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Falcon Heavy

Falcon Heavy is a partially reusable super heavy-lift launch vehicle[a] that can carry cargo into Earth orbit, and beyond. It is designed, manufactured and launched by American aerospace company SpaceX.

The rocket consists of a center core on which two Falcon 9 boosters are attached, and a second stage on top of the center core.[8] Falcon Heavy has the second highest payload capacity of any currently operational launch vehicle behind NASA's Space Launch System (SLS), and the fourth-highest capacity of any rocket to reach orbit, trailing behind the SLS, Energia and the Saturn V.

SpaceX conducted Falcon Heavy's maiden launch on 6 February 2018, at 20:45 UTC.[4] As a dummy payload, the rocket carried a Tesla Roadster belonging to SpaceX founder Elon Musk, with a mannequin dubbed "Starman" in the driver's seat.[9] The second Falcon Heavy launch occurred on 11 April 2019, and all three booster rockets successfully returned to Earth.[10] The third Falcon Heavy launch successfully occurred on 25 June 2019. Since then, Falcon Heavy has been certified for the National Security Space Launch (NSSL) program.[11]

Falcon Heavy was designed to be able to carry humans into space beyond low Earth orbit, although as of February 2018, SpaceX does not intend to transport people on Falcon Heavy, nor pursue the human-rating certification process to transport NASA astronauts.[12] Both Falcon Heavy and Falcon 9 are expected to eventually be superseded by the Starship launch system, currently being developed.[13]

Falcon Heavy

Falcon Heavy test flight launch

Function	Partially reusable heavy-lift – super heavy-lift launch vehicle
Manufacturer	SpaceX
Country of origin	United States
Cost per launch	Reusable: US$97 million (2022)[1] Expendable: US$150 million (2017)[2]
Size	
Height	70 m (230 ft)[3]

History

Concepts for a Falcon Heavy launch vehicle using three Falcon 1 core boosters, with an approximate payload-to-LEO capacity of two tons,[14] were initially discussed as early as 2003.[15] The concept for three core booster stages of the company's as-yet-unflown Falcon 9 was referred to in 2005 as the *Falcon 9 Heavy*.[16]

SpaceX breaking ground at Vandenberg Air Force Base, SLC-4E in June 2011 for the Falcon Heavy launch pad

SpaceX unveiled the plan for the Falcon Heavy to the public at a Washington, D.C., news conference in April 2011, with an initial test flight expected in 2013.[17]

A number of factors delayed the planned maiden flight to 2018, including two anomalies with Falcon 9 launch vehicles, which required all engineering resources to be dedicated to failure analysis, halting flight operations for many months. The integration and structural challenges of combining three Falcon 9 cores were much more difficult than expected.[18]

In July 2017, Elon Musk said, "It actually ended up being way harder to do Falcon Heavy than we thought. ... We were pretty naive about that".[19]

The initial test flight for the first Falcon Heavy lifted off on 6 February 2018, at 20:45 UTC, carrying its dummy payload, Elon Musk's personal Tesla Roadster, beyond Mars orbit.[4]

Conception and funding

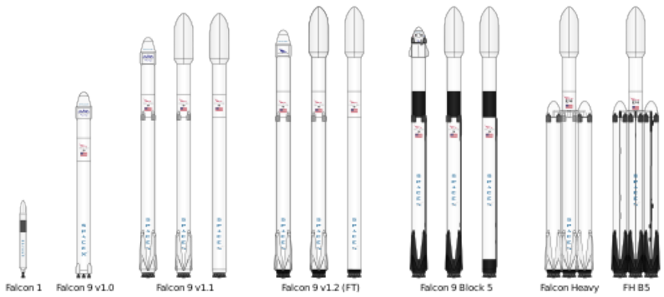
Musk first mentioned Falcon Heavy in a September 2005 news update, referring to a customer request from 18 months prior.[20] Various solutions using the planned Falcon 5 (which was never flown) had been explored, but the only cost-effective, reliable iteration was one that used a 9-engine first stage—the Falcon 9. The Falcon Heavy was developed with private capital with Musk stating that the cost was more than US$500 million. No government financing was provided for its development.[21]

Design and development

The Falcon Heavy design is based on Falcon 9's fuselage and engines. By 2008, SpaceX had been aiming for the first launch of Falcon 9 in 2009, while "Falcon 9 Heavy would be in a couple of years". Speaking at the 2008 Mars Society Conference, Musk also indicated that he expected a hydrogen-fueled upper stage would follow two to three years later (which would have been around 2013).[22]

Diameter	3.66 m (12.0 ft) (each booster)
Width	12.2 m (40 ft)
Mass	1,420 t (3,130,000 lb)
Stages	2.5
Capacity	
Payload to low Earth orbit	
Orbital inclination	28.5°
Mass	63.8 t (141,000 lb)[3]
Payload to geosynchronous transfer orbit	
Orbital inclination	27.0°
Mass	26.7 t (59,000 lb)[3]
Payload to Mars transfer orbit	
Mass	16.8 t (37,000 lb)[3]
Payload to Pluto	
Mass	3.5 t (7,700 lb)[3]
Associated rockets	
Based on	Falcon 9
Comparable	Delta IV Heavy · New Glenn · Saturn C-3 · Space Launch System · Vulcan Centaur
Launch history	
Status	Active
Launch sites	Kennedy Space Center, LC-39A Vandenberg, SLC-6 (future)
Total launches	8
Success(es)	8
Landings	1 center core landed (lost at sea) / 3 attempted 14 side boosters landed / 14 attempted
First flight	6 February 2018[4]

Last flight	13 October 2023
	Boosters
No. boosters	2
Powered by	18 total, 9 Merlin 1D per booster[3]
Maximum thrust	**Sea level:** 7.6 MN; 1,700,000 lbf (770 t_f) (each) **Vacuum:** 8.2 MN; 1,900,000 lbf (840 t_f) (each)
Total thrust	**Sea level:** 15.2 MN; 3,400,000 lbf (1,550 t_f) **Vacuum:** 16.4 MN; 3,700,000 lbf (1,670 t_f)
Specific impulse	**Sea level:** 282 s (2.77 km/s)[5] **Vacuum**: 311 s (3.05 km/s)[6]
Burn time	154.3 seconds
Propellant	Subcooled LOX / Chilled RP-1[7]
	First stage
Powered by	9 Merlin 1D[3]
Maximum thrust	**Sea level:** 7.6 MN; 1,700,000 lbf (770 t_f) **Vacuum:** 8.2 MN; 1,900,000 lbf (840 t_f)
Specific impulse	**Sea level:** 282 s (2.77 km/s) **Vacuum:** 311 s (3.05 km/s)
Burn time	187 seconds
Propellant	Subcooled LOX / Chilled RP-1
	Second stage
Powered by	1 Merlin 1D Vacuum[3]



From left to right, Falcon 1, Falcon 9 v1.0, three versions of Falcon 9 v1.1, three versions of Falcon 9 v1.2 (Full Thrust), three versions of Falcon 9 Block 5, **Falcon Heavy** and Falcon Heavy Block 5

By April 2011, the capabilities and performance of the Falcon 9 vehicle were better understood, SpaceX having completed two successful demonstration missions to low Earth orbit (LEO), one of which included reignition of the second-stage engine. At a press conference at the National Press Club in Washington, D.C., on 5 April 2011, Musk stated that Falcon Heavy would "carry more payload to orbit or escape velocity than any vehicle in history, apart from the Saturn V Moon rocket ... and Soviet Energia rocket".[23] In the same year, with the expected increase in demand for both variants, SpaceX announced plans to expand manufacturing capacity "as we build towards the capability of producing a Falcon 9 first stage or Falcon Heavy side booster every week and an upper stage every two weeks".[23]

In 2015, SpaceX announced a number of changes to the Falcon Heavy rocket, worked in parallel to the upgrade of the Falcon 9 v1.1 launch vehicle.[24] In December 2016, SpaceX released a photo showing the Falcon Heavy interstage at the company headquarters in Hawthorne, California.[25]

Testing

By May 2013, a new, partly underground test stand was being built at the SpaceX Rocket Development and Test Facility in McGregor, Texas, specifically to test the triple cores and twenty-seven rocket engines of the Falcon Heavy.[26] By May 2017, SpaceX conducted the first static fire test of flight-design Falcon Heavy center core at the McGregor facility.[27][28]

In July 2017, Musk discussed publicly the challenges of testing a complex launch vehicle like the three-core Falcon Heavy, indicating that a large extent of the new design "is really impossible to test on the ground" and could not be effectively tested independent of actual flight tests.[19]

By September 2017, all three first stage cores had completed their static fire tests on the ground test stand.[29] The first Falcon Heavy static fire test was conducted on 24 January 2018.[30]

Maximum thrust	934 kN; 210,000 lbf (95.2 t_f)
Specific impulse	348 s (3.41 km/s)
Burn time	397 seconds
Propellant	LOX / RP-1

Maiden flight

In April 2011, Musk was planning for a first launch of Falcon Heavy from Vandenberg Air Force Base, California on the United States west coast in 2013.[23][31] SpaceX refurbished Launch Complex 4E at Vandenberg AFB to accommodate Falcon 9 and Heavy. The first launch from the Cape Canaveral, Florida east coast launch complex was planned for late 2013 or 2014.[32]

Due partly to the failure of SpaceX CRS-7 in June 2015, SpaceX rescheduled the maiden Falcon Heavy flight in September 2015 to occur no earlier than April 2016.[33] The flight was to be launched from the refurbished Kennedy Space Center Launch Complex 39A.[34][35] The flight was postponed again to late 2016, early 2017,[36] summer 2017,[37] late 2017[38] and finally to February 2018.[39]

At a July 2017 meeting of the International Space Station Research and Development meeting in Washington, D.C., Musk downplayed expectations for the success of the maiden flight:

> There's a real good chance the vehicle won't make it to orbit ... I hope it makes it far enough away from the pad that it does not cause pad damage. I would consider even that a win, to be honest.[19]

In December 2017, Musk tweeted that the dummy payload on the maiden Falcon Heavy launch would be his personal Tesla Roadster playing David Bowie's "Space Oddity" (though the song actually used for the launch was "Life on Mars"), and that it would be launched into an orbit around the Sun that will reach the orbit of Mars.[40][41] He released pictures in the following days.[42] The car had three cameras attached to provide "epic views".[9]

On December 28, 2017, the Falcon Heavy was moved to the launch pad in preparation of a static fire test of all 27 engines, which was expected on 19 January 2018.[43] However, due to the U.S. government shutdown that began on 20 January 2018, the testing and launch were further delayed.[44] The static fire test was conducted on 24 January 2018.[30][45] Musk confirmed via Twitter that the test "was good" and later announced the rocket would be launched on 6 February 2018.[46]

On 6 February 2018, after a delay of over two hours due to high winds,[47] Falcon Heavy lifted off at 20:45 UTC.[4] Its side boosters landed safely on Landing Zones 1 and 2 a few minutes later.[48] However, only one of the three engines on the center booster that were intended to restart ignited during descent, causing the booster to be destroyed upon impacting the ocean at a speed of over 480 km/h (300 mph).[49][50]


Maiden launch of the Falcon Heavy

Initially, Elon Musk tweeted that the Roadster had overshot its planned heliocentric orbit, and would reach the asteroid belt. Later, observations by telescopes showed that the Roadster would only slightly exceed the orbit of Mars at aphelion.[51]

Later flights

Falcon Heavy built to Falcon 9 Block 5 specifications on the launch pad in June 2019

A year after the successful demo flight, SpaceX had signed five commercial contracts worth US$500–750 million, meaning that it had managed to cover the development cost of the rocket.[52] The second flight, and first commercial one, occurred on 11 April 2019,[53] launching Arabsat-6A, with all three boosters landing successfully for the first time.

The third flight occurred on 25 June 2019, launching the STP-2 (DoD Space Test Program) payload.[53] The payload was composed of 25 small spacecraft.[54] Operational Geostationary transfer orbit (GTO) missions for Intelsat and Inmarsat, which were planned for late 2017, were moved to the Falcon 9 Full Thrust rocket version as it had become powerful enough to lift those heavy payloads in its expendable configuration.[55][56] In June 2022, the U.S. Space Force certified Falcon Heavy for launching its top secret satellites, with the first such launch being USSF-44 which happened at 1 November 2022;[57] and the second of which being USSF-67,[58] which was launched 11 weeks after USSF-44. ViaSat selected the Falcon Heavy in late 2018 for the launching of its ViaSat-3 satellite which was scheduled to launch in the 2020–2022 timeframe;[59] however it would not launch until 1 May 2023.[60] On 13 October 2023, Falcon Heavy embarked on its 8th flight carrying a NASA Satellite to the Pscyhe asteroid. This mission only had the side boosters return to Earth with the center core expended, a decision made to create more tolerable margins for the mission.

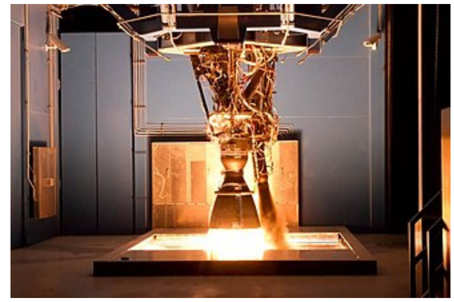
Following the announcement of NASA's Artemis program of returning humans to the Moon, the Falcon Heavy rocket has been mentioned several times as an alternative to the expensive Space Launch System (SLS) program, but NASA decided to exclusively use SLS to launch the Orion capsule.[61][62] However, Falcon Heavy will support commercial missions for the Artemis program,[63] since it will be used to transport the Dragon XL spacecraft to the Lunar Gateway. It was also selected to launch the first two elements of the Lunar Gateway, the Power and Propulsion Element (PPE), and the Habitation and Logistics Outpost (HALO), on a single launch in November 2024,[64] and to launch NASA's VIPER rover aboard Astrobotic Technology's Griffin lander as part of the Artemis Program's Commercial Lunar Payload Services (CLPS) initiative.[65]

Design

Falcon Heavy consists of a structurally strengthened Falcon 9 as the "core" component, with two additional Falcon 9 first stages with aerodynamic nose–cones mounted outboard serving as strap-on boosters,[8] conceptually similar to Delta IV Heavy launcher and proposals for the Atlas V Heavy and Russian Angara A5V. This triple first stage carries a standard Falcon 9 second stage, which in turn carries the payload in a fairing. Falcon Heavy has the second highest lift capability of any operational rocket, with a payload of 63,800 kg (140,700 lb) to low Earth orbit, 26,700 kg (58,900 lb) to Geostationary Transfer Orbit, and 16,800 kg (37,000 lb) to trans-Mars injection.[66] The rocket was designed to meet or exceed all current requirements of human rating. The structural safety margins

Falcon Heavy on pad LC-39A

are 40% above flight loads, higher than the 25% margins of other rockets.[67] Falcon Heavy was designed from the outset to carry humans into space and it would restore the possibility of flying crewed missions to the Moon or Mars.[3]



The Merlin 1D engine

The first stage is powered by three Falcon 9 derived cores, each equipped with nine Merlin 1D engines. The Falcon Heavy has a total sea-level thrust at liftoff of 22.82 MN (5,130,000 lbf), from the 27 Merlin 1D engines, while thrust rises to 24.68 MN (5,550,000 lbf) as the craft climbs out of the atmosphere.[3] The upper stage is powered by a single Merlin 1D engine modified for vacuum operation, with a thrust of 934 kN (210,000 lbf), an expansion ratio of 117:1 and a nominal burn time of 397 seconds. At launch, the center core throttles to full power for a few seconds for additional thrust, then throttles down. This allows a longer burn time. After the side boosters separate, the center core throttles back up to maximum thrust. For added reliability of restart, the engine has dual redundant pyrophoric igniters (Triethylaluminium-Triethylborane) (TEA-TEB).[8] The interstage, which connects the upper and lower stage for Falcon 9, is a carbon fiber aluminum core composite structure. Stage separation occurs via reusable separation collets and a pneumatic pusher system. The Falcon 9 tank walls and domes are made from Aluminium–lithium alloy. SpaceX uses an all-friction stir welded tank. The second stage tank of Falcon 9 is simply a shorter version of the first stage tank and uses most of the same tooling, material, and manufacturing techniques. This approach reduces manufacturing costs during vehicle production.[8]

All three cores of the Falcon Heavy arrange the engines in a structural form SpaceX calls *Octaweb*, aimed at streamlining the manufacturing process,[68] and each core includes four extensible landing legs.[69] To control the descent of the boosters and center core through the atmosphere, SpaceX uses four retractable grid fins at the top of each of the three Falcon 9 boosters, which extend after separation.[70] Immediately after the side boosters separate, the center engine in each burns for a few seconds in order to control the booster's trajectory safely away from the rocket.[69][71] The grid fins then deploy as the boosters turn back to Earth, followed by the landing legs. Each booster lands softly on the ground in fully reusable launch configuration. The two side boosters land on different drone ships in partial reusable configuration. The center core continues to fire until stage separation. In fully reusable launches, its grid fins and legs deploy and the center core touches down either back on land or on a drone ship. If the stages are expended, then the landing legs and grid fins are omitted from the vehicle. The landing legs are made of carbon fiber with aluminum honeycomb structure. The four legs stow along the sides of each core during liftoff and extend outward and down just before landing.[72]

Rocket specifications

Falcon Heavy specifications and characteristics[73] [hide]

Characteristic	First stage core unit (1 × center, 2 × booster)	Second stage	Payload fairing
Height[73]	42.6 m (140 ft)	12.6 m (41 ft)	13.2 m (43 ft)
Diameter[73]	3.66 m (12.0 ft)	3.66 m (12.0 ft)	5.2 m (17 ft)
Dry mass[73]	22.2 t (49,000 lb)	4 t (8,800 lb)	1.7 t (3,700 lb)
Fueled mass	433.1 t (955,000 lb)	111.5 t (246,000 lb)	—
Structure type	LOX tank: monocoque Fuel tank: skin and stringer	LOX tank: monocoque Fuel tank: skin and stringer	Monocoque halves
Structure material	Aluminum–lithium skin; aluminum domes	Aluminum–lithium skin; aluminum domes	Carbon fiber
Engines	9 × Merlin 1D	1 × Merlin 1D Vacuum	—
Engine type	Liquid, gas generator	Liquid, gas generator	
Propellant	Subcooled liquid oxygen, kerosene (RP-1)	Liquid oxygen, kerosene (RP-1)	
Liquid oxygen tank capacity[73]	287.4 t (634,000 lb)	75.2 t (166,000 lb)	
Kerosene tank capacity[73]	123.5 t (272,000 lb)	32.3 t (71,000 lb)	
Engine nozzle	Gimbaled, 16:1 expansion	Gimbaled, 165:1 expansion	
Engine designer/manufacturer	SpaceX	SpaceX	
Thrust, stage total	22.82 MN (5,130,000 lbf), sea level	934 kN (210,000 lbf), vacuum	
Propellant feed system	Turbopump	Turbopump	
Throttle capability	Yes: 419–816 kN (94,000–183,000 lbf), sea level	Yes: 360–930 kN (82,000–209,000 lbf), vacuum	
Restart capability	Yes, in 3 engines for boostback, reentry, and landing	Yes, dual redundant TEA-TEB pyrophoric igniters	
Tank pressurization	Heated helium	Heated helium	
Ascent attitude control: pitch, yaw	Gimbaled engines	Gimbaled engine and nitrogen gas thrusters	
Ascent attitude control: roll	Gimbaled engines	Nitrogen gas thrusters	
Coast/descent attitude control	Nitrogen gas thrusters and grid fins	Nitrogen gas thrusters	Nitrogen gas thrusters
Shutdown process	Commanded	Commanded	—
Stage separation system	Pneumatic	—	Pneumatic

The Falcon Heavy uses a 4.5 m (15 ft) interstage attached to the first stage core.[73] It is a composite structure consisting of an aluminum honeycomb core surrounded by carbon fiber face sheet plies. Unlike for Falcon 9, the black thermal protection layer on the interstage of Block 5 center core boosters is later painted white, as seen in the Falcon Heavy flights so far, probably due to asthetics of the Falcon Heavy Logo, providing it a greyish look.[74] The overall length of the vehicle at launch is 70 m (230 ft), and the total fueled mass is 1,420 t (3,130,000 lb). Without recovery of any stage, the Falcon Heavy can inject a 63.8 t (141,000 lb) payload into a low Earth orbit, or 16.8 t (37,000 lb) to Venus or Mars.[73]

The Falcon Heavy includes first-stage recovery systems, to allow SpaceX to return the first stage boosters to the launch site as well as recover the first stage core following landing at an Autonomous Spaceport Drone Ship barge after completion of primary mission requirements. These systems include four deployable landing legs, which are locked against each first-stage tank core during ascent and deploy just prior to touchdown. Excess propellant reserved for Falcon Heavy first-stage recovery operations will be diverted for use on the primary mission objective, if required, ensuring sufficient performance margins for successful missions. The nominal payload capacity to a geostationary transfer orbit (GTO) is 8 t (18,000 lb) with recovery of all three first-stage cores (the price per launch is US$97 million), versus 26.7 t (59,000 lb) in fully expendable mode. The Falcon Heavy can also inject a 16 t (35,000 lb) payload into GTO if only the two side boosters are recovered.[73]

Capabilities

Twenty-seven Merlin engines firing during launch of Arabsat-6A in 2019

The partially reusable Falcon Heavy falls into the heavy-lift range of launch systems, capable of lifting 20–50 t (44,000–110,000 lb) into low Earth orbit (LEO), under the classification system used by a NASA human spaceflight review panel.[75] A fully expendable Falcon Heavy is in the super heavy-lift category with a maximum payload of 64 t (141,000 lb) to low Earth orbit.

The initial concept (Falcon 9-S9 2005) envisioned payloads of 24.75 t (54,600 lb) to LEO, but by April 2011 this was projected to be up to 53 t (117,000 lb)[76] with geostationary transfer orbit (GTO) payloads up to 12 t (26,000 lb).[77] Later reports in 2011 projected higher payloads beyond LEO, including 19 t (42,000 lb) to geostationary transfer orbit,[78] 16 t (35,000 lb) to translunar trajectory, and 14 t (31,000 lb) on a trans-Martian orbit to Mars.[79][80]

By late 2013, SpaceX raised the projected GTO payload for Falcon Heavy to up to 21.2 t (47,000 lb).[81]

In April 2017, the projected LEO payload for Falcon Heavy was raised from 54.4 to 63.8 t (120,000 to 141,000 lb). The maximum payload is achieved when the rocket flies a fully expendable launch profile, not recovering any of the three first-stage boosters.[1] With just the core booster expended, and two side-boosters recovered, Musk estimates the payload penalty to be around 10%, which would still yield over 57 t (126,000 lb) of lift capability to LEO.[82] Returning all three boosters to the launch site rather than landing them on drone ships would yield about 30 t of payload to LEO.[83]

Maximum theoretical payload capacity

Destination	Falcon Heavy			Falcon 9
	August 2013 to April 2016	May 2016 to March 2017	Since April 2017	
LEO (28.5°) expendable	53 t	54.4 t	63.8 t	22.8 t
GTO (27.0°) expendable	21.2 t	22.2 t	26.7 t	8.3 t
GTO (27.0°) reusable	6.4 t	6.4 t	8 t	5.5 t
Mars	13.2 t	13.6 t	16.8 t	4 t
Pluto	–	2.9 t	3.5 t	–

Long exposure of a night launch, 25 June 2019

Reusability

Falcon Heavy reusable side boosters land in unison at Cape Canaveral Landing Zones 1 and 2 following test flight on 6 February 2018

From 2013 to 2016, SpaceX conducted parallel development of a reusable rocket architecture for Falcon 9, that applies to parts of Falcon Heavy as well. Early on, SpaceX had expressed hopes that all rocket stages would eventually be reusable.[84] SpaceX has since demonstrated routine land and sea recovery of the Falcon 9 first stage, and have successfully recovered multiple payload fairings.[85][86] In the case of Falcon Heavy, the two outer cores separate from the rocket earlier in the flight, and are thus moving at a lower velocity than in a Falcon 9 launch profile.[72] For the first flight of Falcon Heavy, SpaceX had considered attempting to recover the second stage,[87] but did not execute this plan.

Falcon Heavy payload performance to geosynchronous transfer orbit (GTO) is reduced by the reusable technology, but at a much lower price. When recovering all three booster cores, GTO payload is 8 t (18,000 lb).[1] If only the two outside cores are recovered while the center core is expended, GTO payload would be approximately 16 t (35,000 lb).[73] As a comparison, the next-heaviest contemporary rocket, the fully expendable Delta IV Heavy, can deliver 14.2 t (31,000 lb) to GTO.[88]

Propellant crossfeed

Falcon Heavy was originally designed with a unique "propellant crossfeed" capability, whereby the center core engines would be supplied with fuel and oxidizer from the two side cores until their separation.[89] Operating all engines at full thrust from launch, with fuel supplied mainly from the side boosters, would deplete the side boosters sooner, allowing their earlier separation to reduce the mass being accelerated. This would leave most of the center core propellant available after booster separation.[90]

Musk stated in 2016 that crossfeed would not be implemented.[91] Instead, the center booster throttles down shortly after liftoff to conserve fuel, and resumes full thrust after the side boosters have separated.[3]

Environmental impact

BBC Science Focus, in February 2018, published an article on Falcon Heavy's environmental impact. It stated concerns that frequent Falcon Heavy launches can contribute to pollution in the atmosphere.[92]

The Planetary Society was concerned that launching a non-sterile object (as was done on the Falcon Heavy Test Flight) to interplanetary space may risk biological contamination of a foreign world.[93] Scientists at Purdue University thought it was the "dirtiest" man-made object ever sent into space, in terms of bacteria amount, noting the car was previously driven on Los Angeles freeways. Although the vehicle will be sterilized by solar radiation over time, some bacteria might survive on pieces of plastic which could contaminate Mars in the distant future.[94][95]

A study conducted by the Federal Aviation Administration found that the boost-back and landing of Falcon Heavy boosters "would not significantly affect the quality of the human environment".[96]

Launch prices

At an appearance in May 2004 before the United States Senate Committee on Commerce, Science, and Transportation, Musk testified, "Long term plans call for development of a heavy lift product and even a super-heavy, if there is customer demand. We expect that each size increase would result in a meaningful decrease in cost per pound to orbit. ... Ultimately, I believe US$500 per pound or less is very achievable".[97] This $1,100/kg ($500/lb) goal stated by Musk in 2011 is 35% of the cost of the lowest-cost-per-pound LEO-capable launch system in a 2001 study: the Zenit, a medium-lift launch vehicle that could carry 14 t (31,000 lb) into LEO for US$35–50 million.[98] In 2011, SpaceX stated that the cost of reaching low Earth orbit could be as low as $2,200/kg ($1,000/lb) if an annual rate of four launches can be sustained, and as of 2011 planned to eventually launch as many as 10 Falcon Heavies and 10 Falcon 9s annually.[79]

The published prices for Falcon Heavy launches have changed as development progressed, with announced prices for the various versions of Falcon Heavy priced at US$80–125 million in 2011,[76] US$83–128 million in 2012,[77] US$77–135 million in 2013,[99] US$85 million for up to 6.4 t (14,000 lb) to GTO in 2014, US$90 million for up to 8 t (18,000 lb) to GTO in 2016.[100]

From 2017 to early 2022, the price has been stated at US$150 million for 63.8 t (141,000 lb) to LEO or 26.7 t (59,000 lb) to GTO (fully expendable).[101] This equates to a price of US$2,350 per kg to LEO and US$5,620 per kg to GTO. In 2022, the published price for a reusable launch was $97 million;[102] however in 2022 NASA contracted with SpaceX to launch the Nancy Grace Roman Space Telescope on a Falcon Heavy for approximately $255 million, including launch service and other mission related costs.[103]

The nearest competing U.S. rocket is ULA's Delta IV Heavy with a LEO payload capacity of 28.4 t (63,000 lb) costs US$12,340 per kg to LEO and US$24,630 per kg to GTO.[104] The Delta IV Heavy will be retired in 2024 with one flight remaining as of June 2023.

Competitors from 2024 onwards may include SpaceX Starship (100+ t to LEO), Blue Origin's New Glenn (45 t to LEO), Relativity Space's Terran R (34 t to LEO), and United Launch Alliance (ULA) Vulcan Centaur (27 t to LEO).

Launches and payloads

Due to improvements to the performance of Falcon 9, some of the heavier satellites flown to GTO, such as Intelsat 35e[105] and Inmarsat-5 F4,[106] ended up being launched before the debut of Falcon Heavy. SpaceX anticipated the first commercial Falcon Heavy launch would be three to six months after a successful maiden flight,[107][108] but due to delays, the first commercial payload, Arabsat-6A was successfully launched on 11 April 2019, a year and two months after the first flight. SpaceX hoped to have 10 launches every year from 2021 on,[109] but there were no launches in 2020 or 2021.

Falcon Heavy launches[110]

Flight No.	Launch date	Payload and mass	Customer	Price	Outcome
1	6 February 2018 20:45 UTC[4]	Elon Musk's Tesla Roadster ~1,250 kg (2,760 lb)[111]	SpaceX	Internal	Success[112]
In this demonstration flight, a Tesla Roadster was sent to a trans-Mars injection heliocentric orbit.[113][114] Both side boosters landed successfully; the center booster struck the ocean and was destroyed after two of its engines failed to relight during the landing burn, damaging two of the drone ship's engines.[50]					
2	11 April 2019 22:35 UTC[115]	Arabsat-6A 6,465 kg (14,253 lb)[116]	Arabsat	Undisclosed[117]	Success[118]
Heavy communications satellite purchased by the Arab League.[119] All three boosters landed successfully[120] but the center core subsequently fell over and was lost during transport due to heavy seas.[121] The two side-boosters were reused on the STP-2 launch.[122][123]					
3	25 June 2019 06:30 UTC[124]	USAF STP-2 3,700 kg (8,200 lb)	United States Department of Defense	US$160.9 million[125]	Success
The mission supported the U.S. Air Force National Security Space Launch (formerly EELV) certification process for the Falcon Heavy.[119] The original contract price was US$165 million, which was later reduced, in big part due to military's agreement to fly the mission with reused side boosters. Secondary payloads include orbiters: LightSail 2,[126] GPIM,[127][128][129] OTB (hosting the Deep Space Atomic Clock,[130][131]) six COSMIC-2 (FORMOSAT-7),[132][133] Oculus-ASR,[134] Prox-1,[126] and ISAT.[135] Successfully reused the boosters from the second Falcon Heavy flight.[108][122] The center core booster did not land successfully and was destroyed upon impact in the Atlantic Ocean.[136]					
4	1 November 2022 13:41 UTC[137]	USSF-44 ~3,750 kg (8,270 lb)	U.S. Space Force, Millennium Space Systems and Lockheed Martin Space	~US$130 million (from a US$297 million contract including two Falcon 9s[138][139])	Success
First classified flight of Falcon Heavy. The contract was awarded to SpaceX for a price of under 30% of that of a typical Delta IV Heavy launch (US$440 million). Payload includes two separate satellites and at least three additional rideshare payloads (including *TETRA-1*)[140] and weighs roughly 3.7 t (8,200 lb) at launch.[141] They were launched in a direct geosynchronous orbit, necessitating for the first time a planned partially expendable launch, that is, to deliberately expend the center core which lacks grid fins and landing gear needed for a landing,[142] while the two side-boosters landed at Cape Canaveral Space Force Station.[143] It was originally scheduled for Q1 2022, but it was delayed due to payload issues to 1 November 2022.[144] The second stage featured a gray band due to its long coast phase between subsequent burns, to allow more heat from sunlight to be absorbed to warm the RP-1 kerosene tank during the longer coasting period, a first for FH and third for any Falcon rocket. When it gets too cold, kerosene – which freezes at a much higher temperature than Falcon's liquid oxygen oxidizer – becomes viscous and slush-like before it freezes solid. If ingested, slushy fuel would likely prevent ignition or destroy the upper stage's Merlin engine.[145]					
5	15 January 2023 22:56 UTC[146]	USSF-67 ~3,750 kg (8,270 lb)	U.S. Space Force	US$317 million (includes new infrastructure[147])	Success

Used a new center core in an expendable configuration (no grid fins or landing gear), while the two reused[148] side-boosters landed at Cape Canaveral Space Force Station. The second stage had a gray band for thermal purposes as the mission requirements were similar to the USSF-44 mission.[149]					
6	1 May 2023 00:26 UTC[150]	ViaSat-3 Americas Arcturus (Aurora 4A)[151][152] G-Space 1 (aka Nusantara-H1-A)	Viasat Astranis / Pacific Dataport PT Pasifik Satelit Nusantara		Success
Falcon Heavy was originally slated to launch the Viasat-2 satellite, but due to delays an Ariane 5 launch vehicle was used instead.[153] Viasat maintained the launch option and delivered its next Ka-band satellite aboard the Falcon Heavy – this one intended to provide service to the Americas region. Astranis' microGEO satellite, Arcturus, was added as an independent secondary payload in late September 2021. Following a series of MVac engine burns and long periods of coasting, the upper stage of Falcon Heavy deployed the satellite into a near-geosynchronous orbit at approximately T+4:32:27.[154][155] The upper stage went on to successfully deploy the additional payloads, G-Space 1 and Arcturus. The second stage had a gray band for the same reason as on the USSF-44 flight. This was the first Falcon Heavy launch to expend all three first stage cores.					
7	29 July 2023 03:04 UTC[156]	Jupiter-3 (EchoStar-24)[157]	EchoStar		Success
Heaviest commercial geostationary satellite weighing 9,200 kg (20,300 lb) at launch. The second stage had a gray band for the same reason as on the USSF-44 flight, but this time it was configured for medium coast phase.[157] Core expended, two boosters recovered to land. Payload fairing recovery attempted.					
8	13 October 2023 14:19 UTC[158]	*Psyche*	NASA (Discovery)	US$117 million[159]	Success
Falcon Heavy launched the 2.6 t (5,700 lb) Psyche orbiter mission into a heliocentric orbit. From there, the Psyche spacecraft will visit the Psyche asteroid in the main asteroid belt.[159] Core expended, two boosters recovered to land.					
9	NET December 2023[160]	USSF-52	U.S. Space Force	US$149 million[161][162]	Planned
Second classified flight of Falcon Heavy, awarded in June 2018.					
10	NET April 2024[163]	GOES-U	NASA	US$152.5 million	Planned
In September 2021, NASA awarded SpaceX launch services contract for the geostationary GOES-U weather satellite.[164]					
11	NET 10 October 2024	*Europa Clipper*	NASA (Planetary Missions)	US$178 million[165]	Planned
Europa Clipper will conduct a detailed survey of Europa and use a sophisticated suite of science instruments to investigate whether the icy moon has conditions suitable for life. Key mission objectives are to produce high-resolution images of Europa's surface, determine its composition, look for signs of recent or ongoing geological activity, measure the thickness of the moon's icy shell, search for subsurface lakes, and determine the depth and salinity of Europa's ocean. The mission will fly past Mars and Earth before arriving at Jupiter in April 2030.[166][167]					
12	NET November 2024[168][169]	VIPER (Griffin Mission 1)	Astrobotic/NASA (Artemis)	Undisclosed[170] (list price US$90 million)	Planned
Astrobotic's Griffin lunar lander will deliver NASA's *VIPER* spacecraft to the lunar south pole,[171] expected to recover all 3 boosters.					
–	NET December 2024[64]	Power and Propulsion Element (PPE)	NASA (Artemis)	US$331.8 million	Planned

		Habitation and Logistics Outpost (HALO)			
First elements for the Gateway mini-station as part of the Artemis program,[172][173] awarded in February 2021.[174] Maxar had already made $27.5 million in payments to SpaceX for the contract to launch the PPE, but later, NASA decided to launch both PPE and HALO together.[175]					
–	NET October 2026[176]	Nancy Grace Roman Space Telescope	NASA (Launch Services Program)	$255 million	Planned
Infrared space telescope to be stationed at Sun-Earth L2.[177]					
–	2026[178]	TBA	Astrobotic		TBA
–	2028[179][180][181]	GLS-1 (Dragon XL)	NASA (Gateway Logistics Services)		Planned
In March 2020, NASA announced its first contract for the Gateway Logistics Services that guarantees at least two launches on a new Dragon XL resupply spacecraft on top of a Falcon Heavy that will carry over 5 t (11,000 lb) of cargo to the Lunar orbit on 6–12 months long missions.[182][183]					
–	2029[179]	GLS-2 (Dragon XL)	NASA (Gateway Logistics Services)		Planned
Second Dragon XL flight					
–	TBA	TBA	Intelsat		TBA
This was the first commercial agreement of a Falcon Heavy, and was signed in May 2012.[184] In 2018, the option was still maintained but no satellite had been chosen.[185]					

First commercial contracts

In May 2012, SpaceX announced that Intelsat had signed the first commercial contract for a Falcon Heavy flight. It was not confirmed at the time when the first Intelsat launch would occur, but the agreement will have SpaceX delivering satellites to geosynchronous transfer orbit (GTO).[186][187] In August 2016, it emerged that this Intelsat contract had been reassigned to a Falcon 9 Full Thrust mission to deliver Intelsat 35e into orbit in the third quarter of 2017.[55] Performance improvements of the Falcon 9 vehicle family since the 2012 announcement, advertising 8.3 t (18,000 lb) to GTO for its expendable flight profile,[188] enable the launch of this 6 t satellite without upgrading to a Falcon Heavy variant.

In 2014, Inmarsat booked three launches with Falcon Heavy,[189] but due to delays they switched a payload to Ariane 5 for 2017.[190] Similarly to the Intelsat 35e case, another satellite from this contract, Inmarsat 5-F4, was switched to a Falcon 9 Full Thrust due to the increased liftoff capacity.[56] The remaining contract covered the launch of Inmarsat-6 F1 in 2020 on a Falcon 9.[191]

Department of Defense contracts

In December 2012, SpaceX announced its first Falcon Heavy launch contract with the United States Department of Defense (DoD). The United States Air Force Space and Missile Systems Center awarded SpaceX two Evolved Expendable Launch Vehicle (EELV)-class missions, including the Space

Test Program 2 (STP-2) mission for Falcon Heavy, originally scheduled to be launched in March 2017,[192][193] to be placed at a near circular orbit at an altitude of 700 km (430 mi), with an inclination of 70.0°.[194]

In April 2015, SpaceX sent the U.S. Air Force an updated letter of intent outlining a certification process for its Falcon Heavy rocket to launch national security satellites. The process includes three successful flights of the Falcon Heavy including two consecutive successful flights, and the letter stated that Falcon Heavy can be ready to fly national security payloads by 2017.[195] But in July 2017, SpaceX announced that the first test flight would take place in December 2017, pushing the launch of the second launch (Space Test Program 2) to June 2018.[54] In May 2018, on the occasion of the first launch of the Falcon 9 Block 5 variant, a further delay to October 2018 was announced, and the launch was eventually pushed to 25 June 2019.[53] The STP-2 mission used three Block 5 cores.[196]

SpaceX was awarded 40% of the launches in Phase 2 of the National Security Space Launch (NSSL) contracts, which includes several launches and a vertical integration facility and development of a larger fairing, from 2024 to 2027.[197]

Space Test Program 2 (STP-2) mission

The payload for the STP-2 mission of the Department of Defense included 25 small spacecraft from the U.S. military, NASA, and research institutions:[54]

The Green Propellant Infusion Mission (GPIM) was a payload; it is a project partly developed by the U.S. Air Force to demonstrate a less-toxic propellant.[127][198]

Another secondary payload is the miniaturized Deep Space Atomic Clock that is expected to facilitate autonomous navigation.[199] The Air Force Research Laboratory's Demonstration and Science Experiments (DSX) has a mass of 500 kg (1,100 lb) and will measure the effects of very low frequency radio waves on space radiation.[54] The British 'Orbital Test Bed' payload is hosting several commercial and military experiments.

Other small satellites included Prox 1, built by Georgia Tech students to test a 3D-printed thruster and a miniaturized gyroscope, LightSail by The Planetary Society,[126] Oculus-ASR nanosatellite from Michigan Tech,[134] and CubeSats from the U.S. Air Force Academy, the Naval Postgraduate School, the United States Naval Research Laboratory, the University of Texas at Austin, California Polytechnic State University, and a CubeSat assembled by students at Merritt Island High School in Florida.[54]

The Block 5-second stage allowed multiple reignitions to place its many payloads in multiple orbits. The launch was planned to include a 5 t (11,000 lb) ballast mass,[200] but the ballast mass was later omitted from the 3.7 t (8,200 lb) total mass for the payload stack.[201]

NASA contracts

Solar System transport missions

In 2011, NASA Ames Research Center proposed a Mars mission called *Red Dragon* that would use a Falcon Heavy as the launch vehicle and trans-Martian injection vehicle, and a variant of the Dragon capsule to enter the Martian atmosphere. The proposed science objectives were to detect biosignatures and to drill 1 m (3.3 ft) or so underground, in an effort to sample reservoirs of water ice known to exist under the surface. The mission cost as of 2011 was projected to be less than US$425 million, not including the launch cost.[202] SpaceX 2015 estimation was 2,000–4,000 kg (4,400–8,800 lb) to the surface of Mars, with a soft retropropulsive landing following a limited atmospheric deceleration using a parachute and heat shield.[203] Beyond the *Red Dragon* concept, SpaceX was seeing potential for Falcon Heavy and Dragon 2 to carry science payloads across much of the Solar System, particularly to Jupiter's moon Europa.[203] SpaceX announced in 2017 that propulsive landing for Dragon 2 would not be developed further, and that the capsule would not receive landing legs. Consequently, the *Red Dragon* missions to Mars were canceled in favor of Starship, a larger vehicle using a different landing technology.[204]

Lunar missions

Falcon Heavy is the launch vehicle for the initial modules of the Lunar Gateway: Power and Propulsion Element (PPE) and Habitation and Logistics Outpost (HALO).[205] To decrease complexity[206] NASA announced in February 2021 that it is launching the first two elements on a single Falcon Heavy launch vehicle, targeting a launch date no earlier than November 2024.[64][174] Before switching to a merged launch, NASA listed in April 2020 Falcon Heavy as the launch vehicle for PPE lone launch.[207]

In March 2020, Falcon Heavy won the first award to a resupply mission to the Lunar Gateway, placing a new Dragon XL spacecraft on a translunar injection orbit.[183]

Psyche and *Europa Clipper*

NASA chose the Falcon Heavy as the launch vehicle for its Psyche mission to a metallic asteroid; it launched on 13 October 2023.[208] The contract was worth US$117 million.[209][210][211]

Europa Clipper was initially targeted to be launched on an SLS rocket. However, due to extensive delays, in 2021 NASA awarded the launch contract to SpaceX for a fully expendable Falcon Heavy.[212]

See also

- Comparison of orbital launch systems
- Comparison of orbital launchers families
- SpaceX Mars transportation infrastructure
- Saturn C-3
- Delta IV Heavy

Spaceflight portal
United States portal
Companies portal

Notes

1. In some reused configurations, it is heavy lift.

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