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Starlink

Starlink is a satellite constellation being constructed by SpaceX[2][3] to provide satellite Internet access.[4][5] The constellation will consist of thousands of mass-produced small satellites in low Earth orbit (LEO), working in combination with ground transceivers. SpaceX also plans to sell some of the satellites for military,[6] scientific, or exploratory purposes.[7] The SpaceX satellite development facility in Redmond, Washington houses the Starlink research, development, manufacturing, and on-orbit control operations. The total cost of the decade-long project to design, build, and deploy the constellation was estimated by SpaceX in May 2018 to be about US$10 billion.[8]

Product development began in 2015, with the first two prototype test-flight satellites launched in February 2018. A second set of test satellites and the first large deployment of a piece of the constellation occurred in May 2019 when the first 60 operational satellites were launched.[2][9] As of 2020, SpaceX is launching 60 satellites at a time, aiming to deploy 1,584 of the 260 kilograms (570 lb) spacecraft to provide near-global service by late 2021 or 2022.[10] SpaceX is targeting a private beta service in the Northern U.S. and Canada by August 2020 with a public beta following in November 2020.[11]

Concerns have been raised about the long-term danger of space debris resulting from placing thousands of satellites in orbits above 600 kilometres (370 mi)[12][13] and a possible impact on astronomy,[14] although the Starlink satellite orbits were lowered to 550 kilometres (340 mi) or below[15] and SpaceX is reportedly attempting to solve the latter issue. On Starlink 2, one of the satellites has an experimental coating to make it less reflective, and thus impact ground-based astronomical observations less.[16] A June 2020 launch included one satellite with an experimental sunshade.[17]

On 15 October 2019, the U.S. Federal Communications Commission submitted filings to the International Telecommunication Union on SpaceX's behalf to arrange spectrum for 30,000 additional Starlink satellites to supplement the 12,000 Starlink satellites already approved by the FCC.[18]

Contents

Starlink

60 Starlink satellites stacked together before deployment on 24 May 2019.

Manufacturer	SpaceX
Country of origin	United States
Operator	SpaceX
Applications	Internet service
Specifications	
Spacecraft type	Small satellite
Launch mass	227–260 kg (500–573 lb)
Equipment	K_u, K_a, and E-band phased array antennas Hall-effect thrusters
Regime	Low Earth (335.9–1,325 km (208.7–823.3 mi))
Production	
Status	Active
Launched	Total: 540[1] Tintin: 2 v 0.9: 60 v 1.0: 478
Maiden launch	22 February 2018
Last launch	13 June 2020

History

2015–2017

The SpaceX satellite development facility, Redmond, Washington, in use from 2015 to mid-2018

The communication satellite network SpaceX envisions was publicly announced in January 2015, with the projected design capability to support sufficient bandwidth to carry up to 50% of all backhaul communications traffic, and up to 10% of local Internet traffic, in high-density cities.[5][7] CEO Elon Musk said that there is significant unmet demand for low-cost global broadband capabilities.[19]

The opening of the SpaceX satellite development facility in Redmond was announced by SpaceX in January 2015 with partners, to develop and build out the new communication network. At the time, the Seattle-area office planned to initially hire approximately 60 engineers, and potentially 1,000 people by 2018.[20] The company operated in 2,800 square metres (30,000 sq ft) of leased space by late 2016, and by January 2017 had taken on a 3,774.2 square metres (40,625 sq ft) second facility, both in Redmond.[21] In August 2018, SpaceX consolidated all their Seattle-area operations with a move to a larger three-building facility at Redmond Ridge Corporate Center to support satellite manufacturing in addition to R&D.[22]

In July 2016, SpaceX acquired a 740 square meters (8,000 sq ft) creative space in Irvine, California (Orange County).[23] SpaceX job listings indicated the Irvine office would include signal processing, RFIC, and ASIC development for the satellite program.[24]

By January 2016, the company had publicly disclosed plans to have two prototype satellites flying in 2016,[25] and to have the initial satellite constellation in orbit and operational by approximately 2020.[7] By October 2016, SpaceX had developed the initial satellites that they hoped to launch and test in 2017, but the satellite division was focusing on a significant business challenge of achieving a sufficiently low-cost design for the user equipment, aiming for something that ostensibly can be installed easily at end-user premises for approximately US$200. Overall, SpaceX President Gwynne Shotwell said then that the project remained in the "design phase as the company seeks to tackle issues related to user-terminal cost."[4] Deployment, if carried out, would not be until "late in this decade or early in the next".[19] The two original test satellites were not flown and were used only in ground testing. The planned launch of two revised satellites was moved to 2018.[26][27]

In November 2016, SpaceX filed an application with the Federal Communications Commission (FCC) for a "non-geostationary orbit (NGSO) satellite system in the Fixed-Satellite Service using the K_u and K_a frequency bands".[28]

In March 2017, SpaceX filed plans with the FCC to field a second orbital shell of more than 7,500 "V-band satellites in non-geosynchronous orbits to provide communications services" in an electromagnetic spectrum that has not previously been heavily employed for commercial communications services. Called the "Very-Low Earth Orbit (VLEO) constellation",[29] it would comprise 7,518 satellites and would orbit at just 340 kilometres (210 mi) altitude,[30] while the smaller, originally - planned group of 4,425 satellites would operate in the K_a - and K_u-bands and orbit at 1,200 kilometres (750 mi) altitude.[29][30] SpaceX's plans were unusual in two areas: the company intended to utilize the little-used V-band of the communications spectrum, and they intended to use a new orbital regime, the very-low Earth orbit regime of ~340 kilometres (210 mi) altitude, where atmospheric drag is quite high, which normally results in short orbital lifetimes.[31] The March 2017 plan called for SpaceX to launch test satellites of the initial K_a/K_u type in both 2017 and 2018, and begin launching the operational constellation in 2019. Full build-out of the approximately 1,200 km (750 mi) constellation of around 4,440 satellites was not then expected to be completed until 2024.[32]

Some controversy arose in 2015–2017 with regulatory authorities on licensing of the communications spectrum for these large constellations of satellites. The traditional and historical regulatory rule for the licensing spectrum has been that satellite operators could "launch a single spacecraft to meet their in-service deadline [from the regulator], a policy is seen as allowing an operator to block the use of valuable radio spectrum for years without deploying its fleet".[33] By 2017, the FCC had set a six-year deadline to have an entire large constellation deployed to comply with licensing terms. The international regulator, International Telecommunication Union (ITU), proposed in mid-2017 a guideline that would be considerably less restrictive. In September 2017, both Boeing and SpaceX petitioned the US FCC for a waiver of the six-year rule,[33] but they were denied. By 2019, the FCC had ruled that half of the constellation must be in orbit in six years, with the full system in orbit nine years from the date of the license.[34]

SpaceX trademarked the name *Starlink* for their satellite broadband network in 2017;[35] the name was inspired by the book *The Fault in Our Stars*.[36]

SpaceX filed documents in late 2017 with the FCC to clarify their space debris mitigation plan. The company will "implement an operations plan for the orderly de-orbit of satellites nearing the end of their useful lives (roughly five to seven years) at a rate far faster than is required under international standards. [Satellites] will de-orbit by propulsively moving to a disposal orbit from which they will reenter the Earth's atmosphere within approximately one year after completion of their mission".[37] In March 2018, the FCC issued SpaceX approval, with some conditions. SpaceX would need to obtain a separate approval from the International

Telecommunication Union.[38][39] The FCC supported a NASA request to ask SpaceX to achieve an even higher level of de-orbiting reliability than the standard that NASA had previously used for itself: reliably de-orbiting 90% of the satellites after their missions are complete.[40]

2018–2019

In May 2018, SpaceX expected the total cost of development and buildout of the constellation to approach US$10 billion.[8] In mid-2018, SpaceX reorganized the satellite development division in Redmond, and terminated several members of senior management.[22]

In November 2018, SpaceX received US regulatory approval to deploy 7,518 broadband satellites, in addition to the 4,425 approved earlier. SpaceX's initial 4,425 satellites had been requested in the 2016 regulatory filings to orbit at altitudes of 1,110 kilometres (690 mi) to 1,325 kilometres (823 mi), well above the International Space Station. The new approval was for the addition of a very-low Earth orbit non-geostationary satellite orbit constellation, consisting of 7,518 satellites operating at altitudes from 335 km (208 mi) to 346 kilometres (215 mi), below the ISS.[41] Also in November, SpaceX made new regulatory filings with the US Federal Communications Commission (FCC) to request the ability to alter its previously granted license in order to operate approximately 1,600 of the 4,425 K_a-/K_u-band satellites approved for operation at 1,150 kilometres (710 mi) in a "new lower shell of the constellation" at only 550 kilometres (340 mi) orbital altitude.[42][43] These satellites would effectively operate in a third orbital shell, a 550 kilometres (340 mi) orbit, while the higher and lower orbits at approximately 1,200 kilometres (750 mi) and approximately 340 kilometres (210 mi) would be used only later, once a considerably larger deployment of satellites becomes possible in the later years of the deployment process. The FCC approved the request in April 2019, giving approval to place nearly 12,000 satellites in three orbital shells: initially approximately 1,600 in a 550 kilometres (340 mi) - altitude shell, and subsequently placing approximately 2,800 K_u- and K_a-band spectrum satellites at 1,150 kilometres (710 mi) and approximately 7,500 V-band satellites at 340 kilometres (210 mi).[34]

With plans by several providers to build commercial space-Internet mega-constellations of thousands of satellites increasingly likely to become a reality, the US military began to perform test studies in 2018 to evaluate how the networks might be used. In December, the US Air Force issued a US$28 million contract for specific test services on Starlink.[44]

In February 2019, a sister company of SpaceX, SpaceX Services, Inc., filed a request with the FCC to request a license for the operation of up to a million fixed satellite earth stations that would communicate with its non-geostationary orbit satellite (NGSO) Starlink system.[45]

By April 2019, SpaceX was transitioning their satellite efforts from research and development to manufacturing, with the planned first launch of a large group of satellites to orbit, and the clear need to achieve an average launch rate of "44 high-performance, low-cost spacecraft built and launched every month for the next 60 months" to get the 2,200 satellites launched to support their FCC spectrum allocation license assignment.[46] SpaceX said they will meet the deadline of having half the constellation "in orbit within six years of authorization... and the full system in nine years".[34]

By the end of June 2019, SpaceX had communicated with all 60 satellites but lost contact with three; the remaining 57 were working as intended. Forty-five satellites had reached their final orbital altitude of 550 km (340 mi), five were still raising their orbits, and another five were undergoing systems checks before they raise their orbits. The remaining two satellites were intended to be quickly removed from orbit and reenter the atmosphere in order to test the satellite de-orbiting process; the three that lost contact were also expected to reenter, but will do so passively from atmospheric drag as SpaceX was no longer able to actively control them.[47]

In June 2019, SpaceX applied to the FCC for a license to test up to 270 ground terminals – 70 nationwide across the United States and 200 in Washington state at SpaceX employee homes[48][49] – and aircraft-borne antenna operation from four distributed US airfields; as well as five ground-to-ground test locations.[50][51]

By September 2019, SpaceX had gone back to the FCC to apply for more changes to the orbital constellation. SpaceX asked to triple the number of orbital planes in the 550 kilometres (340 mi) orbital shell, from 24 to 72, arguing that they could then place satellites into multiple planes from a single launch. SpaceX argued that this change could bring coverage to the southern US in time for the 2020 hurricane season.[52] The change was approved in December 2019, and will now see only 22 satellites in each plane rather than the 66 that had been a part of the original design. The total number of satellites in the 550 km shell would remain the same, at 1,584.[53]

In October 2019, Elon Musk publicly tested the Starlink network by using an internet connection routed through the network to post a tweet to social media site Twitter.[54]

Falcon 9 lifts off from Cape Canaveral Air Force Station, Florida, delivering 60 Starlink satellites to orbit on 11 November 2019.

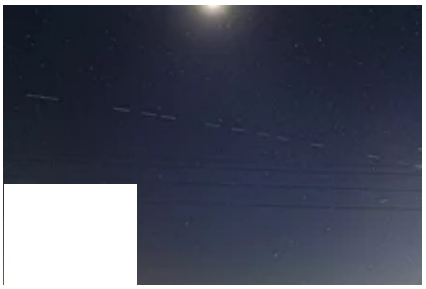
2020

As of 13 June 2020, SpaceX has launched 540 Starlink satellites. They plan to launch 60 more per Falcon 9 flight, with launches as often as every two weeks in 2020. In total, nearly 12,000 satellites are planned to be deployed, with a possible later extension to 42,000.[55] The initial 12,000 satellites are planned to orbit in three orbital shells:

First: approx. 1,584 in a 550 kilometres (340 mi) altitude shell, then
Second: approx. 2,825 K_u-band and K_a-band spectrum satellites at 1,110 km (690 mi), and
Third: approx. 7,500 V-band satellites at 340 kilometres (210 mi).[34]

On 17 April 2020, SpaceX modified the architecture of the Starlink network. SpaceX submitted an application to the Federal Communications Commission (FCC) proposing to operate more satellites in lower orbits than the FCC previously authorized. The first phase will include 1,584 satellites orbiting at 550 kilometres (340 mi) in planes inclined 53.0°. That part of the constellation, for launch through the end of 2020, remains unchanged.[56]

SpaceX previously had regulatory approval from the FCC to operate another 2,825 satellites in higher orbits between 1,110 kilometres (690 mi) and 1,325 kilometres (823 mi), in orbital planes inclined at 53.8°, 70.0°, 74.0° and 81.0°. The modified plan submitted to the FCC by SpaceX foresees K_u-band and K_a-band satellites in the next phase of the Starlink network all operated at altitudes between 540 kilometres (340 mi) and 570 kilometres (350 mi) at inclinations of 53.2°, 70.0° and 97.6°. The application covers 4,408 Starlink satellites, one fewer than envisioned under the previous architecture. SpaceX plans to launch another 7,500 V-band into orbits around 345 kilometres (214 mi)[56]



Starlink satellites passing overhead and visible with a naked eye. These satellites launched on 22 April 2020.

In June 2020, SpaceX applied for use of the E-band in the Gen2 constellation. The generation 2 Starlink constellation is expected to include up to 30,000 satellites and provide complete global coverage.[57]

Launches

The deployment of the first 1,584 satellites will be into 72 orbital planes of 22 satellites each, with a requested lower minimum elevation angle of beams to improve reception: 25° rather than the 40° of the other two orbital shells.[42]:17 SpaceX launched the first 60 satellites of the constellation in May 2019 into a 450 kilometres (280 mi) orbit and expected up to six launches in 2019 at that time, with 720 satellites (12 × 60) for continuous coverage in 2020.[58][59]

In August 2019, SpaceX expected four more launches in 2019[60] and at least nine launches in 2020.[61]

SpaceX expects 24 Starlink launches in 2020.[62] In March 2020, SpaceX reported producing six satellites per day.[63]

Starlink satellites are also planned to launch on Starship, an under-development rocket of SpaceX that will launch 400 satellites at a time.[64]

List of launches

Flight No.	Mission	Date and time (UTC)	Launch site	Launch vehicle[a]	Orbit altitude	Inclination	Number deployed	Version	Outcome
0	**Tintin**	22 February 2018, 14:17[65][66]	Vandenberg, SLC-4E	F9 FT ♺ B1038.2[67]	514 kilometres (319 mi)	97.5°[68]	2	–	Success
		Two test satellites known as Tintin A and B [69] (MicroSat-2a and 2b) that were deployed as co-payloads to the Paz satellite. The two prototypes were still in orbit.[70][71]							
1	**v0.9**	24 May 2019, 02:30[72]	CCAFS, SLC-40	F9 B5 ♺ B1049.3[67]	440–550 kilometres (270–340 mi)[73]	53.0°	60[74][75]	v0.9	Success[76]
		The first launch of 60 Starlink test satellites.[34] Said to be "production design", these are used to test various aspects of the network, including deorbiting.[77] They do not yet have the planned satellite interlink capabilities and they only communicate with antennas on Earth. A day after launch an amateur astronomer in the Netherlands was one of the first to publish a video showing the satellites flying across the sky as a "train" of bright lights.[78] By five weeks post launch, 57 of the 60 satellites were "healthy" while 3 had become non-operational and were derelict, but will deorbit due to atmospheric drag.[79] As of 31 October 2019, 49 satellites were in the target 550 km orbit while the others were still raising their orbits.[73]							
2	**v1.0 L1**	11 November 2019, 14:56[80]	CCAFS, SLC-40	F9 B5 ♺ B1048.4	550 kilometres (340 mi) (target)	53.0°	60[81]	v1.0	Success
		The first launch of 60 Starlink "operational" satellites (v1.0),[82] was the first to include Ka-band antennas.[83]							
3	**v1.0 L2**	7 January 2020, 02:19[84]	CCAFS, SLC-40	F9 B5 ♺ B1049.4	550 kilometres (340 mi)	53.0°	60	v1.0	Success
		One of the satellites, dubbed **DarkSat**,[56] has an experimental coating to make it less reflective, and to reduce the impact on ground-based astronomical observations.[85]							
4	**v1.0 L3**	29 January 2020, 14:06[86]	CCAFS, SLC-40	F9 B5 ♺ B1051.3	550 kilometres (340 mi)	53.0°	60	v1.0	Success
5	**v1.0 L4**	17 February 2020, 15:05[87]	CCAFS, SLC-40	F9 B5 ♺ B1056.4	550 kilometres (340 mi)	53.0°	60	v1.0	Success
6	**v1.0 L5**	18 March 2020, 12:16:39[88]	KSC, LC-39A	F9 B5 ♺ B1048.5	550 kilometres (340 mi)	53.0°	60	v1.0	Success
7	**v1.0 L6**	22 April 2020, 19:30:30[1]	KSC, LC-39A	F9 B5 ♺ B1051.4	550 kilometres (340 mi)	53.0°	60	v1.0	Success
8	**v1.0 L7**	4 June 2020, 01:25:00 [89]	CCAFS, SLC-40	F9 B5 ♺ B1049.5	550 kilometres (340 mi)	53.0°	60	v1.0	Success
		One of the satellites, dubbed **VisorSat**, has a sunshade to reduce the impact on ground-based astronomical observations.[17]							
9	**v1.0 L8**	13 June 2020, 09:21:18 [90]	CCAFS, SLC-40	F9 B5 ♺ B1059.3	550 kilometres (340 mi)	53.0°	58	v1.0	Success

		58 Starlink satellites plus three Planet Labs, SkySats 16-18 Earth-observation satellites.[90]							
10	**v1.0 L9**	23 June 2020, 21:58:00 [91][92]	KSC, LC-39A	F9 B5 ♺ B1051.5	550 kilometres (340 mi)	53.0°	TBD	v1.0	Planned
		Additionally, two satellites, BlackSky Global 5 and 6, has flown as rideshare payloads.[91][93] All of the Starlink satellites are outfitted with the sunshade visor that was tested on a single satellite on the 4 June 2020 launch. One half of Falcon 9's fairing previously flew on the JCSAT-18/Pacific 1 mission, and the other half previously flew on SpaceX's third Starlink mission.[94]							

Deorbited satellites

Starlink-46 (COSPAR ID: 2019-029M, NORAD: 44246) was deorbited on 20 February 2020.[95]

Starlink-1118 (COSPAR ID: 2020-001AL) was deorbited on 2 April 2020.[96]

Starlink-1220 (COSPAR ID: 2020-012AK) was deorbited on 9 March 2020.[97][98]

Services

Global broadband Internet

SpaceX intends to provide satellite internet connectivity to underserved areas of the planet, as well as provide competitively priced service to urban areas. The company has stated that the positive cash flow from selling satellite internet services would be necessary to fund their Mars plans.[99]

In early 2015, two space entrepreneurs announced satellite Internet ventures in the same week. In addition to SpaceX CEO Elon Musk announcing the project that would later be named Starlink, serial-entrepreneur Richard Branson announced an investment in OneWeb, a similar constellation with approximately 700 planned satellites that had already procured communication frequency licenses for their broadcast spectrum.[20][100]

After the failures of previous satellite-to-consumer space ventures, satellite industry consultant Roger Rusch said in 2015, "It's highly unlikely that you can make a successful business out of this".[20] Musk publicly acknowledged that business reality, and indicated in mid-2015 that while endeavoring to develop this technically complicated space-based communication system he wanted to avoid overextending the company, and stated that they are being measured in their pace of development.[101] Nevertheless, internal documents leaked in February 2017 indicated that SpaceX expected more than US$30 billion in revenue by 2025 from its satellite constellation, while revenues from its launch business were expected to reach US$5 billion in the same year.[102][103]

In February 2015, financial analysts questioned established geosynchronous orbit communications satellite fleet operators as to how they intend to respond to the competitive threat of SpaceX and OneWeb LEO communication satellites.[104] In October, SpaceX President Gwynne Shotwell indicated that while development continues, the business case for the long-term rollout of an operational satellite network was still in an early phase.[105]

With the initial launch of the first 60 satellites of the operational constellation in 2019, SpaceX indicated that it would require 420 satellites in the constellation to achieve minor broadband coverage of Earth, and 780 of the first ~1,600 to provide moderate coverage.[75]

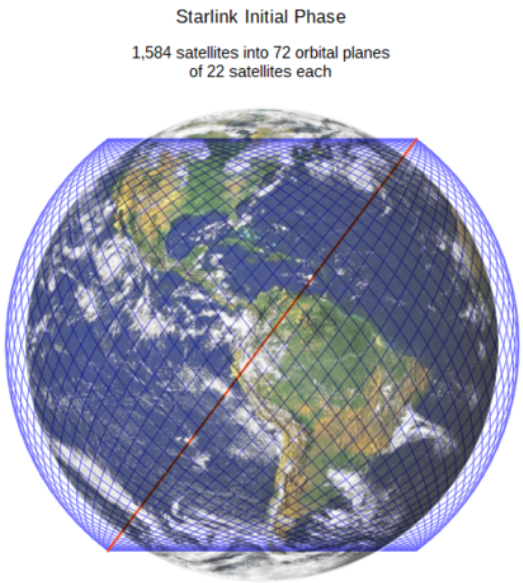
On 17 April 2020, in documentation to the FCC, SpaceX said lower altitude will put the satellites closer to Starlink consumers and allow the network "to provide low-latency broadband to unserved and underserved Americans that is on par with service previously only available in urban areas". The change will also improve service for U.S. government users in polar regions and allow for more rapid deployment of the network, SpaceX said. The lower orbits will help ensure the satellites re-enter the atmosphere in a shorter time in case of failure, and will enable them to broadcast signals at reduced power levels, because they are closer to Earth, which SpaceX said will allow the fleet to be compliant with limits to reduce radio interference with other satellite and terrestrial wireless networks.[56]

Use beyond Earth

SpaceX has long-term plans to develop and deploy a version of the satellite communication system to serve Mars.[19]

Technology

Constellation design and status



The Starlink constellation, phase 1, first orbital shell: 72 orbits with 22 each, 1,584 satellites at 550 km altitude.

Phase	Orbit shells (km)	Number of satellites	Inclination (degrees)	Half size contractual completion time	Full size contractual completion time	Operational satellites deployed (13 June 2020)	Retired satellites (24 April 2020)	Dead satellites (24 April 2020)
1	550	1,584	53.0	March 2024	March 2027	538	15[106]	9[106]
	1,110	1,600	53.8			0		
	1,130	400	70.0			0		
	1,275	374	74.0			0		
	1,325	450	80.0			0		
2	335.9	2,493	42.0	November 2024	November 2027	0		
	340.8	2,478	48.0			0		
	345.6	2,547	53.0			0		

In April 2020 SpaceX requested to lower all higher satellite orbits to about 550 km.[107]

Satellite hardware

The Internet communication satellites were expected to be in the smallsat-class of 100 to 500 kilograms (220 to 1,100 lb)-mass, and were intended to be in Low Earth Orbit (LEO) at an altitude of approximately 1,100 kilometres (680 mi), according to early public releases of information in 2015. In the event, the first large deployment of 60 satellites in May 2019 were 227 kilograms (500 lb)[72] and SpaceX decided to place the satellites at a relatively low 550 kilometres (340 mi), due to concerns about the space environment.[108] Initial plans as of January 2015 were for the constellation to be made up of approximately 4,000 cross-linked[101] satellites, more than twice as many operational satellites as were in orbit in January 2015.[7]

The satellites will employ optical inter-satellite links and phased array beam-forming and digital processing technologies in the K_u and K_a bands, according to documents filed with the U.S. Federal Communications Commission (FCC).[109][110] While specifics of the phased array technologies have been disclosed as part of the frequency application, SpaceX enforced confidentiality regarding details of the optical inter-satellite links.[111] Early satellites are launched without laser links, in October 2019 SpaceX expected satellites with these links to be ready by the end of 2020.[112]

The satellites will be mass-produced, at a much lower cost per unit of capability than existing satellites. Musk said, "We're going to try and do for satellites what we've done for rockets".[113] "In order to revolutionize space, we have to address both satellites and rockets".[7] "Smaller satellites are crucial to lowering the cost of space-based Internet and communications".[20]

In February 2015, SpaceX asked the FCC to consider future innovative uses of the K_a band spectrum before the FCC commits to 5G communications regulations that would create barriers to entry, since SpaceX is a new entrant to the satellite communications market. The SpaceX non-geostationary orbit communications satellite constellation will operate in the high-frequency bands above 24 GHz, "where steerable earth station transmit antennas would have a wider geographic impact, and significantly lower satellite altitudes magnify the impact of aggregate interference from terrestrial transmissions".[114]

Internet traffic via a geostationary satellite has a minimum theoretical round-trip latency of at least 477 ms (between user and ground gateway), but in practice, current satellites have latencies of 600 ms or more. Starlink satellites would orbit at $1/30$ to $1/105$ of the height of geostationary orbits, and thus offer more practical Earth-to-sat latencies of around 25 to 35 ms, comparable to existing cable and fiber networks.[115] The system will use a peer-to-peer protocol claimed to be "simpler than IPv6", it will also incorporate end-to-end encryption natively.[116] However, no details on this have been released as of yet.

Starlink satellites use Hall-effect thrusters with krypton gas as the reaction mass[72][117] for orbit raising and station keeping.[118] Krypton Hall thrusters tend to exhibit significantly higher erosion of the flow channel compared to a similar electric propulsion system operated with xenon, but at a lower propellant cost.[119]

User terminals

The system will not directly connect from its satellites to handsets (unlike the constellations from Iridium, Globalstar, Thuraya and Inmarsat). Instead, it will be linked to flat user terminals the size of a pizza box, which will have phased array antennas and track the satellites. The terminals can be mounted anywhere, as long as they can see the sky.[101]

In 2019, tests by the U.S. Air Force Research Laboratory (AFRL) demonstrated a 610 megabit per second data link through Starlink to a Beechcraft C-12 Huron aircraft in flight.[120]

Satellite revisions

MicroSat

MicroSat-1a and MicroSat-1b were originally slated to be launched into 625 kilometres (388 mi) circular orbits at approximately 86.4° inclination, and to include panchromatic video imager cameras to film images of Earth and the satellite.[121] The two satellites, "MicroSat-1a" and "MicroSat-1b" were meant to be launched together as secondary payloads on one of the Iridium-NEXT flights, but they were instead used for ground-based tests.[122]

Tintin

At the time of the June 2015 announcement, SpaceX had stated plans to launch the first two demonstration satellites in 2016,[25] but the target date was subsequently moved out to 2018.[26] SpaceX began flight testing their satellite technologies in 2018[26] with the launch of two test satellites. The two identical satellites were called **MicroSat-2a** and **MicroSat-2b**[123] during development but were renamed **Tintin A** and **Tintin B** upon orbital deployment on 22 February 2018. The satellites were launched by a Falcon 9 rocket, and they were piggy-pack payloads launching with the Paz satellite.

Tintin A and B were inserted into a 514 kilometres (319 mi) orbit. Per FCC filings,[124] they were intended to raise themselves to an 1,125 kilometres (699 mi) orbit, the operational altitude for Starlink LEO satellites per the earliest regulatory filings, but stayed close to their original orbits. SpaceX announced in November 2018 that they would like to operate an initial shell of about 1600 satellites in the constellation at about 550 kilometres (340 mi) orbital altitude, at an altitude similar to the orbits Tintin A and B stayed in.[42]

The satellites orbit in a circular low Earth orbit at about 500 kilometres (310 mi) altitude[125] in a high-inclination orbit for a planned six to twelve-month duration. The satellites communicate with three testing ground stations in Washington and California for short-term experiments of less than ten minutes duration, roughly daily.[25][126]

V0.9 (test)

The 60 Starlink v0.9 satellites, launched in May 2019, have the following characteristics:[72]

- Flat-panel design with multiple high-throughput antennas and a single solar array
- Mass: 227 kg (500 lb)

- Hall-effect thrusters using krypton as the reaction mass, for position adjustment on orbit, altitude maintenance and deorbit
- Star tracker navigation system for precision pointing
- Able to use Department of Defense-provided debris data to autonomously avoid collision[127]
- Altitude of 550 km (340 mi)
- 95% of "all components of this design will quickly burn in Earth's atmosphere at the end of each satellite's lifecycle".

V1.0 (operational)

The Starlink v1.0 satellites, launched since November 2019, have the additional following characteristics:

- 100% of "all components of this design will quickly burn in Earth's atmosphere at the end of each satellite's lifecycle".
- K_a-band added
- Mass: 260 kg (570 lb)
- One of them, numbered 1130 and called DarkSat, has its albedo reduced
- Another one, called VisorSat, has an experimental visor to block reflectivity from parts of the satellite and further reduce its albedo

Competition and market effects

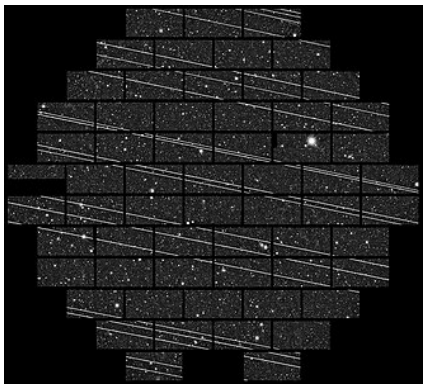
In addition to the OneWeb constellation, announced nearly concurrently with the SpaceX constellation, a 2015 proposal from Samsung outlined a 4,600-satellite constellation orbiting at 1,400 kilometers (900 miles) that could provide a zettabyte per month capacity worldwide, an equivalent of 200 gigabytes per month for 5 billion users of Internet data,[128][129] but by 2020, no more public information had been released about the Samsung constellation. Telesat announced a smaller 117 satellite constellation in 2015 with plans to deliver initial service in 2021.[130] Amazon announced a large broadband internet satellite constellation in April 2019, planning to launch 3,236 satellites in the next decade in what the company calls "Project Kuiper", a satellite constellation that will work in concert[131] with Amazon's previously announced large network of twelve satellite ground station facilities (the "AWS Ground Station unit") announced in November 2018.[132]

By October 2017, the expectation for large increases in satellite network capacity from emerging lower-altitude broadband constellations caused market players to cancel some planned investments in new geosynchronous orbit broadband communications satellites.[133]

Criticism

The planned large number of satellites has met with criticism from the astronomical community because of concerns for light pollution.[134][135][136] Astronomers claim that the number of visible satellites will outnumber visible stars and that their brightness in both optical and radio wavelengths will severely impact scientific observations. Because the Starlink satellites can autonomously change their orbits, observations cannot be scheduled to avoid them. The International Astronomical Union (IAU) and National Radio Astronomy Observatory (NRAO) have released official statements expressing concern on the matter.[14][137]

On 20 November 2019, the 4-meter Blanco telescope of the CTIO recorded strong signal loss and the appearance of 19 white lines on a DECam shot (left image). This image noise was correlated to the transit of a Starlink satellite train, launched a week earlier.[138]



Signal pollution in a 333-second exposure (photograph from the Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory)

SpaceX representatives and Musk have claimed that the satellites will have minimal impact.[139] Many professional astronomers have disputed these claims based on initial observation of the Starlink v0.9 satellites on the first launch, shortly after their deployment from the launch vehicle.[140][141][142][143] In later statements on Twitter, Musk stated that SpaceX will work on reducing the albedo of the satellites and will provide on-demand orientation adjustments for astronomical experiments, if necessary.[144][145] To date, only one Starlink satellite (Starlink 1130 / DarkSat) has experimental coating to reduce its albedo. The reduction in g-band magnitude is 0.8 magnitude (55%).[146][147]

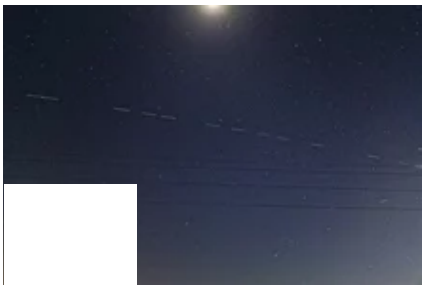
Starlink in Tübingen, Germany

A group of Starlink satellites as seen from the International Space Station

"Beyond this (darkening) treatment, SpaceX is developing new mitigation efforts that it plans to test in the coming months", SpaceX wrote in a Federal Communications Commission (FCC) filing, on 17 April 2020. "Additionally, SpaceX will make satellite tracking data available so astronomers can better coordinate their observations with our satellites". Another change from SpaceX is studying the addition of a sunshade, or visor, to unfurl like an umbrella on Starlink satellites to reduce the amount of sunlight glinting off the spacecraft. Musk tweeted on 22 April 2020 that SpaceX is taking "key steps to reduce satellite brightness". He wrote that the satellites "should be much less noticeable" when they are flying at lower altitudes soon after launch. SpaceX is changing the angle of each satellite's solar panel, and all of the Starlink satellites will have sunshades beginning in June 2020 with the ninth launch of the fleet.[1]

Some Starlink 6 satellites (magnitude 3.3) seen in a 2-second exposure

A new sunshade, or visor, designed to reduce the brightness of SpaceX's Starlink broadband Internet satellites debut on the company's Spacelink 7 launched on 4 June 2020, a measure intended to alleviate astronomers' concerns about impacts on observations through ground-based telescopes, SpaceX founder Elon Musk said on 27 April 2020.[17] To date, only one Starlink satellite (Starlink 1436 / VisorSat) has experimental sunshade.[148]. The effectiveness of the new visor will be closely monitored. If this solution is effective it will be incorporated into future launches.



Forty 3-second exposures of Starlink 6 satellites, made into video, 3.6x actual speed

SpaceX has mitigated concerns about the long-term danger of space junk resulting from placing thousands of satellites in orbit in part by lowering the planned orbit of the satellites. Failed satellites are expected to deorbit within a few years.[13][149][150] Early in the program a near miss occurred when SpaceX did not move a satellite that had a 1 in 1000 chance of colliding with a European one, ten times higher than ESA's threshold for avoidance maneuvers. SpaceX subsequently fixed an issue with their paging system that had disrupted emails between ESA and SpaceX. ESA said it plans to invest in technologies to automate satellite collision avoidance maneuvers.[151][152]

See also

- Globalstar – an operational low Earth orbit (LEO) satellite constellation for satellite phone and low-speed data communications
- Iridium satellite constellation – an operational constellation of LEO satellites for global satellite phone service
- Kuiper Systems – a planned 3236 LEO satellite Internet constellation being built by an Amazon subsidiary[153]
- Laser communication in space – key technology used to establish the inter-satellite links of the Starlink constellation
- O3b Networks – medium Earth orbit (MEO) satellite constellation primarily intended to provide voice and data to mobile operators and Internet service providers, and is a wholly-owned subsidiary of SES S.A.
- OneWeb satellite constellation – an under-construction (but bankrupt as of March 2020) LEO satellite constellation, to provide global Internet broadband service to individual consumers from 2020
- Orbcomm – an operational constellation used to provide global asset monitoring and messaging services from its constellation of 29 LEO communications satellites orbiting at 775 km
- Teledesic – a former (1990s) venture to accomplish broadband satellite Internet services
- ViaSat – offers an operational Internet service from four geostationary satellites

Notes

a. Falcon 9 first-stage boosters are designated with a construction serial number and an optional flight number when reused, e.g. B1021.1 and B1021.2 represent the two flights of booster B1021. Launches using reused boosters are denoted with a recycled symbol (♺).

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External links

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