STARSHIP COST ANALYSIS

Starship's low-cost manufacturing is a breakthrough in rocketry.

Rocket building has historically been an extraordinarily costly endeavor. Legacy launch entities often elect to work with a team of subcontractors to procure high cost of failure specialty parts instead of building in-house. This has resulted in inefficient manufacturing, fraught with delays and cost overruns.

Enter SpaceX:
SpaceX has taken the opposite approach. The rocket giant brought all expensive and integral rocket manufacturing in-house, focusing on cost controls and speed.

Honing in on costs: As SpaceX transitions from Falcon 9 to Starship, it is further refining its manufacturing approach, focusing on ultra-low-cost materials and a "delete the part" design process.

- Falcon 9 is made out of expensive aluminum and carbon fiber.
- For Starship, SpaceX switched to low-cost stainless steel for its frame, saving millions of dollars in production costs. Stainless steel is a low-cost material with high heat resistance.

R&D: Starship's lifetime R&D costs will likely be near $10B. SpaceX crossed $5B of total Starship R&D (infrastructure build + rocket tech) spend by the end of 2023, with $2B of expenses in 2023 alone.[17]

Due to high R&D and startup costs, the amortized costs for early Starship prototypes amount to hundreds of millions of dollars to build. However, for the purposes of this analysis, we will use a near-future, go-forward projection model, as it represents a post-R&D/test production phase.

17. CNBC

OVERVIEW

Note: This is Payload's current estimate and not based on access to any internal SpaceX data or proprietary information.

Current Estimated Starship & Booster Full Stack Cost *($ in thousands)*	
39 Raptor Engines	39,000
Labor	35,000
Structure, plumbing, tiles, parts	13,000
Avionics	3,000
Total	**90,000**
*Payload costs estimates are based on a post-R&D 1-2 year forward-looking model. This is an educated best estimate and not based on SpaceX internal data. Further cost reductions are expected in the long-run.	

$90M cost: Payload estimates it costs $90M to manufacture a fully integrated Starship based on a post-R&D/test production phase near-term model. The go-forward cost does not factor in the near $5B SpaceX has spent on R&D to date.

~70% of costs accrue to Super Heavy and ~30% to Starship upper stage.

Future Starship (upper stage) cost reductions:

As Starfactory comes online and Raptor production is refined, SpaceX aims to reduce costs even further.[18]

A focus on Starship's upper stage: When SpaceX achieves full reusability, production of Starship second stage vehicles will be an order of magnitude higher than booster production.

- The company plans to eventually build multiple second stage Starships per week and reduce Raptor engine's production cost to $250K a pop.

If successful, the long-term cost to mass produce second-stage Starships could drop to $10M to $15M a vehicle. However, for purposes of this report, we will analyze costs as they are today.

Raptor 2 engines ($39M)

Payload estimates each Raptor 2 engine costs ~$1M to build. The 39 engines–which include three additional upper-stage engines that will be added in the future—are by far the biggest Starship cost, adding $39M to total cost.

$1M per Raptor 2 engine is half as expensive as its $2M+ Raptor 1 predecessor.[19, 20] SpaceX hopes to eventually bring the cost per engine down to ~$250K.[21]

Labor ($35M)

Payload estimates labor accounts for $35M of Starship's production costs. Building Starship takes an army of welders, heavy machinery operators, fabricators, and engineers. It is important to note that labor is the most significant variable in our cost analysis, as it depends heavily on the build rate. As SpaceX accelerates the build rate of Starship and improves efficiency, fewer labor hours will be required to complete a rocket.

- SpaceX employs ~2,100 people at Starbase.[22] Assuming an average employment cost of ~$100,000 per employee, SpaceX spends **~$210M a year** on labor at Starbase.

Build Rate:

- SpaceX's 2023 build rate (averaged over 24 months) was roughly three fully stacked Starships per year.
- Payload estimates that SpaceX will ramp up its annual build rate to five or six fully stacked Starships in the next few years.
- Considering the increasing build rate and manufacturing efficiency, we estimate the labor costs per fully integrated rocket going forward is **~$35M.**

Long run: In the long-run, SpaceX is aiming for its Boca Chica-based Starfactory to eventually build multiple Starships per week,[23, 24] which could reduce labor costs per fully stacked Starship to sub-$10M.

Structures ($13M)

Payload estimates SpaceX spends $13M on the physical materials and parts needed for Starship's structure, plumbing, and thousands of non-engine items. Broadly speaking, this category consists of the stainless steel frame, tubes, bulk-formed tanks, COPVs, valves, heat shield, and all other ancillary parts needed for a Starship flight.

Stainless steel structures & plumbing ($5M): The switch from Falcon 9's aluminum/carbon fiber frame to Starship's stainless steel represents a massive cost savings for SpaceX. Falcon 9's aluminum and carbon fiber frame costs upwards of $135/kg .

- Starship is made of 300 series stainless steel. US-supplied stainless steel costs ~$5.00/kg. The cylinder structure of a fully stacked Starship consists of 57 steel rings each stacked on top of each other. In total, the 57 rings make up ~90,000 kg in weight. At $5.00/kg, the cost of the cylinder structure comes out to $450,000.

- However, the specialty stainless steel items—including the bulk formed/stamped structures, interstage, tubes, hot staging ring, valve fitting, and other plumbing that are delivered to Boca

22.myRGV 23.Ars Technica 24.Jeff Foust / SpaceNews

Chica—are significantly more expensive than stainless steel rings.

Adding these specialty items, and processing costs, welds, and scrap rates, Payload estimates total steel structure costs clear $5M.

Heat shield tiles ($2M)
Starship's heat shield is made up of 18,000 ceramic hexagonal thermal protection tiles, each measuring 1 foot in diameter. SpaceX manufactures the tiles in-house.

For the Shuttle program, NASA was sourcing its heat shield tiles at a cost of thousands of dollars per tile.[25] By standardizing all heat shield tiles to a uniform hexagonal shape, SpaceX is able to mass-produce the tiles and cut costs significantly.

- In late 2020, SpaceX employed 20 people at its tile production facility in Florida.[26] Payload estimates the employee base has more than doubled to 50 people. Payload also estimates that the facility produces ~100,000 tiles a year, maintaining pace with the Starship production rate.
- With 100,000 tiles a year, 50 employees, and an average employment expense of $75K a year, the employee cost per tile cost equates to ~$37. Accounting for material and facility costs, Payload estimates heat shield tiles come out to $100 a tile.
- At ~$100 a tile, the cost for the 18,000 Starship tiles amounts to ~$2M.

Tanks ($2M):
There are 15-20 COPVs/large gas tanks on a fully stacked Starship. Tanks can run $100K a pop.

Misc. valves, advanced tech, & parts ($4M):
Valve costs range from a couple of thousand dollars for standard valves to tens of thousands for specialty valves. Other ancillary parts include Tesla motors to control Starship's flap, the "Pez dispenser" to deploy satellites in orbit, grid fins, bolts, vents, and machining.

Avionics ($3M)

Rocket avionics control the vehicle's electronics systems and computers. Engines need instructions, telemetry needs to be recorded, grid fins need mid-flight adjustments, flaps need to be flapped, and a team of batteries needs to keep everything charged. Avionics are largely a fixed cost on rockets and don't scale proportionally with the increased size of a rocket.

Fully Reusable Flight Costs

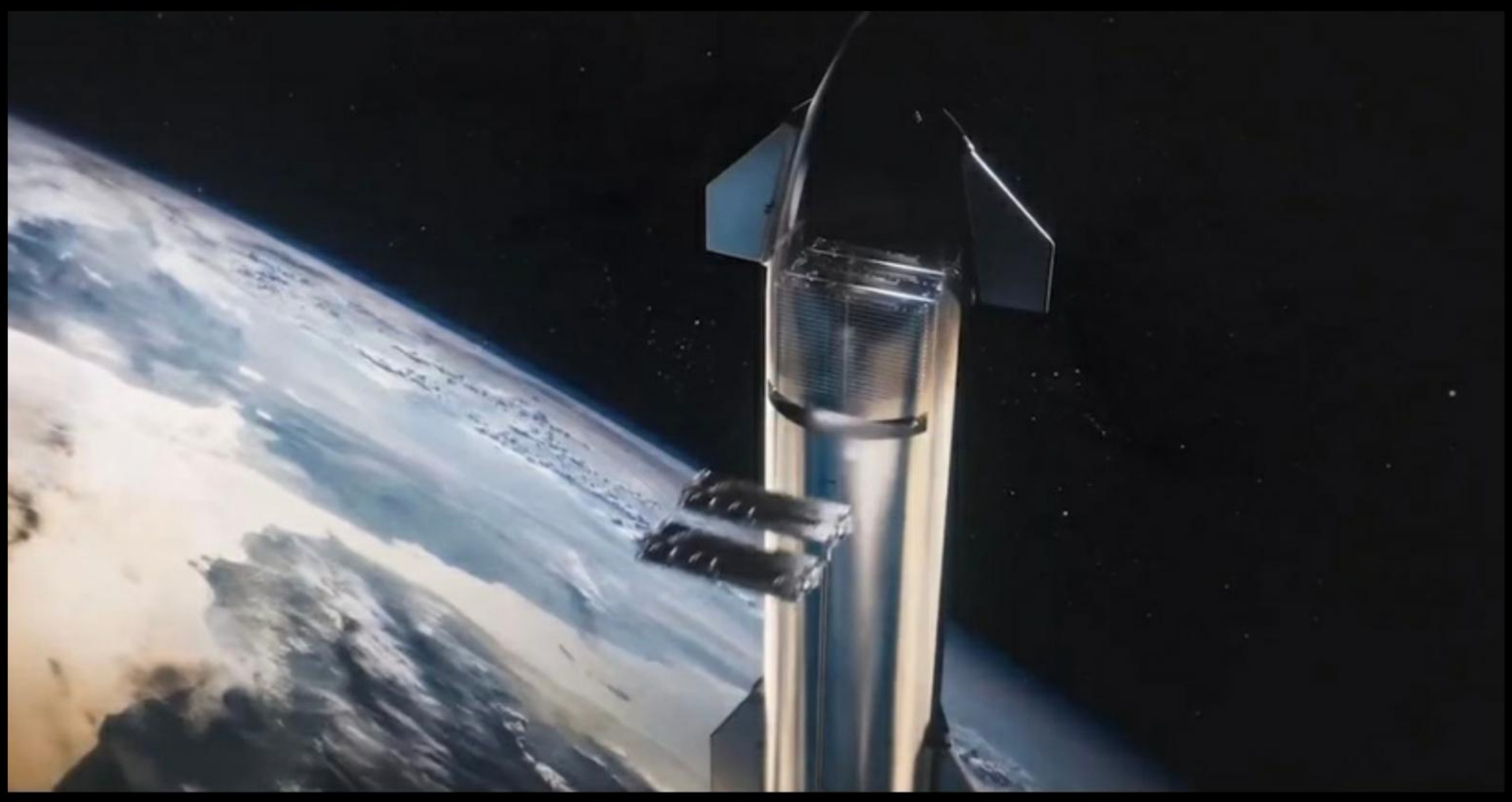
With Starship designed to be fully reusable, the cost per additional flight dramatically declines compared to building a brand new Starship. On a fully reusable basis, the economics of Starship flights begin to look closer to those of an airline.

$10M: Once operational, the fully considered cost per reusable Starship launch could drop to less than $10M. (Note this is SpaceX's internal cost, not the price tag charged to customer).

- Propellant cost amounts to ~$1M.
- Refurbishing, inspections, amortized costs, and miscellaneous launch day costs account for the remaining $9M.

Launch frequency will play a significant role in offsetting fixed costs even further. The higher the number of launches, the more SpaceX can spread fixed costs. As a result, the marginal cost to launch Starship could drop well below $10M in the long-run.

STARLINK AND STARSHIP



The Starlink business model is as follows:

- SpaceX launches customer payloads, generating profits
- Those profits are then used to pay for Starlink-dedicated SpaceX launches
- SpaceX generates recurring revenue through Starlink subscriptions

As of December 2023, SpaceX logged 2.3M Starlink active customers.

Thus far: Starlink makes up over 50% of satellites in orbit. Over half of SpaceX missions are Starlink-dedicated Falcon 9 launches. SpaceX has launched over 5,000 Starlinks into orbit as of August 2023.

Total Starlinks launched:
Jan 2021: 1,000
Jan 2022: 2,000
Aug 2022: 3,000
Aug 2023: 5,000

SpaceX aims to launch 12,000 Starlinks, potentially increasing that number to 42,000. Payload estimates that each Starlink satellite costs ~$300,000 to build.

Starlink 1.0 → 2.0: SpaceX is transitioning from lightweight Starlink satellites to larger versions with higher capacity. The second-generation Starlinks have 4 times more capacity than the first-

generation birds.

V.1: 260 kg.
V.1.5: 305 kg
V.2 Mini: 800kg
V.2: ~1,250 kg (yet to be launched)

Each Falcon 9 dedicated launch contains ~23 V.2 Minis. The Falcon 9 does not have the mass or volume capacity to launch the heavy V.2 Starlink satellites at scale.

This is where Starship comes in.

Starship & Starlink: Starship's LEO payload capacity will be 100 - 150 tons, significantly higher than that of Falcon 9.

When launching Starlinks on a fully reusable basis, Falcon 9 maxes out at ~18.5 tons.

When Starship is launched on a fully reusable basis, we estimate Starship will be able to transport ~100 Starlink V.2 satellites (1,250kg each) per launch.

Replacement rate: The lifespan of a Starlink satellite is five years. This means that once the constellation is complete, SpaceX will still have to launch Starlinks regularly to make up for deorbited/non-functioning churn.

For example: With a 20% annual churn rate, SpaceX must maintain 24+ Starlink-dedicated Starship launches (2,400 Starlink deployments) per year post-constellation completion to maintain a 12,000 Starlink constellation or 84+ launches for a 42,000 Starlink constellation.

HUMAN SPACEFLIGHT USE CASES

SpaceX's Starship is a next-gen spacecraft designed for transporting crew to space, Moon, and Mars.

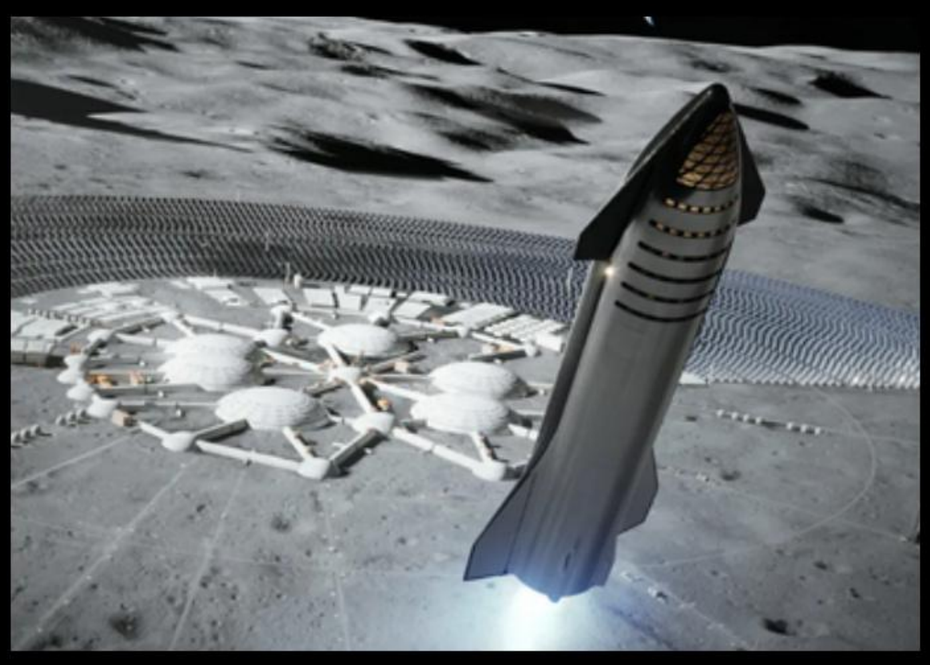
Lunar
Starship will enable large-scale travel between Earth and the Moon. Starship technology is important in NASA's return to the moon under the Artemis program. In 2021, NASA tapped SpaceX to build a Starship lunar lander that will be used to bring Artemis III astronauts to the surface of the Moon this decade.

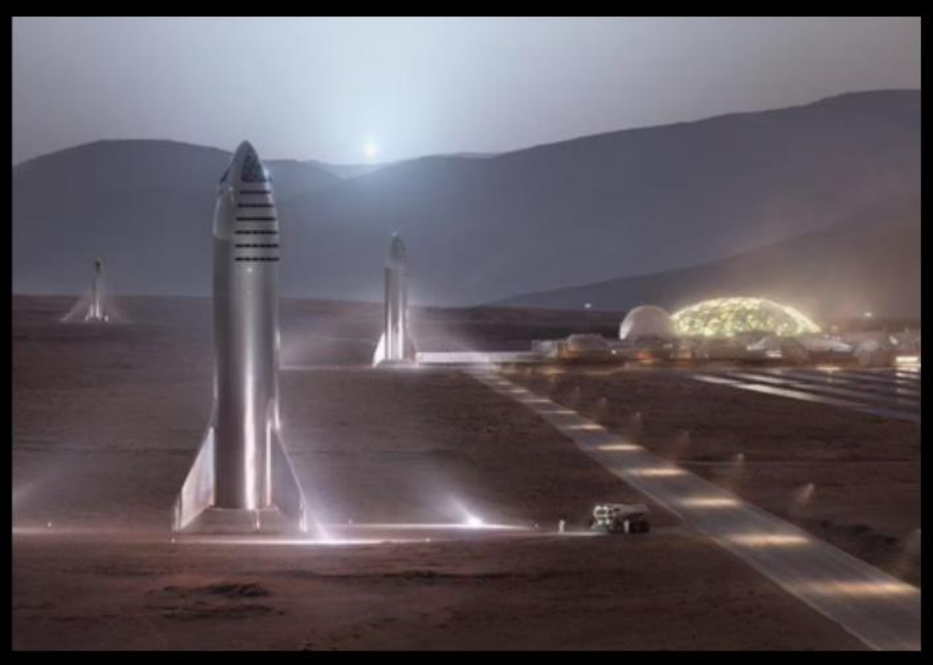
Space tourism
Once operational, the spacecraft will open up a new era of space tourism. SpaceX has already sold tickets to private individuals for Starship lunar trips.

Mars
The ultimate goal of Starship is for it to enable human space travel to Mars. The spacecraft's ability to carry large amounts of cargo makes it ideal for long-duration missions, such as crewed missions to Mars or beyond.

Point to point
The Pentagon is also eyeing the new vehicle for "point-to-point" cargo missions on Earth. Starship could theoretically carry a C-17 cargo load and fly anywhere in the world in an hour. The idea of point-to-point travel on rockets has been around since the beginning of the space program, but Starship may be the first vehicle that could make this economically possible.

Starship space station
NASA and SpaceX are exploring plans to turn Starship into a permanent space station in LEO, supporting dozens of people for long-duration stays. Starship's immense size—larger than the ISS—would allow it to accommodate all the necessary facilities and equipment. Most importantly, since a Starship space station would be deployed in just one launch, the cost to open the station would be relatively inexpensive.





CONCLUDING THOUGHTS

The high cost of launch has long been a significant challenge in space exploration. While near-term pricing is likely to stay on par with Falcon 9, in the long-run, Starship's cost per kg to orbit is expected to decline by an order of magnitude.

One of the most significant aspects of Starship's development is its rapid pace of innovation. In 2019, Starship was just Starhopper, a prototype for testing the Raptor engine. Fast forward to 2023, and SpaceX has conducted two full-stack flight tests and made substantial advancements in their launch infrastructure. As 2024 approaches, SpaceX anticipates the potential for up to five launches, indicating a marked acceleration in the program's pace and scope. This swift progress in the Starship program is poised to significantly influence aerospace engineering, demonstrating the rapid development and impact of a groundbreaking piece of hardware when executed with focus.

2019

Starhopper Flight Test

2021

SN15 Test

2023

Integrated Flight Test 1

Lowering the cost of access to space, as Starship proposes, could unlock new possibilities across various domains, including scientific research, interplanetary colonization, human spaceflight, satellite operations, military communications, and commercial innovation. While Starship still has hurdles to overcome in proving its effectiveness and reliability, SpaceX has consistently shown its capability to tackle some of the most formidable challenges in space engineering.

CONTACT US

This marks the beginning of an ongoing series of updates on SpaceX's Starship, where we'll continuously provide the latest news and in-depth analysis. Keep an eye out for future posts to stay informed on all the exciting developments and insights related to Starship. Stay tuned for more!

Mo Islam
Cofounder
Mo@payloadspace.com

Jack Kuhr
Research Director
Jack@payloadspace.com

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