FIRST INTEGRATED FLIGHT TEST

Following the successful high-altitude test flights of Starship prototypes, SpaceX shifted its focus to preparing for orbital test flights. These tests would involve launching the Starship spacecraft into orbit using the Super Heavy booster and then returning the spacecraft to Earth.

On April 20, 2023, SpaceX launched Starship on its first orbital test flight. The integrated vehicle was the tallest and most powerful rocket ever flown, with twice the thrust of the Saturn V super heavy-lift launch vehicle developed in the 1960s.

Flight Test 1

The mission flight plan was for the Starship spacecraft to orbit the Earth once before performing a targeted splashdown near Hawaii in the Pacific. Additionally, eight minutes after liftoff, the Super Heavy booster targeted a water landing in the Gulf of Mexico.

However, during and after liftoff, Starship encountered multiple engine failures. While the vehicle managed to surpass maximum aerodynamic pressure (Max Q) and reach an altitude of 39 km, all the engine issues made the rocket tumble uncontrollably. The autonomous flight termination system was initiated, which destroyed the vehicle approximately four minutes into the flight.

We highlighted three significant issues in the post-integrated flight test launch analysis.

- Multiple engines flamed out during the launch.

- The 33 Raptor engines cratered the concrete below the Orbital Launch Mount, creating a "rock tornado" of concrete that rained down over hundreds of acres, including a town 5 miles away.
- It took the flight termination system (FTS) 40 seconds post-triggering to destroy the rocket.

IFT-1 to IFT-2 Improvements

Water Deluge System:
SpaceX installed a steel-plate water deluge system below the Starship launch mount. The high-pressure sprinkler shoots water upwards and outwards to meet the intense flames from the 33 Raptor engines and absorb their energy and protect the pad.

Engine Start Ramp:
During the first test flight, SpaceX gradually ramped up Raptor thrust during liftoff, which resulted in Starship taking nearly 10 seconds to clear the pad. SpaceX throttled up faster in the second test to avoid pad damage.

FTS:
SpaceX upgraded its flight termination system to ensure a more powerful and efficient vehicle destruction. To accomplish this, SpaceX moved the FTS higher on the methane tank and increased the size of the charge.

Going Electric:
SpaceX decided to replace the hydraulic system with electric thrust vector controls on the next Super Heavy prototype (Booster 9). The central issue in the first flight was the cascading Raptor failures, where one malfunction triggered another. Electric controls allow the engines to be more isolated.

Hot Staging: SpaceX decided to introduce hot staging, where it will fire up its upper-stage engines before it shuts down all its booster engines. Hot staging ensures continuous thrust throughout ascent, which SpaceX hopes will increase payload capacity by 10%. SpaceX added a shielding and venting ring between the Super Heavy booster and Starship's second stage to avoid damage.

SECOND INTEGRATED FLIGHT TEST

The rocket's second flight test on Nov. 18 notched several successes for the company, marking a significant step forward on the road to getting the paradigm-shifting rocket ready for commercial operations. The test ultimately ended, though, when SpaceX lost contact with the rocket, and the automated flight termination system was triggered.

How it all went down: All 33 Raptor engines ignited and remained lit throughout the flight. While heading toward space, the vehicle made it through Max Q and successfully separated from Super Heavy via hot staging. However, instead of returning to Earth for a controlled water splash down as planned, the booster exploded.

Starship continued on its nominal trajectory for a few minutes with all of its engines lit. The vehicle reached an altitude of 148 km but experienced a fire as it was venting liquid oxygen, ultimately leading to the explosion over the Gulf of Mexico.

The test notched a few successes since last time:

- The water deluge system kept the pad in mint condition—a vast improvement over the first flight test, which destroyed the pad and sent rock and sand particles flying for miles.
- The hot staging approach, which ignited the second stage's engines before stage separation, worked well.
- Starship reached an altitude of 148 km, much farther than the last test, which exploded at 39 km.

Introducing Starship (Second Stage) Version II

With only two integrated test flights of Starship completed, SpaceX revealed that it's already developing version two of the Starship upper stage.

SpaceX plans to finish and launch four or five additional second-stage Starship version 1 prototypes before transitioning to its version two product line.

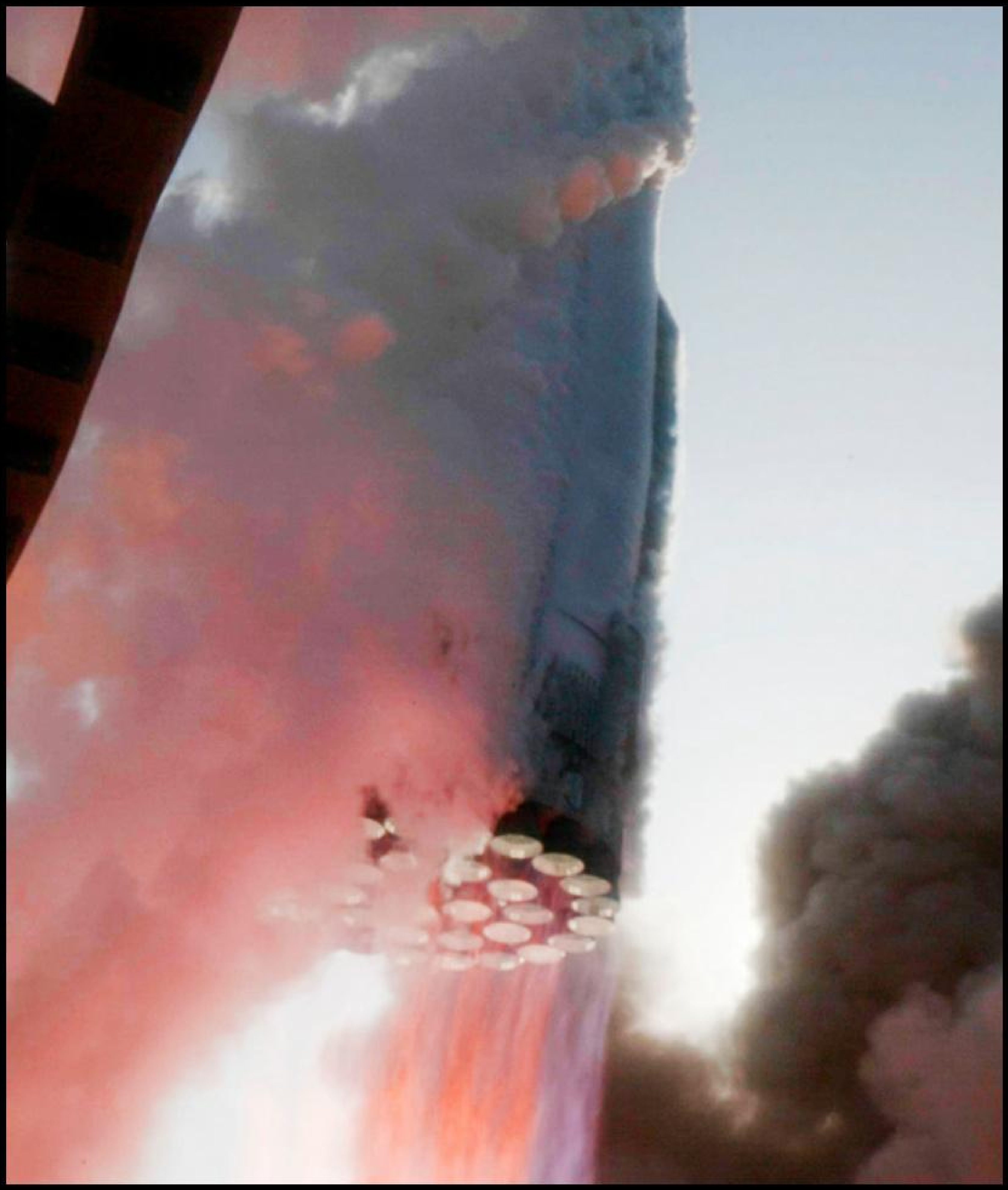
According to Elon Musk, Starship Version 2 will increase propellant capacity, reduce dry mass, and improve overall reliability. While exact specs were not provided, SpaceX has recently outlined several Starship changes it may eventually incorporate.

- **Raptor 3:** Musk has highlighted the development of its next-generation Raptor 3 engine—which he said would have a higher Isp than the Raptor 2, generate 20% more thrust, and be reliable enough not to require a heat shield. Eliminating engine shielding would significantly reduce mass.
- **Six to nine engines:** Starship V2 may be the first time we see nine Raptor engines on the vehicle, a change SpaceX has long wanted to make.
- **Increase propellant volume:** The company has explored increasing propellant volume by altering the shape of the fuel tanks and stretching Starship's height by five to 10 meters.

Starfactory: To increase Starship production, SpaceX will soon open a massive Starfactory production facility at Starbase in Texas (yeah, enough with all these star-names already). Starfactory will be an assembly-line style facility that SpaceX hopes will eventually be able to pump out multiple second-stage Starships per week.

THE IMPLICATIONS OF STARSHIP

Changing design constraints



If a single Starship operates at a frequency of three launches per week, it could transport more mass to orbit within a year than all of humanity's space missions combined. However, this impressive launch capability raises crucial questions: What will all these Starships be transporting?

While SpaceX's Starlink satellites will utilize a good chunk of this capacity, how will the rest of the space industry leverage this immense potential?

Mass limitations have historically restricted the design of missions and systems—a direct consequence of exorbitant launch costs to LEO, which are as high as $10,000/kg.

This, in turn, has impacted every facet of the mission: the schedule, cost structure, volume, selection of materials, labor, power, thermal considerations, guidance/navigation/control, and more. The mass concern is so entrenched that it has propagated across generations of satellites and space vehicles, shaping design to sidestep the detrimental effects of excess weight.

- A potential order of magnitude reduction in cost to orbit with Starship represents a dramatic paradigm shift by not merely pushing the boundaries of the mass constraint, but wholly dismantling it.
- In doing so, it dispels traditional thinking that has historically influenced spacecraft design.

The James Webb Space Telescope (JWST) serves as a classic example of this phenomenon. Initially estimated to cost $500M in 1997, the JWST's eventual price tag soared to $10B. The primary reason for this was volume and mass constraints, which continuously compelled engineers to reduce the size while maintaining performance, thereby increasing complexity and, consequently, cost.

Starship has the potential to disrupt the traditional correlation between mass and cost, where traditionally money is spent on optimizing mass to save on launch costs. Instead, engineers can now focus on the most cost-effective methods of constructing spacecraft, without being constrained by the need for mass optimization. In short, there will be a transition from an era of mass constraints to one of mass abundance. This shift signifies a pivotal change in resource availability and utilization.

Space tourism

Starship would broaden the horizons of space tourism beyond current offerings. Present-day space tourism is mainly limited to brief experiences of weightlessness and terrestrial views before returning to Earth. If a tourist wants to fly to LEO, a ride aboard Falcon 9 costs ~$50M a seat.

- Starship has the potential to significantly reduce the prices for space tourism, making it *relatively* more affordable for a broader range of people.

There is still a lot unknown about life support capabilities and how many people could safely fly on one Starship. However, below is our back-of-the-napkin math on potential cost per seat:

- SpaceX has said Starship can transport up to 100 people. If we assume 100 passengers aboard, and SpaceX eventually gets to a $10M internal marginal cost ($20M total price tag charged to customers), the price tag for a trip to LEO could drop to less than $200,000/seat.

- **Stretch goal:** Starship has a similar internal capacity to a B747. If we similarly pack Starship to the brim and assume 1) 500 passengers aboard for a very short trip to LEO and 2) SpaceX eventually gets to $5M internal margin cost ($10M price charged to customers), the cost could drop to $20,000/seat.

While these dramatic price declines are likely decades away, if achieved, it would open an entire space tourism sector to house, feed, and entertain guests.

IMPROVED ECONOMICS

LEO broadband

Payload's analysis suggests that the commercial justification for many "new space" enterprises hinges largely on decreasing capital intensity and launch costs. This is particularly relevant for LEO broadband mega-constellations, which must put hundreds or thousands of satellites into orbit to offer a feasible broadband service.

- Considering the current costs of satellite construction and launch, and presuming an EBITDA margin similar to terrestrial telecoms, achieving the sales necessary to reach typical telecom ROIC (high-single digits) is challenging.
- However, if Starship can facilitate substantial reductions in launch costs, the route to favorable ROICs from B2C broadband mega-constellations becomes more feasible.
- Starship will also allow SpaceX to accelerate the deployment of its Starlink satellites.

Earth observation:

Starship could also bolster ROICs for other space companies, including those in the Earth observation sector. Lower cost to orbit improves unit economics.

Novel applications and missions

- **Government science missions:** Our analysis suggests that the US government's commitment to missions of scientific importance is likely to be responsive to the reduced technical complexity, shorter timeline, and lower cost offered by Starship. This elasticity may open avenues for government missions to other celestial bodies or to deploy new, larger telescopes.

- **Defense applications:** The Pentagon is beginning to deploy a constellation of hundreds of national security satellites used for comms and missile tracking purposes. The DoD plans to launch many of these missions on Falcon 9. The higher Starship capacity will allow the military to expand its constellation faster.

- **In-space manufacturing:** The unique environment of space, characterized by zero gravity and a natural vacuum, provides a distinctive manufacturing setting ideal for producing specific products, such as certain pharmaceutical ingredients or high-quality fiber-optic cables.

Artemis

NASA has awarded SpaceX ~$4B across two contracts to build a modified Starship Human Landing System (HLS) for the Artemis program. The Starship HLS is scheduled to land a crew on the Moon on the Artemis 3 mission in late 2026. However, given the current rate of development, this date may slip. Nonetheless, Starship represents an important vehicle in enabling NASA's dreams of setting up a permanent base on the Moon.

Architecture: SpaceX estimates it will need to launch ~10 propellant tanker Starships to fill up HLS Starship's 1,200-ton tanks. If that's not complex enough, NASA and SpaceX will need to solve the problem of cryogenic fuel boiling-off in space.

It is a complex architecture, but if achieved, there's a big payoff waiting in the form of a lunar lander capable of transporting a staggering ~100 tons to the lunar surface.

SpaceX president Gwynne Shotwell said she would like to see 100 cargo payload flights launch before putting passengers onboard.[16] While 100 flights by 2025 is not a NASA requirement, the goal underscores SpaceX's desire to test as much as possible before putting humans on board.

Will Starship kill small-to-medium launch vehicles?
We don't think so. SpaceX will inevitably pivot most of its resources toward Starship and beyond-Earth applications at the expense of Falcon 9. While Starship holds great potential for launching satellite constellations and large-scale space infrastructure, it will not be nimble enough to accommodate custom orbit deployment and on-demand launch for small satellites. It's also unlikely to facilitate dedicated rideshare missions for small satellites in the near future. Most estimates predict the first commercial launch won't happen for another 3-5 years, offering a real opportunity for a new player to capture market share. SpaceX will reserve initial Starship launches for Starlink deployment.

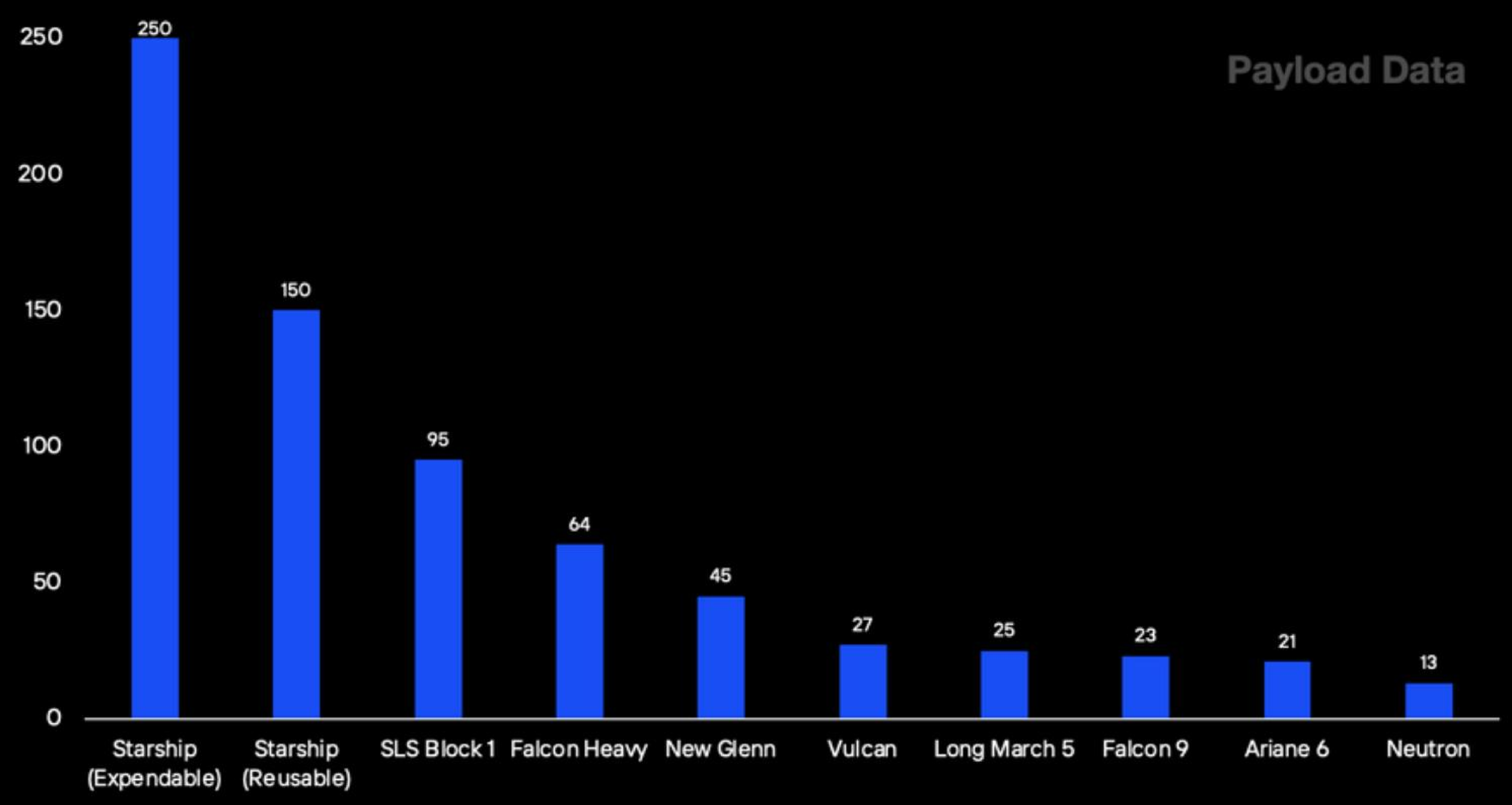
Perhaps the most critical factor is that the US government will always contract with multiple launch providers to encourage competition and not be beholden to one company.

16. SpaceNews

INDUSTRY COMPS

In addition to reusability, Starship is in a league of its own when it comes to thrust and capacity. SLS is the second most powerful rocket after Starship; however, its multi-billion dollar launch price tag and Artemis-focused missions diminish its competitiveness. Blue Origin's New Glenn, which is still in development, may become Starship's closest competitor, depending on its performance, cost, and reusability capabilities.

Launch Vehicle by Metric Tons to LEO



Payload Data	Falcon 9	Starship
Fully Integrated Height	70 M	121 M
Payload/Cabin Volume	145 cubic meters	1,000 cubic meters
Material	Aluminum and carbon fiber	Stainless Steel
Engine	Merlin	Raptor
Engine Type	Open-cycle	Full-flow staged combustion
Total Number of Engines	10	39
Propellant	Kerosene	Methane
Grid Fins	Yes	Yes
Side Flaps	No	Yes
Reusability	Partially	Fully
Payload to LEO, Reusable	18.4 tons	100 - 150 tons
Heat Shield Tiles	No	Yes, on second stage
In-Orbit Refueling	No	Yes, future addition