the speed of a decent 2015 connection, and it works in a canyon where nothing has ever worked, because the satellite overhead is carrying a 223-square-metre antenna and the carrier has leased it its spare spectrum (SE-8). She pays $8 a month extra for it and thinks of it the way she thinks of the seatbelt.

A crew of four lands at the rim of Shackleton crater in 2028, on schedule, on a lander that was fuelled in Earth orbit by eleven tankers in nineteen days; when a Chinese crew lands forty kilometres away two years later, there is already a base on the rim to watch them arrive (SE-1, SE-4). The base they begin is funded on a continuing resolution, and the module that houses them was built under a contract whose name Congress wrote into law and the administration spent two years trying to rename (SE-5). It exists anyway.

A private station the size of a small office building has held paying crews for three years when the ISS is pushed into the Pacific in early 2031; a pharmaceutical company has a quarterly line item for it (SE-7).

And somewhere above the 550-kilometre shell, a satellite with a 70-metre wingspan radiates heat from a panel the size of a large house's roof, the first of a few thousand that together make up a little under a gigawatt — one-hundredth of the hundred that were projected, and a real business, because the operator published its kilograms-per-megawatt and the market could finally price it (SE-10). The conjunction reports it files every six months are boring, and the two fragmentations of 2026 were the last (SE-9). Launch is a utility nobody writes about. That is what the space economy is.

**The world where the tripwires stay silent.**

Starship flies twelve times in 2030 — a triumph by any standard but its own — and each flight is an event, because each carries something irreplaceable. The tanker demonstration succeeded in 2028 but lost a third of its propellant to boil-off, so the lunar mission needs sixteen flights instead of ten, and the schedule for sixteen flights is the schedule for the whole program (SE-1 silent). Ships come back and are rebuilt rather than reflown; the word "refurbishment" has quietly returned to the industry's vocabulary (SE-3 silent). Falcon 9 still does the work — a hundred and fifty flights a year, four in five of them Starlink — and the second and third sources each fly a handful of times, priced high enough to stay alive on government missions (SE-6 silent).

The woman driving to Elko has the same phone and the same canyon. Her carrier offers satellite texting, which works, and "satellite broadband," which is a menu item that delivers three megabits when the beam is not busy; she uses it for the emergency call she once needed and nothing else (SE-8 silent). The company that promised her a hundred megabits trades at a fraction of its 2026 multiple and is owned by its carrier partner.

Artemis IV lands in 2031, eighteen months after China's first crew walked the same rim (SE-4 silent). SLS flies once every two years because its statute says it must, and the Gateway that Congress funded and the administration paused is neither built nor cancelled; it is a line in a continuing resolution that two successive budget requests tried to zero and the House restored (SE-5 silent). The ISS comes down on schedule in 2031, and for twenty-six months there is no American in orbit — the first gap since 2000 (SE-7 silent). It is noticed mainly by the people who notice such things.

Orbital compute exists as a test bed: four satellites of a few hundred kilowatts each, a paper on radiation-tolerant memory, and a kilograms-per-megawatt figure that the industry's trade press treats as a curiosity because the original case for it never carried such a figure at all (SE-10 silent). The hundreds of thousands to a million-plus tonnes of radiator are not launched, which is also why the launch demand that depended on them never arrives. Starlink is a very good business. That is what the space economy is.

**What separates the two.** Not belief, and not money: the same companies, the same budgets and the same physics are at work in both. What separates them is a short list of events that either happen or do not within a few years of this note, and the house will read them the same way regardless of which world they describe. The list is §8's.

TREAD 9

## Risks & Data-Quality Caveats

This note carries several evidentiary gaps forward rather than papering over them:

- **The FCC semi-annual Starlink maneuver filing (207,152/148,696, T6) remains secondary-sourced** — the underlying docket could not be located; multiple matching secondary sources corroborate the figures, but this is not a primary-document read.
- **T10 (lunar dust/PSR extremes), T15 (closed-loop life-support), and T16 (on-orbit servicing) are unsourced** at the primary-document level — flagged as evidentiary gaps in Section 4's box, not sourced findings.
- **Golden Dome's total-program figure is disputed**: $185 billion per the primary evidence base used throughout this note, versus a competing $175 billion press-sourced figure unconfirmed against any DoD document.
- **SpaceX's "AI1" is not named in SEC filings.** The 424B4 discloses "orbital compute" and a "Terafab" partnership, but not "AI1"; the 150 kW/~70m specifications rest on trade-press reporting.
- **Vulcan Centaur's NSSL pause/resumption status is unverified** as of this note's research date; a static-fire requalification completed April 2026, but the pause's current status was not confirmed lifted or still in force.
- **T3's ~16-tonne V2 figure is secondary-sourced** and flagged as needing primary confirmation; it is not the basis for any tripwire or conclusion in this note.

None of these gaps changes the note's core structure — Section 8's tripwires resolve the load-bearing claims regardless of how these secondary items eventually confirm.

TREAD 10

## Sources & Method

**Glossary — every term of art in this note, one line each.**

- **LEO** — low Earth orbit, roughly 160–2,000 km up, where nearly all satellite constellations and crewed spaceflight to date have operated.
- **$/kg** — dollars per kilogram of mass delivered to a stated orbit; this note's master variable.
- **Manifest** — a launch provider's own schedule of upcoming flights and payloads.
- **Cadence** — the rate of launches over a period (e.g., flights per year).
- **Reuse / refurbishment** — reuse is recovering and re-flying a rocket stage instead of discarding it; refurbishment is the inspection, repair, and replacement work a reused vehicle needs before flying again.
- **TPS (Thermal Protection System)** — the outer layer of a reentry vehicle that absorbs or rejects atmospheric-friction heat.
- **Boil-off** — cryogenic propellant absorbing heat and vaporizing rather than staying liquid.
- **Propellant depot** — a vehicle pre-positioned in orbit to store propellant delivered by tanker flights until a mission needs it.
- **HLS** — Human Landing System, the vehicle (SpaceX's Starship variant, Blue Origin's Blue Moon) that lands Artemis astronauts on the Moon.
- **SLS / Orion / Gateway** — SLS is NASA's government-built heavy-lift rocket; Orion is the crew capsule it launches; Gateway is the planned lunar-orbit space station.
- **Cost-plus vs. fixed-price** — cost-plus reimburses a contractor's allowable costs plus a fee, so a schedule slip adds to the government's bill; fixed-price pays a set milestone price, so a slip is absorbed by the contractor.
- **CDR (Critical Design Review)** — the formal milestone at which a spacecraft's design is judged mature enough to proceed to full-scale build.
- **OBBBA** — P.L. 119-21 (2025-07-04), the reconciliation law whose §40005 sets NASA's SLS/Gateway/Orion funding floors.
- **Appropriated vs. requested vs. obligated** — requested is a budget ask, not voted on; appropriated is funds Congress has enacted into law; obligated is a contract signed against appropriated funds.
- **CLPS** — NASA's Commercial Lunar Payload Services program, which contracts private companies to deliver payloads to the Moon.
- **D2C / SCS** — D2C (direct-to-cell) is a satellite constellation broadcasting a cellular signal directly to an unmodified smartphone; SCS (Supplemental Coverage from Space) is the FCC framework letting it lease a terrestrial carrier's spectrum to fill coverage gaps, on a non-interference basis.
- **Link budget** — the full accounting of gain and loss a radio signal experiences from transmitter to receiver.
- **Stefan–Boltzmann (law)** — the physics relating radiated power per unit area to temperature to the fourth power ($\varepsilon \cdot \sigma \cdot T^4$); it governs how much radiator area is needed to reject a given amount of heat.
- **Reject temperature** — the temperature at which a radiator releases waste heat to space; a higher reject temperature shrinks the required radiator area.
- **krad / TID / SEU** — krad(Si) is the unit of cumulative radiation exposure; TID (total ionizing dose) is that cumulative exposure; SEU (single-event upset) is a transient error from a single particle strike.
- **HBM** — high-bandwidth memory, the memory stacked on modern AI accelerator chips.
- **Conjunction / avoidance maneuver** — a conjunction is a predicted close approach between two tracked objects in orbit; an avoidance maneuver is the propulsive move made to prevent a predicted collision.
- **Kessler (syndrome)** — a hypothesized self-sustaining chain reaction of orbital collisions and debris.

- **EV/Sales** — enterprise value (market capitalization plus debt, minus cash) divided by trailing revenue; used here because most of these companies lack positive earnings for a P/E multiple.
- **TTM** — trailing twelve months, the revenue window EV/Sales is measured against.
- **Short interest / days-to-cover** — short interest is the share of a stock's float sold short; days-to-cover is how many trading days it would take, at average volume, for short sellers to buy back their position.
- **Convertible (bond)** — a bond that can convert into shares; investors sometimes buy the bond and short the stock to isolate the bond's value, which can make a name's short interest structural rather than a bet the stock will fall.
- **SPAC** — a special-purpose acquisition company, a shell company that takes a private firm public via merger instead of a traditional IPO; several names in this note went public this way in 2020–22.
- **Tripwire** — a dated, observable event this note tracks so its thesis can be checked against reality rather than argued as a forecast.

Every figure in this note traces to one of the sources below, with vintage noted where it differs from the note's own publication date.

| SOURCE | VINTAGE | USED FOR |
|---|---|---|
| Jones (2018), 48th ICES (ICES-2018-81) | 2018 | $/kg history |
| arXiv 2506.00283 — crowdsourced Starlink direct-to-cell measurement study | dataset Oct 2024–Jul 2025 | T5: 3.1 Mbps median per beam; 18.6 Mbps/beam projection on 2×30 MHz |
| pv magazine, "Thermoacoustic heat pumps on the verge of commercial breakthrough" | 2026-04-23 | T4: thermoacoustic heat pumps as the active route to a higher reject temperature |
| TechCrunch, "Sophia Space raises $10M seed"; Via Satellite, "Sophia Space raises $7M, selects Apex bus" | 2026-02-26; 2026-06-23 | T4: passive vs active heat-pump power budget (92% vs 66–72% of power to compute) |
| SpaceX Form 424B4, SEC EDGAR | Filed 2026-06-12 | Segment definitions, FY2025 figures, orbital-compute disclosure |
| SpaceX Form 10-Q, SEC EDGAR | Period ended 2026-06-30 | Q2 2026 segment revenue |
| SpaceX Form S-1 risk factors | Filed 2026-05-20 | Flight record (7 success/5 RUD) |
| NASA OIG IG-26-004 | 2026-03-10 | HLS cost/schedule, tanker count, elevator/rescue findings, Blue Origin CDR |
| NASA ASAP, 2025 Annual Report | 2026-02-25 | Artemis III risk finding, "dozen V3s" |
| NASA FY2027 Budget Request | ~April 2026 | Program-level dollar figures, Gateway no-ask |
| OBBBA §40005; P.L. 119-74 | 2025-07-04 / 2026-01-23 | SLS/Gateway/Orion floors; two-statute distinction |
| NASA "Ignition Day" release | 2026-03-24 | Gateway pause quote |
| GAO-26-108556; OIG IG-20-005; Boeing 10-K | 2026-07 / 2019-11 / 2025-02-03 | Orion/SLS overruns; Starliner/Dragon cost |

| SOURCE | VINTAGE | USED FOR |
|---|---|---|
| ESA Space Environment Report, Issue 10.0 | 2026-05-01, data through end-2025 | Tracked-object count, deorbit compliance |
| ARK Invest, "Big Ideas 2026" | 2026-01-21 | Orbital-compute claims |
| Google, arXiv:2511.19468 | 2025 | Radiation-test data, downlink comparator |
| TON618 thermal model (stdlib Python, Stefan-Boltzmann) | Run 2026-08-20 | T4 smoke-test physics |
| FCC DA 26-391; FCC Order 22-74 | 2026-04-21 / 2022-09-29 | D2C authorization; debris disposal rule |
| AST SpaceMobile Form 10-Q | Period ended 2026-06-30 | 98.9 Mbps disclosure |
| TON618 comps spread (FINRA SI settlement 2026-07-31 / EDGAR XBRL) | Run 2026-08-21; settlement 2026-07-31 | Comps universe, positioning gate |
| `spcx-first-print-scored` | Scored 2026-08-05 | SPCX fair value $78.51, AVOID |
| SpaceDaily; BryceTech FY2025 report; vehicle-program press releases (Arianespace, Rocket Lab, ULA) | Compiled 2026-08-20 | Flight log, cadence, CLD/CLPS schedule |
| TON618 internal verification pass | 2026-08-21 | Reconciles conflicting figures across research inputs |

**Errata — primary-pass corrections.** (1) **Tanker count:** OIG says "more than 10," not 16–19 — that figure is dropped. (2) **SpaceX segments:** "Space" (includes satellite manufacturing), "Connectivity" (Starlink service), and a broader "AI" segment — no "launch segment." (3) **OBBBA vs. P.L. 119-74:** the dollar floors are in OBBBA itself; the "commercial alternative" language is committee-report text tied to P.L. 119-74. (4) **ESA deorbit compliance:** ranges, not point figures; a "95% threshold" claim is confirmed absent from ESA's text and dropped. (5) **Blue Origin CDR/Artemis V:** now primary-sourced at ~July 2026 / NET March 2030. (6) **Gateway pause quote:** now anchored to a real NASA institutional quote, not first-person paraphrase. (7) **SPCX fair value:** $78.51 (AVOID) against $136.30 — not re-derived here. (8) **FCC maneuver filing:** the 207,152/148,696 figures remain secondary-sourced; the filing itself could not be located.

**Data failures.** The OIG, ASAP, FY2027 budget, OBBBA, and ESA documents all failed initial web-fetch extraction and required direct PDF extraction. SpaceX's comps-engine spread returned "no annual 10-K facts resolved" — an EDGAR-completeness gap; the fallback TTM figure is labeled, not re-derived. FMP and Massive Market Data fundamentals were plan-gated; SEC EDGAR was used directly. China's 2026 YTD launch count (~53–55) is approximate and secondary.

House working files (thermal model script, comps spread, STORM pre-writing dossiers) are archived with the draft and available on request.

**Disclosure.**

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