Federal Aviation Administration

The Annual Compendium of Commercial Space Transportation: 2018

January 2018

About the FAA Office of Commercial Space Transportation

The Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST) licenses and regulates U.S. commercial space launch and reentry activity, as well as the operation of non-federal launch and reentry sites, as authorized by Executive Order 12465 and Title 51 United States Code, Subtitle V, Chapter 509 (formerly the Commercial Space Launch Act). FAA AST's mission is to ensure public health and safety and the safety of property while protecting the national security and foreign policy interests of the United States during commercial launch and reentry operations. In addition, FAA AST is directed to encourage, facilitate, and promote commercial space launches and reentries. Additional information concerning commercial space transportation can be found on FAA AST's website:

http://www.faa.gov/go/ast

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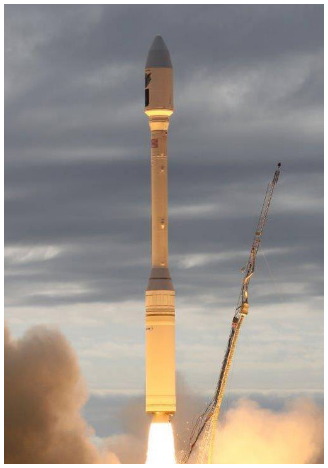
EXECUTIVE SUMMARY

The size of the global space economy, which combines satellite services and ground equipment, government space budgets, and global navigation satellite services (GNSS) equipment, is estimated to be about $345B. At $98B in revenues, or about 28 percent, satellite television represents the largest segment of activity. Following satellite television are services enabled by GNSS, which represent about $85B in revenues, or 25 percent. Government space budgets represent $83B, or 24 percent. Other satellite services (fixed and mobile satellite services, broadband, and remote sensing) generated about $30B in revenues, and ground equipment represents $29B in revenues. Satellite manufacturing generated nearly $14B.

There was continued, strong investment in start-up space ventures. Including acquisitions and debt financing, 2016 was the highest investment year for start-up space. Average deal size increased by about 50 percent, while the number of deals, investors, and firms reporting new funding all decreased by about 30 percent. Well over 100 investors put $2.8B into 43 start-up space ventures across 49 deals. Though figures are yet to be published, 2017 is expected to surpass 2016 in amount of investment and number of deals.



An Orbital ATK Minotaur C is launched from Vandenberg AFB, California carrying 10 satellites for Planet, a data analytics company. (Source: Orbital ATK)

The satellite industry depends upon a robust orbital launch services enterprise. For satellite deployment, global launch service is estimated to account for $5.5B of the $345B total, or only about two percent. Most of this launch activity is captive; that is, the majority of satellite operators have existing agreements with launch service providers or do not otherwise “shop around” for a launch (for example, government payloads are typically launched by indiginous launch service providers). About a third of the $5.5B represents internationally competed, or commercial, transactions.

In 2017, service providers conducted a total of 90 orbital launches from sites in seven countries. While this figure is elaborated upon in greater detail later in this report, there are some interesting events worthy of note. Since 2014, U.S. providers have begun to cut into the existing share of commercial launches occupied by Russian providers. This U.S. gain is the result of a combination of factors. First, the entrance of Space Exploration Technologies (SpaceX), which has been offering its Falcon 9 vehicle to the global market at comparatively lower prices, is attracting significant business. During the past several years, launch failures, quality control problems, and supply chain issues have continued to affect the Russian space industry, leading some customers to seek alternative providers. Meanwhile, Europe’s Arianespace remains a steadfast option, offering services via the Ariane 5 ECA, Soyuz 2, and Vega. Sea Launch, for a time a key player but never a dominant one, has essentially ceased operations. Finally, Japan’s Mitsubishi Heavy Industries (MHI) Launch Services and India’s Antrix have become more aggressive at marketing their H-IIA/B and Polar Satellite Launch Vehicle (PSLV), respectively. Notably, Rocket Lab and Vector started flight-testing their small launch vehicles in 2017, with intent to providing regular service in 2018.

Since about 2004, the annual number of orbital launches conducted worldwide has steadily increased. This increase has primarily been due to government activity outside the U.S., as U.S. government launches remain relatively steady. For example, retirement of the Space Shuttle in 2011 decreased the number of U.S. launches per year relative to the previous three decades. However, commercial cargo missions to the International Space Station (ISS) have helped to fill the resulting gap, along with anticipated commercial crew missions beginning in 2018.

In the U.S., 2017 marked a significant year in terms of launch activity. A record 23 launches were conducted under licenses issued by the Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST), the highest number since 1989 when the first licensed launch took place. Of these, 22 were orbital and one was suborbital. Launches performed by SpaceX have increased the market share for the U.S. when compared to international providers like Arianespace, International Launch Services (ILS), and others, with the greatest market share being recorded in 2017 at 54 percent (13 launches). Further growth is expected in the years to come as the SpaceX launch cadence increases and new companies like Virgin Orbit and Rocket Lab begin operations.

The U.S. government made significant decisions regarding its future in space following the election of Donald Trump as president. In June, the President signed an executive order resurrecting the National Space Council (NSC), which had been disbanded over two decades earlier. The NSC met for the first time in October during a public session designed to gather inputs from government agencies, corporations, and academic institutions. In December, the President issued White House Policy Directive 1, a change in national space policy that authorizes a U.S. government-led program in partnership with industry to send astronauts to the Moon and later to Mars.

Perhaps the most notable changes in government launch activity outside the U.S. occurred in China. The number of orbital launches conducted by China has steadily increased each year since 2010, with a peak of 22 launches in 2016. Since 2015, China has introduced several new vehicles (Kaitouzhe 2, Kuaizhou 11, Long March 5, Long March 6, and Launch March 7) and inaugurated a new launch site on Hainan Island. China's human spaceflight program continues in a deliberate fashion, with the 2017 launch of Tianzhou 1, a cargo vehicle that docked with the Chinese space station Tiangong 2. The Chinese National Space Agency (CNSA) is also continuing to develop its robotic investigations of the Moon with plans for venturing further. These signs point to a robust future in Chinese spaceflight, expanding the Chinese slice of the pie.

In contrast, Russia's space industry has experienced a gradual decrease in the number of annual launches, with an even more dramatic decrease in the number of launches performed under internationally competed launches. In addition, there have been notable problems encountered, such as failures related to the Fregat upper stage used by the Soyuz vehicle and first stage anomalies on the Proton M. The Russian government has sought measures to address these issues, with the most dramatic example being the restructuring of state-owned corporations and other institutions under an umbrella organization called Roscosmos.

Overall, the commercial launch market has not grown significantly during the past decade; instead, the market shares have changed size, with U.S. providers expanding their cut from zero percent in 2011 to 54 percent in 2017. The number of FAA AST-licensed launches, which went from a low of one in 2011 to a high of 23 in 2017, also indicates strong commercial launch service growth in the U.S. Indeed, this is the highest number of licensed launches ever, and the growth trend is expected to continue as SpaceX fulfills its backlog and new companies like Blue Origin, Rocket Lab, Vector, and others introduce launch services.

However, there are signs that the launch market may grow in the coming years. Several new launch vehicles are being developed specifically to address what some believe is latent demand among small satellite operators. These vehicles are designed to launch payloads with masses under 500 kg (1,102 lb) to low Earth orbit (LEO). Though the price per kilogram remains high relative to larger vehicles, the value is in scheduling. Previously, these small satellites would routinely “piggyback” as a secondary payload on a launch carrying a much larger payload that would dictate the schedule and the orbital destination. Today, these new vehicles will give small satellite operators, especially those with constellations of many satellites, greater control over their business plans. Some of these new vehicles have recently launched or are in advanced stages of development, like Electron, LauncherOne, and Vector H, with all three vehicles expected to start launching payloads in 2018. In fact, there are about 50 proposed small launch vehicles being developed worldwide, though most are in conceptual stages.

Five launch failures occurred in 2017. The year started with the inaugural launch of Japan’s SS-520-4, a vehicle designed to carry just four kilograms (8.8 lb) to LEO. It was lost shortly after launch. In May, the first orbital launch test of Rocket Lab’s Electron vehicle ended in failure, though the company immediately traced the problem to a fault in ground equipment, rather than the vehicle. In July, China lost a Long March 5A vehicle, destroying its Shijian 18 payload. The Indian Space Research Organization (ISRO) experienced a launch failure of its PSLV in August, grounding the vehicle for the remainder of the year. Finally, a Soyuz 2.1b failed to deploy its cargo of 19 payloads, apparently due to a coding error within the operating software aboard the vehicle’s Fregat upper stage.

There were some notable activities in 2017 relating to suborbital reusable vehicles. Virgin Galactic conducted four glide tests of its second SpaceShipTwo vehicle, the *VSS Unity*. The company received a license from FAA AST in July 2016 and is planning to conduct powered flights in 2018. Vector conducted two successful suborbital tests of its Vector R vehicle as the company prepares to provide orbital flights in 2018. The first flight of Blue Origin’s third New Shepard vehicle successfully flew in December from the company’s site in western Texas.

The year in space transportation represented activity similar to each of the previous five years—but it belies what is taking place behind the scenes. New vehicles are being developed to replace older ones or to augment capabilities, while new satellite operators stand poised to release large constellations of telecommunication and remote sensing satellites. Human spaceflight activities continue, with operational flights of suborbital systems and test flights of commercial orbital systems expected to begin in 2018.

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INTRODUCTION

THE FEDERAL AVIATION ADMINISTRATION OFFICE OF COMMERCIAL SPACE TRANSPORTATION

The mission of the Federal Aviation Administration Office of Commercial Space Transportation (FAA AST) is to protect the health and safety of the public and safety of property, while protecting the national security and foreign policy interests of the United States during commercial launch and reentry activities. In addition, FAA AST is directed to encourage, facilitate, and promote U.S. commercial space transportation.

The office was established in 1984 as part of the Office of the Secretary of Transportation within the Department of Transportation (DOT). In November 1995, AST was transferred to the FAA and was established to:

- Regulate, only to the extent necessary, the U.S. commercial space transportation industry, ensure compliance with international obligations of the United States, and protect the public health and safety, safety of property, and national security and foreign policy interests of the United States;
- Encourage, facilitate, and promote commercial space launches and reentries by the private sector;
- Recommend appropriate changes in federal statutes, treaties, regulations, policies, plans, and procedures; and
- Facilitate the strengthening and expansion of the United States space transportation infrastructure both domestically and internationally.

FAA AST manages its licensing and regulatory work as well as a variety of programs and initiatives to ensure the health and facilitate the growth of the U.S. commercial space transportation industry through the Office of the Associate Administrator along with its five divisions:

- Space Transportation Development Division
- Licensing and Evaluation Division
- Regulations and Analysis Division
- Safety Inspection Division
- Operations Integration Division

The office also has directorates for Strategic Operations and Innovation and Special Projects, both of which are focused on interim and long-term objectives. FAA AST issues licenses and permits for commercial launches of orbital and suborbital rockets, and issues licenses for reentry events. The first U.S. licensed launch was a suborbital launch of a Starfire vehicle on March 29, 1989. Since then, FAA AST has authorized over 330 launches and reentries. The FAA AST also issues licenses for the operations of non-federal launch sites, or “commercial spaceports.” Since 1996, FAA AST has issued site operator licenses for 10 commercial launch and reentry sites.

THE ANNUAL COMPENDIUM

The Annual Compendium is published in January of each year. The Compendium represents a consolidation of information designed to provide the reader with a general and current understanding of the commercial space transportation industry.

General Description

The body of the document is composed of four parts, supplemented by introductory matter and appendices. The first part provides narrative detail on the space transportation industry, covering topics such as launch vehicles, spacecraft, and launch and reentry sites. The second part summarizes worldwide space activities during the previous calendar year and integrates some of this review with space transportation activities that have taken place during the past five years. The third part provides a 10-year commercial space transportation forecast. Finally, a fourth section covers policies and regulations relevant to commercial space transportation.

The appendices include definitions, acronyms, and the orbital launch manifest for the previous year. Launch vehicle fact sheets are also included in the appendices. Each two-page sheet covers a particular launch vehicle currently in service and those in an advanced stage of development, providing more detailed information than what is available in the body of the report.

An Ariane 5 ECA carrying Hellas-Sat 3 and GSAT 17 is launched into orbit from the Guiana Space Center on June 28, 2017. *Source: Arianespace.*

THE SPACE TRANSPORTATION INDUSTRY

At nearly $6B in revenues in 2016, the global space transportation industry is a relatively small part of the overall $345B global space economy. However, without space transportation, space-based services would be impossible. Space transportation is an enabling capability, one that makes it possible to send national security and commercial satellites into orbit, probes into the solar system, and humans on exploration missions.

THE SPACE INDUSTRY

The global space economy, consisting of private industry revenues and government budgets, was $345B in 2016. About $261B (76%) was revenue generated by companies providing services like television; mobile, fixed, and broadband communications; remote sensing; satellite systems and ground equipment manufacturing and sales; and, of course, launch services. The remaining $84B (24%) constitutes government space budgets ($83B) and commercial human spaceflight (almost $2B).

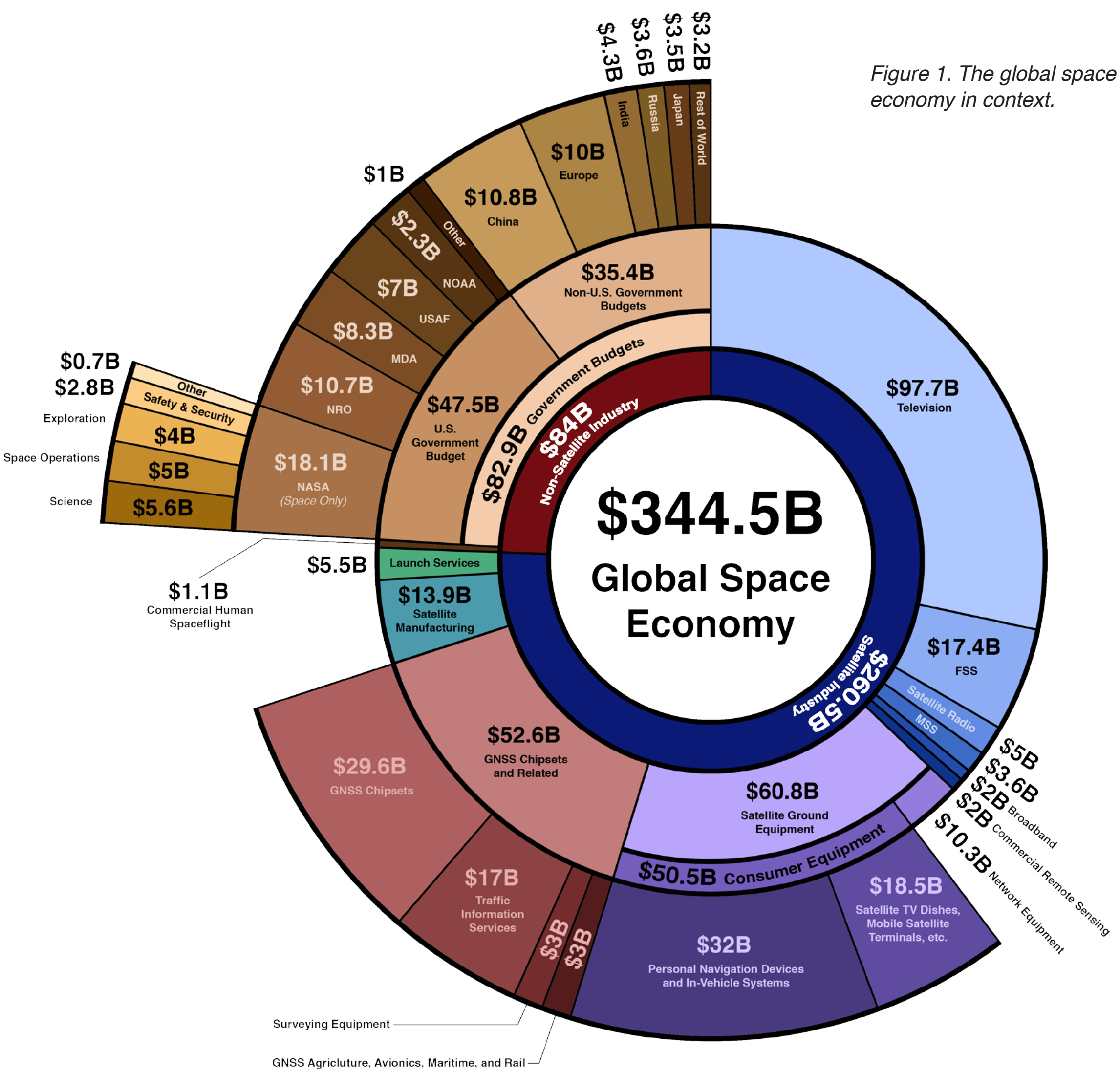


Figure 1. The global space economy in context.

The U.S. space industry was approximately $158B in 2016. This figure includes over $110B in revenues generated by satellite services, satellite manufacturing, satellite ground equipment, and launch services, as well as almost $48B spent on space programs by the U.S. government. U.S. launch service providers accounted for about $2.2B in total internationally competed contract revenues (40 percent of global revenues). FAA AST-licensed launches accounted for $784M of the $2.2B.

LAUNCH VEHICLES

The story of space transportation can be traced at least one thousand years ago when the Chinese invented the rocket. At this time, the rocket was essentially a small firework, powered by gunpowder. During the 16th century, Conrad Haas, an engineer who provided military expertise to the Kingdom of Hungary, was the first to conceive of multi-stage missiles. But it wasn't until 1903, when Russian mathematician Konstantin Tsiolkovsky published details on his plans for a multi-stage, liquid-fueled rocket that the era of modern rocketry dawned. Tsiolkovsky recognized that a combination of stages and liquid fuels was necessary to send a payload into orbit but never built such a machine. These plans were realized through the work of an American, Robert Goddard, who independently invented a liquid-fueled rocket and launched it in 1926. His work was largely conducted in secret, and his impact on the industry was negligible. Hermann Oberth, of German descent but born in Austria-Hungary, also invented a rocket, unaware of the works of Tsiolkovsky and Goddard. He published his invention in 1923. This work is generally credited with introducing the rocket to the public. Soon after, he and fellow rocket enthusiasts established Verein für Raumschiffahrt (VfR), a rocket club. Similar clubs sprouted elsewhere around the world during the 1920s and 1930s, but it was the VfR that received substantial funding by the German military to scale up the technology. In 1942, VfR became the first group to successfully launch a ballistic missile into suborbital space. Following the end of World War II, many international teams elaborated upon the rocket, most notably in the U.S. and Soviet Union, but also in China, Japan, India, and others.

Today, there are nearly 90 orbital launch vehicles in service, counting variants within a family (for example, there are ten variants within the Atlas V family). These vehicles are launched by government and commercial organizations across ten countries, though routine activity takes place primarily from the U.S., Russia, China, Europe, India, and Japan. The most frequently purchased launch vehicles used to launch large commercial satellites are the Ariane 5, operated by Arianespace; the Proton M, launched by ILS; and the Falcon 9, provided by SpaceX. In addition, there are over 50 new vehicle systems in development. Some of these are expected to replace retiring systems, but others are designed to tap emerging markets like commercial human spaceflight and the deployment of large constellations of very small satellites.

Typical Launch Vehicle Subsystems

A typical launch vehicle system consists of several basic subsystems, including propulsion; power; guidance, navigation, and control (GNC); payload adapters; and fairings. This report focuses primarily on the propulsion subsystem, specifically rocket engines themselves. Brief descriptions of major rocket engines used on U.S. launch vehicles follow.

A rocket engine is a propulsion device that burns liquid propellant, while a rocket motor burns solid propellant. There are also examples of hybrid engines that feature both solid and liquid propellants.

Liquid Rocket Engines

A rocket engine that burns liquid propellants is significantly more complex and expensive than a solid motor. There are two types of liquid rocket engines: bipropellant and monopropellant. Bipropellant engines burn a mixture of liquid fuel and liquid oxidizer using an igniter or, in the case of a hypergolic engine, the propellants spontaneously ignite when they come in contact with each other. The former is used for most launch vehicles, while the latter is preferred for on-orbit maneuvering because there are fewer parts involved and combustion is virtually guaranteed. Monopropellant engines use a liquid fuel that does not require an oxidizer and is ignited using a catalyst. An example would be liquid hydrogen peroxide introduced to a silver mesh catalyst, an interaction that rapidly produces a high-pressure, moderately high temperature gas. All of these engines rely on a pressurant system using inert gas, combined with pumps, to ensure that propellant is constantly fed into the engine regardless of the orientation of the vehicle.

Liquid rocket engines are complex for a variety of reasons. Often, the propellants used are cryogenic, meaning the liquid is several hundred degrees below zero Celsius. The engine can be throttled, necessitating an engine controller and associated hardware. These rocket engines can use bleed-off exhaust products to spin up the turbopumps and often feature recirculating cryogenic propellants to cool the nozzle jacket. Liquid rocket engines can also employ preburners to warm the cryogenic propellant immediately prior to ignition. In addition, the propellant tanks, pressurant tanks, and plumbing represent added complexity when compared to solid motors. A reusable liquid rocket engine, such as those once employed by the Space Shuttle orbiters, represents another level of complexity because of the need to engineer robustness into a system that experiences very broad temperature extremes and high pressures.

The following liquid rocket engines are used in currently available U.S. launch vehicles. Also included are engines designated for use on vehicles under development.

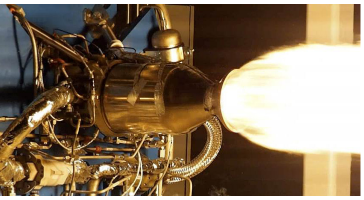
- BE-4: The BE-4 is an engine under development by Blue Origin. BE-4 will burn a mixture of liquid oxygen (LOX) and liquefied natural gas (LNG), mostly composed of methane) and produce 2,447 kN (550,000 lbf) of thrust. This is the baseline engine for the company's orbital launch vehicles and the first stage of ULA's Vulcan. Blue Origin is planning to have the BE-4 available for operational flights in 2017. The BE-4 is derived from the LOX-liquid hydrogen BE-3, an engine being used for Blue Origin's New Shepard suborbital launch vehicle.
- AR-1: The AR-1 is an engine currently under development by Aerojet Rocketdyne. The engine, which will burn a LOX-kerosene mixture, is designed to produce about 2,224 kN (500,000 lbf) of thrust. The AR-1 was proposed as a replacement for the Russian-built RD-180, used by the Atlas V vehicle, but United Launch Alliance (ULA) has elected to replace the Atlas V with the new Vulcan vehicle powered by Blue Origin's BE-4. However, ULA has designated the AR-1 as an alternative to the BE-4 in the event the latter engine is delayed.

A model of the BE-4 engine (Blue Origin)

A 3D model of the AR1 engine (Aerojet Rocketdyne)

An AR-22 being prepared for a test firing (Aerojet Rocketdyne)

A Merlin-1D engine (SpaceX)



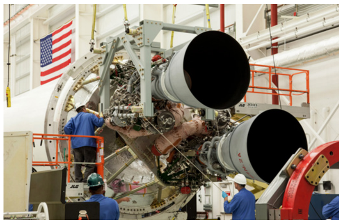
A NewtonOne engine undergoing a test (Virgin Orbit)

An RD-180 engine installed ont he first stage of an Atlas V (ULA)

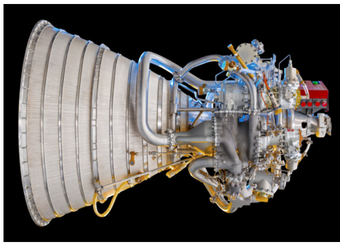
- AR-22: The AR-22, built by Aerojet Rocketdyne, is an expendable version of the AR-22, also called the Space Shuttle Main Engine (SSME). Four RS-25E engines will be used for each core stage of NASA's upcoming SLS. Sixteen SSMEs from the retired Space Transportation System (STS) Program have been refurbished and stored for use on four SLS missions, which begin in late 2018. The AR-22 will be used on subsequent SLS vehicles. Each AR-22 will burn a LOX-liquid hydrogen propellant mixture and produce about 2,277 kN (512,000 lbf) of thrust. Though the original SSMEs were expensive, NASA is working with Aerojet Rocketdyne to develop manufacturing methods for the AR-22 designed to increase performance while at the same time reduce the per-unit cost.
- Merlin 1D: The Merlin 1D is the engine used to power both the first and second stages of SpaceX's Falcon 9 and Falcon Heavy launch vehicles. This engine produces about 756 kN (185,500 lbf) of thrust and burns a LOX-kerosene mixture. Nine of these engines power the Falcon 9 first stage (for a total thrust of about 6,806 kN or 1,530,000 lbf) and one is used to power the second stage. The Merlin 1D is a fourth generation SpaceX engine that traces its lineage to the Merlin 1A that powered the Falcon 1 vehicle. The Merlin 1A leveraged technology developed for NASA's Fastrac engine, which used a pintle single-feed injector as opposed to the more typical arrangement of hundreds of injector holes. The Merlin 1C was used for the Falcon 9 v1.0 vehicle, whereas the Merlin 1D powers the Falcon 9 Full Thrust (Falcon 9 FT), which features a higher thrust capability and giving the vehicle a 30 percent increase in performance from the Falcon 9 v1.1. This upgraded vehicle was introduced in late 2015.
- Newton: The Newton series of engines being developed by Virgin Orbit will power the company's air-launched LauncherOne vehicle. These engines use LOX and kerosene as propellants. The NewtonThree, which produces 327 kN (73,500 lbf) of thrust, will power the LauncherOne first stage. A NewtonFour engine, producing 22 kN (5,000 lbf) of thrust, will power the second stage to orbit. First flight of LauncherOne is expected in 2018.
- Raptor: SpaceX is developing a liquid rocket engine capable of burning LOC and LNG with a thrust level of 1,700 kN (380,000 lbf). It will be at least twice as powerful as the company's Merlin 1D engine and is expected to be used for the BFR, a launch vehicle SpaceX is designing to send cargo and crew to Mars. The first successful test firing of the engine was conducted in September 2016.
- RD-180: The RD-180 is a Russian-built engine that powers the Common Core Booster (CCB) of the Atlas V vehicle using a LOX-kerosene propellant mixture. RD-180 produces a thrust of about 3,830 kN (860,000 lbf). The engine is built by RD AMROSS (a joint effort between Aerojet Rocketdyne, previously Pratt & Whitney Rocketdyne, and NPO Energomash). Following the collapse of the Soviet Union, the U.S. government negotiated an agreement whereby Russia would manufacture relatively inexpensive rocket engines to support the Evolved Expendable Launch Vehicle (EELV) program that led to the Atlas V and Delta IV. The original plan called for eventual manufacture of the engine in the United States. However, world events and market driven competition has removed the RD-180 from the supply chain. In fact,

the National Defense Authorization Act of 2015 limits the use of the RD-180 for national security missions and the government has directed a replacement engine be in operation by 2019.

- RD-181: The RD-181 is an engine being developed by NPO Energomash for the Antares vehicle built and offered by Orbital ATK. The original Antares, which was used on four missions, used two AJ26 engines on its first stage. The AJ26 was essentially a significantly modified NK-33 engine. Aerojet purchased 36 of the original 150 NK-33 engines, which were inspected, refurbished, and designated AJ26. Following the loss of the fourth Antares vehicle in October 2014 due to an engine failure, Orbital ATK moved to replace the engines on future Antares vehicles. In 2015, Orbital ATK contracted with NPO Energomash for 20 RD-181 units. The Antares will feature two LOX-kerosene RD-181 engines, each producing about 1,913 kN (430,000 lbf) of thrust. The first launch of the Antares using the new engines took place in 2016.
- RL10: The first variant of the RL10 engine was designed in 1959 by Pratt & Whitney (now part of Aerojet Rocketdyne). The engine was first used in 1962 for the Centaur upper stage of Atlas missiles converted as launch vehicles. The engine burns LOX-liquid hydrogen and produces a thrust of about 110 kN (25,000 lbf). The current model of this engine, the RL10A-4-2, continues to power the Centaur upper stage for the Atlas V. The RL10B-2 is used for the Cryogenic Upper Stage of the Delta IV vehicle. Further development of the RL10 is underway to support ULA's Advanced Cryogenic Evolved Stage (ACES) for the company's Vulcan launch vehicle.
- RS-27A: The RS-27A is the engine used to power the core stage of the Delta II. Also developed by Aerojet Rocketdyne, the RS-27A burns LOX and kerosene, producing a thrust of about 890 kN (200,100 lbf).
- RS-68: Aerojet Rocketdyne also produces the RS-68, a more powerful engine than the RS-27 that burns a LOX-liquid hydrogen propellant mix. From 2002 to 2012, each Common Booster Core (CBC) of the Delta IV was powered by a single RS-68 engine, which produces about 2,950 kN (660,000 lbf) of thrust. An upgraded version of the engine, called the RS-68A, was introduced in 2012 as a replacement to the RS-68. RS-68A can produce 3,137 kN (705,000 lbf) of thrust.
- Rutherford: Rocket Lab has designed the Rutherford engine for use in the first stage of the company's Electron vehicle. The engine burns a mixture of LOX and kerosene, producing a thrust of about 22 kN (5,000 lbf). Rocket Lab is employing additive manufacturing (3D printing) in the construction of all primary components of the Rutherford, making it a unique example in the industry. 3D printing reduces costs by simplifying the manufacturing process. The first launch of the Electron is expected in 2017 from a site in New Zealand.

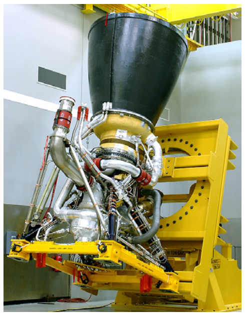


Two RD-181 beng integrated with an Antares launch vehicle (NASA)

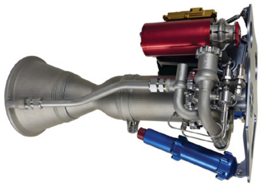


An RL10B-2 powers the Delta IV cryogenic upper stage (Aerojet Rocketdyne)

An RS-27A undergoing ground testing (Aerojet Rocketdyne)



An RS-68A being prepared for installation on a Delta IV CBC (Aerojet Rocketdyne)

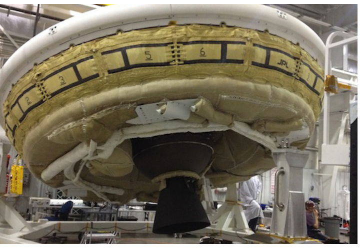


The Rutherford engine (Rocket Lab)

Solid Motors

Rocket engines that burn solid propellant are simpler in construction, relatively inexpensive, and can be stored for long periods of time, making them ideal for missiles in particular. Once ignited, engines burning solid propellant cannot be throttled at will or shut off. These characteristics make solid propellant a potentially controversial option for launch systems designed to carry people. The engine, often referred to as a solid motor, consists of a metal or composite casing filled

A 5-segment Solid Rocket Booster being prepared for ground test firing (Orbital ATK)



A STAR-48 motor used for NASA's Low-Density Supersonic Decelerator project (NASA)

A GEM-60 being prepared for integration on a Delta IV (Orbital ATK)

An AJ-60A being integrated with an Atlas V (ULA)

with a viscous propellant that cures and becomes solid. The central axis of the motor is hollow and serves as the combustion volume; combustion takes place along the entire length of the motor. The propellant contains a fuel, such as aluminum powder, and an oxidizer, such as ammonium perchlorate. The mixture also contains a binding agent. A catalyst or igniter is used to start the motor. Once ignited, the exhaust is ejected through the nozzle to create thrust.

The following solid motors are used in currently available U.S. launch vehicles. Also included are engines designated for use on vehicles under development.

- Five-Segment Solid Rocket Boosters (SRB): The five-segment SRB is derived from the four-segment SRBs used for STS from 1981 to 2011. The boosters were originally designed and manufactured by Thiokol, which was purchased by Alliant Techsystems (ATK) in 2001. The company merged with Orbital Sciences Corporation in 2014 and is now known as Orbital ATK. Two five-segment SRBs will be used to augment the core stage of the Space Launch System (SLS), currently being developed by NASA. The SRBs will burn a polybutadiene acrylonitrile (PBAN)-based ammonium perchlorate composite propellant (APCP). The mixture includes ammonium perchlorate as the oxidizer, aluminum powder as the fuel, PBAN as a binding agent, an iron oxide catalyst, and an epoxy-curing agent. Each booster can produce 16,000 kilonewtons (kN), or 3,600,000 pounds of force (lbf) of thrust. Together, the thrust of both boosters is about 32,000 kN (7,200,000 lbf). Orbital ATK successfully completed four full-scale, full-duration static fire tests of the five-segment SRB in 2015. The first mission employing SLS will be Exploration Mission-1 (EM-1), scheduled for late 2018.
- STAR motors: The STAR line of solid motors, first produced by Thiokol and now manufactured by Orbital ATK, is used for upper stage elements in launch vehicles. The motors are designated by case diameter, so the STAR-37 means the casing diameter is 94 cm (37 in). The most commonly used STAR motors today are the STAR-37 and STAR-48 as upper stages or kick motors designed to insert payloads into their final orbits.
- GEM Strap-on Booster System: The Graphite Epoxy Motor (GEM) provided by Orbital ATK was introduced in 1991 to supplement the first stage thrust of the Delta II launch vehicle. This version, called the GEM-40, had a 102-cm (40-in) diameter. The Delta III, which only flew three times from 1998 to 2000 as a transitional vehicle between the Delta II and Delta IV, used the GEM-46. The GEM-60, with a 60-inch diameter, is currently used for the Delta IV Medium. The vehicle will fly with either two (2,491 kN or 560,000 lbf) or four (5,338 kN or 1.2 million lbf) GEM-60 motors. The GEMs burn a propellant mixture called Hydroxyl-terminated polybutadiene (HTPB) and can feature vectorable nozzles. In 2015, Orbital ATK won a contract to provide the slightly larger GEM-63 motor for use on the Atlas V provided by United Launch Alliance (ULA), replacing the AJ-60A booster provided by Aerojet Rocketdyne in 2018. A longer version of this motor, called the GEM-63XL, will be used on ULA's Vulcan vehicle. Orbital ATK has not yet released performance data for the GEM-63.
- AJ-60A Solid Rocket Motor: The AJ-60A solid motors, manufactured by Aerojet Rocketdyne, have been used to supplement first stage thrust for the Atlas V since 2002. The 157-cm (62-in) diameter boosters burn HTPB. One

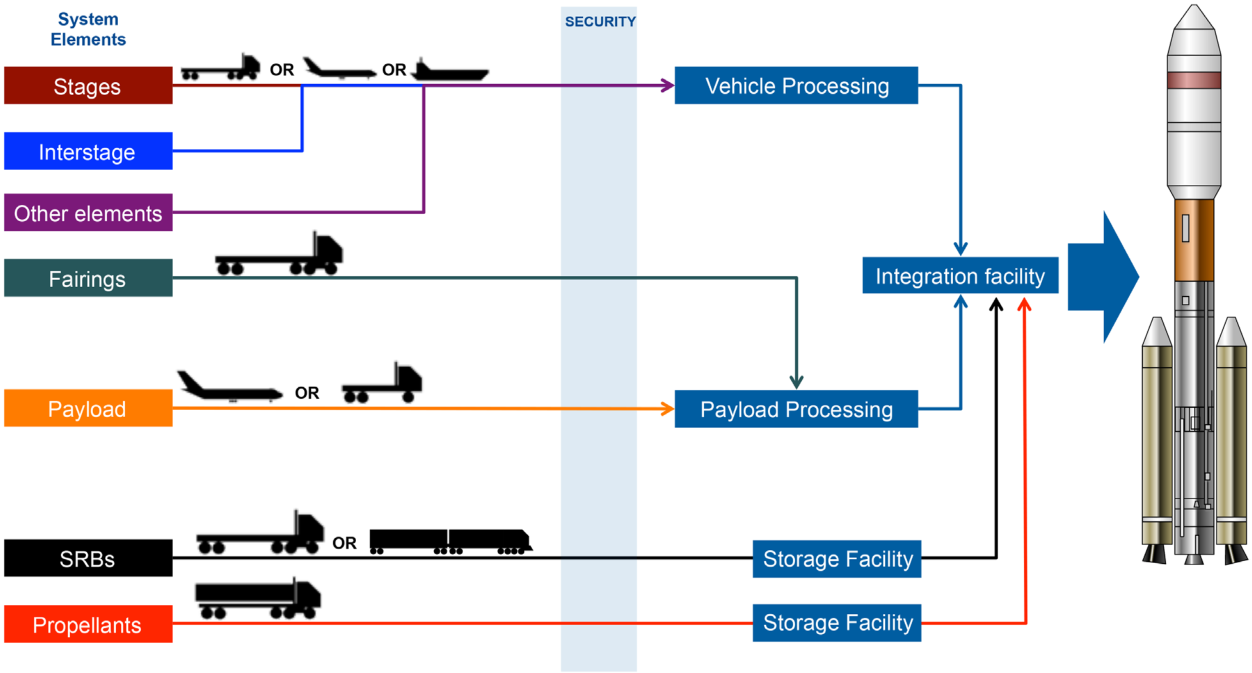


Figure 2. A typical launch vehicle integration and processing scheme.

to five boosters can be used, depending on the Atlas V variant. The AJ-60A is being replaced with the Orbital ATK's GEM-63 motors.

Launch Vehicle Integration and Processing

Since there are many different types of launch vehicles, there are many different ways to integrate and launch them. In general, however, vehicle assemblies and subsystems are manufactured in several locations and then transported via rail, air, or sea to the launch site where the parts come together as a complete launch vehicle. Figure 2 illustrates the basic process using a generic vehicle as an example.

Once the launch vehicle is fully integrated, it is then joined with its payload. This process is called payload integration. The payload arrives at the launch site from the manufacturing or checkout site to a specialized facility designed to handle the unique needs of the payload. For example, payloads may require fueling, last-minute integration with components, or final testing and checkout. The payload is then attached to a payload adapter. The payload adapter is the physical connection between the payload and the launch vehicle and can be integrated with the launch vehicle either horizontally or vertically depending on the vehicle. Once integrated, the payload fairing is installed. The vehicle and payload then make their way to the launch pad, where the combination continues to be monitored during a technical checklist called a countdown. Fueling of a vehicle using liquid propellants takes place at the pad, usually immediately prior to launch.

While the launch vehicle and payload are handled at the launch site, other operations take place to support launch activities. These are managed by a launch range or launch site operator, which is tasked with ensuring that the launch is conducted efficiently and safely. Typically, the range arranges for the appropriate control or warnings necessary to protect aircraft, waterborne

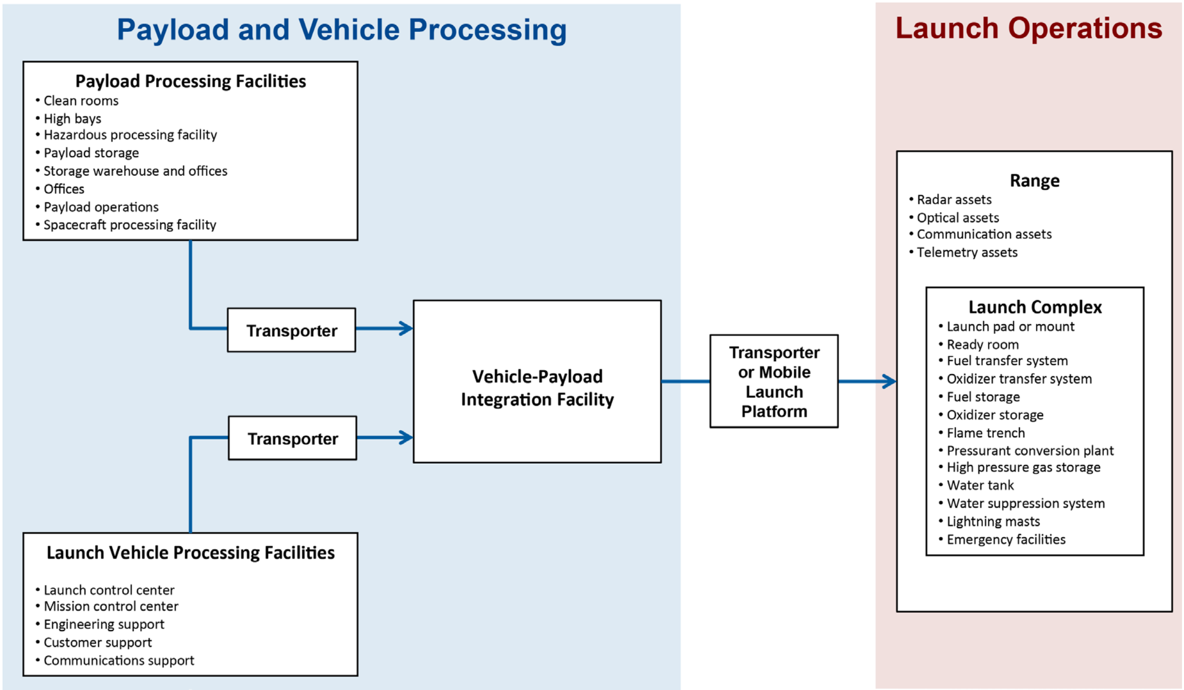


Figure 3. A typical arrangement for a launch site and range.

vessels, and the public.

Figure 3 describes the typical elements of a launch site and range, using a generic vehicle as an example.

Operational Orbital Launch Vehicles

By the end of 2017, there were nearly 90 different orbital launch vehicles operating around the world. This figure includes variants of a family of vehicles. For example, there are 10 Atlas V variants defined by the number of solid rocket boosters used, type of fairing by diameter, and type of Centaur upper stage (single or dual engine). Not all of these vehicles are available for commercial use, whereby a payload customer can “shop around” for a ride into orbit.

There are six expendable launch vehicle types available for commercial use by launch providers in the United States (see Table 1). The Delta II will fly one more time (ICESat-2) before being retired in 2018. U.S. launch service providers include Maryland-based Lockheed Martin, Virginia-based Orbital ATK, California-based SpaceX, and Colorado-based ULA. ULA has historically only served U.S. government customers but has indicated plans to open its Atlas V and future Vulcan vehicles for international competition.

Several orbital launch vehicles are under development with inaugural launches planned during the next two to five years. Some of these are operated by non-U.S. companies but are expected to fly from U.S. sites. These are listed in Table 2.

Other U.S. vehicles are under various stages of development, including CubeCab’s Cab-3A, Firefly Aerospace’s Alpha, and others. The Defense Advanced Research Projects Agency (DARPA) is also sponsoring development of a vehicle that may be available for commercial use, the XS-1.

There are 17 expendable launch vehicle types available for commercial use outside the United States: Angara, Ariane 5, GSLV, LVM3, H-IIA/B, Kuaizhou 1/1A and 11, LandSpace 1, Long March 2D, Long March 3A, Long March 3B, Long March 5, Long March 6, Long March 11, Proton M, PSLV, Rockot, Soyuz 2, and Vega. The commercial status of the Dnepr and Zenit vehicles is unclear.

Vehicle	Operator	Year of First Launch	Total 2017 Launches	Active Launch Sites	Mass to LEO kg (lb)	Mass to SSO kg (lb)	Mass to GTO kg (lb)	Estimated Price per Launch
Antares	Orbital ATK	2013	1	MARS	3,500-7,000 (7,716-15,432)	2,100-3,400 (4,630-7,496)	N/A	$80M-$85M
Atlas V	ULA and LMCLS	2002	6	CCAFS VAFB	8,123-18,814 (17,908-41,478)	6,424-15,179 (14,163-33,464)	3,460-8,900 (7,620-19,620)	$110M-$230M
Electron	Rocket Lab	2017	1	PSCA Mahia, NZ	225 (496)	150 (331)	N/A	$4.9M
Falcon 9	SpaceX	2010	18	CCAFS VAFB KSC	13,150 (28,991)	Undisclosed	4,850 (10,692)	$61.2M
Minotaur-C	Orbital ATK	2017	1	CCAFS MARS VAFB WFF	1,278-1,458 (2,814-3,214)	912-1,054 (2,008-2,324)	N/A	$40M-$50M
Pegasus XL	Orbital ATK	1994	0	CCAFS Kwajalein VAFB WFF	450 (992)	325 (717)	N/A	$40M

Table 1. Orbital vehicles currently available for commercial use by U.S. providers.

Vehicle	Operator	Year of First Launch	Active Launch Sites	Mass to LEO kg (lb)	Mass to SSO kg (lb)	Mass to GTO kg (lb)	Estimated Price per Launch
Alpha	Firefly Aerospace	TBD	TBD	1,000 (2,205)	650 (1,433)	N/A	$10M
Cab-3A	CubeCab	2017	TBD	5 (11)	Undisclosed	N/A	$250K
Falcon Heavy	SpaceX	2017	KSC VAFB	63,800 (140,660)	Undisclosed	26,700 (58,860)	$90M
LauncherOne	Virgin Orbit	2017	Spaceport America	500 (1,102)	300 (661)	N/A	$10M
New Glenn	Blue Origin	2020	CCAFS	45,000 (99,208)	Undisclosed	13,000 (28,660)	Undisclosed
NGL	Orbital ATK	2021	KSC, VAFB	Undisclosed	Undisclosed	8,500 (18,739)	Undisclosed
Stratolaunch	Stratolaunch Systems	2018	Mojave KSC	1,350 (2,976)	975 (2,150)	N/A	Undisclosed
Vector R/H	Vector Space Systems	2017	CCAFS PSCA	60-110 (132-243)	40-75 (88-165)	N/A	$3M
Vulcan	ULA	2019	CCAFS VAFB	9,370-18,510 (20,657-40,510)	7,724-15,179 (17,029-33,464)	4,750-8,900 (10,472-19,621)	$85M-$260M

Table 2. Projected orbital launch vehicles that may be available for commercial use in the United States.

Operational Suborbital Launch Vehicles

Sounding Rockets

Sounding rockets typically employ solid propellants, making them ideal for storage. Sounding rockets differ from amateur or hobbyist rockets in several ways: They climb to higher altitudes but do not enter a sustainable orbit, and they carry out missions on behalf of commercial, government, or non-profit clients. Sounding rockets are used for atmospheric research, astronomical observations, and microgravity experiments that do not require human tending. Amateur rockets are powered by a motor or motors having a total impulse of 200,000 pound-seconds or less. Since licensed sounding rockets have more total impulse, they generally reach higher altitudes.

Three sounding rocket systems are currently available to U.S. customers, with two that have a long history of providing highly reliable services. Canada-based Bristol Aerospace has provided sounding rockets that have been used in the U.S. for decades. They are available to the U.S. scientific community through the NASA Sounding Rockets Operations Contract (NSROC), managed by the NASA Sounding Rockets Program Office (SRPO), located at Wallops Flight Facility (WFF) in Virginia.

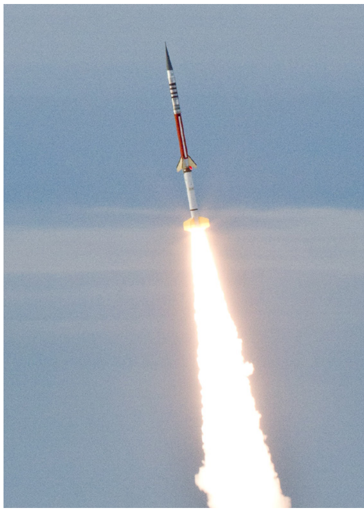
NASA's SRPO conducts sounding rocket launches for NASA, universities, and other customers. Supplied vehicles include Bristol Aerospace's Black Brant series in several vehicle configurations, from a single-stage vehicle to a four-stage vehicle stack (described in a previous section); the Improved Orion; and the Terrier-Improved Orion. NASA's SRPO integrates the subassemblies, which, with the exception of Black Brant, consist of military surplus Orion and Terrier motors. Payloads are typically limited to science and hardware testing. SRPO conducts about 15-20 sounding rocket launches per year from WFF in Virginia, Poker Flat Research Range in Alaska, White Sands Missile Range in New Mexico, and Andoya Rocket Range in Norway.

A Black Brant sounding rocket launched in 2011 (NASA)

A description of major U.S. sounding rockets is provided below:

- Black Brant: The Black Brant sounding rocket system is a flexible, multi-configuration family of upper- and exo-atmospheric launch vehicles. Over 1,000 Black Brant rockets have launched since production began in 1962. The Black Brant rocket motor, the related Nihka rocket motor, and supporting hardware are all manufactured in Canada by Bristol Aerospace, a subsidiary of Magellan Aerospace Limited. U.S.-manufactured Terrier, Talos, and Taurus motors are on several Black Brant configurations. The SRPO has made extensive use of the Black Brant vehicles. The Black Brant family of vehicles can launch a 113-kg (250-lb) payload to an altitude of at least 1,400 km (870 mi), a 454-kg (1,000-lb) payload to an altitude of at least 400 km (250 mi), or a 680-kg (1,500-lb) payload to an altitude of at least 260 km (160 mi). These vehicles can provide up to 20 minutes of microgravity time during a flight. Payloads with diameters of up to 56 cm (22 in) have flown successfully. The smallest version of the Black Brant family is the Black Brant V, which is 533 cm (210 in) long and 43.8 cm (17.24 in) in diameter. The rocket produces an average thrust of 75,731 N (17,025 lbf). The Black Brant V motor can be used on its own, as a single-stage vehicle, or used as the second or third stage in larger, multi-stage versions of the Black Brant. The most powerful configuration of the family, the Black Brant XII, is a four-stage vehicle that uses the Black Brant V motor as its third stage and Bristol Aerospace's Nihka motor as its fourth stage. The Black Brant remains in active use today, after nearly 50 years of reliable service. The Black Brant sounding rocket system continues to be the workhorse of the NASA Sounding Rocket Program.

- Improved Orion and Terrier-Improved Orion: The Terrier-Improved Orion consists of a 46-cm (18-in) diameter Terrier first stage and a 36-cm (14-in) diameter Improved Orion second stage. This vehicle, which has a diameter of 36 cm (14 in), can carry a payload of up to 363 kg (800 lb) to an altitude of 75 km (47 mi) or 100 kg (220 lb) to an altitude of 225 km (140 mi). The Terrier-Orion is launched from WFF. SRPO launched three Terrier-Orion vehicles in 2010, with the first launched from Poker Flat Research Range on February 2, 2010. Two others were launched from WFF, on June 24, 2010, and September 21, 2010. A Terrier-Improved Malemute launched on March 27, 2010, to test the Malemute upper stage and carry two student CubeSats. The Malemute is a surplus missile motor and no longer used by SRPO.



A Terrier-Improved Malemute successfully launched in 2012 from the Wallops Flight Facility (NASA)

Suborbital Reusable Vehicles

Suborbital reusable vehicles (SRVs) are part of an emerging industry with the potential to support new markets. SRVs are commercially developed reusable space vehicles that travel just beyond the threshold of space, about 100 km (62 mi) above the Earth. While traveling through space, the vehicles experience between one to five minutes of microgravity and provide relatively clear views of the Earth. Currently planned vehicles can carry up to 770 kg (1,698 lb) of payload and some will carry people. The companies developing SRVs typically target a high flight rate and relatively low cost.

Current ticket prices for human spaceflight vary from $95,000 to $250,000 per seat. These vehicles have been developed using predominantly private investment as well as some government support. Having gained momentum in 2012, each of the SRV companies has continued its research and development activities. In 2015, Blue Origin's New Shepard flew twice under an FAA AST Experimental Permit, with the second flight achieving a historic milestone by becoming the first vehicle to launch vertically, enter space (100.5 km or 62.4 mi), and land vertically. Table 3 provides a description of SRVs currently under development.

Operator	Vehicle	Seats*	Maximum Payload kg (lb)	Price	Announced Operational Year
Blue Origin	*New Shepard*	6	22.7 (50)**	TBD	2017
Masten Space Systems	Xodiac	N/A	TBD	TBD	2016
UP Aerospace	SpaceLoft XL	N/A	36 (79)	$350,000 per launch	2006 (actual)
Virgin Galactic	SpaceShipTwo	6 passengers 2 crew	600 (1,323)	$250,000 per seat	2018
World View	Voyager	6 passengers 2 crew	TBD	$75,000	2018

Table 3. U.S.-based providers of SRVs.
** Spaceflight participants only; several vehicles are piloted.*
*** Net of payload infrastructure*

A SpaceX Falcon 9 is readied for launch at Vandenburg AFB, California It carried ten Iridium NEXT satellites into orbit on January 14, 2017. *Source: SpaceX.*

LAUNCH AND REENTRY SITES

Launch sites are facilities dedicated to launching orbital or suborbital vehicles into space. These sites provide the capability to integrate launch vehicle components, fuel and maintain vehicles, and integrate vehicles with payloads. Launch sites can facilitate vertical takeoff, vertical landing (VTVL) vehicles or horizontal takeoff, horizontal landing (HTHL) vehicles. From the launch point, a launch vehicle travels through an area called the launch range or launch site, which typically includes tracking and telemetry assets. These range assets can monitor the vehicle's performance until it safely delivers a payload into orbit or returns to Earth. Tracking and telemetry assets may also facilitate recovery of reusable stages.

FAA AST licenses commercial launch and reentry sites in the United States. As of the end of 2017, FAA AST has issued 10 launch site operator licenses. Table 4 lists the FAA AST-licensed launch sites. Table 5 identifies the locations of all federal and non-federal launch sites in United States territory. FAA AST-licensed launch and reentry sites are often co-located with federal locations, including Cape Canaveral Air Force Station (CCAFS) in Florida, Vandenberg Air Force Base (VAFB) in California, and WFF in Virginia.

Launch Site and State	Operator	License First Issued	Expires	2017 FAA AST-Licensed or Permitted Flights
California Spaceport, CA	Harris Corporation	1996	9/18/2021	6
Mid-Atlantic Regional Spaceport, VA	Virginia Commercial Space Flight Authority	1997	12/18/2022	1
Pacific Spaceport Complex - Alaska, AK	Alaska Aerospace Corporation	1998	9/23/2018	0
Florida Spaceport, FL	Space Florida	1999	6/30/2020	14
Mojave Air and Space Port, CA	Mojave Air and Space Port	2004	6/16/2019	0
Oklahoma Spaceport, OK	Oklahoma Space Industry Development Authority	2006	6/11/2021	0
Spaceport America, NM	New Mexico Spaceport Authority	2008	12/14/2018	0
Cecil Field Spaceport, FL	Jacksonville Aviation Authority	2010	1/10/2020	0
Midland International Airport, TX	Midland International Airport	2014	9/14/2019	0
Ellington Airport, TX	Houston Airport System	2015	6/25/2020	0

Table 4. FAA AST-licensed launch and reentry sites, in order of when it was first issued a site license.

Of the 19 active launch and reentry sites, the U.S. government manages eight, state agencies manage ten FAA AST-licensed commercial sites in partnership with private industry, and a university manages one (Alaska's Poker Flat site, which is not licensed by FAA AST). Four sites are dedicated to orbital launch activity, ten facilitate suborbital launches only, and five can host both types of operations.

In addition to these sites, there are three non-licensed sites where individual companies conduct launches using a licensed or permitted vehicle. Because the companies own and operate these sites using their own vehicles exclusively, a site license is not required. SpaceX conducts flight tests at its McGregor, Texas site and Blue Origin conducts FAA-permitted flight tests from its site near Van Horn, Texas.

Launch Site	Operator	State or Country	Type of Launch Site	Type of Launches Supported	Currently Available for Commercial Operations?
California Spaceport	Harris Corporation	CA	Commercial	Orbital	Yes
Cape Canaveral Air Force Station	U.S. Air Force	FL	Government	Orbital	SLC-41 (Atlas V) SLC-37B (Delta IV) SLC-40 (Falcon 9) SLC-36 (Blue Origin) Landing Strip
Cecil Field Spaceport	Jacksonville Airport Authority	FL	Commercial	Suborbital	Yes
Edwards Air Force Base	U.S. Air Force	CA	Government	Suborbital	No
Ellington Airport	Houston Airport System	TX	Commercial	Suborbital	Yes
Florida Spaceport	Space Florida	FL	Commercial	Orbital/ Suborbital	Yes
Kennedy Space Center	NASA	FL	Government	Orbital	LC-39A (Falcon 9/Heavy) Shuttle Landing Facility
Mid-Atlantic Regional Spaceport	Virginia Commercial Space Flight Authority	VA	Commercial	Orbital	Yes
Midland International Air and Space Port	Midland International Airport	TX	Commercial	Suborbital	Yes
Mojave Air and Space Port	East Kern Airport District	CA	Commercial	Suborbital	Yes
Oklahoma Spaceport	Oklahoma Space Industry Development Authority	OK	Commercial	Suborbital	Yes
Pacific Missile Range Facility	U.S. Navy	HI	Government	Suborbital	No
Pacific Spaceport Complex Alaska	Alaska Aerospace Corporation	AK	Commercial	Orbital/ Suborbital	Yes
Poker Flat Research Range	University of Alaska Fairbanks Geophysical Authority	AK	Non-Profit	Suborbital	Five pads available for suborbital launches
Ronald Reagan Ballistic Missile Defense Test Site	U.S. Army	Republic of the Marshall Islands	Government	Orbital/ Suborbital	Omelek Island launch pad
Spaceport America	New Mexico Spaceport Authority	NM	Commercial	Suborbital	Yes
Vandenberg Air Force Base	U.S. Air Force	CA	Government	Orbital/ Suborbital	SLC-2 (Delta II) SLC-3E (Atlas V) SLC-4E (Falcon 9 and Falcon Heavy) SLC-6 (Delta IV) SLC-8 (Minotaur) SLC-576E (Minotaur-C)
Wallops Flight Facility	NASA	VA	Government	Orbital/ Suborbital	No
White Sands Missile Range	U.S. Army	NM	Government	Suborbital	No

Table 5. Active U.S. government and commercial launch and reentry sites.

U.S. FEDERAL SITES

Cape Canaveral Air Force Station

CCAFS is an installation of Air Force Space Command's 45th Space Wing and the primary launch head of America's Eastern Range, with three active launch pads, Space Launch Complexes (SLC) 37, 40, and 41. CCAFS is located on Merritt Island, south of NASA's Kennedy Space Center, and has a 10,000-foot-long runway. CCAFS has been used by the U.S. government since 1949 and has been home to a number of firsts, including launching the first U.S. Earth Satellite in 1958, the first U.S. astronaut in 1961, and the first spacecraft to orbit Mars in 1971 and roam its surface in 1996. In April 2014, SpaceX launched its Dragon spacecraft to resupply the International Space Station from SLC-40 at CCAFS and unveiled its Crew Dragon, designed to take people into space, the following month.

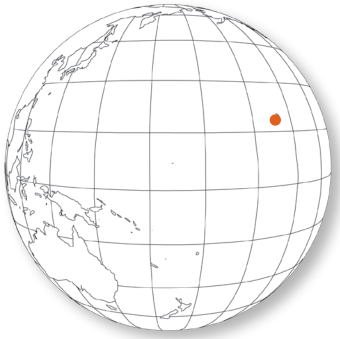
Edwards Air Force Base

Edwards Air Force Base (EAFB) is a U.S. Air Force installation near Rosamond, California. EAFB houses the Air Force Flight Test Center and is the Air Force Materiel Command center for conducting and supporting research and development of flight, as well as testing aerospace systems. EAFB is also home to NASA's Armstrong Flight Research Center (AFRC) and host to commercial aerospace industry testing activities. AFRC began in 1946 when 13 National Advisory Committee for Aeronautics (NACA) Langley Memorial Aeronautical Laboratory engineers began work to support the first supersonic research flights at EAFB. The AFRC's most notable research projects include the Controlled Impact Demonstration and the Linear Aerospike SR-71 Experiment. In addition, the Air Force Research Laboratory (AFRL) Propulsion Directorate maintains a rocket engine test facility on site.

Kennedy Space Center

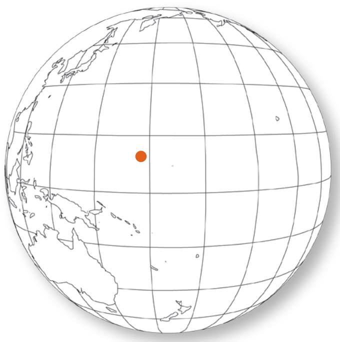
Kennedy Space Center (KSC) is NASA's Launch Operations Center. KSC supports Launch Complex 39 (LC-39), originally built for the Saturn V, one of the largest and most powerful operational launch vehicles in history, for the Apollo program. Since the Apollo program, LC-39 has been used to launch every NASA human spaceflight, including Skylab, the Apollo-Soyuz Test Project, and the Space Shuttle Program. Most recently, SpaceX signed an agreement with NASA to lease LC-39A for the Falcon Heavy, and the company began modifying the facility in 2014. SpaceX conducted its first launch from

LC-39A in early 2017 with a cargo mission to ISS, representing the first launch from that facility since the final Space Shuttle mission in 2011. The Falcon Heavy is currently set to launch from that pad in early 2018. Beginning in 2014, KSC's OPF-1 and OPF-2 began the modification process to accommodate the Air Force's X-37B space plane, and Boeing signed a lease agreement with NASA in 2014 to use OPF-3 for the CST-100 Starliner crewed capsule currently in development.



Pacific Missile Range Facility

The Pacific Missile Research Facility (PMRF), Barking Sands, is a U.S. air and naval facility, located in Hawaii. PMRF is the largest instrumented, multi-dimensional testing and training missile range in the world. At this location, submarines, surface ships, aircraft, and space vehicles operate and are tracked simultaneously. PMRF has over 108,780 km^2 (42,000 mi^2) of controlled airspace, with its base covering nearly 2,400 acres, with a 1,829-m (6,000-ft) runway. The U.S. Army acquired Barking Sands from the Kekaha Sugar Company in 1940, expanded in 1941 to over 2,000 acres, and was used as an airport for both private and military aircraft until 1954, when it was designated as Bonham Air Force Base. Naval missile testing operations began two years later with the Regulus I. In 1964, the facility was transferred to the U.S. Navy and became the PMRF, Barking Sands. Two Missile Defense Agency programs use PMRF currently, the Navy's Aegis Ballistic Missile Defense System and the Army's Terminal High Altitude Area Defense System (THAAD). Additionally, the Hawaii Space Flight Laboratory focuses on space exploration, tracking and controlling satellites launched from PMRF. The laboratory is housed in the Daniel K. Inouye Technology Center, which opened in October 2013.



Ronald Reagan Ballistic Missile Defense Test Site

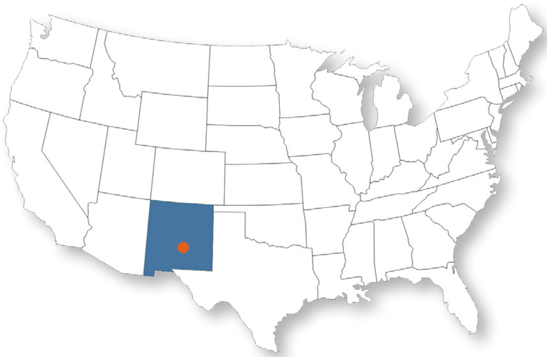
The Ronald Reagan Ballistic Missile Defense Test Site (Reagan Test Site), formerly the Kwajalein Missile Range, is a test range in the Pacific Ocean on the Republic of Marshall Islands (RMI). The Reagan Test Site includes several rocket launch sites spread across the Kwajalein Atoll, Wake Island, and the Aur Atoll. The Reagan Site is also a test facility for missile defense, a host for space research programs, and the terminal area for ballistic missile test launches for reentry vehicle testing. Among these programs, the Reagan Test Site serves as a tracking station for manned and unmanned spaceflight. The Reagan Test Site tracks approximately 50,000 objects per year in space, including foreign and domestic satellites and other objects as small as 10 cm (4 in).

Vandenberg Air Force Base

VAFB is located near the town of Lompoc, California, and is under the jurisdiction of the 30th Space Wing, Air Force Space Command (AFSPC). VAFB is the only location in the United States where both commercial and government polar orbiting satellites are launched. Launches from VAFB are unique in that an entire mission, from launch to orbital insertion, takes place over open water. The Titan IV, Pegasus, Taurus, Delta II, Atlas IIAS, Minotaur, Falcon 1, Atlas V, Delta IV, and SpaceX's Falcon 9 have all been launched from VAFB. VAFB also conducts ballistic missile defense missions. The base started as a U.S. Army training center, Camp Cooke, in 1941, and was officially transferred to the U.S. Air Force in 1957. It has conducted space and missile launches since 1959, launching the world's first polar orbiting satellite, Discoverer I, on February 28, 1959. VAFB also manages the West Coast Off-shore Operating Area, which controls air space for aircraft testing.

Wallops Flight Facility

WFF, located 161 km (100 mi) northeast of Norfolk, Virginia, is the primary provider of NASA's science suborbital and small orbital flight programs. WFF is owned and operated by the Goddard Space Flight Center in Greenbelt, Maryland. Annually, WFF conducts approximately 30 sounding rocket missions from this site and others worldwide. It also conducts about 20 high altitude balloon missions per year and several hundred hours of piloted and unpiloted aircraft missions. In addition, WFF manages the Wallops Research Range (WRR), consisting of a launch range, mobile range, and airport. WRR has conducted more than 16,000 launches over its 70-year history and annually supports approximately 20 suborbital launches using its six launch pads.



White Sands Missile Range

White Sands Missile Range (WSMR) is a 3,200-square-mile rocket range in southern New Mexico, operated by the U.S. Army. WSMR is the largest military operation in the United States and the site of the first atomic bomb test, codenamed Trinity, conducted in July 1945. It was also the testing site of the German V-2 rocket in April 1946. The test range, designated WSMR in May 1958, houses the Launch Abort Flight Test Complex for the Orion Project, which had its groundbreaking at LC-32 for the Orion Abort Test Booster in November 2007; NASA's White Sands Test Facility's ground station for Tracking and Data Relay Satellites; and the North Oscura Peak facility of the AFRL, among others. In September 2015, Orbital ATK launched flight tights from WSMR to complete its 50th and 51st missions of its "Coyote" target vehicle for the U.S. Navy.

FAA AST-LICENSED SITES

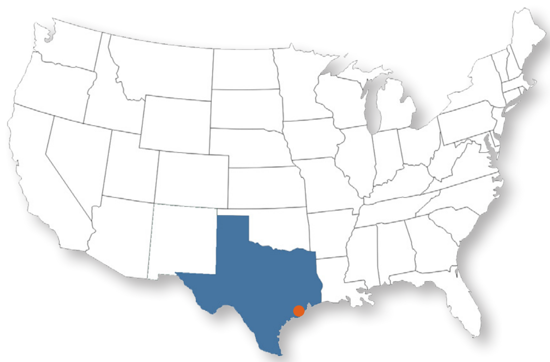
California Spaceport

Spaceport Systems International, L.P. (SSI), established in 1993, operates The California Spaceport, which came into being just two years later in 1995, when SSI signed a lease with the Air Force. The California Spaceport is a commercial launch and satellite processing facility located on California's central coast at VAFB, near the town of

Lompoc, California. SSI signed a 25-year lease with the Air Force to provide commercial launch services from the 100-acre plot it currently occupies. The lease includes an Integrated Processing Facility (IPF), originally built for the STS and designed to process three shuttle-class payloads simultaneously. The Commercial Launch Facility (CLF), known as Space Launch Complex 8 (SLC-8), was also included as part of the lease. In 1996, FAA AST issued the first Commercial Space Launch Site Operator's License to SLC-8. In 1999, this launch complex was also the first commercial launch site to become fully operational. SLC-8 is currently the only exclusively commercially operated launch site in the United States, receiving no federal or state taxpayer funds to operate.

Cecil Field Spaceport

Cecil Field Spaceport (CFS) is the only licensed horizontal launch commercial spaceport on the East Coast, and it is owned and operated by the Jacksonville Aviation Authority (JAA). CFS is positioned on 150 acres of dedicated spaceport development property, adjacent to the runway and taxiway system at Cecil Airport near Jacksonville, Florida. CFS is specially designed with a 12,500-foot-long runway, 18L-36R, to launch and recover space vehicles that take off and land horizontally. Following four years of feasibility and development studies, JAA was granted a Launch Site Operator License in January 2010. Prompted by a Space Florida resolution, legislation to amend the Florida Statutes to designate CFS a "Space Territory" was passed, allowing Space Florida to include it in master planning efforts and space-related infrastructure upgrades.



Ellington Field

The Ellington Airport, future home to the Houston Spaceport, is a civilian and military use airport in Texas. It is owned by the City of Houston, and operated by the Houston Airport System (HAS). In April 2014, Sierra Nevada Corporation (SNC) ratified an agreement with HAS officials to research Ellington's potential as a commercial Spaceport. SNC hopes to use the site to land its Dream Chaser space plane. The feasibility study estimated a cost of \$48M for properly outfitting Ellington as a spaceport to undertake the landing mission and close to \$122M for equipping the airport to handle landing and launching small space vehicles regularly. FAA AST granted a launch site license to Ellington Airport in June 2015, becoming the 10th commercial spaceport in the United States. In October of 2015, the Houston City Council approved the \$6.9M purchase of a building, adjacent to the Ellington Airport, to be used as an incubator for early-stage space industry companies. To date, prospective tenants include Intuitive Machines and United Kingdom-based Catapult Satellite Applications. This 4,924 m^2 (53,000-ft^2) facility marks the first dedicated infrastructure project for the Houston Spaceport.

Florida Spaceport

Space Florida, which was founded in 2006 to foster growth and development of a sustainable space industry in the State of Florida, operates the Florida Spaceport. In 2010, the FAA authorized Space Florida to operate a launch site at SLC-46 for commercial and U.S. Government launches. SLC-46 is the easternmost launch complex at CCAFS.

SLC-46 was originally used for tests of the Trident II missile between 1987 and 1989. SLC-46 was redesigned to support commercial launches, such as an Athena II and an Athena I in 1998 and 1999 respectively. In July 2015, the U.S. Air Force and Orbital ATK announced a Minotaur IV launched from SLC-46 would be used for the ORS-5 mission in 2017. As of February 2014, NASA plans to launch the Orion Multi-Purpose Crew Vehicle Ascent Abort 2 test flight (AA 2) from SLC-46 in 2018.

Mid-Atlantic Regional Spaceport

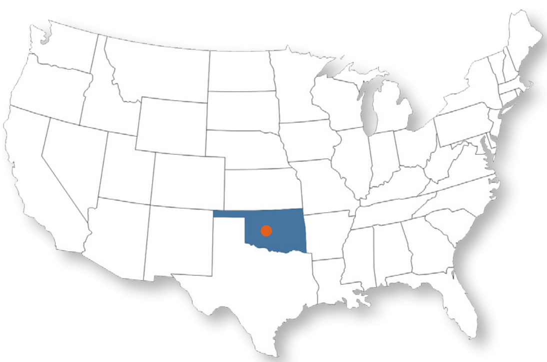
The Mid-Atlantic Regional Spaceport (MARS) is a commercial space launch facility, formerly known as the Virginia Space Flight Center that was developed using a combination of federal, state, and private sector funds from the Virginia Commercial Space Flight Authority (VCSFA). Created in 1995, VCSFA began its lease at Wallops Island in 1997 and expanded the MARS facilities to its present state by 2006 with two active launch facilities (one mid-class and one small-class launch facility). Through agreements with NASA, VCSFA also added access to support infrastructure facilities, such as vehicle and payload processing integration facilities and instrumentation and emergency facilities. MARS consists mainly of Launch Pads 0A and 0B, as well as supporting facilities. Launch Pad 0A cost about $160M to support Orbital ATK's Antares vehicle: $90M was provided by the Commonwealth of Virginia, $60M from NASA, and $10M from Orbital ATK. In October 2014, the facility suffered significant damage to LP-0A due to the Antares launch failure. Repairs or replacement to various facilities was completed as scheduled and within the overall budget while keeping a small management reserve for final system performance testing, which started September 25, 2015. MARS was able to begin rebuilding its damaged launch pad, and repairs were completed September 30, 2015 to support a March 2016 launch.

Midland International Air and Space Port

The Midland International Air and Space Port is a city-owned international airport located between the cities of Midland and Odessa, Texas. It is the latest commercial launch site licensed by FAA AST, having been awarded the license in September 2014. The Air and Space Port is located on the same site as Sloan Field, a small airport founded in 1927. The airport was used as a training base during World War II, known as Midland Army Air Field, before reverting back to commercial operations in late 1945. The airfield is owned by the city of Midland, Texas. In October 2014, Orbital Outfitters, a company that specializes in space suits and space vehicle mockups, moved its operations to Midland. Orbital Outfitters constructed the Midland Altitude Chamber Complex, a facility that includes three hypobaric chambers for scientific and human high-altitude testing and training.

Mojave Air and Space Port

The Mojave Air and Space Port is an aerospace test center and launch and reentry site, operated by the East Kern Airport District in the Mojave Desert. Certified by FAA in June 2004, the Mojave Air and Space Port is the first facility to be licensed in the United States for horizontal launches of reusable spacecraft. Kern County established the airport in 1935, and it became the Marine Corps Auxiliary Air Station (MCAAS) in 1941, following the attack on Pearl Harbor. The base was closed in 1947 and remained so until the outbreak of the Korean War. In 1961, Kern County again obtained the title to the airport and established the East Kern Airport District (EKAD) in 1972 to administer the airport. EKAD administers the Air and Space Port to this day. Sixty companies operate out of Mojave, including Interorbital Systems, Scaled Composites, Masten Space Systems, Orbital ATK, and Virgin Orbit.



Oklahoma Spaceport

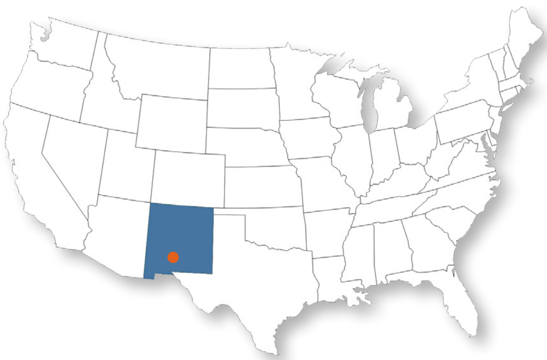
Oklahoma Spaceport is managed by the Oklahoma Space Industry Development Authority (OSIDA), created in 1999, and was granted a license to the site by the FAA in June 2006. The site is located near the community of Burns Flat, Oklahoma and is part of what is also known as the Clinton-Sherman Industrial Airpark. It is the only spaceport with an FAA-approved spaceflight corridor that is not in restricted airspace or Military Operation Areas (MOAs). The Oklahoma Spaceport has facilities in place for aerospace testing, research and development, flights and launches, with its 4,116-m (13,503-ft) by 91-m (300-ft) concrete runway meant for both civilian and military use. Oklahoma lawmakers voted to give OSIDA $372,887 for 2015 operations costs, in addition to federal funding. While the spaceport has yet to launch any orbital or suborbital flights and be used for space travel, its aviation facility conducts approximately 35,000 flight operations annually.

Pacific Spaceport Complex – Alaska

The Pacific Spaceport Complex – Alaska (PSCA, formerly Kodiak Launch Complex, or KLC) is a commercial rocket launch facility for suborbital and orbital space launch vehicles, located on Kodiak Island, Alaska. It is owned and operated by the Alaska Aerospace Corporation (AAC), created in 1991, which is an independent political and corporate entity located within the Alaska Department of Military and Veterans' Affairs. PSC is the first FAA-licensed launch site not co-located on a federally controlled launch site; however, the majority of the launches it has managed since its inception in 1998 have been U.S. government launches. PSC has one launch pad, Launch Pad 1 (LP-1), which can launch intermediate-class payloads to low Earth orbit (LEO) or polar orbits. The complex also has a suborbital launch pad (LP-2) for missile testing. Development of a third launch pad for the Athena

III began in 2012, and this launch pad is intended to allow the facility to support launches of satellites in under 24 hours.

In August 2014, LP-1 was damaged when an Air Force Advanced Hypersonic Weapons test ended in failure, the test vehicle having been destroyed by range control personnel following an anomaly. Soon afterward, Alaska Aerospace made plans to repair and upgrade the facilities to support larger rockets, but state funding priorities prohibited repairs to PSCA.



Spaceport America

Spaceport America is the world's first purpose-built, commercial spaceport. The site is located in Sierra County, near the city of Truth or Consequences, New Mexico, and is operated by the New Mexico Spaceport Authority. The spaceport was officially opened for business in October 2011, and its first FAA-licensed launch took place in October 2012. The New Mexico Spaceport Authority received its license for horizontal and vertical launch from FAA AST in December 2008. Virgin Galactic, the anchor tenant, signed a 20-year lease agreement immediately after issuance of the license. The main terminal hangar is capable of housing two WhiteKnightTwo aircraft and five Virgin Galactic SpaceShipTwo spacecraft.

Delays experienced by launch service providers like Virgin Galactic have inspired the New Mexico Spaceport Authority to explore alternative means of generating revenue at the spaceport until flight operations begin. Negotiations with several potential tenants took place in 2014. The Spaceport hired a marketing firm to solicit sponsors but was unsuccessful. At the moment, Spaceport America is mostly vacant. The spaceport is entirely financed by the taxpayers of New Mexico, and is substantially complete at a cost of $209M. In early 2015, a bill was introduced to the New Mexico Legislature that the State of New Mexico sell the public spaceport to commercial interests to begin recouping some of the state's investment. Action on the bill was postponed indefinitely later that year.

NON-LICENSED U.S. SITES

SpaceX McGregor Rocket Development and Test Facility

SpaceX purchased the testing facilities of defunct Beal Aerospace in McGregor, Texas, announcing plans in 2011 to upgrade the former bomb manufacturing plant to allow for launch testing of a VTVL rocket. The next year, SpaceX constructed a half-acre concrete launch facility on the property to support the Grasshopper test flight program. The total facility comprises 900 acres and is currently being used for research and development of new rocket engines and thrusters. The facility is also used to test final manufactured engines and their various

components as well as potential reusable boosters. The facility currently has 11 test stands that operate 18 hours per day, six days per week. Thus far, SpaceX has used the site to test the Merlin 1D engine, and the Falcon 9 v1.1, as well as flight testing of Grasshopper v1.1, which was permitted by FAA AST until October 2014. Recovered SpaceX Dragon spacecraft are also sent to McGregor to be refurbished for potential reuse.

Blue Origin West Texas Rocket Flight Facility

Blue Origin, LLC is an American-owned, privately funded aerospace development and manufacturing company, established by Amazon.com founder Jeff Bezos. The company is currently developing technologies to enable commercial spaceflight with lower costs and increased reliability. Blue Origin's West Texas high-altitude rocket flight facility is located near the town of Van Horn, Texas.

Poker Flat Rocket Range

The Poker Flat Rocket Range (PFRR) serves as a launch facility and sounding rocket range near Fairbanks, Alaska. It is the only U.S. launch facility owned and operated by a non-profit, the University of Alaska, Fairbanks (UAF), which has owned the site since 1948 and is currently under contract to NASA WFF. PFRR is home to five launch pads, two of which are optimized for extreme weather conditions. The 5,000-acre facility has performed more than 1,700 launches to study the Earth's atmosphere and its interaction with the space environment.

NON-U.S. SITES

There are many active orbital and suborbital launch sites across 10 different countries and territories. The most significant of these sites are described briefly in the following paragraphs.

Russian service providers launch vehicles from four operational sites: Baikonur Cosmodrome, located in Kazakhstan as a byproduct of the collapse of the Soviet Union in 1991; Plestesk Cosmodrome, in the western part of the country; Dombarovsky Air Base near the western Kazakh border, and Vostochny Cosmodrome near the eastern coast. Virtually all Russian vehicles launch from Baikonur, including the Angara, Dnepr, Proton M, Rockot, Soyuz (including missions to ISS), and Zenit, among others. The Soyuz and Rockot vehicles launch from Plestesk, and only the Dnepr launches from Dombarovsky. Vostochny, the newest launch site, supports launches of Angara and Soyuz.

China is home to four launch sites. The Jiuquan Satellite Launch Center is located in Inner Mongolia and is the most active site, with launches of the Long March 2C, 2D, and 2F typically taking place. Taiyuan Satellite Launch Center is located in the northeast of the country, with Xichang Satellite Launch Center located further south. Polar-bound Long March 4 vehicles tend to launch from Taiyuan, whereas GEO-bound Long March 3B vehicles launch from Xichang. The Wencheng Satellite Launch Center is the newest, having supported its first launch.

The French space agency Centre National d'Études Spatiales (CNES), together with the European Space Agency (ESA) operates the Guiana Space Center in French Guiana. This site is used to launch the Ariane 5, Soyuz 2, and Vega, all provided by Arianespace.

Japan has two active launch sites: The Tanegashima Space Center and the Uchinoura Space Center. The Tanegashima Space Center is the larger of the two and where the H-IIA and H-IIB vehicles are launched. Previously known as Kagoshima Space Center, the Uchinoura Space Center is the launch site for the newly introduced small-class vehicle called Epsilon.

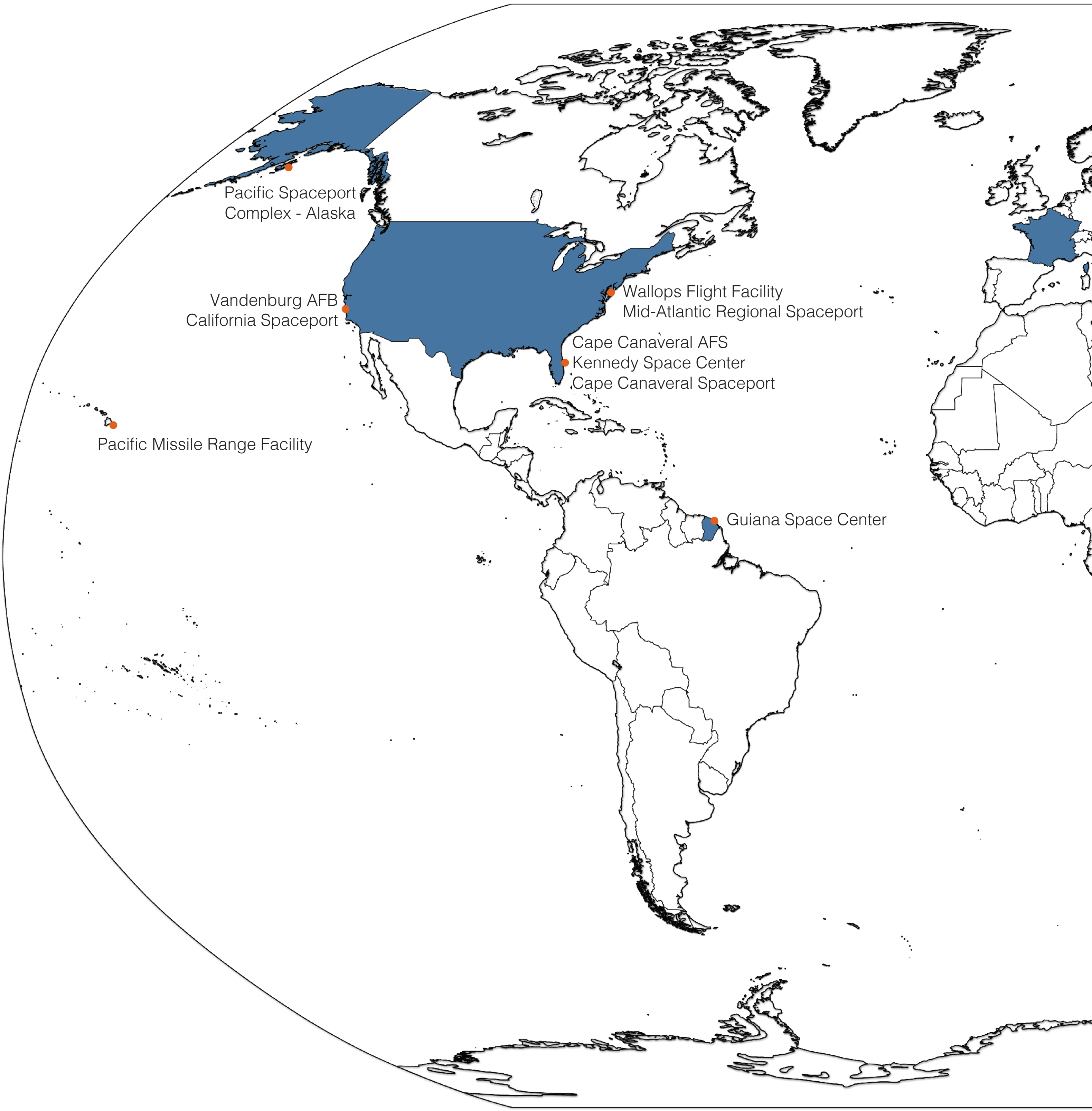
The Indian Space Research Organization (ISRO) operates India's sole launch site, the Satish Dhawan Space Center located near Sriharikota. Inaugurated in 1971, this is the launch site for ISRO's Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV). ISRO's next vehicle, the more powerful LMV-3, will also launch from this site.

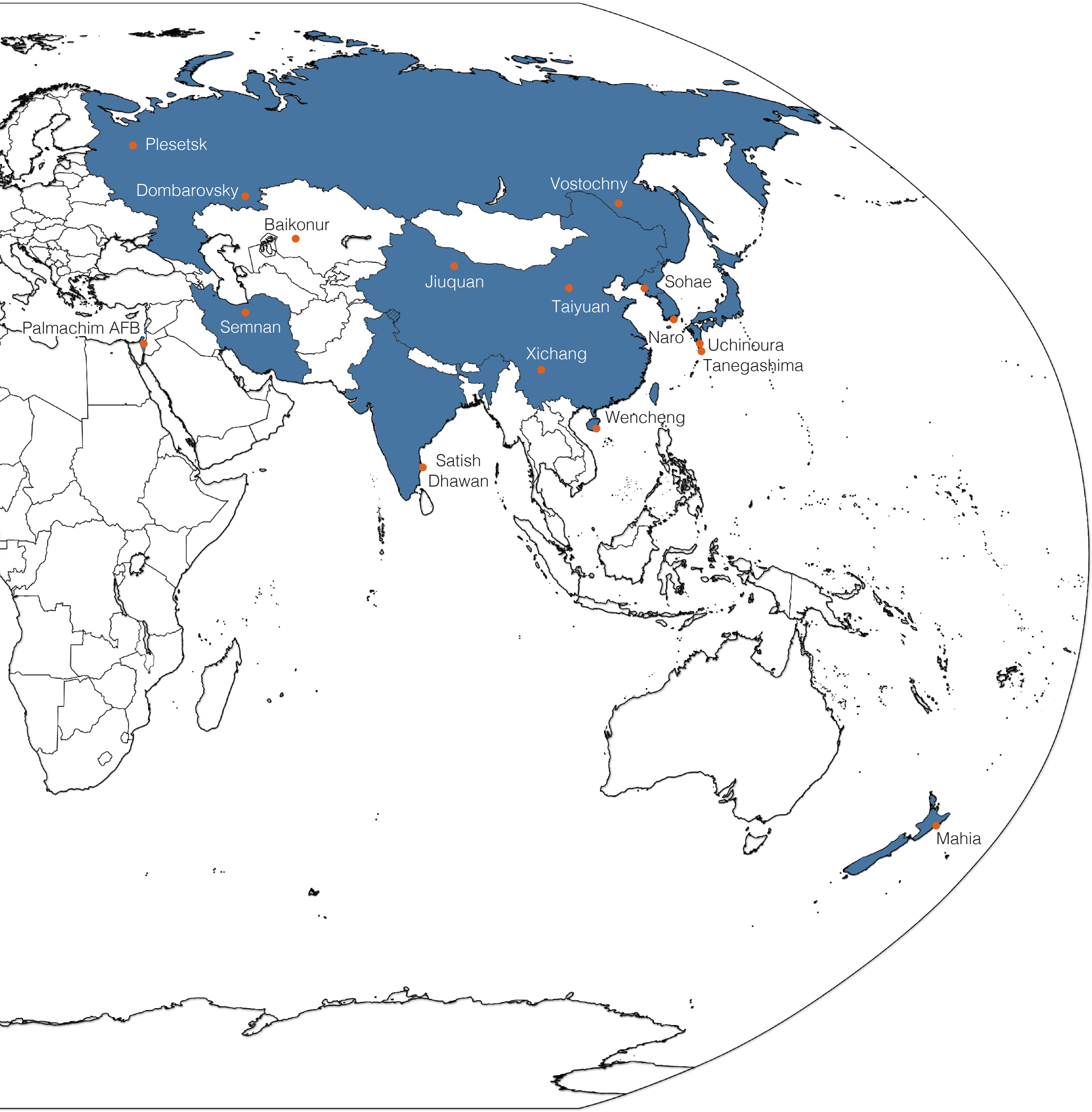
The Israeli Defense Force operates an orbital launch pad from Palmachim Air Force Base, from which the country's Shavit vehicle is launched. Iran launches its Safir orbital vehicle from Semnan located in the north of the country near the Caspian Sea. North Korea's Unha launch vehicle is launched from the Sohae Satellite Launching Station located in the country's northeast. Finally, South Korea's launch site for the Naro-1 vehicle is located at the Naro Space Center.

In September 2016, the world's newest orbital launch site opened for business. Located on the Mahia Peninsula in New Zealand, it features a single pad with supporting facilities owned and operated by Rocket Lab. The first launch took place from Mahia in May 2017.

Figure 4 on the next two pages shows the locations of these launch sites as well as active suborbital sites.

Figure 4. The location of orbital launch sites worldwide.




Plesetsk
Dombarovsky
Baikonur
Vostochny
Jiuquan
Sohae
Taiyuan
Palmachim AFB
Semnan
Naro
Uchinoura
Tanegashima
Xichang
Wencheng
Satish
Dhawan
Mahia

Orbital ATK cargo mission OA-7, named in honor of astronaut John Glenn, being berthed at the International Space Station in April 2017. *Source: NASA.*

SPACECRAFT IN 2017

In the case of an orbital launch, a spacecraft can be a satellite, a space probe, an on-orbit vehicle, or a platform that carries humans, animals, experiments, or cargo. These are separate from a launch vehicle's upper stage to continue their spaceflight independently, in or beyond an Earth orbit.

Suborbital reusable vehicles can carry various types of payloads, including but not limited to humans, scientific instruments, or hardware and materials subject to microgravity and other space environment testing that are subsequently returned to the ground inside or on the suborbital vehicles that launched them. In cases when a suborbital vehicle would be used to launch a satellite or another type of spacecraft, the vehicle will carry an upper stage to deploy the payload on orbit.

STATE OF THE SPACECRAFT INDUSTRY

The first spacecraft were satellites launched into low Earth orbit (LEO). These satellites were followed by on-orbit vehicles and platforms launched into other orbits and to different destinations. Space stations carrying humans have been launched into LEO and satellites carrying payloads for Earth observation, communications, and scientific sensors, telescopes, and transponders have launched into LEO, sun-synchronous orbits (SSO), highly elliptical orbits, and geosynchronous orbit (GEO). Scientific probes traveled to such destinations as the Moon, planets, and other locations within and beyond our solar system.

Government and commercial manufacturers worldwide produce these spacecraft. Some organizations are also launch vehicle manufacturers but most are companies that design and build spacecraft exclusively, produce these spacecraft. Commercially launched spacecraft are typically used for the following mission types:

- Commercial communications satellites;
- Commercial remote sensing or Earth observation satellites;
- Commercial crew and cargo missions, including on-orbit vehicles and platforms;
- Launch vehicle test and demonstration missions, typically involving telemetry packages or dummy payloads; and
- Other commercially launched payloads, usually satellites launched for various purposes by governments of countries not having indigenous orbital launch capability.

All spacecraft can be divided into FAA AST mass classes, described in Appendix 1 on Page 94.

GLOBAL SPACECRAFT INDUSTRY

Countries and jurisdictions worldwide that possess functional and operating indigenous payload manufacturing sectors are the United States, Russia, China, Europe, India, and Japan, among others. Organizations from nearly 60 countries have developed and built at least one orbital payload since 1957, usually a satellite. The payload building capability of more than half of these countries is limited to CubeSats, small satellites built from pre-fabricated kits by universities and government and non-profit organizations.

Table 6 presents civil, military, and commercial orbital spacecraft, by country of manufacturer, in 2017. Launch service providers worldwide sent 466 spacecraft on their way to orbit, though 23 failed to reach their destinations due to a launch failure. Ninety-seven percent of these spacecraft were satellites (450), while 14 were vehicles supporting crew and cargo missions to the International Space Station (ISS), one was an X-37B mission, and one was a telemetry test package carried by Rocket Lab's inaugural Electron vehicle. Of the 450 satellites launched, 403 were launched to LEO (including SSO), 40 were launched to GEO, and 7 to medium Earth orbits (MEO). This was also a record year for CubeSats, with 290 launched (67 destined for deployment from ISS), more than any previous year since CubeSats were introduced in 2003.

Country of Manufacturer	Civil	Military	Non-Profit	Commercial	Total
Argentina	0	0	0	1	***1***
Australia	0	0	5	0	***5***
Canada	2	0	1	0	***3***
Chile	0	0	1	0	***1***
China	9	14	7	6	***36***
Ecuador	0	0	1	0	***1***
Europe	8	1	25	57	***91***
India	8	0	1	0	***9***
Israel	1	0	1	0	***2***
Japan	6	2	5	3	***16***
Kazakhstan	0	0	1	0	***1***
Russia	13	5	5	1	***24***
South Africa	0	0	2	0	***2***
South Korea	0	0	3	0	***3***
Taiwan	1	0	1	0	***2***
Turkey	0	0	2	0	***2***
UAE	0	0	1	0	***1***
Ukraine	0	0	1	0	***1***
USA	9	13	22	224	***268***
TOTALS	***57***	***35***	***85***	***292***	***469***

Table 6. Number of civil, military, non-profit, and commercial, spacecraft launched in 2017 by country of manufacturer.

Sixty-three percent (292) of the spacecraft launched were designed to generate revenue, with 209 dedicated to remote sensing missions, 63 to communication missions, 6 supporting cargo transportation services to the ISS, and the remaining for testing, research, and development.

U.S. SPACECRAFT INDUSTRY

The backbone of the United States spacecraft industry consists of the established aerospace companies (including major U.S. government space and defense prime contractors) developing and manufacturing commercially launched spacecraft:

- Ball Aerospace
- The Boeing Company
- Lockheed Martin Corporation

- Northrop Grumman
- Orbital ATK
- Space Systems Loral (SSL)

These companies build spacecraft, mostly of large- and medium- but also small-mass class, for civil, military and commercial uses. Three of the six companies, Boeing, Lockheed Martin, and Orbital ATK, are also launch vehicle manufacturers. Ball Aerospace and SSL are strictly payload (spacecraft) companies. Meanwhile, companies such as Harris, Northrop Grumman, and Raytheon develop and produce specialized payload components, including antennas, electronics, and other subsystems. Note that in 2017, Northrop Grumman acquired Orbital ATK, a deal that will close in 2018. Other U.S. companies, many established in the last 15 years, manufacture spacecraft of all mass classes, for civil, military, and commercial use.

COMMERCIAL ON-ORBIT VEHICLES AND PLATFORMS

NASA started the commercial crew and cargo program to help commercial companies develop new capabilities for transporting crew and cargo to the ISS. These services are intended to replace some of the ISS resupply missions once performed by the Space Shuttle. The first of these vehicles, SpaceX's Dragon, became operational in 2012, restoring NASA's ability to deliver and retrieve cargo in LEO. Orbital ATK followed with its Cygnus spacecraft, which is capable of delivering cargo to ISS but is not designed to be recovered following reentry. In 2016, NASA awarded a second cargo resupply services contract to SpaceX, Orbital ATK, and Sierra Nevada Corporation (which is developing a cargo system based on its Dream Chaser vehicle) to cover the period 2019 through 2024. Crewed vehicles made many advances in 2017 and are expected to become operational in 2019.

On-orbit vehicle and platform development by commercial companies conducted in 2017 included the missions:

- Four cargo missions were conducted as part of NASA's ISS Commercial Resupply Services (CRS) contracts with SpaceX
- Two Orbital ATK Cygnus missions were conducted using Atlas V (OA-7) and Antares (OA-8E)

Boeing continues to develop the CST-100 Starliner, and SpaceX is developing the Crewed Dragon for the NASA Commercial Crew Transportation Capability (CCtCap) program. Blue Origin tested the third version of its New Shepard suborbital vehicle in 2017, and announced in 2017 a significantly larger payload fairing than previously announced for its New Glenn launch vehicle.

Table 7 lists on-orbit vehicles currently offered or being developed in the U.S.

Operator	Vehicle	Launch Vehicle	Maximum Cargo kg (lb)	Maximum Crew Size	First Flight
SpaceX	Dragon	Falcon 9	6,000 (13,228)	0	2010
SpaceX	Crewed Dragon	Falcon 9	TBD	7	2018
Orbital ATK	Cygnus	Antares	3,500 (7,716)	0	2013
Boeing	CST-100 Starliner	Atlas V, Falcon 9	TBD	7	2018
Sierra Nevada Corp.	Dream Chaser	Atlas V	5,500 (12,125)	0	2020

Table 7. On-orbit vehicles in service or under development.

The penultimate launch of a Delta II, this time carrying the JPSS-1 weather satellite into orbit from VAFB, California in November, 2017. *Source: ULA.*

2017 LAUNCH EVENTS

Space launch activity worldwide is carried out by the civil, military, and commercial sectors. This section summarizes U.S. and international orbital launch activities for calendar year 2017, including launches licensed by the Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST).

Countries and jurisdictions worldwide that possess functional and operating indigenous orbital launch capability are the United States, Russia, China, Europe, India, Japan, Israel, Iran, North Korea, South Korea, and New Zealand. Organizations in several other countries, including Argentina, Brazil, and Indonesia are developing launch vehicle technologies.

Table 8 presents civil, military, and commercial orbital launches by country in 2017.

Country/Region	Civil	Military	Commercial	Total
USA	2	6	21	**29**
China	10	8	0	**18**
Russia	11	5	3	**19**
Europe	3	0	8	**11**
India	5	0	0	**5**
Japan	5	2	0	**7**
New Zealand	0	0	1	**1**
TOTALS	***36***	***21***	***33***	***90***

Table 8. Total orbital launches in 2017 by country and type.

In 2017, the United States, Russia, Europe, China, Japan, India, and New Zealand conducted a total of 90 orbital launches, 33 of which were commercial (see Figure 5). For comparison, in 2016 there were 85 launches, including 22 commercial launches.

Five of the 90 launches failed. These included four government launches: a Soyuz 2.1b carrying the Meteor-M 2-1 satellite and 18 secondary payloads, a PSLV XL carrying the IRNSS-1H satellite, a Long March 5A carrying the Shijan 18-01 satellite,

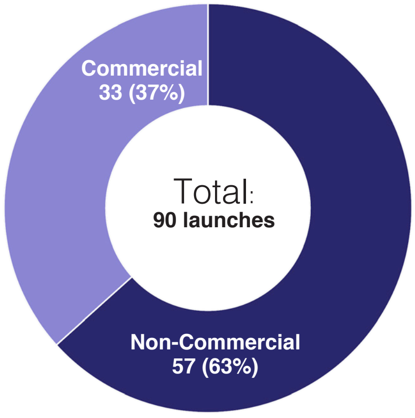


Figure 5. 2017 total worldwide launch activity.

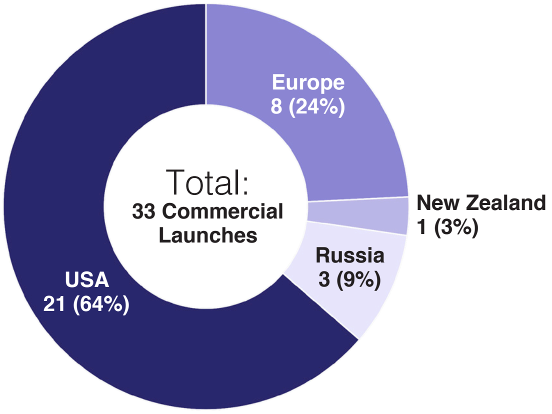


Figure 6. 2017 total worldwide commercial launch activity.

an Electron carrying a telemetry package called Humanity Star, and a SS-520 Upgrade carrying TRICOM-1 satellite. China's Long March 3B launch in June was a partial success when Chinasat 9A (Sinosat 4) was placed in an incorrect orbit. The satellite will lose ten years of lifespan in order to reach its correct orbit.

Highlights of 2017 in the orbital space launch industry:

- FAA AST licensed 22 orbital launch events (21 taking place from the U.S. and one from New Zealand), the highest since 1998, when 22 licensed launches took place;
- NASA continued its ISS Commercial Resupply Services (CRS) program, with the launch of five resupply missions;
- SpaceX resumed launching payloads for commercial clients with 17 commercial launches, including seven to GEO, nine to LEO and one to SSO. Three out of the nine launches to LEO were for the ISS CRS program. In March, SpaceX was the first launch provider to reuse a previously landed first stage;
- In February, the Indian PSLV-XL successful launched 104 satellites in one mission. In doing so, India tripled the previous record held by Russia of the most satellites launched during a single launch event; and
- In May, a new launch vehicle was tested for the first time. While Electron's test was unsuccessful, Rocket Lab plans to begin providing commercial launches in 2018.

Revenues from the 33 commercial orbital launches in 2017 are estimated to be just over \$3B, a healthy increase from \$2.5B in 2016. The estimated commercial orbital launch revenues of \$1.7B for U.S. providers, compared to \$1.2B in 2016, reflects flights from seventeen Falcon 9 FTs, an Atlas V, an Antares, an Electron, a Minotaur-C, and a Minotaur IV. (See Figure 7). These 22 missions were licensed by FAA AST.

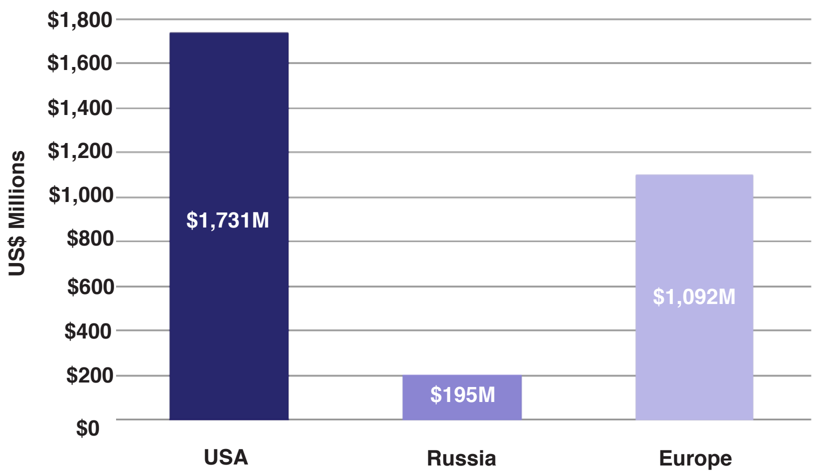


Figure 7. 2017 estimated revenues for commercial launches by country of service provider.

FAA AST 2017 ORBITAL LAUNCH ACTIVITY

FAA AST licensed 22 commercial orbital launches in 2017, compared to eleven licensed launches in 2016 (Table 9). SpaceX's Falcon 9 vehicle was used in seventeen licensed launches. Four launches were conducted in February, June, August, and December under NASA's CRS program. Ten launches were conducted for commercial satellite operators including: Iridium (four launches), Echostar (twice), SES, Inmarsat, Bulsatcom, Intelsat, and KT Sat. Two launches were for government clients, including one military launch for the National Reconnaissance Office (NRO) and a civil launch for Taiwan's national space agency. ULA's Atlas V vehicle successfully launched a Cygnus cargo module to ISS on behalf of Orbital ATK. Orbital ATK itself conducted three launches; an Antares 230 vehicle sent a Cygnus cargo module to ISS, a Minotaur-C successfully deployed 10 satellites for Planet (six SkySat satellites and four Flock-3m CubeSats), and a Minotaur IV sent the Air Force's SensorSat and three other satellites into orbit. In March, the first test launch of Electron failed when it reached space but was unable to achieve orbit.

Date	Vehicle	Primary Payload	Orbit	Launch Outcome
1/14/17	Falcon 9 FT	Iridium NEXT 1	LEO	Success
2/19/17	Falcon 9 FT	Spx 10	LEO	Success
3/16/17	Falcon 9 FT	EchoStar XXIII	GEO	Success
3/30/17	Falcon 9 FT	SES 10	GEO	Success
4/18/17	Atlas V 401	OA 7	LEO	Success
5/1/17	Falcon 9 FT	NRO L-76	LEO	Success
5/15/17	Falcon 9 FT	Inmarsat 5F4	GEO	Success
5/24/17	Electron	Humanity Star	LEO	Failure
6/3/17	Falcon 9 FT	Spx 11	LEO	Success
6/23/17	Falcon 9 FT	BulgariaSat 1	GEO	Success
6/25/17	Falcon 9 FT	Iridium NEXT 11	LEO	Success
7/5/17	Falcon 9 FT	Intelsat 35e	GEO	Success
8/14/17	Falcon 9 FT	Spx 12	LEO	Success
8/24/17	Falcon 9 FT	Formosat 5	LEO	Success
8/25/17	Minotaur IV	SensorSat	LEO	Success
10/9/17	Falcon 9 FT	Iridium NEXT 21	LEO	Success
10/11/17	Falcon 9 FT	SES 11	GEO	Success
10/30/17	Falcon 9 FT	KoreaSat 5A	GEO	Success
10/31/17	Minotaur C	SkySat C6	LEO	Success
11/12/17	Antares 230	OA 8E	LEO	Success
12/15/17	Falcon 9 FT	Spx 13	LEO	Success
12/22/17	Falcon 9 FT	Iridium NEXT 31	LEO	Success

Table 9. 2017 FAA AST-licensed orbital launch events.

Figure 8 shows the number of FAA AST-licensed orbital launches for 2013 through 2017.

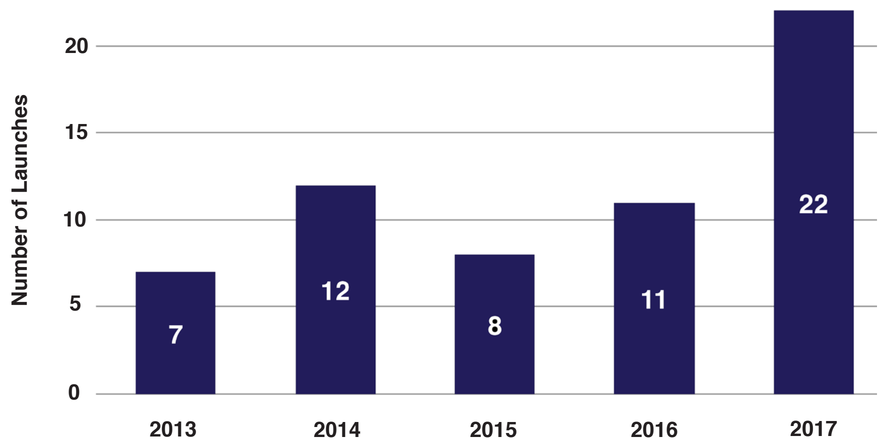


Figure 8. FAA AST-licensed orbital launch events, 2013-2017.

Table 10 on the next page provides specifications for the six vehicle types that were launched during 2017 under an FAA AST license. Note that the Falcon 9 FT was introduced in 2015 and that earlier variants flew successfully 18 times since 2010 and one launch resulted in a failure.

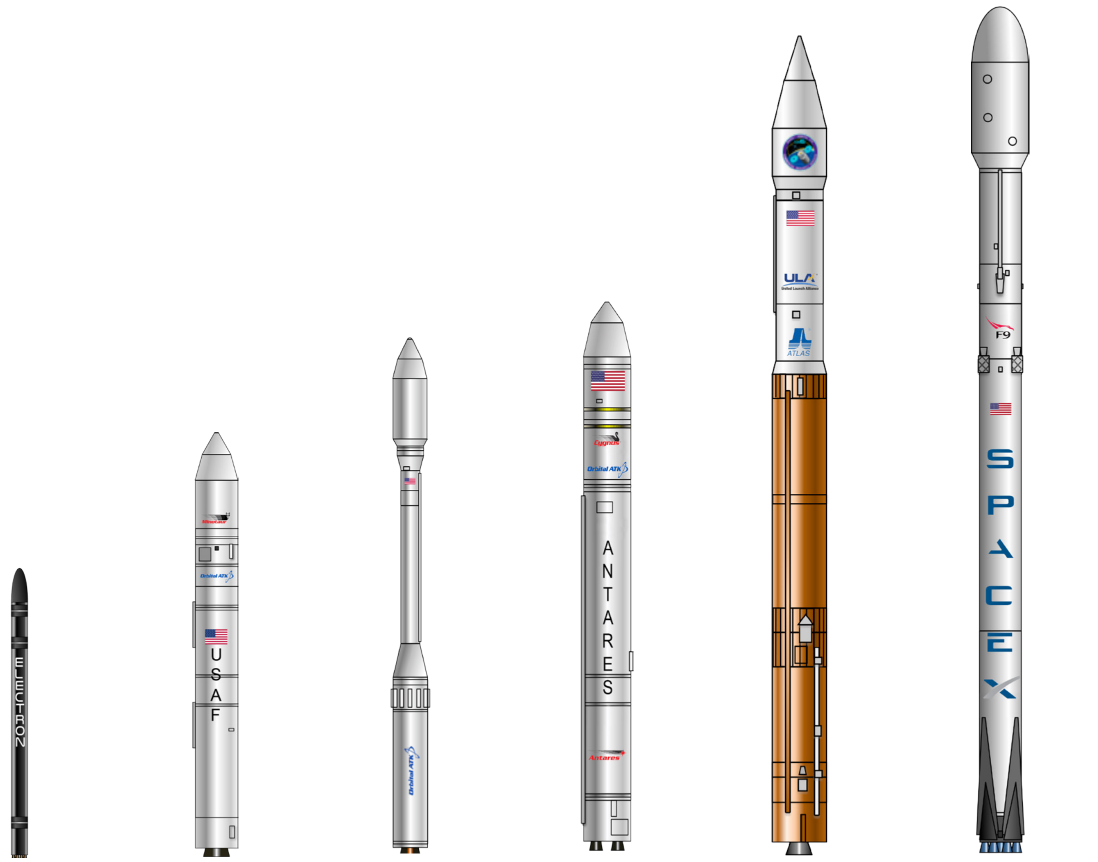
FAA AST 2017 REENTRY LICENSE SUMMARY

There were three reentries conducted under an FAA AST reentry license in 2017. Though four SpaceX Dragon spacecraft were launched during the year, only three had returned. The fourth, launched in December, remained docked to the ISS through the end of 2017.

FAA AST 2017 SUBORBITAL LAUNCH SUMMARY

One suborbital launch was conducted under an FAA AST license. Blue Origin successfully launched its third New Shepard vehicle on December 12, 2017 from the company's launch site in Texas.

No suborbital launch activity took place under an FAA AST Experimental Permit during 2017.



Vehicle	Electron	Minotaur IV	Minotaur C	Antares	Atlas V	Falcon 9 FT
2017 Total Launches	1	1	1	1	6	18
2017 Licensed Launches	1	1	1	1	1	17
Launch Reliability (2017)	0/1 0%	1/1 100%	1/1 100%	1/1 100%	6/6 100%	17/17 100%
Launch Reliability (Last 10 Years)	0/1 0%	4/4 100%	10/10 100%	6/7 86%	74/74 100%	45/46 98%
Year of First Launch*	2017	2010	1994*	2013	2002	2010**
Active Launch Sites	Mahia	CCAFS, VAFB, MARS, PSCA	CCAFS, VAFB, MARS, PSCA	MARS	CCAFS, VAFB	CCAFS, VAFB
LEO kg (lbs)	150 (331)	1,600 (3,527)	1,458 (3,214)	6,200-6,600 (13,669-14,551)	8,123-18,814 (17,908-41,478)	22,800 (50,265)
GTO kg (lbs)	N/A	N/A	N/A	N/A	2,690-8,900 (5,930-19,621)	8,300 (18,300)

** The Minotaur C is an upgraded variant of the Taurus vehicle introduced in 1994.*
*** Reliability figures are for the Falcon family.*

Table 10. U.S. and FAA AST-licensed launch vehicles active in 2017.

An Atlas V 401 provided by United Launch Alliance stands ready to send an Orbital ATK Cygnus from Cape Canaveral AFS to the International Space Station in April 2017. *Source: ULA.*

2018 COMMERCIAL SPACE TRANSPORTATION FORECAST

EXECUTIVE SUMMARY

The Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST) has prepared this forecast of global demand for commercial space launch services in 2018 through 2027.

This forecast addresses demand for commercial orbital launch of payloads in five industry segments, defined by the spacecraft type of service provided by such payloads:

- Commercial Telecommunications
- Commercial Remote Sensing
- Commercial Cargo and Crew Transportation Services
- Other Commercially Launched Satellites
- Launch Vehicle Test and Demonstration (previously Technology Test and Demonstration)

The commercial telecommunications segment includes payloads launched to geosynchronous orbit (GSO) and non-geosynchronous orbits (NGSO). All other segments include payloads launched to NGSO, such as low Earth orbit (LEO), medium Earth orbit (MEO), elliptical (ELI) orbits, and external (EXT) trajectories beyond orbits around the Earth.

The forecast projects an average of 42.3 commercial launches per year for 2018 through 2027 for all commercial launch industry segments.

By orbital destination, the projection is 18 commercial GSO launches per year and 24.3 NGSO launches per year for 2018 through 2027. Table 11 shows the number of payloads and launches projected from 2018 through 2027, by industry segment and by orbital destination.

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	Total	Avg.
Payloads												
GSO Forecast	28	23	23	20	21	20	20	20	20	20	215	21.5
NGSO Forecast	341	397	339	305	256	253	260	242	243	210	2,846	284.6
Total Payloads	***369***	***420***	***362***	***325***	***277***	***273***	***280***	***262***	***263***	***230***	***3,061***	***306.1***
Launches												
GSO Medium-to-Heavy	21	19	19	17	17	18	16	17	18	18	180	18
NGSO Medium-to-Heavy	17	18	18	15	15	15	16	13	14	12	153	15.3
NGSO Small	14	13	14	8	7	8	8	6	6	6	90	9
Total Launches	***52***	***50***	***51***	***40***	***39***	***41***	***40***	***36***	***38***	***36***	***423***	***42.3***

Table 11. Commercial space transportation payload and launch forecast.

Figure 9 shows the total historical commercial launches and commercial launch forecast. Figure 10 and Figure 11 break the launches down by industry segment and by orbital destination respectively.

It is important to distinguish between forecast demand and the number of satellites actually launched. Launch vehicle and satellite programs are complex and susceptible to delays, which generally makes the forecast demand for launches the upper limit of actual launches in the near-term forecast.

The market demand for launches to GSO is projected at an average of 21.5 satellites per year. Figure 12 shows the GSO forecast. An annual average of

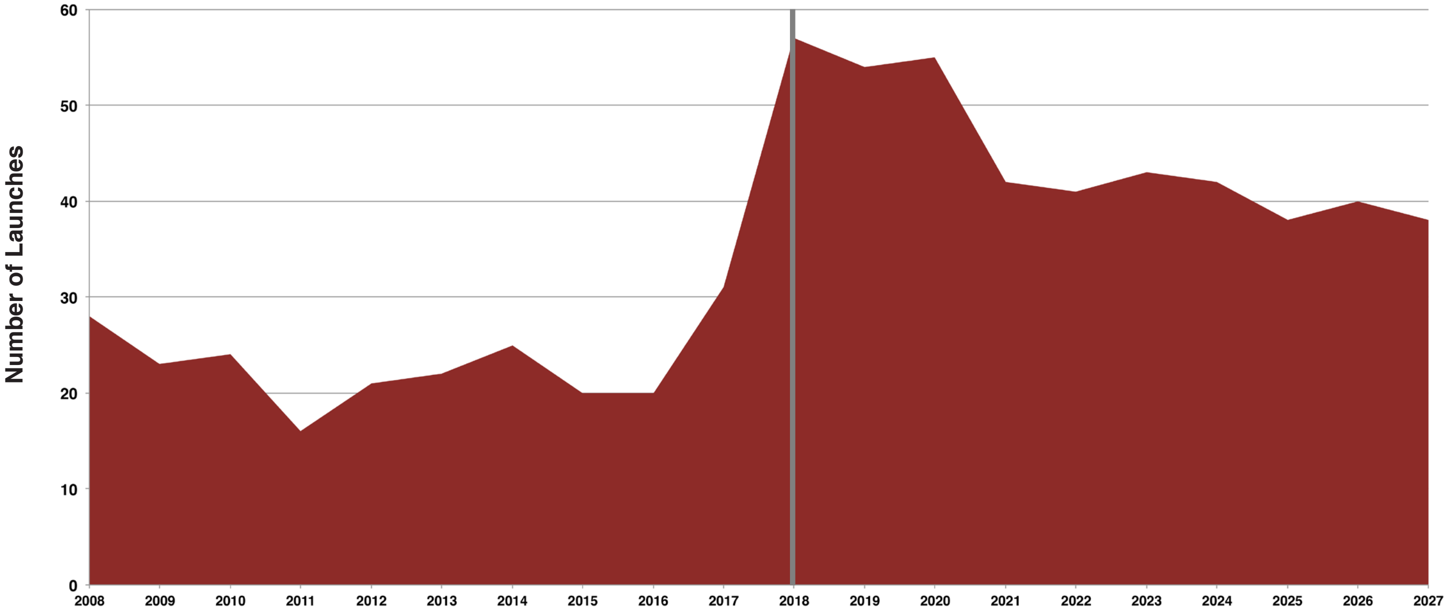


Figure 9. Historical and projected commercial orbital launches.

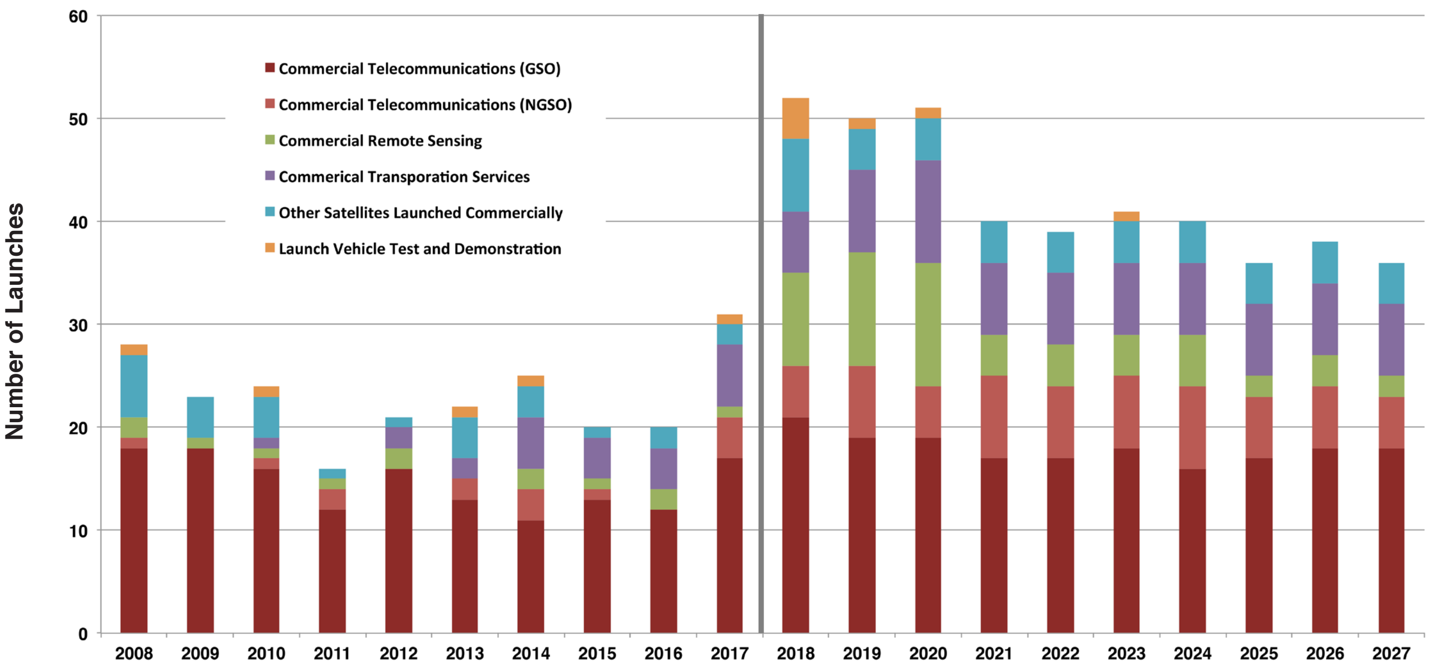


Figure 10. Historical and projected commercial orbital launches by industry segment.

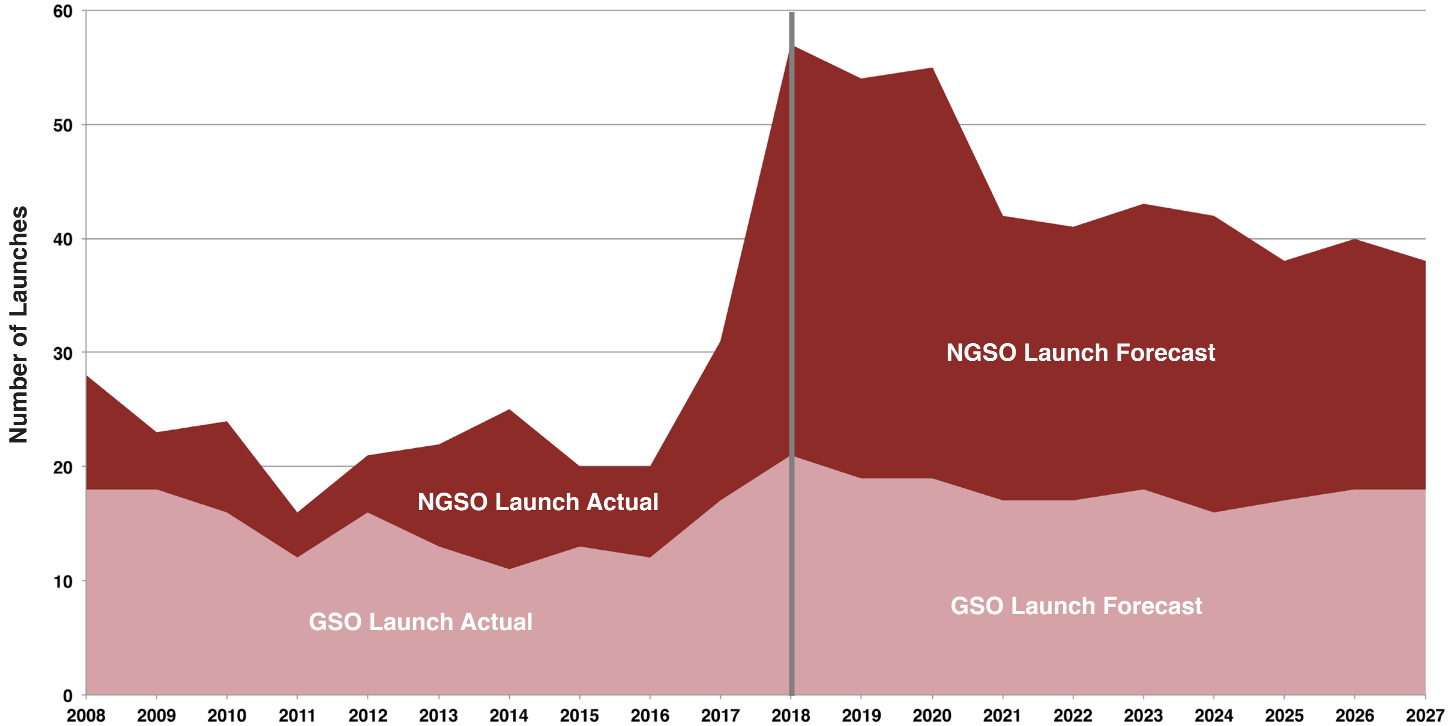


Figure 11. Historical and projected commercial orbital launches by orbital destination.

11.6 of the GSO satellites projected to launch from 2018 to 2027 are in the heaviest mass class (above 5,400 kg, or 11,905 lb). At the same time, 10 percent (or 2.1 per year) of the satellites in the same period are in the lowest mass class (below 2,500 kg, or 5,512 lb). In 2017, unaddressable launches, or launch contracts that are not open to international (including U.S.) competition, accounted for four launches (compared to three in 2016). However, the annual

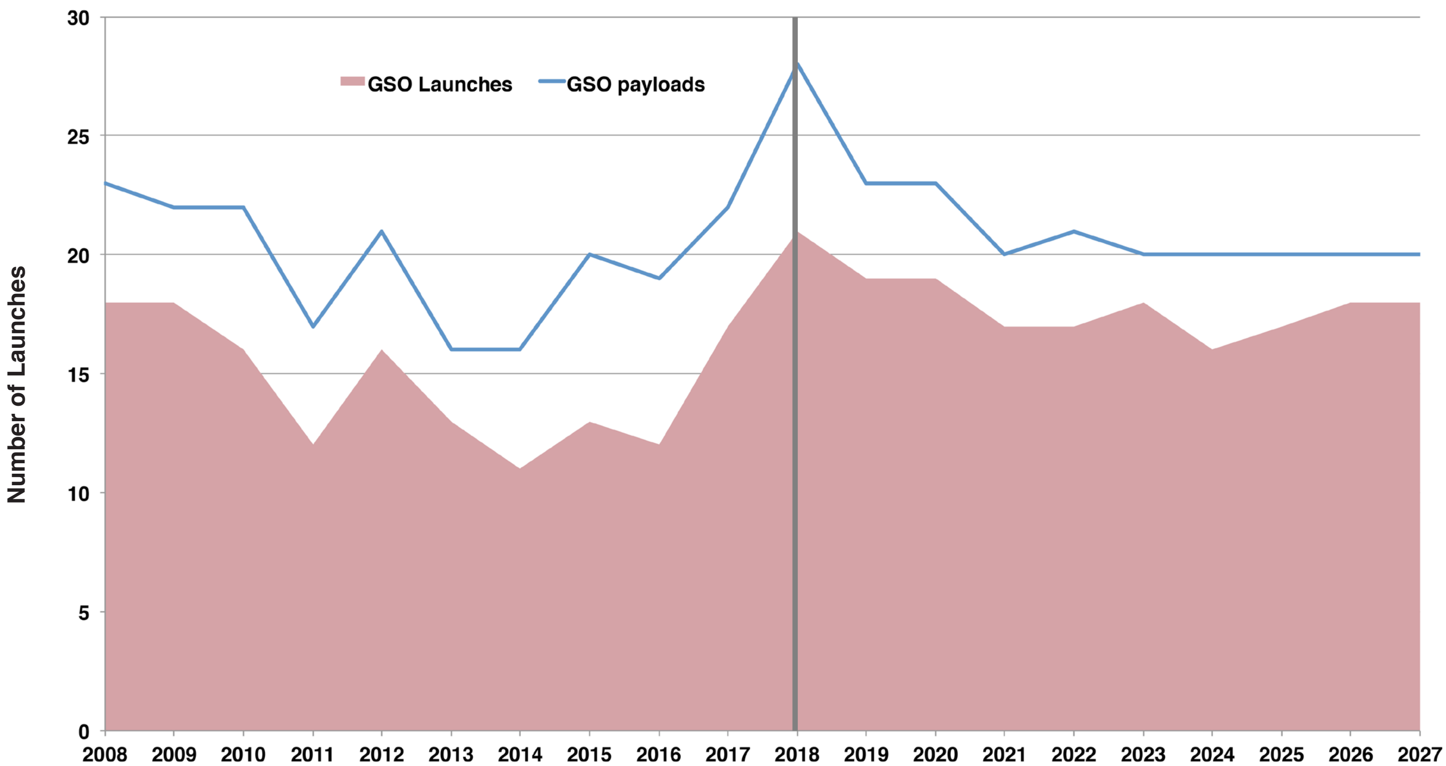


Figure 12. GSO historical launches and launch forecast.

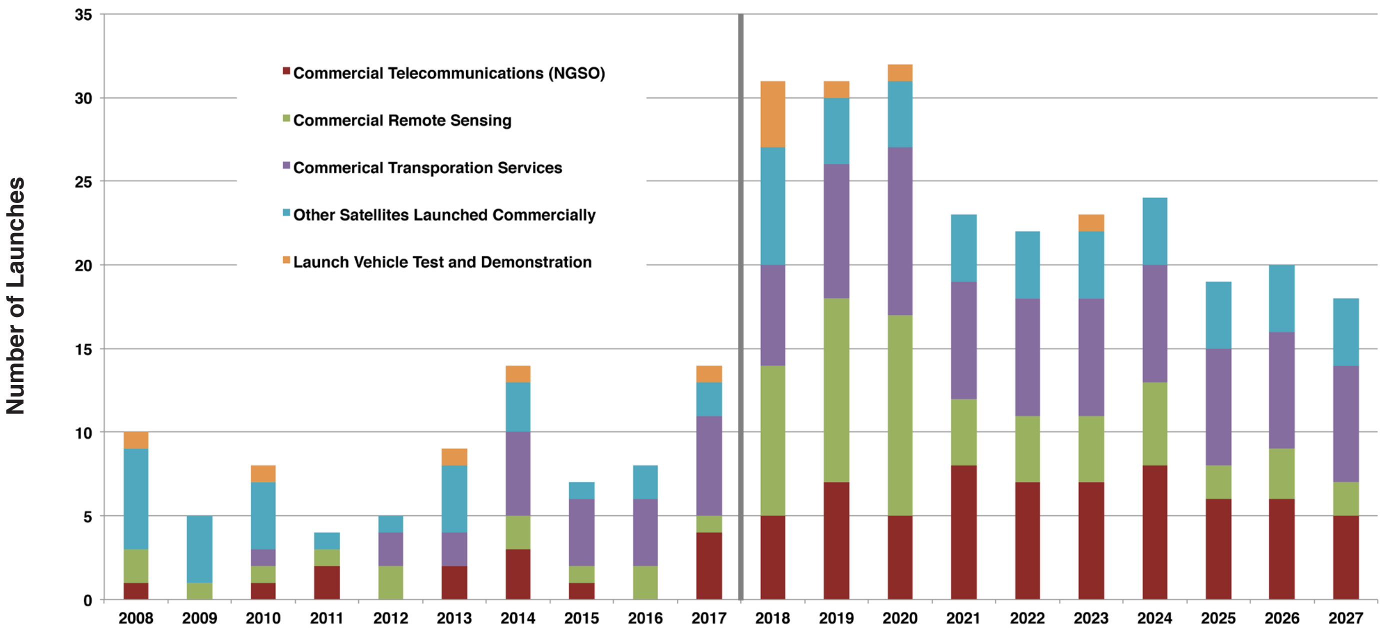


Figure 13. NGSO historical launches and launch forecast.

number of unaddressable launches is projected to increase during the forecast period as Chinese and Russian government-owned aerospace companies routinely package satellites, launches, and financing together. The satellite services market is generally robust, and new launch vehicle options will affect the dynamics of the launch industry. Operators are cautious about the impact of the economy on their plans but are generally satisfied with satellite and launch vehicle offerings.

The demand for commercial NGSO launches is expected to be at a comparably high level as major NGSO telecommunication constellations are being planned and existing ones are replenished. Additionally, the regular cadence of commercial crew and cargo resupply missions to the ISS also keep NGSO launch levels high. The annual average of NGSO commercial launches is expected to grow from 8.4 launches a year over the last ten years to about 27 launches annually.

From 2018 to 2027, 2,846 payloads are projected to launch commercially, driving 243 launches factoring in multi-manifesting. This projection reflects an industry planning to launch more small and very small (mini-, micro-, and nano-class) payloads in clusters, instead of increasing the demand for individual launches. Figure 13 shows the historical and projected NGSO launches. Launches taking place during the 10-year period are predominantly commercial resupply and crew missions to the ISS and for commercial satellite remote sensing and telecommunication deployments, which require medium-to-heavy vehicles. Sixty-eight percent of all commercial NGSO launches during the forecast period are missions launched by medium-to-heavy vehicles. The slightly higher number of small launches is due to the use of newly introduced small launch vehicles beginning in 2018.

The report that follows provides detailed information on the commercial orbital launch market segments.

METHODOLOGY

This forecast is based on FAA AST research and discussions with the U.S. commercial space industry, including satellite service providers, spacecraft manufacturers, launch service providers, system operators, government offices, and independent analysts. The forecast examines progress for publicly announced payloads (satellites, space vehicles, and other spacecraft) and considers the following factors:

- Publicly announced payload manufacturing and launch services contracts,
- Projected planned and replenishment missions,
- Growth in demand from new and existing services and applications,
- Availability of financing and insurance,
- Potential consolidation among operators,
- New launch vehicle capabilities,
- Hosted payload opportunities,
- Regulatory developments,
- Overall economic conditions and investor confidence, and
- Competition from space and terrestrial sectors.

This report includes five payload segments, defined by the type of service the spacecraft offer:

- Commercial Telecommunications
- Commercial Remote Sensing
- Commercial Cargo and Crew Transportation Service
- Other Commercially Launched Satellites
- Launch Vehicle Test and Demonstration (previously Technology Test and Demonstration)

Future deployments of payloads that have not yet been announced are projected based on market trends, the status of payloads currently on orbit, and the economic conditions of potential payload developers and operators. Follow-on systems and replacement satellites for existing systems are evaluated on a case-by-case basis. In some cases, expected future activity is beyond the timeframe of the forecast or is not known with enough certainty to merit inclusion in the forecast model. For the Other Commercially Launched Satellites market, the forecast used near-term primary payloads generating individual commercial launches in the model and estimated future years based on historical and near-term activity. The projected launches for commercial cargo and crew transportation services are based on the National Aeronautics and Space Administration (NASA) ISS traffic model and manifested launches for cargo and human spaceflight.

The forecast is updated annually, using inputs from commercial satellite operators, satellite manufacturers and launch service providers.

The methodology for developing the forecast has remained consistent throughout its history. The Forecast Team, through FAA AST, requests projections of satellites to be launched over the next 10 years from global satellite operators, satellite manufacturers, and launch service providers. The provided projections include the organizations' launch plans as well as a broad, industry-wide estimate of total launches. In addition, input is sought on a variety of factors that might affect satellite and launch demand.

COMMERCIAL TELECOMMUNICATIONS SATELLITES

The telecommunications satellite market consists of medium-to-heavy communications satellites providing Fixed Satellite Service (FSS) as well as Direct-to-Home (DTH) and Digital Radio (DARS) broadcast service. The market also contains GSO and large NGSO constellations of small-to-medium-sized satellites that provide FSS and Mobile Satellite Service (MSS) with global or near-global communications coverage.

GSO Commercial Telecommunications Satellite Launch Demand Projection

The GSO forecast projects global demand for commercial GSO satellites and launches addressable by the U.S. space launch industry—that is, launches open to internationally competitive (including U.S.) launch service procurement. The report provides analysis of satellites scheduled for launch in the next three years and a broader forecast of launch demand for the subsequent seven years. The production cycle for today's satellites is typically two to three years, but it can be longer for heavier or more complex satellites. Orders within a two- to three-year horizon are thus generally reliable. Satellite orders more than three years out can be difficult to identify, as many of these programs are in early stages of planning or procurement. Beyond five years, new markets and new uses of satellite technology may emerge that are currently unanticipated.

Both satellite and launch demand projections are included in this report. The satellite demand is a forecast of the number of addressable commercial GSO satellites that operators expect will be launched. The launch demand is determined by the number of addressable satellites to be launched adjusted by the number of satellites projected to be launched together on a single launch vehicle, referred to in the report as "dual-manifest" launches.

Figure 14 provides a summary of the forecast, showing annual projected satellites and launches. Table 12 provides the corresponding values, including the projected number of dual-manifested launches.

The key findings in the GSO forecast follow below:

- The forecast projects 28 addressable commercial GSO satellites on 21 launches in 2018
- There is an annual average of 21.5 satellites on 18 launches for the period from 2018 through 2027.
- The average number of satellites to be launched during the next three years is 25, an increase from the average of 20 for the period 2015-2017.

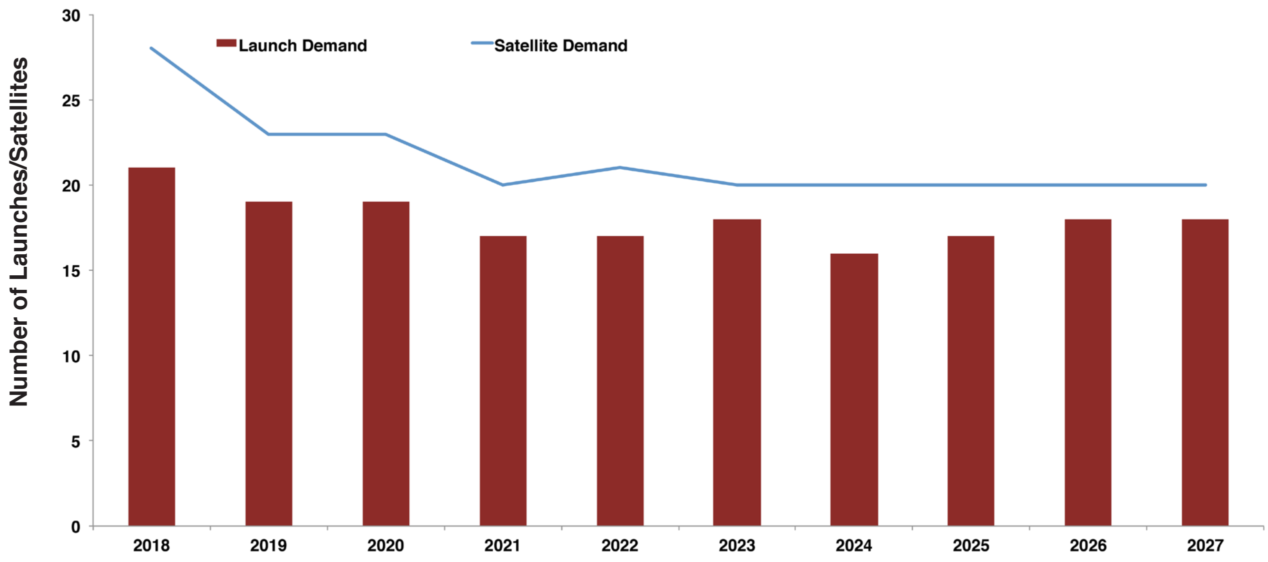


Figure 14. Forecast commercial GSO satellite and launch demand.

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	Total	Average
Satellite Demand	28	23	23	20	21	20	20	20	20	20	215	21.5
Launch Demand	21	19	19	17	17	18	16	17	18	18	180	18
Dual Launch Demand	7	4	4	3	4	2	4	3	2	2	35	3.5

Table 12. Forecast commercial GSO satellite and launch demand.

The number of launches is also projected to increase, from an average of 14 during 2015-2017 to 20 during 2018-2020.

- The emerging satellite servicing market will begin to play a significant role beginning in 2018, and new launch vehicle options have altered the dynamics of the launch industry.

It is important to distinguish between forecast demand and the number of satellites that are actually launched. Satellite programs are susceptible to delays, so the forecast demand is an upper limit on the number of satellites that may actually be launched. To account for these differences, the forecast team developed a "launch realization factor." This factor is based on historical data comparing actual satellites launched with predicted satellite demand from previous reports. This factor is then applied to the near-term forecast to provide a range of satellites reasonably expected to be launched. For example, while 28 satellites are projected to be launched in 2018, applying the realization factor adjusts this to a range of 24 to 26 satellites.

Addressable versus Unaddressable

To clarify which launch opportunities can be "addressed" by U.S. launch providers, satellite launches are classified as either "addressable" or "unaddressable." Addressable, in the context of this report, is defined as commercial GSO satellite launches that are open to an internationally competitive (including U.S.) launch service procurement process. Satellites and launches bundled in government-to-government deals, launches captive to particular launch service providers, and others that are not internationally competed are classified as unaddressable.

The number of unaddressable launches has been substantial over the years, as Chinese, Indian, and Russian government-owned or -supported aerospace organizations continue packaging satellites, launches, financing and insurance for commercial satellites on a strategic, non-competitive basis. Figure 15 and Table 13 compare the numbers of addressable and unaddressable satellites since 2008.

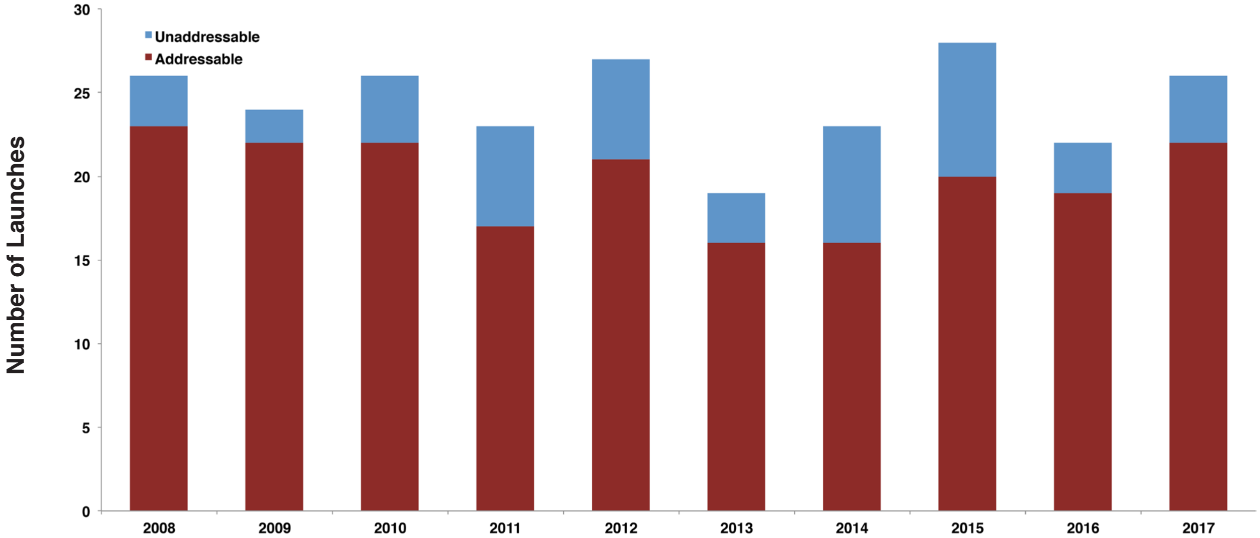


Figure 15. Addressable and unaddressable satellites since 2008.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	Average
Addressable	23	22	22	17	21	16	16	20	19	22	198	19.8
Unaddressable	3	2	4	6	6	3	7	8	3	4	46	4.6
Total	***26***	***24***	***26***	***23***	***27***	***19***	***23***	***28***	***22***	***26***	***244***	***24.4***

Table 13. Addressable and unaddressable satellites since 2008.

GSO Commercial Telecommunication Satellite Mass Classes

One of the primary metrics for determining launch requirements is satellite mass. Mass classes based on ranges of satellite masses are used to analyze developments in satellite and launch demand. Four mass classes are currently used, as shown in Table 14.

The upper limit of the smallest mass class was increased in 2008 from 2,200 kg (4,850 lb) to 2,500 kg (5,512 lb). This adjustment captured the growth in mass of the smallest commercial GSO satellites being manufactured. As an example, Orbital's GEOStar 2 bus, which dominated the lower end of the mass scale in previous years, has recently been used for satellites in excess of 3,200 kg (7,055 lb), which fall in the intermediate mass class range. Unaddressable launches in this smallest class abound, with one to four medium class satellites being launched in most years.

One technical development that has affected the trend towards increasing satellite mass is the development of satellites using electric propulsion rather

Class	Separated Mass	Representative Satellite Bus Models
Medium	Below 2,500 kg (<5,510 lb)	Lockheed Martin A-2100, Orbital GEOStar, Boeing BSS-702, SSL-1300
Intermediate	2,500 - 4,200 kg (5,510 - 9,260 lb)	A-2100, IAI Amos, MELCO DS-2000, GEOStar, SSL-1300, Thales SB-4000
Heavy	4,200 - 5,400 kg (9,260 - 11,905 lb)	Astrium ES-3000, BSS-702, IAI Amos, A-2100, DS-2000, GEOStar, SSL-1300, SB-4000
Extra Heavy	Above 5,400 kg (>11,905 lb)	ES-3000, BSS-702, A-2100, SSL-1300, SB-4000

Table 14. GSO satellite mass class categorization.

than chemical propulsion (such as liquid apogee motors) for orbit-raising. By reducing the mass of propellant used for orbit-raising, which in many cases is greater than the dry mass of the satellite, the satellite can carry a significantly larger payload. Alternatively, by keeping the satellite mass low, two satellites, each with the payload capacity of a large satellite, can be launched together.

The heaviest mass class continues to dominate, with 54 percent of satellites launched in 2017 falling into this mass class.

Table 15 and Figure 16 show the total mass launched per year and the average mass per satellite launched. The total mass launched per year correlates with the number of satellites launched per year. The average mass of satellites launched in the past ten years was 4,596 kg (9,846 lb), reaching a new high of over 5,000 kg (11,023 lb) in 2013. The average mass in 2018–2020 is expected to be just over 5,000 kg (11,023 lb) range. Figure 17 and Table 16 show the trends in satellite mass class distribution.

	Actual										Forecast	
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Mass Launched per Year (kg)	99,692	94,921	85,724	72,068	103,499	80,921	74,752	87,363	91,929	108,198	137,010	118,460
Average Mass per Satellite (kg)	4,334	4,315	4,286	4,239	4,929	5,058	4,672	4,368	4,838	4,918	4,893	5,150

Table 15. Total satellite mass launched per year and average mass per satellite.

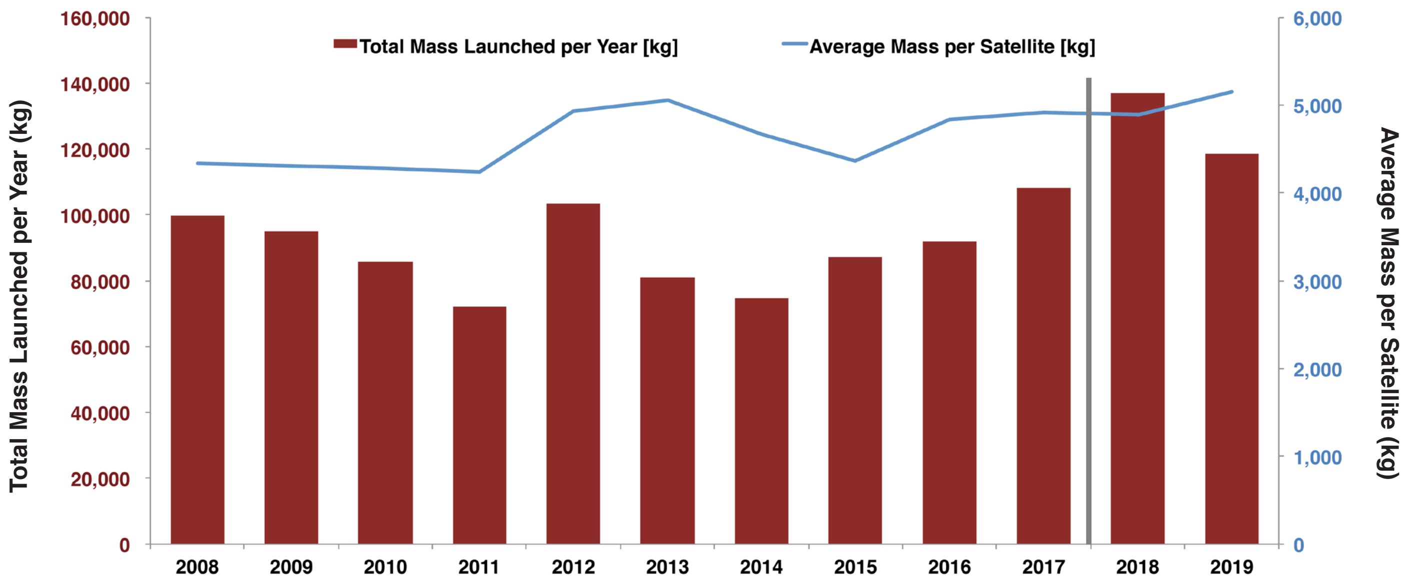


Figure 16. Total Satellite Mass Launched per Year and Average Mass per Satellite

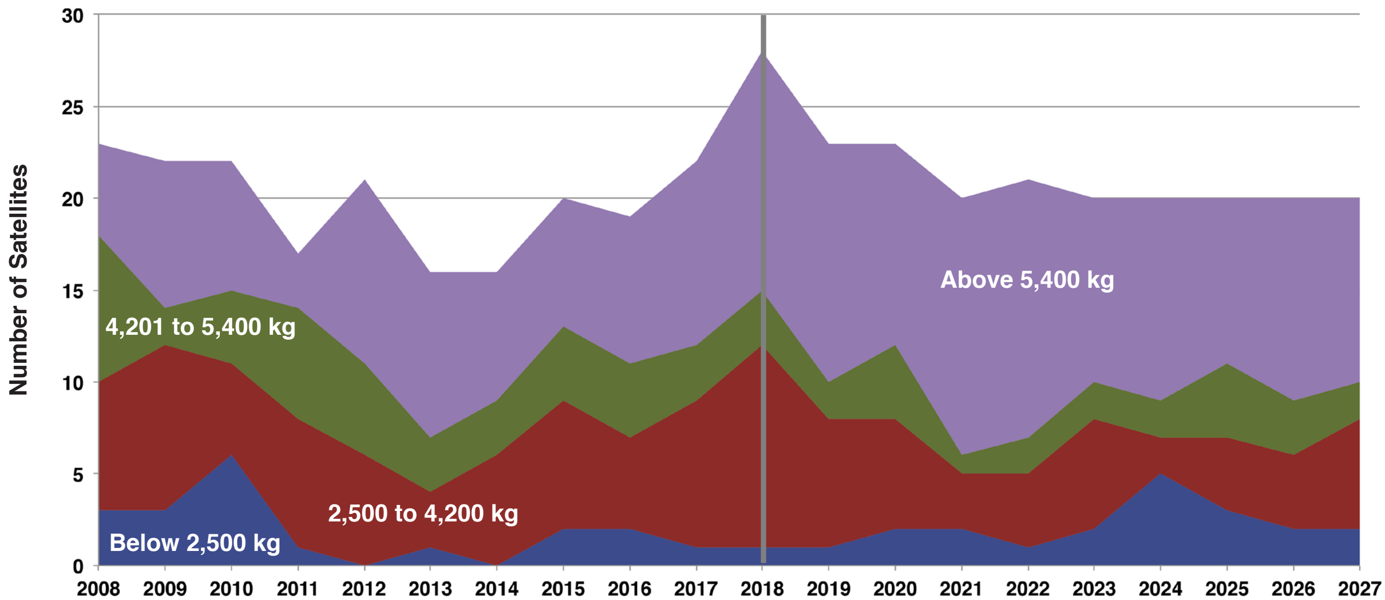


Figure 17. Trends in satellite mass class distribution.

	Actual										Forecast										Total 2018 to 2027	Avg. 2018 to 2027	% of Total 2018 to 2027
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027			
Above 5,400 kg	5	8	7	3	10	9	7	7	8	10	13	13	11	14	14	10	11	9	11	10	116	11.6	54%
4,201 - 5,400 kg	8	2	4	6	5	3	3	4	4	3	3	2	4	1	2	2	2	4	3	2	25	2.5	12%
2,500 - 4,200 kg	7	9	5	7	6	3	6	7	5	8	11	7	6	3	4	6	2	4	4	6	53	5.3	25%
Below 2,500 kg	3	3	6	1	0	1	0	2	2	1	1	1	2	2	1	2	5	3	2	2	21	2.1	10%
Total	***23***	***22***	***22***	***17***	***21***	***16***	***16***	***20***	***19***	***22***	***28***	***23***	***23***	***20***	***21***	***20***	***20***	***20***	***20***	***20***	***215***	***21.5***	***100%***

Table 16. Trends in satellite mass class distribution.

Dual-Manifesting of GSO Commercial Telecommunications Satellites

Several launch services providers are capable of lofting two satellites simultaneously into geosynchronous transfer orbit (GTO). Demand analysis for launch vehicles must take this capability into consideration and carefully include launch vehicles based upon the addressability of each of the satellites flown. A launch vehicle such as Ariane 5 or Falcon 9, which has the launch services competitively procured for both satellites, is included in the forecast and counted as a dual manifested launch. A vehicle such as Proton, which may have only one of the two satellite launch services contracts competitively procured, is also included in the forecast, but counted as a single launch. Proton has flown several dual launches, but typically one spacecraft is a Russian domestic or government satellite. A Proton that launches two Russian domestic satellites is not counted in the forecast, as these satellites are not open for competition to launch services providers. Such Russian, Chinese, and Indian launches flying on domestic launch vehicles are counted in the non-addressable market.

Dual-manifesting of two communications satellites in the 5,000+ kg (11,023+ lb) Heavy and/or Extra Heavy mass classes is not yet available. Arianespace typically attempts to match satellites that together have a total effective mass of up to 10,500 kg (23,149 lb). Arianespace has terminated its plans for a Mid-Life Evolution upgrade, which would have been capable of carrying two 5,000 kg (11,023 lb) satellites, in favor of developing Ariane 6 for debut in 2020–2021. The larger Ariane 6 configuration with up to four solid rocket boosters will have a 10,500 kg (23,149 lb) GTO capacity. ILS plans to phase out Proton and replace it with Angara A5 by 2020. Angara A5 may carry up to 7,500 kg (16,535 lb) to GTO and will likely be used to fly two small satellites directly into GSO, as Proton does now. The debut of the Falcon Heavy launch vehicle in 2018, with 26,700 kg (58,860 lb) capability to GTO, may also permit dual manifesting of large satellites in the future.

From a spacecraft technology development perspective, however, the introduction of electric propulsion technology may reverse the growth trend in overall satellite mass, thus enabling more dual manifesting on existing launch vehicles.

Figure 18 shows the single- and dual-manifest satellite and launch demand forecast from 2018 through 2027 and the actual launch statistics from 2008 through 2017. After the next three years, the number of addressable dual manifest launches will likely stabilize, with the transition to new and replacement launch vehicles and more options of single manifest launch at a comparable price. However, if dual manifest launches on such new vehicles as Angara A5 and Falcon Heavy proves a reliable and more economical option, this number may increase.

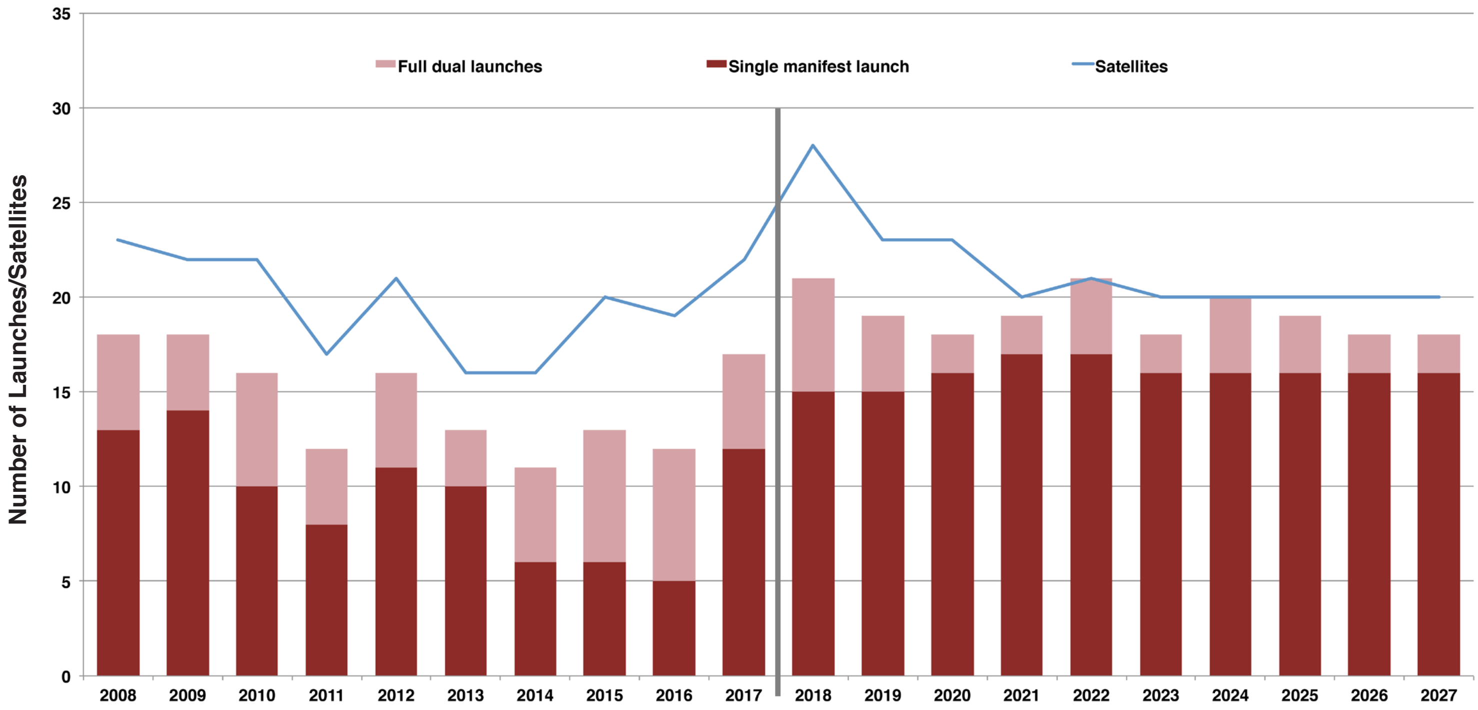


Figure 18. Dual manifesting and launch demand. "Full dual launches" includes only launches carrying two commercial satellites.

Near-Term Demand Forecast of GSO Commercial Telecommunications Satellites

Table 17 shows the GSO satellites projected to be launched in the next three years. The projections for 2018 to 2020 show an increase in the number of satellites to be launched over the previous three years (2015–2017). One has to keep in mind, that this increase is at least partially due to a significant number of satellites delayed from the previous year, so some of the satellites originally scheduled for 2018 may be launched in the following year(s) while the launch industry is making up for the down time after several launch incidents.

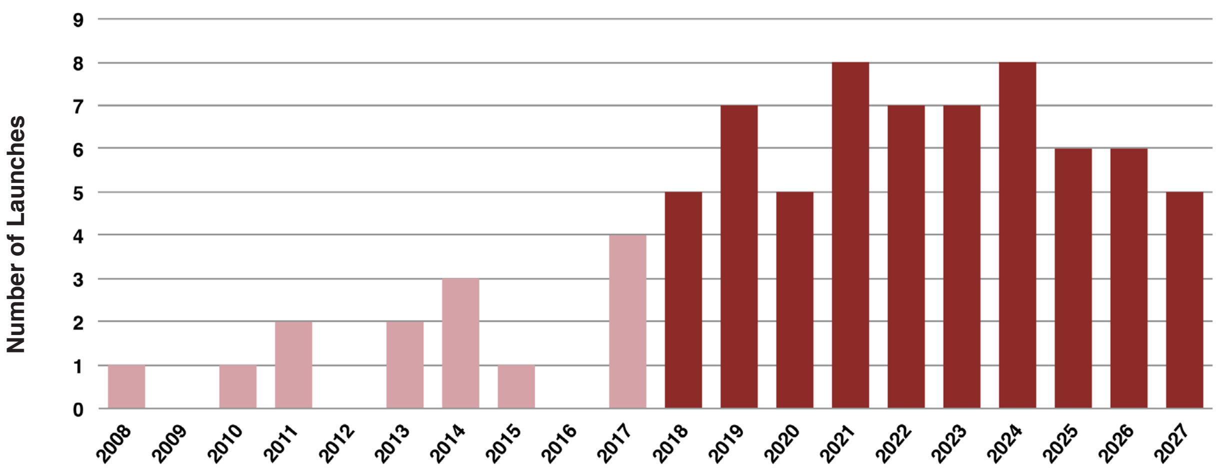
	2018			2019			2020		
Total Launches	**21**			**19**			**19**		
Total Satellites	**28**			**23**			**23**		
Below 2,500 kg	**1**			**1**			**1**		
	DM	MEV 1	Proton M	DM	MEV 2	TBD	DM	ABS 8	TBD
2,500 - 4,200 kg	**11**			**7**			**5**		
	DM	Al Yah 3	Ariane 5		BSAT 4B	TBD	DM	Al Yah 4	TBD
	DM	AzerSpace 2 (Intelsat 38)	Ariane 5	DM	Eutelsat BB4A	Ariane 5		Eutelsat HB13E	TBD
		Bangabandhu BS 1	Falcon 9	DM	Eutelsat Quantum	Ariane 5		Optus 11	TBD
	DM	Eutelsat 5WB	Proton M	DM	GEO Kompsat GK2B	Ariane 5		Turksat 5A	TBD
	DM	Eutelsat 7C	Ariane 5	DM	Inmarsat 5F5	Ariane 5		Turksat 5B	TBD
	DM	GEO Kompsat GK2A	Ariane 5		Thor 8	TBD			
	DM	GSAT 21	Ariane 5		Turksat 6A	TBD			
	DM	HYLAS 4	Ariane 5						
		MEASAT 2A	TBD						
		SES 16 (GovSat)	Falcon 9						
		Sky Mexico 2	TBD						
4,201 - 5,400 kg	**3**			**2**			**3**		
	DM	DSN 1 (JCSAT SB 8)	Ariane 5		Es'Hail 2	Falcon 9		Es'Hail 3	TBD
	DM	SES 12	Ariane 5		NileSat 301	TBD		Mexico Broadband	TBD
		SES 14 + GOLD	Falcon 9					Paksat 2	TBD
Above 5,400 kg	**13**			**13**			**14**		
	DM	Arabsat 6A	Falcon Heavy		Amos 17	Falcon 9		Arabsat 6D	TBD
		DirecTV 16	Ariane 5		Arabsat 6C	TBD		DirecTV 18	TBD
		EchoStar XX	Falcon 9		DirecTV 17	TBD		Eutelsat 12WB	TBD
	DM	GSAT 11	Ariane 5		Eutelsat 48E	TBD	DM	Eutelsat 7WB	TBD
	DM	HellasSat 4 (SaudiGEOSat 1)	Ariane 5		Eutelsat 69WA	TBD		Inmarsat 6F1	TBD
		Hispasat 30W 6 1F + PODS	Falcon 9		GISAT	Falcon 9		Intelsat 10-02RE	TBD
	DM	Intelsat 39	Ariane 5	DM	Horizons 3E	Ariane 5	DM	Satcomhan 1	TBD
		KMILCOMSAT	TBD		Intelsat 906RE	TBD		Sirius SXM 8	TBD
		PSN 6	Falcon 9	DM	JCSAT 17	Ariane 5		Sky Brazil 2	TBD
		Silkwave 1	TBD		JCSAT 18 (Kasific)	Falcon 9	DM	Skynet 5E	TBD
		Telkom 4	TBD		Silkwave 2	TBD		Skyterra 2	Proton M
		Telstar 18V (Apstar 5C)	Falcon 9		Sirius SXM 7	Falcon 9		Telstar 20V	TBD
		Telstar 19V	Falcon 9	DM	Star One D2	Ariane 5	DM	Viasat 3 Americas	Ariane 5
								Viasat 3 EMEA	Falcon Heavy

DM = Potential Dual-Manifested Satellites

Table 17. Commercial GSO satellite near-term manifest.

NGSO Commercial Telecommunications Satellite Launch Demand Projection

From 2018 through 2027, an average of 6.4 launches of NGSO telecommunications satellites will occur each year, dominated by deployment of Iridium NEXT and OneWeb satellite constellations. Iridium NEXT intends to finish the replacement of its existing constellation by early 2018, deploying its new satellites on seven Falcon 9 launch vehicles. OneWeb will continue to deploy its 700+ satellite constellation on Soyuz 2 and LauncherOne vehicles for the much of the 10-year forecast period. Figure 19 provides a representation of telecommunications launch history and projected launch plans.



2018	2019	2020	2021
Iridium NEXT (10) - Falcon 9	Iridium NEXT (2) - Falcon 9	OneWeb (2) - LauncherOne	Globalstar (6) - Soyuz
Iridium NEXT (10) - Falcon 9	O3b (4) - Soyuz	OneWeb (2) - LauncherOne	O3b (2) - Soyuz
Iridium NEXT (10) - Falcon 9	OneWeb (32) - Soyuz	OneWeb (32) - Soyuz	OneWeb (2) - LauncherOne
O3b (4) - Soyuz	OneWeb (32) - Soyuz	OneWeb (32) - Soyuz	OneWeb (2) - LauncherOne
OneWeb (10) - Soyuz	OneWeb (32) - Soyuz	OneWeb (32) - Soyuz	OneWeb (2) - LauncherOne
	LeoSat (2) - TBD		OneWeb (32) - Soyuz
	Spacebelt (1) - LauncherOne		OneWeb (32) - Soyuz
			OneWeb (32) - Soyuz

Figure 19. Commercial telecommunications launch history and projected launch plans.

Narrowband NGSO Telecommunications Systems (M2M and AIS Services)

Narrowband LEO systems (Table 9) operate at frequencies below one gigahertz (GHz) and primarily provide Machine-to-Machine (M2M) and Automatic Identification System (AIS) telecommunications services. These systems also provide narrowband data communications, such as email; two-way paging; and simple messaging for automated meter reading, vehicle fleet tracking, and other remote data monitoring applications.

System/ Operator	Prime Contractor	Satellites In Orbit	Satellites Mass (kg)	Orbit	First Launch	Status
ORBCOMM/ ORBCOMM Inc.	Orbital (1st Gen.) LuxSpace (Vesselsat) SNC (2nd Gen.)	93	43 (1st Gen) 29 (Vesselsat) 142 (OG2)	LEO	1997	Second generation (OG2) satellites fully deployed
AprizeStar/ ExactView	SpaceQuest	10	10	LEO	2002	The company expects to continue launching satellites and, possibly hosted payloads depending on available funding and launch opportunities

Table 18. Narrowband systems.

Wideband NGSO Telecommunications Systems (MSS)

Wideband LEO systems (Table 19) use frequencies in the range of 1.6–2.5 GHz (L- and S-band frequencies). Wideband systems provide mobile voice telephony and data services. The two wideband systems Globalstar and Iridium are on orbit and operational.

Broadband NGSO Telecommunications Systems (FSS)

Broadband systems (Table 20) reside in LEO and MEO and provide high-speed data services at Ka- and Ku-band frequencies.

System/ Operator	Prime Contractor	Satellites In Orbit	Satellites Mass (kg)	Orbit	First Launch	Status
Globalstar	SS/Loral (1st Gen.) Thales Alenia Space (2nd Gen.)	46	447 (1st Gen.) 700 (2nd Gen.)	LEO	1998	Six additional satellites ordered from Thales Alenia Space in September 2012. No launch contract or tentative launch plans announced yet
Iridium	Motorola (Iridium) Thales Alenia Space (Iridium NEXT)	70	680 (Iridium) 800 (Iridium NEXT)	LEO	1997	Multiple launches of Iridium NEXT constellation to begin in 2017

Table 19. Wideband systems.

Globalstar

Globalstar, Inc. is a publicly traded wideband system operator primarily serving the commercial global satellite voice and data markets. Full service offering began in 2000.

Arianespace, through its Starsem affiliate, launched 24 Globalstar second generation satellites. The first six satellites were launched into orbit in 2010, the next 12 launched in 2011, and the remaining six in February 2013. All launches were from Baikonur, Kazakhstan on Soyuz rockets carrying six satellites per launch. Globalstar reported significant improvement in service availability, quality, and revenue after the new generation satellites came online.

System/ Operator	Prime Contractor	Satellites		Orbit	First Launch	Status
		In Orbit	Mass (kg)			
Operational						
O3b/O3b Networks Ltd.	Thales Alenia Space	12	700	MEO	2013	The first four satellites of the constellation launched in 2013. Eight more deployed in 2014. Four more satellites under construction by Thales Alenia Space, tentatively to launch in 2018
Planned						
OneWeb/ OneWeb LLC	Airbus Defense and Space	700+	~125	LEO	TBD	A joint venture between OneWeb and Airbus to manufacture the OneWeb satellites is building a factory in Florida
SpaceX constellation/ SpaceX	SpaceX	4,425	386	LEO	TBD	Multiple orbits with altitude from 1,110 km to 1,325 km and inclinations 53° – 81°

Table 20. Broadband systems.

Thales Alenia Space (TAS) developed and built the 25 second generation satellites (including one ground spare) for Globalstar. Together with the eight first generation replacement satellites launched in 2007, Globalstar has a 32-satellite system since the initial deployment of its new constellation concluded.

Globalstar reported it is in negotiations with TAS for an option of manufacturing 23 additional satellites in the coming years. The spacecraft would be spares for the existing fleet and launch as needed. An order for manufacturing of the first six was placed with TAS in September 2012. Currently, there is no launch contract for these additional satellites, and any launch would be contingent on the health of the satellites on orbit.

Globalstar's 2016 revenue was $96.9M, higher than in 2015 ($90.5M). Revenue data for 2017 has not yet been released publicly.

Iridium

Iridium Communications Inc. is the successor to the original Iridium LLC that built and launched the Iridium satellite constellation in the late 1990s. Iridium Communications Inc. owns and operates a constellation of 72 operational commercial communications satellites: 66 active spacecraft and 6 orbiting functional spares. In 2010, Iridium selected TAS as the prime contractor for the system development of a second generation satellite constellation, named Iridium NEXT. Each satellite in the new constellation can carry a hosted payload in addition to the primary communications payload.

SpaceX will be the primary launch provider for Iridium NEXT. The company plans to launch 72 satellites (66 to enter active service and 6 to serve as on-orbit spares), a process that began in 2017. Iridium revenue in 2016 was $433.6M, slightly up from $411.4M in 2015. Revenue data for 2017 has not yet been released publicly.

ORBCOMM

Between 1995 and 1999, ORBCOMM deployed a narrowband constellation of 35 satellites, most of which are still operational today. It is the only company to have fully deployed a system that provides low-bandwidth packet data services worldwide. ORBCOMM focuses on providing data services for M2M applications.

ORBCOMM's replacing of its current constellation has completed successfully. Six satellites of the second generation (OG2) constellation were launched aboard SpaceX's Falcon 9 in 2014. Eight more were launched, also by a Falcon 9, in 2015. All satellites in the constellation include automatic identification system (AIS) payloads. The OG2 satellites were built by Sierra Nevada Corporation (SNC), with subcontractors Boeing and ITT Corporation.

ORBCOMM revenues grew from $178.3M in 2015 to $186.7M in 2016. Revenue data for 2017 has not yet been released publicly.

Aprize Satellite

Aprize Satellite, Inc. has deployed a 12-satellite system and may add more depending on funding opportunities and customer demand for data communication and AIS data service. A total of 12 AprizeStar satellites weighing 10 kg (22 lb) each launched as secondary payloads on Russian Dnepr vehicles. These satellites were launched two a year in 2002, 2004, 2009, 2011, 2013, and 2014. The company may need to launch additional satellites, as well as any replacement satellites as existing satellites approach the end of their orbit life. Any additional satellites are likely to launch as secondary payloads and not generate demand for a launch. As of today, the Aprize satellites operate as part of a larger AIS satellite constellation ExactEarth, operated by ExactEarth Ltd. based in Cambridge, ON (Canada).

O3b

O3b Networks is headquartered in St. John, Jersey, Channel Islands and is a subsidiary of a major GSO satellite operator SES. It provides broadband FSS connectivity to underserved parts of the world.

The O3b constellation operates in the Ka-band in an equatorial orbit with a minimum of five satellites to cover +/-45° of latitude around the Equator.

Offering to bridge the gap between current satellites and fiber optic cables, O3b Networks provides fiber-like trunking capacity to telecommunications operators, backhaul directly to cellular and WiMAX towers, and connectivity to mobile and maritime clients, in partnership with Harris CapRock.

TAS is under contract to build 16 communications satellites for O3b, 12 of which have been successfully deployed. Four additional satellites are to be deployed in 2018.

In 2016, O3b filed an application with the FCC for a new 24-satellite O3bN constellation in the same MEO orbit. These are planned to be second generation O3b satellites and work as a separate network. To supplement the O3bN network, a 16-satellite O3bL constellation is proposed, in two orbital planes at 70° each. No launches have been scheduled for these planned new constellations.

Startup Broadband Ventures Planned for NGSO

Several entrepreneurs have announced plans to launch multi-satellite LEO broadband constellations and revolutionize the delivery of internet access to customers, especially in remote and underserved regions.

SpaceX submitted to international regulators the documentation for a 4,000-satellite broadband Internet LEO constellation, claimed to begin initial service within five years. In 2016, SpaceX followed up with an FCC application for a LEO constellation of 4,425 satellites in multiple orbital planes at various altitudes. The company's first two prototype satellites are expected to launch in 2018, designed to validate in-house technology ahead of an operational launch campaign in 2019. The constellation will be designed to provide continuous global internet coverage in both Ka- and Ku-band frequencies and use optical inter-satellite links. SpaceX stated it expected to deploy all of these satellites in 2019–2025, with no details on launch arrangements available.

OneWeb LLC, formerly called WorldVu Satellites, is developing a constellation of 650 to 900 125-kg (276-lb) satellites operating in LEO at 1,200 km (746 mi) altitude, each providing an eight Gbps Ku-band Internet access to residential and mobile customers. The satellites will be built by Airbus Defense and Space. OneWeb plans to start launching satellites in 2018 and achieve deployment of a functional initial constellation by 2019. OneWeb has contracts for 21 Soyuz 2 launches with Arianespace and 39 LauncherOne small launches with Virgin Orbit.

LeoSat, a company founded by former Schlumberger executives Cliff Anders and Phil Marlar, plans a constellation of 78 to 108 small high-throughput Ka-band satellites in six polar orbital planes in order to form a global fixed, maritime, and mobile Internet service provider. The company aims at offering initial service by 2019. It has selected European satellite manufacturer Thales Alenia Space to perform a one-year cost study of its planned LEO constellation and likely to manufacture the satellites, provided sufficient funding is available.

GEO satellite operators Telesat and Viasat also filed FCC applications for satellites in NGSO orbits. Telesat proposed a 117-satellite LEO constellation in ten (five polar and five at 37.4°) orbital planes to operate in Ka-band. Meanwhile, Viasat applied for a 24-satellite MEO constellation to complement its planned Viasat-3 global GSO system, operating in Ka-band and parts of V-band.

More filings from such jurisdictions as Canada, France, Liechtenstein, and Norway for similar LEO satellite constellations operating in different parts of the VHF-, UHF-, X-, Ku-, and Ka-band spectrum were recently made with the International Telecommunication Union (ITU). The ITU filings are made on behalf of countries, and the six applicant organizations from the four countries have not yet been disclosed.

Although at least two of the above satellite projects are backed by launch providers, all of them are currently in their initial planning and development phases. The launch schedule, number of launches, and number of spacecraft per launch may vary significantly depending on the final design of the spacecraft and the constellations. Also, any existing launch plans of any of these constellations may be delayed or significantly altered because of the frequency coordination procedures within the ITU and FCC. These procedures can potentially be problematic, especially concerning interference with the existing Ku- and Ka-band GEO satellite systems. Launches of these satellites have not been included in this forecast, while respective launch projections will be included in the future reports as these satellite system designs mature and firm launch plans are announced for them.

Telecommunications Satellite Fleet Replacement After 2027

NGSO telecommunications satellites launched in the 1990s and early 2000s had an estimated design life of four (ORBCOMM) to seven and a half (Globalstar) years (see Table 20). However, the majority of these satellites are still in orbit and continue to provide telecommunications services. For example, most of the first generation Globalstar, Iridium, and ORBCOMM constellations have exceeded their design life two to three times. For financial reasons, many of the satellites were not replaced when their estimated design life ended. Operators were able to continue providing services until second generation spacecraft were ready.

Now most of the satellites launched or prepared for launch by NGSO communications satellite operators have an estimated design life of up to 15 years, which places the estimated replacement dates beyond the time period covered by the forecast. The exception is ORBCOMM, with a minimum design life estimate of a conservative five years. If any of these satellites need to be replaced within the 2018–2027 period, they will likely be launched as piggyback payloads, unlikely to generate demand for a dedicated launch.

Satellite System	1st Generation Satellite Design Life	Current Status	2nd or Current Generation Satellite Design Life
Globalstar	7.5 years	Most of the satellites in orbit, operational	15 years
Iridium	5 years	Most of the satellites in orbit, operational	10 years (design), 15 years projected
ORBCOMM	4 years	Most of the satellites in orbit, operational	More than 5 years
Aprize Satellite	N/A	10 in orbit, 8 in service, launching more to complete system	10 years
O3b Network	N/A	Most of the satellites in orbit, operational	10 years

Table 20. Commercial telecommunications satellite systems' design life.

COMMERCIAL REMOTE SENSING SATELLITES

Remote sensing refers to any orbital platform with sensors trained on Earth to gather data across the electromagnetic spectrum for geographic analysis, military use, meteorology, climatology, or other uses. The remote sensing industry generally comprises three markets:

- Aerial imagery
- Satellite imagery
- Value-added services, including geographic information systems (GIS)

GIS consists of images obtained from aircraft or satellites integrated with layers of information, usually customized according to user needs. It constitutes the largest part of the industry both in terms of demand and revenue generation. GIS is part of a larger data analytics industry, estimated to have generated nearly $200B in revenues during 2017.

The satellite imagery market is composed of companies that acquire and operate their own remote sensing satellites. Such companies include DigitalGlobe, Airbus Defense and Space, ImageSat, Planet, and Spire Global, among others. New companies like Spire Global, BlackSky Global, and many others are expected to deploy satellites during the forecast period. For all of these companies, data analytics is the main generator of revenue. In some cases, imagery obtained from government satellites is made available to customers through a GIS company. For example, imagery from two Pleiades satellites operated by the French government is made available through Airbus Defense and Space. In other cases, the operation of remote sensing satellites, the imagery obtained from them, and the sales of GIS products and services is managed through a public-private partnership (PPP). The TerraSAR-X and TanDEM-X satellites are managed by a PPP that includes the German Space Agency (DLR) and Airbus Defense and Space.

The remote sensing forecast also includes radio occultation (RO) satellite systems designed for weather forecasting and radio frequency (RF) mapping. RO does not depend on imagery but rather radio signals generated by navigation satellites that transit the Earth’s atmosphere. The behavior of these radio signals, such as the magnitude of refraction and Doppler shift, can reveal details about the atmosphere’s temperature, pressure and water vapor content in support of weather forecasting. GeoOptics, PlanetiQ, and Spire Global represent newly established companies seeking to deploy constellations of satellites to provide this kind of service. HawkEye 360 will deploy a constellation of satellites to conduct RF mapping of the Earth to help monitor air, land, and sea transportation and assist with search and rescue operations.

This forecast captures only commercial remote sensing satellite companies that procure internationally competed launches. For organizations that depend on a particular launch provider, either because of a commitment to a national industrial base or through a previously established agreement with the launch provider, the launch is not considered internationally competed.

Operator	System	Manufacturer	Satellites	Mass kg (lb)	Highest Resolution (m)	Revisit Time (hrs)	Launch Year
Airbus Defence and Space	DMC3	SSTL	DMC3 1-3	350 (771)	1	24	2015
	SPOT	EADS Astrium (Airbus)	SPOT 5 SPOT 6	3,085 (6,801) 712 (1,570)	2.5 1.5	120 24	2002 2012
	Pleiades Neo	Airbus	Pleiades Neo 1-4	~1,000 (2,205)	0.3	24	2020-2021
	TerraSAR/ TanDEM X	Airbus	TerraSAR-X TanDEM X TerraSAR L	1,023 (2,255) 1,023 (2,255) 2,500 (5,512)	3 0.5 0.25	264 264 264	2007 2010 2022
Astro Digital	LandMapper/ CORVUS	Astro Digital	30	10-20 (22-44)	2.5-22	24-96	2017
AxelSpace	GRUS	AxelSpace	50	95 (209)	2.5	24	2017
Capella Space	Capella	Capella	30	TBD	1	TBD	2020
Changguang Satellite Technology Company	Jilin	CST Co. Ltd.	60+	420 (926)	0.7-2.8	<24	2015
DigitalGlobe	GeoEye	Lockheed Martin	GeoEye 1	907 (2,000)	0.41	50-199	2008
	WorldView	Ball Aerospace/Lockheed Martin	WorldView 1 WorldView 2 WorldView 3 WorldView 4	2,500 (5,510) 2,800 (6,175) 2,800 (6,175) 2,087 (4,601)	0.5 0.5 0.3 0.25	41-130 26-89 <24 <72	2007 2009 2014 2016
	SCOUT	TAQNIA	SCOUT (6)	150 (331)	TBD	TBD	2019
	WorldView Legion	SSL	WorldView Legion (4)	TBD	0.3	<24	2020
Earth-i	Carbonite	SSTL	Carbonite	80 (176)	0.6	24	2019
GeoOptics	CICERO	GeoOptics/LASP	CICERO 1-24	TBD	N/A	24	TBD
HawkEye 360	HawkEye 360	HawkEye360/DSI	3	TBD	N/A	TBD	2017
Hera Systems	HOPSat	Hera Systems	48	12	1	<24	2017
ICEYE	ICEYE	York Space Systems	10-20	150 (331)	TBD	TBD	2017
ImageSat	EROS	IAI	EROS A EROS B EROS C	280 (617) 350 (772) 370 (816)	1.5 0.7 0.3	24-288	2000 2006 2019
MacDonald, Dettwiler and Associates (MDA)	RADARSAT	MDA	RADARSAT 2 RCM 1-3	2,195 (4,840) 1,200 (2,645)	3 TBD	48-72 TBD	2007 2018
Orbital Micro Systems	OMS GEMS	Orbital Micro Systems	OMS (4) GEMS (35)	<10 (22) TBD	TBD TBD	24 TBD	2018 TBD
Planet	Dove	Planet	100+	<10 (22)	3-5	<24	2013
	RapidEye	MDA	RapidEye 1-5	150 (330)	6.5	24	2008
	SkySat	Skybox Imaging/SSL	24	91 (200)	<1	<24	2013
PlanetiQ	PlanetiQ	Blue Canyon Technologies	18	20 (44)	N/A	24	TBD
SatByul	Perseus	SatByul/Dauria	8	10 (22)	22	TBD	TBD
Satellogic	ÑuSat	Satellogic	25	37 (82)	TBD	<24	2017
Siwei Star Company	Gaojing/ SuperView	CAST	24+	TBD	0.5	TBD	2017
Spaceflight Industries	BlackSky	Spaceflight Industries/ Thales Alenia	60	55 (121)	1.1	<24	2018
SpaceVR	Overview	SpaceVR	Overview 1a Overview 1b	4 (9)	215	TBD	TBD
Spire Global	Lemur	Spire Global/Clyde Space	50+	4 (9)	N/A	<24	2016
UrtheCast	Deimos	Dauria Aerospace	Deimos 1 Deimos 2	120 (265) 300 (661)	20 0.75	24 24	2009 2014
	OptiSAR	SSTL	16	SAR: 1,400 (3,086) Optical: 670 (1,477)	TBD	<24	2021
	UrtheDaily	SSTL	8	TBD	5	24	TBD

Table 21. Current and near-term commercial remote sensing satellites and launches.

The major companies operating or actively developing remote sensing satellites across the globe are profiled in Table 21. These satellites have been or are likely to be launched commercially.

Licenses Issued by the U.S. National Oceanic and Atmospheric Administration

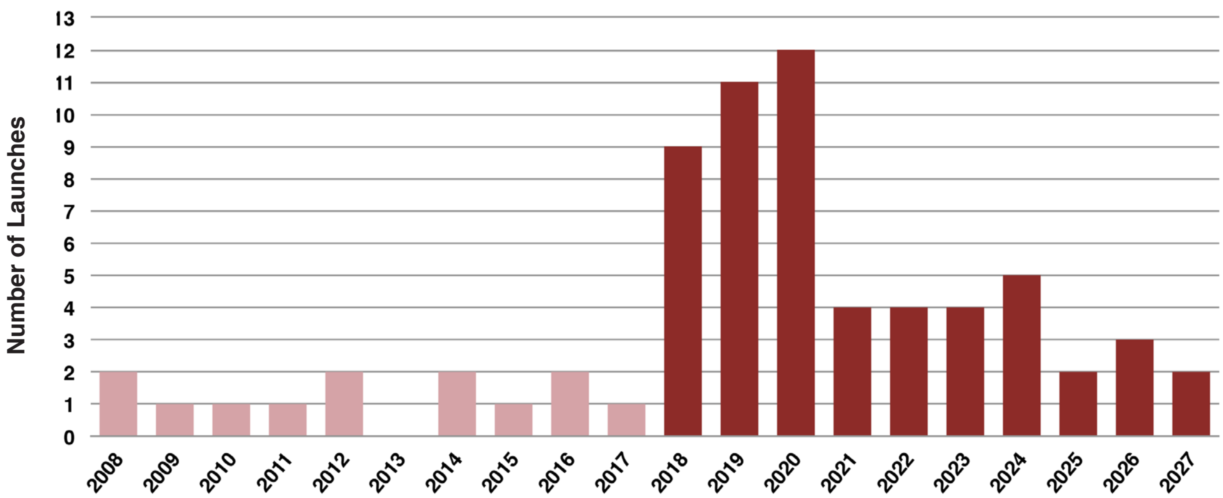
The U.S. National Oceanic and Atmospheric Administration (NOAA) licenses U.S. commercial remote sensing systems in accordance with the Land Remote Sensing Policy Act of 1992. The number of license applications has risen substantially in recent years. From 1996 to 2010, the number of licenses issued was 26. From 2010, when U.S. commercial satellite remote sensing activity began to surge, to 2017, the number was 93. In 2017 alone, 16 new licenses were issued and 7 amendments were issued for existing licenses.

Remote Sensing Launch Demand Summary

From 1999 to 2013, the commercial satellite remote sensing industry has been characterized by relatively stable satellite replacement schedules, generating about one to two launches per year. Many data analytics and satellite remote sensing companies have emerged in recent years eager to launch their constellations into orbit. This has translated into a substantial increase in the number of projected commercial launches to support constellation deployment. Peaks in the number of launches can be seen during 2018 through 2020, reflecting projected deployment of satellites operated by ICEYE and Planet, both of which have contracted with launch providers that will supply dedicated launches aboard newly introduced small launch vehicles. It is possible Vector H launches of ICEYE satellites in particular will be delayed as the vehicle is introduced in 2018. Figure 20 on the next page provides a launch history and projected launch plans for commercial remote sensing satellites.

A little over 1,600 commercial remote sensing satellites are projected to be launched through 2027, an unprecedented number. The vast majority of these will be very small, including CubeSats. In most cases, these will be launched in clusters as secondary payloads, meaning that they do not generate launches. This may change as very small launch vehicles (those with LEO capacities below 200 kg, or 441 lb) become available during the next few years. The total projected number of internationally competed launches supporting commercial satellite remote sensing missions during the forecast period is 56, the vast majority of these (50) being conducted by small vehicles like Electron, LauncherOne, and Vector H.

Commercial remote sensing satellites in the near-term forecast (2018–2020) have been announced by their respective companies, are under construction, and are scheduled for a launch. Satellites projected for the latter portion of the forecast (2021–2027) are based on published statements regarding the service lives of satellites currently operating on orbit. There are many announced systems; only a selected number are highlighted in the following paragraphs.



2018	2019	2020	2021
RCM (3) - Falcon 9	WorldView Scout (6) - TBD	Pleiades Neo (2) - Vega	Pleiades Neo (2) - Vega
Planet (30) - Electron	Earth-i (5) - TBD	WorldView Legion (1) - TBD	Earth-i (5) - TBD
Alba (1) - Vector H	Planet (30) - Electron	Earth-i (5) - TBD	Planet (30) - Electron
GalacticSky, Nexus (2) - Vector H	ICEYE (1) - Vector H	Planet (30) - Electron	Spire (TBD) - Electron
Spire (TBD) - Vector H	ICEYE (1) - Vector H	ICEYE (1) - Vector H	
ICEYE (1) - Vector H	ICEYE (1) - Vector H	ICEYE (1) - Vector H	
ICEYE (1) - Vector H	ICEYE (1) - Vector H	ICEYE (1) - Vector H	
ICEYE (1) - Vector H	ICEYE (1) - Vector H	ICEYE (1) - Vector H	
Spire (TBD) - Electron	ICEYE (1) - Vector H	ICEYE (1) - Vector H	
	Spire (TBD) - Electron	ICEYE (1) - Vector H	
	EROS C (1) - TBD	Spire (TBD) - Electron	
		UrtheDaily (8) - TBD	

Figure 20. Commercial telecommunications launch history and projected launch plans.

Optical and Synthetic Aperture Radar (SAR) Systems

Airbus Defense and Space

Airbus Defense and Space owns and operates Satellite Pour l'Observation de la Terre (SPOT), consisting of two satellites operated by Airbus subsidiary SPOT Image, the German SAR remote sensing missions TerraSAR-X and TanDEM-X, and the DMC constellation operated by Airbus subsidiary DMCii. Airbus also handles sales of imagery obtained by two Pléiades satellites operated by Centre National d'Etudes Spatiales (CNES), SPOT 7 operated by Azercosmos, and KazEOSat-1 operated by Kazakhstan Gharysh Sapary.

CNES, France's space agency, was majority shareholder of SPOT Image until 2009, when responsibility for the system transferred to EADS Astrium. In 2011 Astrium formed the Geo Information Division to manage the SPOT satellites and data sales. EADS Astrium built and owned SPOT-6 and SPOT-7, which launched in 2013 and 2014, respectively. In 2014, EADS Astrium was acquired by Airbus Group, and SPOT-7 (renamed Azersky) was sold to Azercosmos, based in Azerbaijan.

The TerraSAR-X and TanDEM-X missions represent public private partnerships between the German space agency Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German Federal Ministry of Education and Research, and Airbus. DLR operates the two identical satellites and is responsible for the scientific use of the data. Airbus holds the exclusive commercial exploitation rights for imagery acquired by TerraSAR-X (launched in 2007) and TanDEM-X (launched in 2010). The two satellites are expected to remain in service beyond 2018. Work is currently underway for a new satellite called TanDEM-L, with a launch planned in 2022.

The original DMC constellation (Alsat-1, Beijing-1, BilSat, Nigeriasat-1, and UK-DMC1) became fully operational in 2006. Four additional satellites were launched between 2009 and 2011, and the current retinue of operating satellites include China's Beijing-1, Nigeria's Nigeriasat-2 and NX, and the United Kingdom's UK-DMC2. In June 2011, DMCii signed a seven-year deal with China-based Twenty First Century Aerospace Technology Company Ltd. (21AT) to lease the imaging capacity aboard a three-satellite constellation called DMC3. The lease allows 21AT to obtain timely imagery without procuring and operating a constellation themselves. The constellation, designed and manufactured by SSTL, is owned and operated by DMCii and successfully launched in 2015 aboard an Indian PSLV-XL vehicle. Each DMC3 satellite provides 1-m (3.3-ft) panchromatic and 4-meter multispectral imaging.

Astro Digital

Astro Digital (formerly Aquila Space) is a U.S.-based company founded in 2014. The data analytics company is developing the Landmapper constellation, which consists of 34 satellites. The satellites are relatively small, each composed of six integrated CubeSat units (6U). Twelve of the satellites will be part of the Broad Coverage (BC) providing 22-m (72-ft) multispectral imagery, with twenty more satellites representing the High Definition (HD) component, providing imagery with a ground resolution of 2.5 m (8.2 ft).

Astro Digital, which generates revenue from its data analytics services, has raised nearly $17M in investment funding for its constellation and four of its satellites have been launched. Therefore, the forecast includes six Corvus BC satellites as secondary payloads in 2018, followed by 20 Corvus HD satellites in 2019, also as secondary payloads.

AxelSpace

Japan-based AxelSpace is developing a 50-satellite constellation as part of the company's AxelGlobe system, which is designed to support customers in agriculture, forestry, and infrastructure monitoring. Each satellite, called GRUS, have a mass of 80 kg (176 lb) and will provide multispectral imagery with a ground resolution of 2.5 m (8.2 ft).

The forecast projects the first ten GRUS satellites will launch in 2018 and 2019, followed by 40 more satellites by 2022. None of these satellites are expected to generate a launch—all are expected to launch as secondary payloads.

Capella Space

Founded in 2016, U.S.-based Capella Space aims to deploy a constellation of 36 SAR satellites. Each satellite has a mass of about 60 kilograms and will be outfitted with SAR capable of obtaining data at one-meter resolution. The satellites are composed of 12 CubeSat units (12U), a very small platform when compared to traditional SAR satellites, which typically have a mass over 1,000 kg (2,205 lb).

Though the company has raised $12M in investment funding and the company plans to deploy 36 satellites by 2020, no manufacturing or launch contracts have been announced. Therefore, deployments of Capella satellites are not included in the forecast.

Changguang Satellite Technology Company

China-based Changguang is developing and launching the Jilin constellation, expected to include up to 138 satellites by 2030. Each satellite has a mass under 100 kilograms and features a panchromatic sensor capable of imaging the Earth's surface at a ground resolution of just over one meter. The satellites will deliver data designed to generate revenue, representing one of two Chinese commercial satellite remote sensing systems. Because these satellites will be launched from China and launch contracts will likely not be competed internationally, these satellites are not included in the forecast.

DigitalGlobe

Established in 1992, DigitalGlobe is a commercial high-resolution remote sensing satellite operator and GIS provider headquartered in Longmont, Colorado. The company operates imaging satellites and provides GIS products using satellite and aerial imagery. Following a merger with GeoEye, Inc. on January 31, 2013, DigitalGlobe currently operates five remote sensing satellites: GeoEye-1, WorldView-1, WorldView-2, WorldView-3, and WorldView 4. WorldView-4 was successfully launched in 2016 aboard an Atlas V 401 vehicle.

The U.S. National Geospatial-Intelligence Agency (NGA) partially funded the development of the current generation of DigitalGlobe (including the former GeoEye) satellites. In 2010, NGA awarded both DigitalGlobe and GeoEye 10-year contracts worth up to $7.35B as part of the EnhancedView program. These contracts are intended to extend NGA's ability to tap imagery from the private sector and help guarantee the availability of commercial remote sensing products into the decade. In July 2012, due to planned cuts to the EnhancedView budget, DigitalGlobe and GeoEye announced plans to merge, a process completed in January 2013.

In 2016, DigitalGlobe entered into a partnership agreement with TAQNIA in Saudi Arabia to develop six satellites. Details of this constellation are limited, but the satellites will be relatively small, each with a mass of about 150 kg (331 lb). DigitalGlobe is also planning to deploy its WorldView Legion series of satellites in 2020. Though details of this system have not been published, it is anticipated that one WorldView Legion satellite will be launched every two years during the forecast period.

DigitalGlobe was acquired by MDA in 2017 for $2.4B, a process completed in October of that year. Following the acquisition, MDA rebranded as Maxar Technologies.

Earth-i

Earth-i is a UK-based company that offers data analytics products, including analysis based on imagery from the DMC3 constellation and South Korea's Arirang-2 (Kompsat-2) satellite. The company announced plans to deploy its own constellation of fifteen satellites, each with a mass of about 100 kilograms, in 2017. The satellites will be built by Surrey Satellite Technologies, Ltd. (SSTL) and will be based on Earth-i's Carbonite-2 satellite (also built by SSTL) scheduled for launch in 2018 aboard a PSLV.

The forecast includes 15 Earth-i satellites launched in groups of five beginning in 2019. Though no launch contracts have been signed, the company expects to have each group of satellites launched aboard dedicated launch vehicles.

Hera Systems

Based in San Jose, California, Hera Systems is planning to deploy a constellation of 48 small satellites designed to capture imagery of the Earth at a sub-meter ground resolution. Most notable about Hera is its announced pricing objective: the company aims to provide images of the Earth for about $1 for archived one-meter resolution imagery, $2 for new one-meter imagery orders, and $3 for 0.5-m (1.6-ft) resolution products.

Though the company has raised just over $4M in investment funding and has a plan to deploy 48 satellites by 2021, no major updates have taken place in 2017 and manufacturing or launch contracts have been announced. As a result, the forecast does not include any Hera satellite deployment.

ICEYE

Finland-based ICEYE that provides SAR-based data analytics products using aerial platforms and, it hopes, space-based platforms. ICEYE is planning to deploy 18 satellites equipped with SAR, each with a mass of no more than 100 kg (220 lb). The satellites will provide 10-m (32.8-ft) resolution data. The company had raised at least $17M in funding by the end of 2017.

The ICEYE satellites, built by York Space Systems (bus) and ICEYE itself (payload), will begin deploying in 2018 aboard Vector H vehicles provided by Vector. The company signed a contract with Vector in 2016 for 21 launches, presumably 18 plus options for three launches in the event of a failure. A prototype satellite designed to test the system's uniquely small SAR technology will also launch in 2018, but this will be deployed by a PSLV as a secondary payload.

ImageSat International NV

Israel-based ImageSat, founded as West Indian Space in 1997 and officially a Curacao company, provides commercial sub-meter resolution imagery with the Earth Remote Observation Satellite (EROS) family of satellites. Like many remote sensing companies, ImageSat's major customers are governments. Israel

Aerospace Industries Ltd. (IAI) manufactures the EROS satellites, and Elbit Systems develops the imaging system.

ImageSat currently operates two satellites, EROS A and EROS B. EROS A launched in December 2000 aboard a Russian Start-1 small launch vehicle and should continue to operate until at least 2015, five years beyond its projected service life. EROS B launched aboard a Start-1 in 2006 and should continue to operate until 2022.

IAI is currently building the EROS-C satellite. Though no launch year has been selected, recent published accounts indicate the satellite will be launched in 2019 aboard a small vehicle.

MacDonald, Dettwiler and Associates (MDA)

MDA works with the Canadian Space Agency (CSA) in a public-private partnership to operate RADARSAT-2. The company is a commercial provider of advanced geospatial information products derived from the satellite. It also markets and sells data derived from commercial optical satellites and from aerial systems.

RADARSAT-1 was launched on November 4, 1995, aboard a Delta II launch vehicle. The satellite, which was operated by the Canadian Space Agency (CSA), was retired in 2013. RADARSAT-2 launched aboard a Starsem Soyuz intermediate vehicle on December 14, 2007 and remains healthy. RADARSAT-2 features a SAR system capable of producing imagery with one-meter resolution.

To provide space-based radar data continuity, the Government of Canada, through the CSA, proposed the three-satellite RADARSAT Constellation Mission (RCM). In March 2010, the CSA authorized MDA to perform the Phase C design phase of the RCA program, after MDA successfully completed Phases A and B. In January 2013, CSA signed a CAD $706M contract with MDA for the construction, launch and initial operations of the three RCM satellites. In July 2013, MDA secured a launch reservation with SpaceX for the launch of all three satellites aboard a Falcon 9 vehicle in 2018.

Orbital Micro Systems

UK-based Orbital Micro Systems is a data analytics company specializing in providing meteorological products and services. In addition to providing data analysis, the company is developing a constellation of 35 small satellites as part of its Global Environmental Monitoring Satellite (GEMS). Each satellite will be small, possibly based on the CubeSat standard, consisting of three units (3U).

As the first four satellites are financed through the Innovate UK program managed by the Satellite Applications Catapult, the forecast includes four 3U satellites being launched in 2018 as secondary payloads for later deployment from ISS via a NanoRacks contract. As no financing has been secured and no manufacturing or launch contracts have been announced for the full constellation, the forecast does not include deployment of the GEMS system.

Planet

Planet (formerly Cosmogia then Planet Labs), based in California, is a data analytics company focused on producing and sustaining a fleet of at least 100 very small satellites designed to continually gather Earth observation data. The satellite platform is a 3U CubeSat with a sensor focal length capable of producing images with resolutions of 3 to 5 meters, which is still adequate for environmental monitoring, change detection, and other applications. The large number of very small satellites ensures global coverage for a relatively small investment. Planet raised $183M by the end of 2016.

In 2015, Planet purchased the 5-satellite RapidEye constellation operated by German company Black Bridge. The BlackBridge satellites provide wide-area, repetitive coverage and 5-meter-pixel-size multi-spectral imagery. The constellation is expected to remain in service until at least 2019, four years beyond the designed service life. In February 2017, Planet purchased Google's Terra Bella system for an undisclosed amount. Four Terra Bella SkySat satellites were launched in 2016 aboard a PSLV, and six SkySat satellites followed in 2017 aboard an Orbital ATK Minotaur-C vehicle. Before being acquired by Planet, Terra Bella had been in discussions with Virgin Orbit for the launch of satellites aboard LauncherOne, a new small-class launch vehicle.

In 2016, Planet signed a contract with Rocket Labs for three dedicated launches of Electron, each vehicle carrying no more than 30 satellites. These launches are expected to begin in 2018. Because Planet has raised in excess of $183M, is generating revenue, continues to build and deploy satellites on a regular basis, and has launch contracts in place, the forecast projects deployment of 75 satellites per year to maintain the constellation.

SatByul

Founded in 2014, South Korea-based SatByul is a small satellite builder and component provider. It is developing a constellation of 8 small satellites (called Perseus-O) capable of imaging the Earth's surface with a ground resolution of 22 m (72 ft). The 10-kg (22-lb) satellites are based on the CubeSat standard, consisting of six interconnected units (6U).

The company aims to deploy its constellation by the end of 2019. However, due to a lack of updates during 2017 and absence of a launch contract, no deployment is captured in the forecast.

Satellogic

Satellogic is an Argentinian company developing a large constellation of small satellites. By the end of 2017, it had raised about $27M in investment funding and deployed six satellites. Its long-term plan is to deploy and operate hundreds of satellites with panchromatic sensors capable of imaging the Earth with a ground resolution of one meter and hyperspectral sensors producing data with 30-meter resolution. It is one of the few companies in the world pursuing a satellite system featuring hyperspectral sensors, though it remains unclear if there is a market for services related to this capability.

The forecast includes a total of 60 satellites deployed during 2018 and 2019, all as secondary payloads, since Satellogic has successfully raised funding and continues to manufacture and deploy satellites. Satellogic plans a full deployment of up to 300 satellites, but the additional 240 satellites are not captured in this forecast.

Siwei Star Company

Late in 2016, a Long March 2D vehicle carried two GaoJing (or SuperView) satellites into orbit. These satellites have a mass of about 560 kg (1,235 lb) and have panchromatic sensors capable of imaging the Earth's surface at a ground resolution of under a meter (3.3 ft). The full constellation of 16 satellites is expected to be operational by 2020. Because these satellites will be launched from China and launch contracts will likely not be competed internationally, these satellites are not included in the forecast.

Spaceflight Industries

In addition to being a launch broker and provider of distributed launch services for secondary payload customers, Spaceflight Industries offers data analytics services. As part of this effort, the company is planning to deploy a 60-satellite constellation called BlackSky. Each satellite will have a mass of about 55 kilograms and will feature multispectral sensors capable of acquiring imagery of the Earth at a ground resolution of one meter. The constellation is designed to enable daily revisit rates. In 2017, Spaceflight Industries signed a contract with Thales Alenia Space to build the constellation.

Pathfinder 1, the prototype satellite, was launched in 2016 as a secondary payload. Because Spaceflight Industries has raised well over $50M in investment funding and is generating revenue, the forecast projects that the full constellation will be deployed by 2020, but that all satellites will be launched as secondary payloads.

SpaceVR

SpaceVR was founded in 2015 to deliver virtual reality options designed to connect people with locations in outer space. Put another way, the company aims to develop technologies that enable an average person to become a virtual astronaut through smart devices. This, the company hopes, will be enabled by deploying "millions of robots by the end of the decade."

One option being explored by SpaceVR is the deployment of a constellation of small satellites. The company secured a NOAA license in 2016 for two 3U CubeSats, each equipped to provide panchromatic imagery with a ground sample distance of 215 m (705 ft). Because SpaceVR has only raised just under $2M in investment funding and satellite manufacturing or launch contracts have not been announced, the forecast does not include a projection for SpaceVR.

UrtheCast

Founded in 2010, UrtheCast is a data analytics and satellite imagery company based in Vancouver, Canada. Its first project involved the installation of high-resolution video cameras aboard the ISS, with imagery made available to the public. In 2015, UrtheCast purchased Deimos-1 (launched in 2009) and Deimos-2 (launched in 2014) satellites and the associated data archive from Spain-based Elecnor Deimos. Since then, UrtheCast has moved forward with additional plans, leveraging about $100M in revenues and venture investment funding.

The company is developing two constellations. The first, UrtheDaily, consists of eight satellites, all of which are to be launched together aboard a single vehicle in 2020. This system will feature multispectral sensors with a ground resolution of 5 meters and a daily revisit time. The second is OptiSAR, a 16-satellite constellation with projected deployment taking place between 2022 and 2023. The constellation, which will be distributed along one orbital plane, will consist of 8 satellites with multispectral sensors and 8 satellites with SAR. The optical and radar satellites will orbit in pairs, providing near simultaneous acquisition of 1-meter panchromatic imagery, 2-m (6.6-ft) multispectral imagery, 1-m (3.3-ft) L-band SAR data, and 5-m (167-ft) X-band radar data. In addition to the planned 16-satellite system, UrtheCast plans to deploy up to three standalone satellites in 2021, based on separate contracts signed with various unnamed backers.

Radio Occultation (RO) Systems

GeoOptics

U.S.-based GeoOptics is seeking to develop a constellation of small satellites. The satellites, called CICERO (Community Initiative for Continuous Earth Remote Observation), are not equipped with imaging sensors. Instead, CICERO will collect environmental earth observation data like temperature, air pressure, and water vapor by measuring the attenuation of signal-strength from global navigation satellite system (GNSS) satellites (like the U.S. Navstar Global Positioning System) as their L-band signal enters and exits the atmosphere in a proven process called radio occultation. GeoOptics has been working with the University of Colorado Laboratory for Atmospheric and Space Physics (LASP) on the development of the satellites since 2010.

The National Oceanic and Atmospheric Administration (NOAA) issued contracts in 2016 to GeoOptics and Spire Global for RO data. Those contracts ran through the end of April, but GeoOptics was unable to provide data to NOAA due to delays in satellite deployment. Four GeoOptics satellites were launched in 2017; however, three failed on orbit along with most of the other co-manifested payloads, apparently due to failure of the Soyuz launch vehicle's Fregat upper stage.

The forecast projects that GeoOptics will deploy 12 additional satellites by the end of 2019. The company, which has raised just over $5M in investment funding, expects to have all of its satellites launched by smallsat launch providers like Virgin Orbit. However, because the company has not yet announced additional details about this arrangement, the forecast assumes the satellites will be launched as secondary payloads according to a similar arrangement used to deploy the first four.

PlanetiQ

PlanetiQ, established in 2012, plans to operate 18 microsatellites, at 20 kg (44 lb) each, to provide weather, climate, and space weather data. The satellites are not equipped with imaging sensors. Instead, the satellites will collect atmospheric data including temperature, pressure, and water vapor by measuring the bending of signals broadcast from global navigation satellite systems (like the U.S. Navstar system) in a proven process called radio occultation.

The current plan is to launch 12 satellites by the end of 2019, all as secondary payloads. However, PlanetiQ is currently raising funds to support construction of the constellation and no major updates were provided in 2017. As a result, the forecast does not include any PlanetiQ satellite deployments.

Spire Global

Spire Global is a U.S.-based company focused on delivering maritime and weather data to enterprise and public sector clients via its planned constellation of at least 50 CubeSats that will operate in LEO. Spire satellites, called Lemurs and built by the company itself, will capture and aggregate signals from the already entrenched automatic identification system (AIS) onboard most commercial maritime vessels. Using technology similar to that from the successful Formosat-3/Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) public sector mission, Spire will deploy GNSS radio occultation capability onboard its satellites to measure and track global weather profiles at scale. Spire's constellation will provide a 20-minute revisit time to any point on Earth (on average), diminishing further as it adds to its initial satellite deployments.

Within 12-months of its founding, Spire built and deployed the world's first crowd funded satellite, a CubeSat called Ardusat, which was successfully launched in 2013. Spire launched two additional Ardusats and the Lemur-1 demonstration satellite that same year. In 2014, Spire raised $25M in investor funding, bringing its total funding at that time to about $29M. Ardusat was spun off from Spire as a separate company to pursue further education applications and has since successfully raised a $1M round of funding from outside investors. By the end of 2017, Spire had raised about $150M.

Spire satellites will likely be launched as secondary payloads—by the end of 2017, Spire had deployed 60 Lemur satellites in this fashion, using the Antares, Atlas V, H-IIA, Soyuz, and PSLV vehicles. Because Spire has raised significant investment funding, is generating revenue, and has deployed its initial constellation, the forecast includes 50 Lemur satellites deployed each year, many of which aboard a single Electron launch, thanks to a contract signed with Rocket Lab in 2017.

Radio Frequency (RF) Systems

HawkEye 360

Established in 2015 and a subsidiary of Lockheed Martin and Allied Minds, U.S.-based HawkEye 360 is a data analytics firm developing a constellation of RF mapping satellites. The company's efforts are captured in the forecast's remote sensing section, even though it aims to capture RF data from telecommunication activity, because it will be mapping RF use and provide related data analytics to paying customers. By the end of 2017, the company had raised $11M in investment funding.

The satellites will be designed and built by Deep Space Industries and the University of Toronto Institute for Aerospace Studies (UTIAS) Space Flight Laboratory. The payload will be developed by Denmark-based GOMSpace. The satellites will be launched in groups of three, each going to a single orbital plane. Though no launch contracts had been announced by the end of 2017, a satellite manufacturing contract has been signed and the company is backed by Lockheed Martin. Therefore, the forecast assumes deployment of the 30-satellite constellation by 2020, with the satellites deployed as secondary payloads.

COMMERCIAL CARGO AND CREW TRANSPORTATION SERVICES

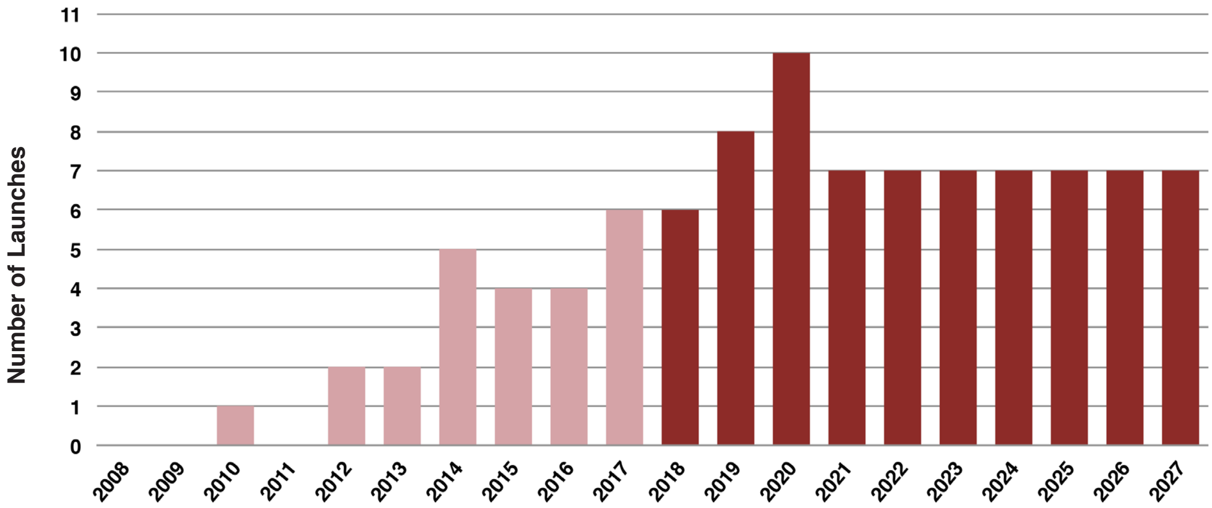
Commercial cargo and crew transportation capabilities include commercial launches of cargo and humans to LEO, the Moon, or other solar system destinations. Specifically, commercial cargo and crew transportation captures commercial crew and cargo services in support of NASA's mission and other private industry efforts that may require cargo and crew flights, such as space stations, tourism, privately sponsored scientific expeditions, and the prospecting and mining of non-terrestrial resources. All commercial launches supporting cargo and crew missions conducted from the U.S. are licensed by FAA AST.

Commercial Cargo and Crew Transportation Services Launch Demand Summary

Seventy-three commercial cargo and crew launches are projected from 2018 to 2027. Most (69) of the launches forecasted in the next ten years are in support of commercial crew and cargo resupply to the ISS. In addition, Axium and Ixion are planning one mission each, and iSpace is planning two. Figure 21 provides a launch history and projected launch plans for commercial cargo and crew transportation services. Figure 22 shows the distribution of ISS commercial cargo and crew flights from 2010 to 2027 (it is assumed that ISS operations will continue beyond 2024). Note that the first test flights of Falcon 9 and Antares were not funded by NASA and are captured in the forecast section entitled Technology Test and Demonstration Launches.

NASA COTS

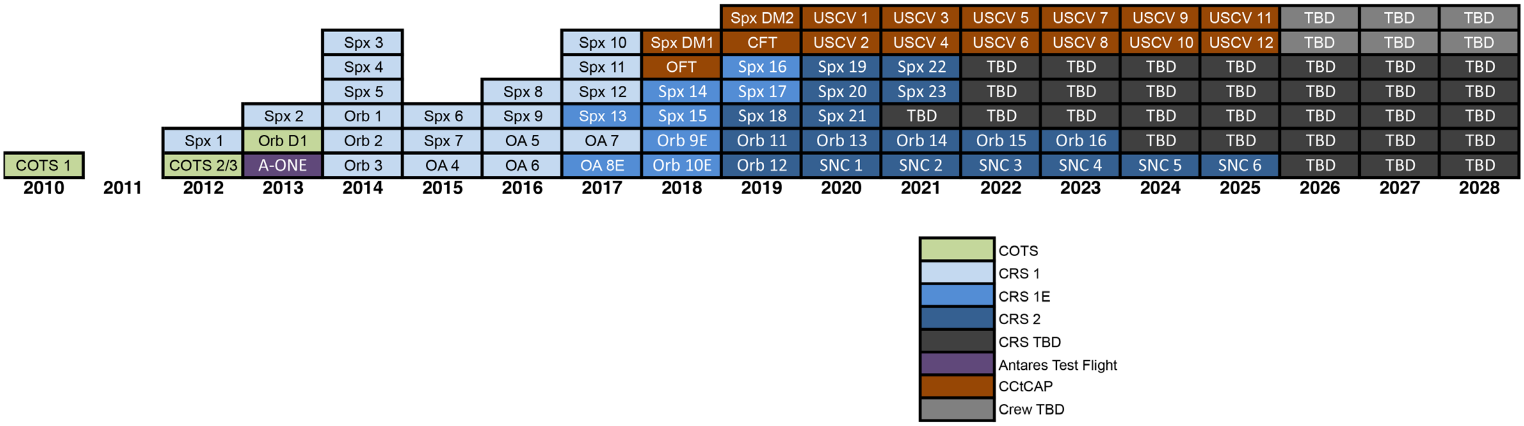
In 2006, NASA announced Commercial Orbital Transportation Services (COTS), a program focused on the development and demonstration of commercial cargo transportation systems. Total Space Act Agreement (SAA) funding under this program was $889M. Under COTS, SpaceX developed the intermediate Falcon 9 launch vehicle and the Dragon spacecraft, completing its COTS milestones in 2012. Orbital Sciences Corporation then developed the Cygnus spacecraft and the medium-class Antares launch vehicle. Orbital's test flight of Antares launched on April 21, 2013, carrying a Cygnus mass simulator. The company conducted its COTS demonstration mission in September 2013, featuring a fully operational Cygnus that berthed with the ISS. The successful completion of this mission concluded NASA's COTS program.



2018	2019	2020	2021
Spx 14 - Falcon 9	Spx 16 - Falcon 9	Spx 19 - Falcon 9	Spx 22 - Falcon 9
Spx 15 - Falcon 9	Spx 17 - Falcon 9	Spx 20 - Falcon 9	Spx 23 - Falcon 9
Orb 9E - Antares	Spx 18 - Falcon 9	Spx 21 - Falcon 9	Cargo TBD - TBD
Orb 10E - Antares	Orb 11 - Antares	Orb 13 - Antares	Orb 14 - Antares
Spx DM1 - Falcon 9	Orb 12 - Antares	SNC 1 - TBD	SNC 2 - TBD
OFT - Atlas V	Spx DM2 - Falcon 9	USCV 1 - Falcon 9	USCV 3 - Falcon 9
	CFT - Atlas V	USCV 2 - TBD	USCV 4 - TBD
	iSpace - TBD	Ixion - TBD	
		Axium - TBD	
		iSpace - TBD	

Figure 21. Commercial crew and cargo launch history and projected launch plans.

Figure 22. NASA commercial crew and cargo projections.



NASA CRS

In 2008, NASA awarded two Commercial Resupply Services (CRS) contracts to SpaceX and Orbital. SpaceX won a contract valued at $1.6B for 12 flights through 2015, and Orbital won a $1.9B contract for 8 flights during the same period. Operational flights began in October 2012, with the successful launch of SpaceX's Dragon resupplying the ISS. Orbital's resupply missions began in January 2014. In 2015, NASA awarded contracts to SpaceX ($1.2B) and Orbital ATK ($475M) extending the number of missions required under CRS 1 to five and three, respectively. In January 2016, NASA awarded a second commercial resupply services contract (CRS 2) to SpaceX, Orbital ATK, and Sierra Nevada Corporation (SNC). CRS 2 requires that each company provide six cargo missions ISS through 2024.

NASA Commercial Crew

To stimulate commercial development of a crew transportation capability, NASA initiated the Commercial Crew Development (CCDev) effort in 2010 with $50M of 2009 American Recovery and Reinvestment Act funding. CCDev focused on development of commercial space transportation concepts and enabling capabilities. The 2010 CCDev awardees were Blue Origin, Boeing, Paragon Space Development Corporation, Sierra Nevada Corporation, and United Launch Alliance (ULA).

In 2011, after completion of the initial CCDev effort, NASA continued investing in commercial crew transportation development with a second competition known as CCDev2. This follow-on effort further advanced commercial crew space transportation system concepts, maturing the design and development of system elements such as launch vehicles and spacecraft. Blue Origin, Boeing, Sierra Nevada Corporation (SNC), and SpaceX won awards totaling $315M. Additionally, NASA awarded unfunded agreements to provide limited technical assistance for advancement of commercial crew space transportation to ULA, Alliant Techsystems (ATK, now Orbital ATK), and Excalibur Almaz, Inc.

In 2012, NASA announced the next phase of commercial crew development, Commercial Crew Integrated Capability (CCiCAP). This new initiative aims to facilitate the industry's development of an integrated crew transportation system. CCiCap is expected to result in significant maturation of commercial crew transportation systems. Boeing, SpaceX, and Sierra Nevada Corporation won awards totaling over $1.1B. In December 2012, NASA awarded $30 million in Certification Products Contracts (CPC) to Boeing, Sierra Nevada, and SpaceX. Under this contract, each of these companies will work toward certifying its spacecraft as safe to carry humans to the ISS. In September 2014, NASA awarded contracts under the Commercial Crew Transportation Capability (CCtCap) to Boeing for the CST-100 Starliner (up to $4.2B) and SpaceX for the Crewed Dragon (up to $2.6B). Under CCtCap, the final design, development, test, and evaluation activities necessary to achieve NASA's certification of a Crew Transportation System (CTS) will be conducted. SNC's Dream Chaser concept was not selected. Uncrewed flight tests of both the SpaceX Dragon and Boeing CST-100 Starliner are planned for 2018, followed by the first crewed launch of these spacecraft late in 2018 or early 2019.

Table 22 describes NASA COTS, CRS, and CCDev Awards.

Contract	Year	Amount	Company	Remarks
COTS	2006	$396 million	SpaceX	Dragon
COTS	2006	$207 million	Kistler*	K-1
COTS	2008	$288 million	Orbital	Cygnus
CRS 1	2008	$1.6 billion	SpaceX	Dragon (12 flights)
CRS 1	2008	$1.9 billion	Orbital	Cygnus (8 flights)
CCDev	2010	$20 million	Sierra Nevada Corp.	Dream Chaser
CCDev	2010	$18 million	Boeing	CST-100 Starliner
CCDev	2010	$6.7 million	United Launch Alliance (ULA)	Atlas V human rating
CCDev	2010	$3.7 million	Blue Origin	Launch abort systems
CCDev	2010	$1.4 million	Paragon Space	Life support
CCDev2	2011	$112.9 million	Boeing	CST-100 design maturation
CCDev2	2011	$105.6 million	Sierra Nevada Corp.	Dream Chaser design maturation
CCDev2	2011	$75 million	SpaceX	Crewed Dragon development
CCDev2	2011	$22 million	Blue Origin	Launch abort systems
CCDev2	2011	Unfunded	ULA	Atlas V human rating
CCDev2	2011	Unfunded	ATK/Astrium	Liberty development
CCDev2	2011	Unfunded	Excalibur Almaz	Spacecraft development
CCiCAP	2012	$460 million	Boeing	CST-100 Starliner crewed maturation
CCiCAP	2012	$440 million	SpaceX	Crewed Dragon maturation
CCiCAP	2012	$212.5 million	Sierra Nevada Corp.	Dream Chaser crewed maturation
CPC	2012	$10 million	Boeing	Crew Certification
CPC	2012	$10 million	Sierra Nevada Corp.	Crew Certification
CPC	2012	$10 million	SpaceX	Crew Certification
CCtCap	2014	$4.2 billion	Boeing	Final development phase of CST-100 Starliner
CCtCap	2014	$2.6 billion	SpaceX	Final development phase of Dragon V2
CRS 1E	2015	$1.2 billion	SpaceX	Extension of five missions from 2017 to 2018
CRS 1E	2015	$475 million	Orbital ATK	Extension of one mission from 2017 to 2018
CRS 2	2016	$900 million	SpaceX	Six missions from 2019 to 2024
CRS 2	2016	$1.4 billion	Orbital ATK	Six missions from 2019 to 2024
CRS 2	2016	Undisclosed	Sierra Nevada Corp.	Six missions from 2019 to 2024

Table 22. NASA commercial crew and cargo awards.

Other Potential Sources of Future Launch Demand

Axiom

Axiom Space, based in the U.S., was founded in 2015 to develop the world's first privately financed space station. Its founding was motivated by the timetable for the ISS, which may be retired before 2030. It will be designed to host a crew to conduct research, provide a means for customers to install experiments at low cost, create a capability to enable development of new technologies, and serve as a foundation for human space exploration beyond LEO. The company has raised at least $3M in seed funding since its founding.

The company envisions a multi-module complex, with four modules connected to a central node. The central node will feature an airlock and a power terminal topped with solar arrays. The forecast include a single module developed by Axiom, launched in 2020 by a medium- to large-class launch vehicle. This module will be attached to the ISS. Sometime between 2024 and 2028, Axiom will detach the module from SIS and use it as a foundation for its commercial space station.

Bigelow Aerospace

Nevada-based Bigelow Aerospace is developing expandable space habitat technology to support a variety of public and private activities including commercial space stations in LEO and human spaceflight missions beyond LEO. Its manufacturing plant, which occupies 31,731 square meters (341,550 square feet), is located in North Las Vegas, Nevada. Bigelow Aerospace has launched two prototype spacecraft, Genesis I and Genesis II, on separate Russian Dnepr launch vehicles in 2006 and 2007, respectively. Bigelow Aerospace used these missions to validate its habitat designs and engineering in an actual on-orbit environment.

In December of 2012, NASA awarded Bigelow Aerospace a $17.8M contract to develop the Bigelow Expandable Activity Module (BEAM), which was launched in 2016 aboard ISS cargo mission Spx-8. The BEAM is designed for a nominal two-year technology demonstration period, wherein ISS crewmembers will gather data on the performance of the module. NASA may extend the BEAM mission period, but at the end of its life BEAM will be jettisoned from the ISS and burn up during reentry.

Bigelow Aerospace has also been continuing work on full-scale expandable modules. Specifically, the company is developing the BA 330 and the BA 1200 or ‘Olympus’. The BA 330 will offer 330 cubic meters of internal volume and accommodate a crew of up to six, and the BA 2100 will provide roughly 2,100 cubic meters of internal volume. In 2013, Bigelow Aerospace announced that it could modify the BA 330 in a number of ways depending on mission needs. The BA 330-DS would be designed for missions beyond LEO requiring additional radiation shielding. The BA 330-MDS would be designed for surface installations on the Moon.

Finally, Bigelow Aerospace is considering a version of the BA 2100 that could carry spacecraft as well as crew, using a large airlock to facilitate transfers. These modules can be linked together to form space stations and do so with any of a variety of tugs that the company intends to provide, including a Standard Transit Tug, a Solar Generator Tug, a Docking Node Transporter, and a Spacecraft Capture Tug.

Bigelow Aerospace is also involved in crew transportation. The company is a member of the Boeing CCDev team working on the CST-100 Starliner reusable in-space crew transport vehicle.

iSpace Technologies

Japan-based iSpace, founded in 2010 as a lunar resource company, made headlines in 2017 by raising $90M from 12 investors during a Series A round.

The company plans to use the funds to develop two missions to the Moon by the end of 2020. These missions will involved a lander. In 2019, the lander will orbit the Moon, conducting a survey of the surface, but will not touch down. In 2020, a second lander will be launched, this time to actually settle on the lunar surface. If these demonstration missions are successful, iSpace intends to begin offering regular transportation services to the Moon for paying customers, presumably science organizations and companies seeking opportunities to test technologies in a lunar environment. The maximum payload capacity will be about 30 kg (66 lb).

The forecast includes two missions, one in 2019 and another in 2020, each launched by a dedicated medium- to heavy-class launch vehicle.

Ixion

In mid-2017, U.S.-based NanoRacks signed a contract with NASA under the agency's NextSTEP-2 public-private partnership model to develop a concept study for a commercial orbital habitat called Ixion. The Ixion project will also include Space Systems Loral and United Launch Alliance (ULA).

Ixion will involve the use of a spent launch vehicle upper stage as the basis for development of a habitat. The partnership aims to purchase a dedicated launch in which the vehicle's upper stage will be vented of excess propellant and attached to the ISS for testing. This mission is captured in the forecast as a single launch event taking place in 2020.

OTHER COMMERCIALLY LAUNCHED SATELLITES

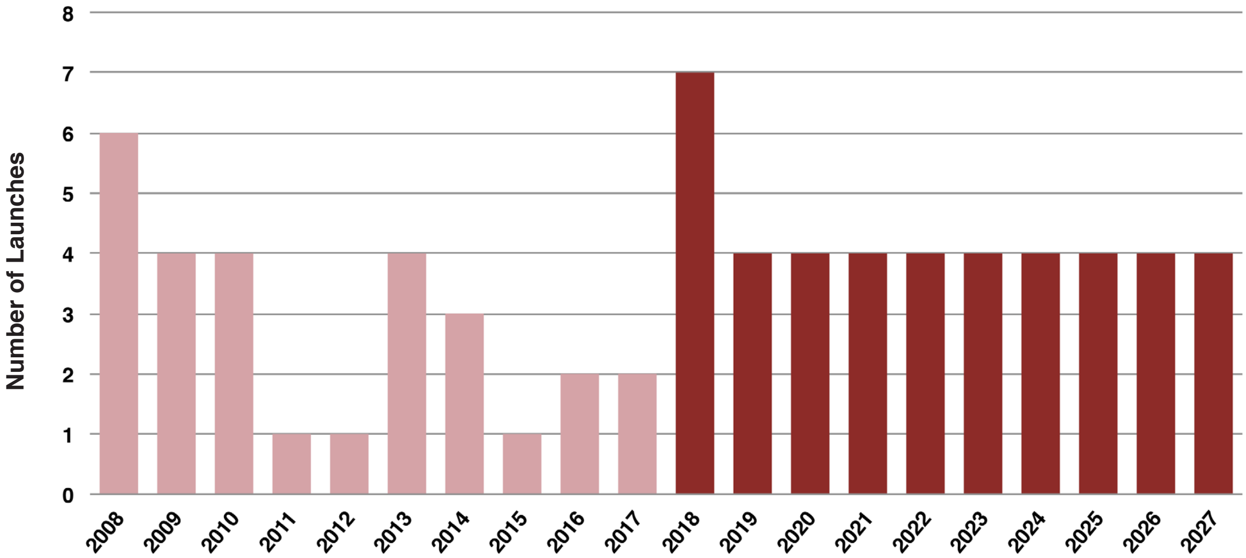
This section contains predominantly government satellites launched commercially. It also includes university payloads that are scientific, education, or outreach. Though many government missions do not commercially procure or obtain commercial licenses for their launches, there are select missions that do, particularly by governments without domestic launch capabilities. Government Earth observation and remote sensing programs and scientific missions are significant customers of commercial launch services to NGSO.

Other Commercially Launched Satellites Demand Summary

The market characterization of the near term (2018–2020) includes 15 manifested launches. For the period 2021–2027, forecasting projects 28 launches for an average of four in each of the seven out years. Figure 23 provides a launch history and projected launch plan demands for Other Commercially Launched Satellites.

Google Lunar X PRIZE

TThe Google Lunar X PRIZE is a $30M purse open to teams from around the world. To win the grand prize of $20M, private teams (those with no more than 10 percent in government funding) must have landed a robot safely on the Moon; move 500 m (1,640 ft) on, above, or below the Moon's surface; and send back high definition video before the December 31st, 2016 deadline. In 2015,



2018	2019	2020	2021
FalconEye 1 - Vega	FalconEye 2 - Vega	Kompsat 6 - Angara 1.2	Al Amal - H-IIA
SAOCOM 1A - Falcon 9	SARah (2) - Falcon 9	EnMAP - PSLV	UN Dream Chaser - TBD
Formosat 7 - Falcon Heavy	SAOCOM 1B - Falcon 9	Korea Pathfinder - Falcon 9	TBD - TBD
PAZ - Falcon 9	Moon Express - Electron	TBD - TBD	TBD- TBD
SARah 1 - Falcon 9			
Moon Express - Electron			
Moon Express - Electron			

Figure 23. Other commercially launched satellites launch history and projected launch plans.

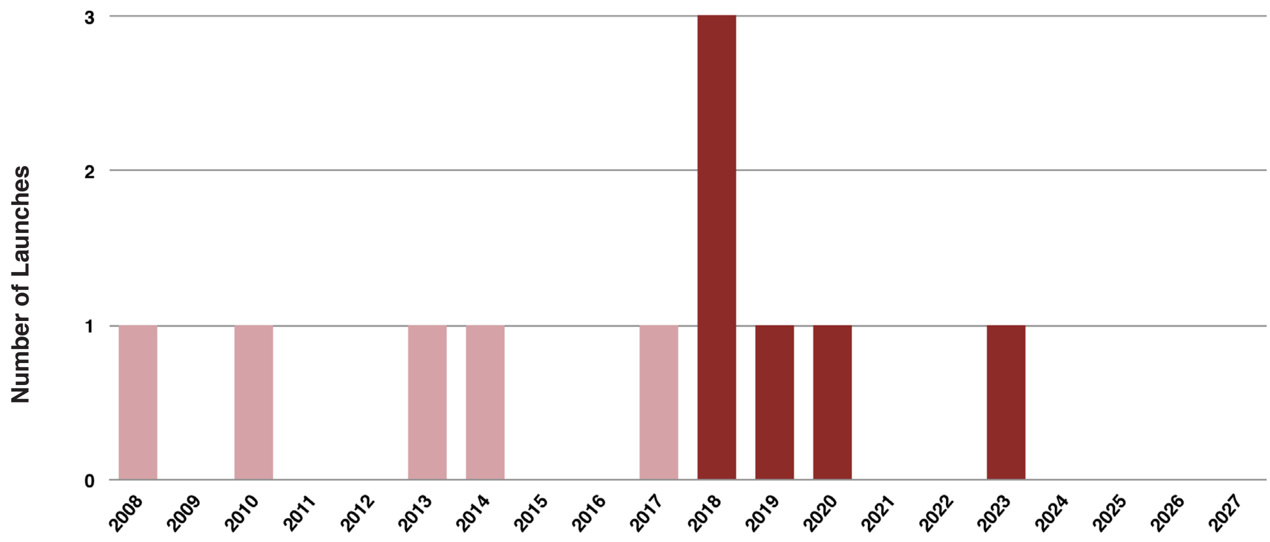
Google Lunar X PRIZE announced the competition deadline would be extended to December 31, 2017 if at least one team could secure a verified launch contract by December 31, 2015. Two teams secured such a launch contract, and the deadline was extended.

LAUNCH VEHICLE TEST AND DEMONSTRATION LAUNCHES

Launch vehicle test and demonstration launches are conducted to test primarily new launch and space vehicles. By their nature, these are not events taking place on a regular basis. Figure 24 provides a launch history and projected launch plans for technology test and demonstration launches.

Launch Vehicle Test and Demonstration Demand Summary

The inaugural launch of SpaceX's Falcon Heavy launch vehicle is now planned for launch in 2018. The report also includes the technology test and demonstration launches of new small class commercial launch vehicles like Electron (2017 and 2018), LauncherOne (2018), New Glenn (2020), Vector (2018), Vulcan (2019), and Vulcan with Advanced Cryogenic Evolved Stage (2023). Test flights of other new orbital launch vehicles currently in development are anticipated in the same time frame and are not reflected in this forecast if their inaugural launches carry payloads for commercial or government customers.



2018	2019	2020	2021
LauncherOne Test	Vulcan Test	New Glenn Test	
Electron Test #2			
Vector H Test			

Figure 24. Launch vehicle test and demonstration launch history and projected launch plans.

FACTORS THAT AFFECT LAUNCH PROJECTIONS

The estimated demand for launches is historically larger than the number of payloads that will actually be launched in a year. Some factors that contribute to the difference between forecast and realized launches are:

- Payload technical issues: Payload manufacturers may have manufacturing, supplier, or component issues that delay the delivery of a satellite or spacecraft. On-ground and in-orbit anomalies can affect the delivery of payloads under construction until fleet-wide issues (such as commonality of parts, processes, and systems) are resolved. Delays in delivery of spacecraft to the launch site then impact the scheduling of launches.
- Launch vehicle technical issues: Launch vehicle manufacturers and launch service providers may have manufacturing, supplier, or component issues that cause launch delays. Recovery from launch anomalies and failures can also significantly affect launch schedules. Delays have a cascading effect on subsequent launches, and some science missions have specific launch windows that, if missed, may result in lengthy delays and manifest issues.
- Weather: Inclement weather, including ground winds, flight winds, cloud cover, lightning, and ocean currents often cause launch delays, though these are typically short-term (on the order of days).
- Range availability issues: The lack of launch range availability due to prioritized government missions, schedule conflicts with other launch providers, launch site maintenance, and other range-related issues can cause launch delays.

- Dual- and multi-manifesting: Dual- and multi-manifesting requires that two or more payloads are delivered to the launch site on time. A delay on one payload results in a launch delay for the other one and subsequent payloads. Payload compatibility issues (such as mass mismatch, technical differences, and differing orbit insertion requirements) can also cause delays.
- Business issues: Corporate reprioritization, changing strategies and markets, and inability to obtain financing may delay or cancel satellite programs; however, this can free up launch slots for other customers.
- Regulatory issues: Export compliance, FCC or international licensing, and frequency coordination can cause delays, launch vehicle shifts, and satellite program cancellations. U.S. government policy regarding satellite and launch vehicle export control can make it difficult for U.S. satellite manufacturers and launch vehicle operators to work with international customers.
- Geopolitical issues: Temporary economic sanctions that affect U.S. satellites launching from foreign launch sites, or from vehicles with foreign components, may cause delays in export licensing approvals of satellites and launch related services.

PROJECTING ACTUAL SATELLITES LAUNCHED USING A REALIZATION FACTOR

Over the history of this Report, the forecast demand for satellites and launches has almost always exceeded the number of payloads and launches actually accomplished in each of the first three years of a forecast period. To better estimate the number of near- term launches, the near-term demand is adjusted by a “realization factor.” This factor is derived by comparing forecast launches with actual launches accomplished in the five years prior to the current Report.

There are two slightly different methodologies employed for the projections of the GSO satellites launched and the number of launches to NGSO.

The range of GSO satellite launches expected to be realized is calculated by multiplying the near-term forecast by the highest and lowest variations of forecast versus actual over the preceding five years. Since 1993, the actual number of GSO satellites launched in the first year of the forecast was 58 percent to 100 percent of the forecast number, with an average of 80 percent. For the past five years, the range was 80 percent to 100 percent, with an average of 89 percent. Based on this methodology, while 27 satellites are forecast for launch in 2017, the expected realization for 2017 is 24 to 26 GSO satellites.

The consistent overestimation illustrates the “bow-wave” effect of the forecast: satellites that were planned to be launched the previous year but slipped into the subsequent year are often carried over without compensating for the subsequent year’s satellite launches concurrently slipping forward.

The calculation becomes less precise for the second out-year. The forecast has almost always overestimated the actual launches two years hence. Since 1993, the actual realization for the second out-year ranged from 48 percent to 105 percent, with an average of 76 percent. For the past five years, the range was 68 percent to 95 percent, with an average of 78 percent. Using the same methodology, while 23 GSO satellites are forecast to be launched in 2019, the expected realization for 2018 is 18 to 24 satellites.

The expected realization of launches to NGSO is calculated for full launches, not satellites or payloads, due to a high share of NGSO multi-manifested launches. While 36 and 35 launches to NGSO are projected for 2018 and 2019, the expected realization is 20 to 22 launches for 2018 and 19 to 21 launches for 2019.

Since the launch realization factor was added to the Report in 2002, the actual number of satellites launched has usually fallen within the launch realization range, demonstrating the robustness of the realization factor methodology.

Blue Origin's third New Shepard vehicle makes a successful landing shortly after separation from the capsule it was carrying on December 12, 2017. *Source: Blue origin.*

U.S. COMMERCIAL SPACE TRANSPORTATION LAW AND POLICY

National governments, acting both independently and cooperatively, develop laws and guidelines to assign responsibility and to provide direction and accountability for space activities, including space transportation. The U.S. government also works with other countries to develop and advance cooperation and best practices for space transportation operations.

This section briefly describes the international treaties that provide a global framework for the space activities of signatories, as well as U.S. law and policy that specifically govern U.S. space activities.

INTERNATIONAL TREATIES

The foundational instrument of the outer space legal regime is the 1967 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* (referred to as the “Outer Space Treaty” or OST). The treaty, drafted by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), entered into force on October 10, 1967. As of December 31, 2015, there are 104 state signatories to the treaty.

The OST established a series of broad principles that have been elaborated upon and implemented in a series of subsequent international treaties and national laws. These principles include:

- The exploration and use of outer space shall be carried on for the benefit and in the interests of all mankind;
- Outer space and celestial bodies are free for exploration and use by all States;
- Outer space and celestial bodies are not subject to national appropriation;
- No weapons of mass destruction are permitted in outer space;
- The Moon and other celestial bodies shall be used exclusively for peaceful purposes;
- States shall be responsible for their national activities in outer space, whether carried on by governmental or non-governmental entities;
- The activities of non-governmental entities in outer space shall require the authorization and continuing supervision by the appropriate State;
- States shall retain jurisdiction and control over their space objects and any personnel thereon;
- States shall be liable for damage caused by their space objects; and
- States shall avoid the harmful contamination of outer space.

The OST was followed by the 1968 *Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space*, the 1972 *Convention on International Liability for Damage Caused by Space Objects*, the 1975 *Convention on Registration of Objects Launched into Outer Space*, and the 1979 *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, the latter of which has not been ratified by the United States.

The U.S. government carries out its space-related responsibilities through several different agencies. AST regulates the U.S. commercial space transportation industry; encourages, facilitates, and promotes commercial space launches and reentries by the U.S. private sector; recommends appropriate changes in federal statutes, treaties, regulations, policies, plans, and procedures; and facilitates the strengthening and expansion of the U.S. space transportation infrastructure. The National Oceanic and Atmospheric Administration (NOAA) is responsible for issuing licenses to U.S-based non-federal organizations that intend to operate remote sensing satellites (under the 1992 Land Remote Sensing Policy Act). The Federal Communications Commission (FCC) requires operators of non-federal satellites that employ radio communications to be licensed. The provisions of the 1976 Arms Export Control Act are implemented under the International Traffic in Arms Regulations (ITAR), which control the export and import of defense-related technologies and services identified on the United States Munitions List (USML) managed by the Department of State, which includes some space hardware. In addition to ITAR, there is the Export Administration Regulations (EAR), which contains the Commercial Control List (CCL) managed by the Department of Commerce. The CCL also captures various space-related technologies.

U.S. LAW AND POLICY

Commercial Space Launch Act of 1984

The Commercial Space Launch Act of 1984 (CSLA), as amended and re-codified at 51 U.S.C. 50901-50923, authorizes DOT and, through delegation, AST, to oversee, authorize, and regulate both launches and reentries of launch and reentry vehicles, and the operation of launch and reentry sites when carried out by U.S. citizens or within the United States. The CSLA directs the FAA to exercise this responsibility consistent with public health and safety, safety of property, and the national security and foreign policy interests of the United States. The CSLA also directs AST to encourage, facilitate, and promote commercial space launches and reentries by the private sector, including those involving spaceflight participants.

U.S. Commercial Space Launch Competitiveness Act

During FY 2015, both houses of the U.S. Congress passed bills exclusively focused on commercial space activities. A compromise bill, the U.S. Commercial Space Launch Competitiveness Act (CSLCA), was passed and signed by President Barack Obama on November 25, 2015. The full text of the act is available on the AST website.

Generally, the CSLCA covers responsibilities under the Department of Transportation and Department of Commerce as they relate to commercial space activities. The CSLCA extends the indemnification provision of the CSLA for U.S. launch providers for third-party claims that exceed the maximum probable loss through 2025. It also extends, through 2023, the “learning period” restrictions that limit AST’s ability to enact regulations governing the design or operation of launch vehicles to protect the health and safety of crew, government astronauts, and space flight participants. The CSLCA also directs the President to facilitate commercial exploration for and commercial recovery of space resources by United States citizens and affirms the entitlement of United States citizens to use and sell asteroid and space resources obtained in accordance with applicable U.S. and international law.

AST Advisory Circulars, Guidelines, and Handbooks

Guidance documents provide information to aid understanding and compliance with specific FAA regulations. They include Advisory Circulars, guidelines, handbooks, and sample applications about commercial space transportation safety and other regulatory matters. Although not guidance, per se, legal interpretations from the FAA’s Office of the Chief Counsel address specific legal issues that have precedential effect. AST has issued legal interpretations on subjects, such as the regulation of spacecraft that produce sonic booms, launch site-licensing requirements, delivery of regulations to mobile devices, and legal definitions. These documents are available on the AST website.

2010 National Space Policy

The National Space Policy expresses the President’s direction for the nation’s space activities. Broadly, it recognizes the rights of all nations to access, use, and explore space for peaceful purposes; promotes international cooperation in space science and exploration, Earth sciences, and space surveillance; and emphasizes openness and transparency. Specific to U.S. activities in space, the policy recommends that the U.S. government use commercial space products and services in fulfilling governmental needs, and emphasizes the need for partnerships between NASA and the private sector. It highlights the need to invest in space situational awareness capabilities, orbital debris mitigation, and launch vehicle technologies, among other issues relating to national security in particular. Finally, it states that the U.S. will accelerate the development of satellites to observe and study the Earth’s environment, and conduct research programs to study the Earth’s lands, oceans, and atmosphere.

2013 National Space Transportation Policy

On November 21, 2013, the White House issued the 2013 National Space Transportation Policy, which updates and replaces the 2004 U.S. Space Transportation Policy. It provides guidance to federal departments and agencies on the development and use of commercial and governmental space transportation systems. The policy provides comprehensive guidance to all federal departments and agencies on U.S. priorities and on roles and responsibilities with respect to space transportation issues and programs.

The overarching goal of the policy is to have assured access to diverse regions of space in support of civil and national security missions. To further this goal, the policy prescribes actions aimed at improving U.S. launch industry robustness, cost effectiveness, innovation, entrepreneurship, and international competitiveness.

Under the policy, the U.S. government will use commercial space transportation products and services to help fulfill government needs, invest in new and advanced technologies and concepts, and use a broad array of partnerships with industry to promote innovation. The policy is also designed to encourage partnerships with private industry to put U.S. government instruments on non-governmental spacecraft, which will increase scientific and other capabilities, facilitate access to space, and save taxpayer dollars using arrangements known as “hosted payloads.” It also aims to foster cooperation with industry to develop guidelines for the development and expansion of current and future U.S. space transportation systems and directs further research and development to improve the reliability, responsiveness, performance, and cost effectiveness of the U.S. commercial human spaceflight market.

National Space Council

President George H. W. Bush established a National Space Council in 1989 when he signed Executive Order 12675. After only a few years, the council was disbanded (though not disestablished) and its functions shifted to the National Science and Technology Council. In June 2017, President Donald Trump signed Executive Order 13803, resurrecting the National Space Council. The council met for the first time in October, an event that was televised for the public. It received inputs from various government, industry, and academic experts as it considers the future of America’s role in space.

DEFINITIONS

Commercial Suborbital or Orbital Launch

A commercial suborbital or orbital launch has one or more of these characteristics:

- The launch is licensed by FAA AST.
- The primary payload's launch contract was internationally competed (see definition of internationally competed below). A primary payload is generally defined as the payload with the greatest mass on a launch vehicle for a given launch.
- The launch is privately financed without government support.

Launch Failure

A launch failure happens when the payload does not reach a usable orbit (an orbit where some portion of the mission can be salvaged) or is destroyed as the result of a launch vehicle malfunction.

Internationally Competed

An internationally competed launch contract is one in which the launch opportunity was available in principle to any capable launch service provider. Such a launch is considered commercial.

Commercial Payload

A commercial payload has one or both of these characteristics:

- The payload is operated by a private company.
- The payload is funded by the government, but provides satellite service partially or totally through a private or semi-private company. This distinction is usually applied to certain telecommunications satellites whose transponders are partially or totally leased to a variety of organizations, some or all of which generate revenues. Examples include Russia's Express and Ekran series of spacecraft.

All other payloads are classified as non-commercial (government civil, government military, or non-profit).

Orbits

A spacecraft in geostationary Earth orbit (GSO) is synchronized with the Earth's rotation, orbiting once every 24 hours, and appears to an observer on the ground to be stationary in the sky. Geosynchronous (GEO) is a broader category used for any circular orbit at an altitude of 35,852 km (22,277 mi) with a low inclination (i.e., near or on the equator). A Molniya orbit is technically considered GEO. It has a period of ½ a sidereal day, and the inclination is such that oblateness effects cause the right ascension to precess at a rate that ensures the apogee will always be over the same longitude. A Tundra orbit is similarly geosynchronous, but with a period of one sidereal day.

Non-geosynchronous orbit (NGSO) satellites are those in orbits other than GEO. They are located in low Earth orbit (LEO, lowest achievable orbit to about 2,400 km, or 1,491 mi), medium Earth orbit (MEO, 2,400 km, 1,491 mi to GEO), SSO (Sun Synchronous Orbit), and all other orbits or trajectories. ELI (“elliptical”) describes a highly elliptical orbit, and EXT (“external”) describes trajectories beyond GEO (such as interplanetary trajectories).

Vehicle Mass Class

Small launch vehicles are defined as those with a payload capacity of less than 2,268 kg (5,000 lb) at 185 km (115 mi) altitude and a 28.5° inclination. Medium to heavy launch vehicles are capable of carrying more than 2,269 kg (5,002 lb) at 185 km (115 mi) altitude and a 28.5° inclination.

Spacecraft Mass Class

Table 11 provides the spacecraft mass classes used by FAA AST.

Class Name	Kilograms (kg)	Pounds (lb)
Femto	0.01 - 0.09	0.02 - 0.19
Pico	0.1 - 1	0.2 - 2
Nano	1.1 - 10	3 - 22
Micro	11 - 200	23 - 441
Mini	201 - 600	442 - 1,323
Small	601 - 1,200	1,324 - 2,646
Medium	1,201 - 2,500	2,647 - 5,512
Intermediate	2,501 - 4,200	5,513 - 9,259
Large	4,201 - 5,400	9,260 - 11,905
Heavy	5,401 - 7,000	11,906 - 15,432
Extra Heavy	>7,001	>15,433

Table 11. Spacecraft mass classes.

ACRONYMS

21AT	Twenty First Century Aerospace Technology Company Ltd.
ABS	Asia Broadcast Satellite
AIS	Automatic Identification System
ADF	Australian Defense Force
ATK	Alliant Technologies
ATV	Automated Transfer Vehicle
BEAM	Bigelow Expandable Activity Module
BMBF	Federal Ministry of Education and Research
BPA	Blok Perspektivnoy Avioniki
CASSIOPE	Cascade, Smallsat, and Ionospheric Polar Explorer
CAST	Chinese Academy of Space Technology
CCAFS	Cape Canaveral Air Force Station
CCDev	Commercial Crew Development
CCiCAP	Commercial Crew Integrated Capacity
CEO	Chief Executive Officer
CHIRP	Commercially Hosted Infrared Payload Flight Demonstration Program
COTS	Commercial Orbital Transportation Services
CPC	Certification Product Contract
CRS	Commercial Resupply Services
CSA	Canadian Space Agency
CSSWE	Colorado Student Space Weather Experiment
CST-100	Crew Space Transportation-100 (CST-100 Starliner)
CXBN	Cosmic X-Ray Background
DARS	Digital Audio Radio Service
DBS	Direct Broadcasting Services
DEM	Digital Elevation Model
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German space agency)
DMC	Disaster Monitoring Constellation
DMCii	DMC International Imaging, Ltd.
DTH	Direct-to-Home
EADS	European Aeronautic Defence and Space Company
EAL	Excalibur Almaz, Ltd.
ECA	Export Credit Agency
EDRS	European Data Relay System
EGNOS	European Geostationary Navigation Overlay Service

ELaNa	Educational Launch of Nanosatellites
ELI	Highly Elliptical Orbit (also refered to as HEO)
EROS	Earth Remote Observation Satellite
ESA	European Space Agency
EXIM	Export-Import Band
EXT	External or Non-Geocentric Orbit
FAA AST	Federal Aviation Administration, Office of Commercial SpaceTransportation
FCC	Federal Communications Commission
FY	Fiscal Year
FSS	Fixed Satellite Services
GEO	Geosynchronous Orbit
GIS	Geographic Information Systems
GMW	GeoMetWatch
GPS	Global Positioning System
GSLV	Geosynchronous Satellite Launch Vehicle
GSO	Geostationary Orbit
GTO	Geosynchronous Transfer Orbit
HDTV	High Definition Television Services
HPA	Hosted Payload Alliance
ICL	Imperial College London
ILS	International Launch Services
IPO	Initial Public Offering
ISRO	Indian Space Research Organization
ISS	International Space Station
ITAR	International Traffic in Arms Regulations
ITT	International Telephone & Telegraph
ITU	International Telecommunications Union
KARI	Korea Aerospace Research Institute
KSLV	Korean Space Launch Vehicle
LEO	Low Earth Orbit
LCRD	Laser Communications Relay Demonstration
LLC	Limited Liability Company
MEO	Medium Earth Orbit
MHI	Mitsubishi Heavy Industries, Ltd.
MPCV	Multi Purpose Crew Vehicle

MSS	Mobile Satellite Services
NASA	National Aeronautics and Space Administration
NEC	Nippon Electric Company
NGA	National Geospatial-Intelligence Agency
NGSO	Non-Geosynchronous Orbits
NOAA	National Oceanic and Atmospheric Administration
O3b	Other Three Billion Networks, Ltd.
OHB	Orbitale Hochtechnologie Bremen
Orbital	Orbital Sciences Corporation
PSLV	Polar Satellite Launch Vehicle
RCM	RADARSAT Constellation Mission
RRV	Reusable Return Vehicle
SAA	Space Act Agreement
SAR	Synthetic Aperture Radar
SBAS	Satellite-Based Augmentation Systems
SNC	Sierra Nevada Corporation
SpaceX	Space Exploration Technologies Corporation
SPOT	Satellite Pour l'Observation de la Terre
SSL	Space Systems Loral
SSO	Sun-Synchronous Orbit
SSTL	Surrey Satellite Technology Limited
TBD	To Be Determined
TSX	TerraSAR X-band
UAE	United Arab Emirates
UCISAT	University of California, Irvine Satellite
UHF	Ultra-High Frequency
ULA	United Launch Alliance
USLM	United States Munitions List
USAF	United States Air Force
WAAS	Wide Area Augmentation System

2017 Worldwide Orbital Launch Events

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
01-Jan-17			Long March 3B	Xichang		TJS 2	GEO	China National Space Agency (CNSA)	Shanghai Academy of Space Technology (SAST)	Communications		S	S
09-Jan-17			Kuaizhou 1A	Jiuquan		Lingqiao (Jilin-1 03)	SSO	CNSA	Chang Guang Satellite	Remote Sensing		S	S
						Kaidun 1 (Caton 1)	SSO	CNSA	Beijing Kaidun Universal Technology Co.	Remote Sensing			S
						Xingyun Shiyan 1	SSO	CNSA	Northwestern Polytechnical University	Remote Sensing			S
14-Jan-17	√	+	Falcon 9	Vandenberg AFB (VAFB)	*	Iridium NEXT 1-10	LEO	Iridium	Thales Alenia Space	Communications	$62M	S	S
14-Jan-17			SS-520 Upgrade	Uchinoura	*	TRICOM 1	LEO	University of Tokyo	University of Tokyo	Development		F	F
21-Jan-17			Atlas V 401	Cape Canaveral AFS (CCAFS)		SBIRS GEO 3	GEO	U.S. Air Force (USAF)	Lockheed Martin Corp.	Early Warning		S	S
24-Jan-17			H-IIA 204	Tanegashima		DSN 2	GEO	DSN Corp./Japan Self-Defense Forces (JSDF)	NEC Corp.	Communications		S	S
28-Jan-17	√		Soyuz 2.1b	Guiana Space Center	*	Hispasat AG1	GEO	Hispasat	OHB System	Communications	$80M	S	S
14-Feb-17	√		Ariane 5 ECA	Guiana Space Center	*	Intelsat 32e (SkyBrasil 1)	GEO	Intelsat/SKY Brasil	Airbus	Communications		S	S
					*	Telkom 3S	GEO	PT Telekomunikasi Indonesia (Telkom)	Thales Alenia Space	Communications			S
15-Feb-17			PSLV XL	Satish Dhawan		Cartosat 2D	SSO	Indian Space Research Organization (ISRO)	ISRO	Remote Sensing		S	S
						INS 1A and 1B	SSO	ISRO	ISRO	Development			S
					*	Flock 3p (88)	SSO	Planet	Planet	Remote Sensing			S
					*	Lemur 2 (8)	SSO	Spire Global	Spire Global	Remote Sensing			S
						BGUSat	SSO	Ben Gurion University	Ben Gurion University	Development			S
					*	DIDO 2	SSO	SpacePharma	SpacePharma	Scientific			S
						PEASSS	SSO	PEASSS consortium	PEASSS consortium	Development			S
						Al-Farabi 1	SSO	Al-Farabi Kazakh National University	Al-Farabi Kazakh National University	Development			S
						Nayif 1	SSO	Emirates Institution for Advanced Science and Technology (EIAST)	EIAST	Development			S
19-Feb-17	√	+	Falcon 9 FT	Kennedy Space Center (KSC)	*	Spx 10	LEO	SpaceX	SpaceX	Cargo Transport	$62M	S	S
22-Feb-17			Soyuz U	Baikonur		Progress MS-5	LEO	Roscosmos	RKK Energia	Cargo Transport		S	S
01-Mar-17			Atlas V 401	VAFB		NRO L-79 (USA 274)	LEO	National Reconnaissance Office (NRO)	Classified	ELINT		S	S
02-Mar-17			Kaitouzhe 2	Jiuquan		Tiankun 1	SSO	China Aerospace Science & Industry Corporation (CASIC)	CASIC	Development		S	S
07-Mar-17			Vega	Guiana Space Center		Sentinel 2B	SSO	European Space Agency (ESA)	Airbus	Remote Sensing		S	S
16-Mar-17	√	+	Falcon 9 FT	KSC	*	EchoStar XXIII	GEO	EchoStar	Space Systems Loral (SSL)	Communications	$62M	S	S
17-Mar-17			H-IIA 202	Tanegashima		IGS Radar 5	SSO	JSDF	Mitsubishi Electric (MELCO)	IMINT		S	S
19-Mar-17			Delta IV Medium+ (5,4)	CCAFS		WGS 9 (USA 275)	GEO	USAF	Boeing	Communications		S	S
30-Mar-17	√	+	Falcon 9 FT	KSC	*	SES 10	GEO	SES	Airbus	Communications		S	S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
12-Apr-17			Long March 3B/E	Xichang		Shijian 13	GEO	People's Liberation Army (PLA)	China Academy of Space Technlogy (CAST)	Development		S	S
18-Apr-17	√	+	Atlas V 401	CCAFS	*	OA 7 (*SS John Glenn*)	LEO	Orbital ATK	Orbital ATK	Cargo Transport	$150M	S	S
					*	Lemur 2 (4)	LEO	Spire Global	Spire Global	Remote Sensing			S
					*	Altair 1	LEO	Millennium Space Systems	Millennium Space Systems	Development			S
						IceCube	LEO	National Aeronautics and Space Administration (NASA)	NASA	Development			S
						CSUNSat 1	LEO	California State University	California State University	Development			S
						CXBN 2	LEO	Morehead State University	Morehead State University	Scientific			S
						NASA TBD	LEO	NASA	NASA	Development			
						Biarri-Point	LEO	NRO Colony-2	Various	Development			S
						QB50 (28)	LEO	von Karman Institute	Various	Scientific			S
20-Apr-17			Soyuz FG	Baikonur		Soyuz MS-4	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
20-Apr-17			Long March 7	Wenchang		Tianzhou 1	LEO	CNSA	CAST	Cargo Transport		S	S
						Silu 1	LEO	Xi'an Institute of Surveying and Mapping	Xi'an Institute of Surveying and Mapping	Remote Sensing			S
01-May-17	√	+	Falcon 9 FT	KSC		NRO L-76 (USA 276)	LEO	NRO	Classified	IMINT	$62M	S	S
04-May-17	√		Ariane 5 ECA	Guiana Space Center	*	Koreasat 7 (Mugungwha 7)	GEO	KT Corporation	Thales Alenia Space	Communications	$178M	S	S
					*	SGDC 1	GEO	Telebras	Thales Alenia Space	Communications			S
05-May-17			GSLV Mk. II	Satish Dhawan		GSAT 9	GEO	ISRO	ISRO	Communications		S	S
15-May-17	√	+	Falcon 9 FT	KSC	*	Inmarsat 5F4	GEO	Inmarsat	Boeing	Communications	$62M	S	S
18-May-17	√		Soyuz 2.1a	Guiana Space Center	*	SES 15	GEO	SES	Boeing	Communications	$80M	S	S
25-May-17	√	+	Electron	Mahia		Humanity Star	LEO	Rocket Lab	Rocket Lab	Test	$4.9M	F	F
25-May-17			Soyuz 2.1b	Plesetsk		EKS 2	ELI	Russian Ministry of Defence	RKK Energia	Early Warning		S	S
01-Jun-17	√		Ariane 5 ECA	Guiana Space Center	*	ViaSat 2	GEO	ViaSat	Boeing	Communications	$178M	S	S
					*	Eutelsat 172B	GEO	Eutelsat	Airbus	Communications			
01-Jun-17			H-IIA 202	Tanegashima		QZS 2	ELI	Japan Aerospace Exploration Agency (JAXA)	MELCO	Navigation		S	S
03-Jun-17	√	+	Falcon 9 FT	KSC	*	Spx 11	LEO	SpaceX	SpaceX	Cargo Transport	$62M	S	S
						Bird B (BRAC Onnesha)	LEO	Kyushu Institute of Technology (KIT)	Kyushu Institute of Technology (KIT)	Development			S
						Bird G (GhanaSat 1, ANUSAT 1)		Kyushu Institute of Technology (KIT)	Kyushu Institute of Technology (KIT)	Development			S
						Bird J (Toki)		Kyushu Institute of Technology (KIT)	Kyushu Institute of Technology (KIT)	Development			S
						Bird M (Mazaalai, NUMSAT 1)		Kyushu Institute of Technology (KIT)	Kyushu Institute of Technology (KIT)	Development			S
						Bird N (EduSat 1)		Kyushu Institute of Technology (KIT)	Kyushu Institute of Technology (KIT)	Development			S
05-Jun-17			LVM 3	Satish Dhawan		GSAT 19	GEO	ISRO	ISRO	Communications		S	S
08-Jun-17	√		Proton M	Baikonur	*	EchoStar XXI	GEO	EchoStar	SSL	Communications	$65M	S	S
14-Jun-17			Soyuz 2.1a	Baikonur		Progress MS-6	LEO	Roscosmos	RKK Energia	Cargo Transport		S	S
						Tanyusha-YuZGU 1	LEO	Southwestern State University (SWSU)	SWSU	Development			S
						Tanyusha-YuZGU 2	LEO	SWSU	SWSU	Development			S
						Sfera 53	LEO	Roscosmos	Roscosmos	Scientific			S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
15-Jun-17			Long March 4B	Jiuquan		HXMT (Huiyan)	SSO	CNSA	CAST	Development		S	S
						Zhuhai-1 01 and 02	SSO	Zhuhai Orbita Control Engineering Ltd.	Zhuhai Orbita Control Engineering Ltd.	Remote Sensing			S
					*	ÑuSat 3	SSO	Satellogic	Satellogic	Remote Sensing			S
18-Jun-17			Long March 3B/E	Xichang		ChinaSat 9A (Zhongxing-9A)	GEO	China Satcom	CAST	Communications		P	P
23-Jun-17			PSLV XL	Satish Dhawan		Cartosat 2E	SSO	ISRO	ISRO	Remote Sensing		S	S
					*	Lemur 2 (8)	SSO	Spire Global	Spire Global	Remote Sensing			S
						NIUSAT (Keralshree)	SSO	Noorul Islam University (NIU)	NIU	Remote Sensing			S
					*	CE-SAT 1	SSO	Canon Electronics	Canon Electronics	Remote Sensing			S
						Max Valier Sat	SSO	Gewerbeoberschule Bozen/Meran/ Amateurastronomen	Gewerbeoberschule Bozen/Meran/ Amateurastronomen	Scientific			S
						Venta 1	SSO	Ventspils University	University of Applied Sciences Bremen	Development			S
					*	CICERO 6	SSO	GeoOptics	Tyvak	Remote Sensing			S
					*	Blue Diamond	SSO	Sky and Space Global	GOMSpace	Communications			S
					*	Green Diamond	SSO	Sky and Space Global	GOMSpace	Communications			S
					*	Red Diamond	SSO	Sky and Space Global	GOMSpace	Communications			S
					*	D-Sat	SSO	D-Orbit	D-Orbit	Development			S
					*	PACSCISAT	SSO	PacSci EMC	Tyvak	Development			S
						Aalto 1	SSO	Aalto University	Aalto University	Development			S
						ROBUSTA 1B	SSO	University of Montpellier II	University of Montpellier II	Development			S
						SUCHAI	SSO	Universidad de Chile	Universidad de Chile	Development			S
						skCUBE	SSO	Slovak Organization for Space Activities	Slovak Organization for Space Activities	Development			S
						QB50 (8)	SSO	von Karman Institute	Various	Scientific			S
23-Jun-17			Soyuz 2.1v	Plesetsk		Cosmos 2519	LEO	Russian Misistry of Defence	Lavotchkin	Scientific		S	S
23-Jun-17	√	+	Falcon 9 FT	KSC	*	BulgariaSat-1	GEO	Bulsatcom	SSL	Communications	$62M	S	S
25-Jun-17	√	+	Falcon 9 FT	VAFB	*	Iridium NEXT 11-20	LEO	Iridium	Thales Alenia Space	Communications	$62M	S	S
28-Jun-17	√		Ariane 5 ECA	Guiana Space Center	*	EuropaSat (Hellas Sat 3)	GEO	Hellas Sat	Thales Alenia Space	Communications	$178M	S	S
					*	GSAT 17	GEO	ISRO	ISRO	Communications			S
02-Jul-17			Long March 5	Wenchang		Shijian 18	GEO	PLA	CAST	Communications		F	F
05-Jul-17	√	+	Falcon 9 FT	KSC	*	Intelsat 35e	GEO	Intelsat	Boeing	Communications	$62M	S	S
14-Jul-17			Soyuz 2.1a	Baikonur		Kanopus V-IK	SSO	Roscosmos	NPO VNIIEM	Remote Sensing		S	S
					*	Lemur 2 (8)	SSO	Spire Global	Spire Global	Remote Sensing			P
					*	CORVUS BC (2)	SSO	Astro Digital	Astro Digital	Remote Sensing			S
					*	CICERO (3)	SSO	GeoOptics	Tyvak	Remote Sensing			P
					*	Flock 2k (48)	SSO	Planet	Planet	Remote Sensing			P
						MKA N1 and N2	SSO	Roscosmos	Dauria Aerospace	Remote Sensing			F
						NORSAT 1 and 2	SSO	Norsk Romsenter	University of Toronto	Remote Sensing			S
						Flying Laptop	SSO	Institut für Raumfahrtsysteme	Institut für Raumfahrtsysteme	Development			S
						WNISAT 1R	SSO	Weather News Inc.	AXELSPACE	Remote Sensing			S
						Technosat	SSO	TU Berlin	TU Berlin	Development			S
					*	NanoACE	SSO	Tyvak	Tyvak	Development			S
						Mayak	SSO	Moscow State University	CosmoMayak	Development			F
						Iskra-MAI-85	SSO	Moscow Aviation Institute (MAI)	MAI	Development			F
						UTE-UESOR	SSO	Universidad Tecnológica Equinoccial (UTE)	UTE	Development			S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
28-Jul-17			Soyuz FG	Baikonur		Soyuz MS-5	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
02-Aug-17			Vega	Guiana Space Center		OPTSAT 3000	SSO	Italian Ministry of Defence	Israel Aerospace Industries (IAI)	IMINT		S	S
						VENμS	SSO	Centre National d'Etudes Spatiales (CNES)	AIA	Remote Sensing			S
14-Aug-17	√	+	Falcon 9 FT	KSC	*	Spx 12	LEO	SpaceX	SpaceX	Cargo Transport	$62M	S	S
						OSIRIS 3U	LEO	Pennsylvania State University	Pennsylvania State University	Scientific			S
						Kestrel Eye 3M	LEO	U.S. Army	Maryland Aerospace	IMINT			S
						Dellingr/RBLE	LEO	NASA	NASA	Scientific			S
						ASTERIA	LEO	Massachusetts Institute of Technology (MIT)	MIT	Development			S
16-Aug-17			Proton M	Baikonur		Blagovest 11L	GEO	Russian Ministry of Defense	ISS Reshetnev	Communications		S	S
18-Aug-17			Atlas V 401	CCAFS		TDRS M	GEO	NASA	Boeing	Communications		S	S
19-Aug-17			H-IIA 204	Tanegashima		QZS 3	ELI	JAXA	MELCO	Navigation		S	S
24-Aug-17	√	+	Falcon 9 FT	VAFB		Formosat 5	SSO	National Space Program Office (NSPO)	NSPO	Remote Sensing		S	S
26-Aug-17	√	+	Minotaur IV	CCAFS		SensorSat	LEO	Operationally Responsive Space Office	RKK Energia	Development		S	S
						DHFR	LEO	Defense Advanced Research Projects Agency (DARPA)	DARPA	Development			S
						Prometheus 2.2 and 2.4	LEO	Los Alamos National Laboratory (LANL)	LANL	Development			S
31-Aug-17			PSLV XL	Satish Dhawan		IRNSS 1H	GEO	ISRO	ISRO	Navigation		F	F
07-Sep-17			Falcon 9 FT	KSC		X-37B OTV 5 (USA 277)	LEO	USAF	Boeing	Classified		S	S
11-Sep-17	√		Proton M	Baikonur	*	Amazonas 5	GEO	Hispasat	SSL	Communications		S	S
12-Sep-17			Soyuz FG	Baikonur		Soyuz MS-6	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
22-Sep-17			Soyuz 2.1b	Plesetsk		Glonass M752	MEO	Roscosmos	ISS Reshetnev	Navigation		S	S
24-Sep-17			Atlas V 541	VAFB		NRO L-42 (USA 278)	LEO	NRO	Classified	ELINT		S	S
28-Sep-17	√		Proton M	Baikonur	*	AsiaSat 9	GEO	AsiaSat	SSL	Communications		S	S
29-Sep-17			Long March 2C	Xichang		Yaogan 30A	LEO	Chinese Academy of Sciences (CAS)	CAS	SIGINT		S	S
						Yaogan 30B	LEO	CAS	CAS	SIGINT			S
						Yaogan 30C	LEO	CAS	CAS	SIGINT			S
29-Sep-17	√		Ariane 5 ECA	Guiana Space Center	*	Intelsat 37e	GEO	Intelsat	Boeing	Communications	$178M	S	S
					*	BSat 4a	GEO	Broadcasting Satellite System Corporation (B-SAT)	SSL	Communications			S
09-Oct-17			Long March 2D	Jiuquan		VRSS 2	SSO	Bolivarian Agency for Space Activities	CAST	Remote Sensing		S	S
09-Oct-17	√	+	Falcon 9 FT	VAFB	*	Iridium NEXT 21-30	LEO	Iridium	Thales Alenia Space	Communications	$62M	S	S
09-Oct-17			H-IIA 202	Tanegashima		QZS 4	ELI	JAXA	MELCO	Navigation		S	S
11-Oct-17	√	+	Falcon 9 FT	KSC	*	SES 11 (EchoStar 105)	GEO	SES/EchoStar	Airbus	Communications	$62M	S	S
13-Oct-17			Rockot	Plesetsk		Sentinel 5P	SSO	ESA	Airbus	Remote Sensing		S	S
14-Oct-17			Soyuz 2.1a	Baikonur		Progress MS-7	LEO	Roscosmos	RKK Energia	Cargo Transport		S	S
15-Oct-17			Atlas V 421	CCASF		NRO L-52 (USA 279)	GEO	NRO	Classified	Communications		S	S
30-Oct-17	√	+	Falcon 9 FT	KSC	*	Koreasat 5A	GEO	KT Corporation	Thales Alenia Space	Communications	$62M	S	S
31-Oct-17	√	+	Minotaur C	VAFB	*	SkySat (6)	SSO	Planet	SSL	Remote Sensing	$40M	S	S
					*	Flock 3m (4)	SSO	Planet	Planet	Remote Sensing			S
05-Nov-17			Long March 3B/ YZ-1	Xichang		BeiDou 3 M1	MEO	CNSA	CAS	Navigation		S	S
						BeiDou 3 M2	MEO	CNSA	CAS	Navigation			S
08-Nov-17	√		Vega	Guiana Space Center		Mohammed VI A	LEO	Government of Morocco	Airbus	Remote Sensing	$37M	S	S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
12-Nov-17	√	+	Antares 230	Mid-Atlantic Regional Spaceport (MARS)	*	OA 8E	LEO	Orbital ATK	Orbital ATK	Cargo Transport	$80M	S	S
					*	Lemur 2 (8)	LEO	Spire Global	Spire Global	Remote Sensing			S
						OSCD (2)	LEO	The Aerospace Corp.	The Aerospace Corp.	Development			
						EcAMSat	LEO	NASA	NASA	Scientific			S
						TechEdSat 6	LEO	San Jose State University (SJSU)	SJSU	Development			S
						PropCube 2	LEO	Naval Postgraduate School (NPS)	NPS	Development			S
						CHEFSat	LEO	Naval Research Lab (NRL)	NRL	Development			S
						Asgardia 1	LEO	Asgardia Space	Asgardia Space	Development			S
14-Nov-17			Long March 4C	Taiyuan		Fengyun 3D	SSO	National Satellite Meteorological Centre	SAST	Meteorology		S	S
					*	HEAD 1	SSO	HEAD Aerospace	HEAD Aerospace	Remote Sensing			S
18-Nov-17			Delta II 7920	VAFB		NOAA 20 (JPSS 1)	SSO	National Oceanic and Atmospheric Administration (NOAA)	Ball Aerospace	Meteorology		S	S
						Buccaneer RMM	SSO	University of South Wales	University of South Wales	Development			S
						EagleSat	SSO	Embry-Riddle Aeronautical University	Embry-Riddle Aeronautical University	Development			S
						MakerSat 0	SSO	Northwest Nazarene University	Northwest Nazarene University	Development			S
						MiRaTA	SSO	MIT	MIT	Development			S
						RadFxSat (Fox 1B)	SSO	AMSAT, Vanderbilt University	AMSAT	Communications			S
21-Nov-17			Long March 6	Taiyuan		Jilin 1-04	SSO	Changguang Satellite Technology Company (CSTC)	CSTC	Remote Sensing		S	S
						Jilin 1-05	SSO	CSTC	CSTC	Remote Sensing			S
						Jilin 1-06	SSO	CSTC	CSTC	Remote Sensing			S
24-Nov-17			Long March 2C	Xichang		Yaogan 30D	LEO	CAS	CAS	SIGINT		S	S
						Yaogan 30E	LEO	CAS	CAS	SIGINT			S
						Yaogan 30F	LEO	CAS	CAS	SIGINT			S
28-Nov-17			Soyuz 2.1b	Vostochny		Meteor-M No.2-1	SSO	Roshydromet	NPO VNIIEM	Remote Sensing		F	F
					*	Lemur 2 (10)	SSO	Spire Global	Spire Global	Remote Sensing			F
					*	CORVUS BC (2)	SSO	Astro Digital	Astro Digital	Remote sensing			F
						Baumanets 2	SSO	Bauman Moscow State Technical University	Bauman Moscow State Technical University	Development			F
						LEO Vantage 2	SSO	TeleSat Canada	SSL	Development			F
					*	IDEA-OSG 1	SSO	Astroscale	Astroscale	Development			F
						AISSat 3	SSO	Norsk Romsenter	UTIAS	Remote Sensing			F
						D-Star One	SSO	German Orbital Systems GmbH	German Orbital Systems GmbH	Development			F
						SEAM	SSO	Various	Various	Development			F
02-Dec-17			Soyuz 2.1b	Plesetsk		Cosmos 2524	LEO	Russian Ministry of Defense	TsSKB-Progress	ELINT		S	S
03-Dec-17			Long March 2D	Jiuquan		LKW 1	LEO	PLA	CAS	Remote Sensing		S	S
10-Dec-17			Long March 3B	Xichang		Alcomsat 1	GEO	Algerian Space Agency	CAST	Communications		S	S
12-Dec-17			Ariane 5 ES	Guiana Space Center		Galileo-FOC FM15 (Nicole)	MEO	European GNSS Agency	OHB System	Navigation		S	S
						Galileo-FOC FM16 (Zofia)	MEO	European GNSS Agency	OHB System	Navigation			S
						Galileo-FOC FM17 (Alexandre)	MEO	European GNSS Agency	OHB System	Navigation			S
						Galileo-FOC FM18 (Irina)	MEO	European GNSS Agency	OHB System	Navigation			S
15-Dec-17	√	+	Falcon 9 FT	CCAFS	*	Spx 13	LEO	SpaceX	SpaceX	Cargo Transport	$62M	S	S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
17-Dec-17			Soyuz FG	Baikonur		Soyuz MS-7	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
23-Dec-17			H-IIA 202	Tanegashima		GCOM C (Shikisai)	SSO	JAXA	JAXA	Remote Sensing		S	S
						SLATS (Tsubame)	SSO	JAXA	MELCO	Development			S
23-Dec-17	√	+	Falcon 9 FT	VAFB	*	Iridium NEXT 31-40	LEO	Iridium	Thales Alenia Space	Communications	$62M	S	S
23-Dec-17			Long March 2D	Jiuquan		LKW 2	LEO	PLA	CAS	Remote Sensing		S	S
25-Dec-17			Long March 2C	Xichang		Yaogan 30G	LEO	CAS	CAS	SIGINT		S	S
						Yaogan 30H	LEO	CAS	CAS	SIGINT			S
						Yaogan 30I	LEO	CAS	CAS	SIGINT			S
26-Dec-17			Zenit 3F	Baikonur		AngoSat 1	GEO	Government of Angola	RKK Energia	Communications		S	S

√ Denotes commercial launch, defined as a launch that is internationally competed or FAA-licensed, or privately financed launch activity. For multiple manifested launches, certain secondary payloads whose launches were commercially procured may also constitute a commercial launch.
\+ Denotes FAA-licensed launch.
* Denotes a commercial payload, defined as a spacecraft that serves a commercial function or is operated by a commercial entity.
L and M refer to the outcome of the Launch and Mission: S=Success, P=Partial Success, F=Failure.
Notes: All prices are estimates.
All launch dates are based on local time at the launch site.

Launch Vehicle Fact Sheet

Alpha 1.0

U.S.-based company Firefly Aerospace Inc. (“Firefly”) plans to offer the Alpha launch vehicle to service the burgeoning small-satellite industry. Alpha is a two-stage vehicle, utilizing composite materials to create strong lightweight primary structures such as the airframe and propellant tanks.

Led by CEO Tom Markusic and a team of space industry veterans, Firefly has recently reorganized in response to a funding shortfall in the fall of 2016. Firefly Aerospace is now majority-owned by Noosphere Ventures, the strategic venture arm of Noosphere Global, which has the resources to independently and fully fund Firefly through first launch. Firefly has re-hired much of its core team and the company is on track to achieve its launch goals. Work on the upgraded Alpha launch vehicle, scheduled for launch in mid-2019, and the conceptual design of its larger Beta vehicle, is advancing rapidly through engineering and regular engine testing.

Texas is home to both Firefly’s headquarters and test facilities. A 20,000-square foot design campus in Cedar Park, Texas, just north of Austin, houses the corporate headquarters, engineering staff, prototyping facilities and machine shop. Firefly is establishing additional international offices and strategic partnerships to effectively serve the global small-satellite launch market.

Launch Service Provider
Firefly Aerospace, Inc.

Organization Headquarters
USA

Manufacturer
Firefly Aerospace, Inc.

Mass, kg (lb)
54,000 (119,050)

Length, m (ft)
29 (95)

Diameter, m (ft)
2 (6.6)

Year of Planned First Launch
2019

Launch Site
Undisclosed

LEO Capacity, kg (lb)
1,000 (2,205)

SSO Capacity, kg (lb)
650 (1,433)

Estimated Price per Launch
$10M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

Publication produced for FAA AST by The Tauri Group under contract.

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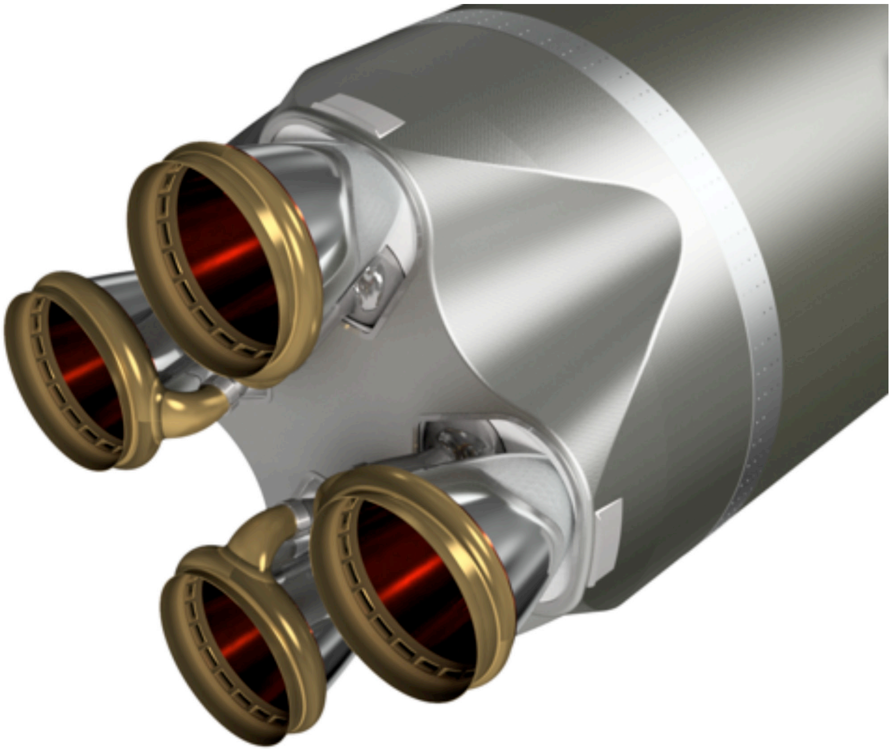
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Alpha 1.0



A 3D diagram of the four Reaver engines that will be used to power the Alpha's first stage. (Source: Firefly Aerospace)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	5 (16.4)	2 (6.6)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	18.3 (60)	5.9 (19.4)
Diameter, m (ft)	1.8 (6)	1.8 (6)
Manufacturer	Firefly Aerospace, Inc.	Firefly Aerospace, Inc.
Propellant	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	729 (164,000)	80 (18,000)
Engine(s)	4 x Reaver	1 x Lightning
Engine manufacturer	Firefly Aerospace	Firefly Aerospace
Engine thrust, kN (lbf)	182 (41,000)	80 (18,000)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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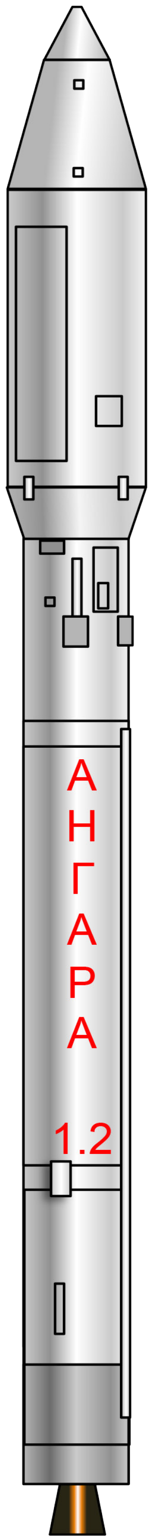
Launch Vehicle Fact Sheet

Angara 1.2



Russia's Angara series of launch vehicles is being developed by Khrunichev, designed to ultimately replace the Proton M and a variety of medium and small vehicles like Dnepr and Rockot. The Universal Rocket Module (URM-1) forms the modular core of every Angara vehicle.

The smallest version of the Angara family is called the Angara 1.2. This version features a URM-1 core and a modified Block I second stage.

The Angara 1.2 made its inaugural suborbital flight on July 9, 2014 (the mission was called Angara 1.2PP for "pervyy polyot," or "first flight"). This flight lasted 22 minutes and carried a mass simulator weighing 1,430 kilograms (3,150 pounds). The URM-1 core stage was supplemented by a partially fueled URM-2, allowing each of the major components of Angara A5 to be flight tested before that version's first orbital launch, conducted on later that year.

International Launch Services (ILS) announced its first Angara 1.2 contract on August 1, 2016 for the launch of KOMPSAT-6, a 1,700-kilogram remote sensing satellite owned and operated by Korea Aerospace Research Institute (KARI). KOMPSAT-6 is scheduled for launch in 2020. KARI's Naro-1 launch vehicle, which successfully placed a satellite into orbit for the first time in 2013, uses a URM-1 for the first stage.

Launch Service Provider
VKS/Roscosmos/ILS

Organization Headquarters
Russia

Manufacturer
Khrunichev

Mass, kg (lb)
171,000 (376,990)

Length, m (ft)
42.2 (138.5)

Diameter, m (ft)
2.9 (9.5)

Year of Planned First Launch
2018

Launch Sites
Plesetsk (LS-35)
Vostochny (LS-1A)

LEO Capacity, kg (lb)
3,000 (6,614)

SSO Capacity, kg (lb)
1,990 (4,387)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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Launch Vehicle Fact Sheet

Angara 1.2

FAA AST

An Angara 1.2 vehicle is prepared for launch, in this case for a suborbital test flight that took place in 2014. (Source: Khrunichev)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	9.2 (30.2)	2.9 (9.5)

	1st Stage	2nd Stage
Stage designation	URM-1	URM-2
Length, m (ft)	25.1 (82.3)	8.5 (27.9)
Diameter, m (ft)	2.9 (9.5)	2.9 (9.5)
Manufacturer	Khrunichev	Khrunichev
Propellant	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	127,362 (280,785)	35,222 (77,651)
Total thrust, kN (lbf)	1,922 (432,083)	294.3 (66,161)
Engine(s)	1 x RD-191	1 x RD-0124A
Engine manufacturer	NPO Energomash	DB Khimmash
Engine thrust, kN (lbf)	1,922 (432,083)	294.3 (66,161)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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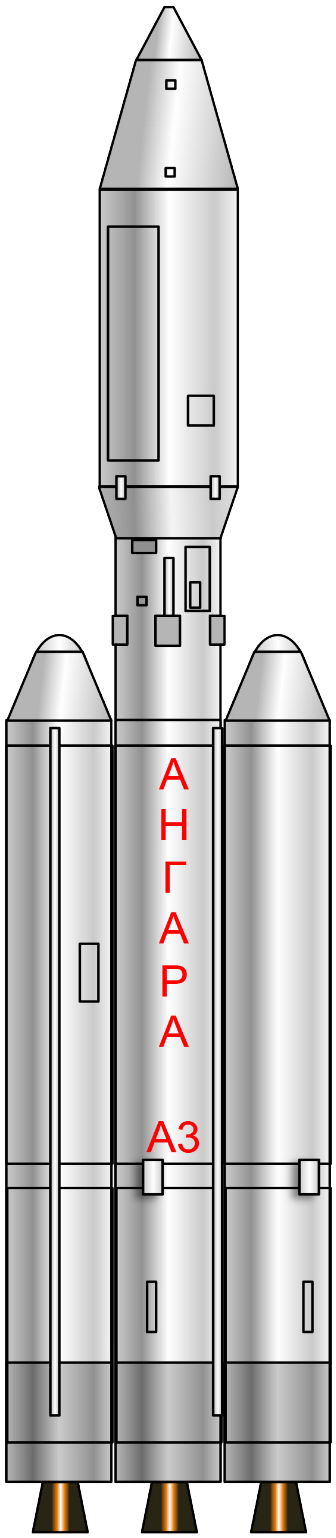
Launch Vehicle Fact Sheet

Angara A3



The Khrunichev State Research and Production Space Center has been developing the Angara series of vehicles to replace virtually all vehicles in service with the exception of the Soyuz. The Angara 1.2 is expected to replace the Rockot and Dnepr while the Angara A5 is expected to replace the Proton M. The Universal Rocket Module (URM-1) forms the modular core of every Angara vehicle, with a URM-2 used as a second stage. A Breeze-M upper stage serves as an optional third stage.

The Angara A3 employs three URM-1 boosters, two less than the Angara A5. Nevertheless, the Angara A3 is largely a conceptual vehicle since no demand for it has materialized as of the printing of this report.

Launch Service Provider
VKS/Roscosmos/ILS

Organization Headquarters
Russia

Manufacturer
Khrunichev

Mass, kg (lb)
481,000 (1,060,423)

Length, m (ft)
45.8 (150.3)

Diameter, m (ft)
8.9 (29.2)

Year of Planned First Launch
TBD

Launch Sites
Plesetsk (LS-35)
Vostochny (LS-1A)

GTO Capacity, kg (lb)
2,400-3,600 (5,291-7,937)

LEO Capacity, kg (lb)
14,000 (30,865)

SSO Capacity, kg (lb)
2,570 (5,666)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Angara A3

FAA AST

Models of the Angara family, as seen at the MAKS 2009 Airshow in Moscow, Russia. The Angara A3 second from left. (Source: Wikipedia)

Fairing	Length, m (ft)	Diameter, m (ft)
Short Fairing	13.3 (43.6)	4.4 (14.4)
Long Fairing	15.3 (50.2)	4.4 (14.4)

	Liquid Boosters*	1st Stage	2nd Stage	3rd Stage
Stage designation	2 x URM-1	URM-1	URM-2	Breeze-M
Length, m (ft)	25.6 (84)	25.6 (84)	6.9 (22.6)	2.7 (8.9)
Diameter, m (ft)	2.9 (9.5)	2.9 (9.5)	3.6 (11.8)	4 (13)
Manufacturer	Khrunichev	Khrunichev	Khrunichev	Khrunichev
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene	N_2O_4/UDMH
Propellant mass, kg (lb)	127,362 (280,785)	127,362 (280,785)	35,222 (77,651)	19,800 (43,651)
Total thrust, kN (lbf)	3,844 (864,166)	1,922 (432,083)	294.3 (66,161)	19.2 (4,411)
Engine(s)	1 x RD-191	1 x RD-191	1 x RD-0124A	1 x 14D30
Engine manufacturer	NPO Energomash	NPO Energomash	DB Khimmash	DB Khimmash
Engine thrust, kN (lbf)	1,922 (432,083)	1,922 (432,083)	294.3 (66,161)	19.6 (4,411)

* *Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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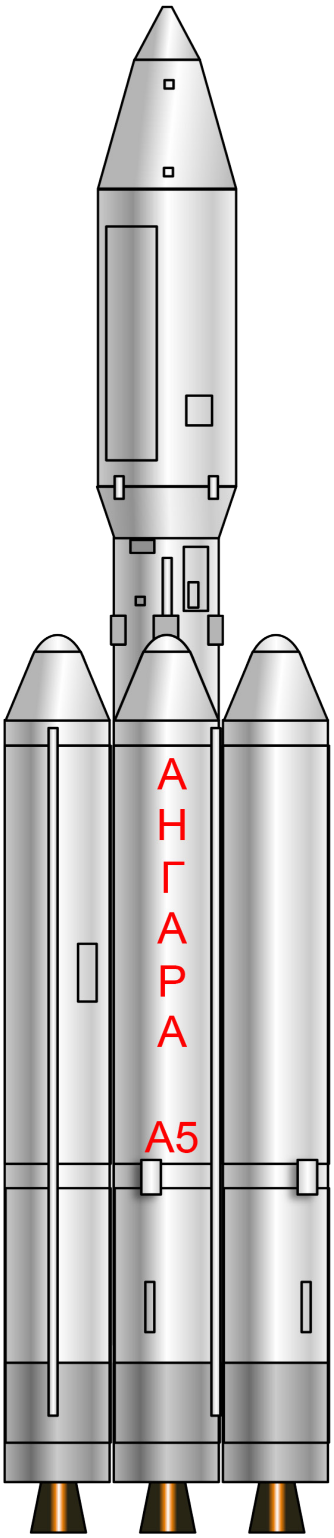
Launch Vehicle Fact Sheet

Angara A5



The Khrunichev State Research and Production Space Center has been developing the Angara series of vehicles to replace virtually all vehicles in service with the exception of the Soyuz. The Angara 1.2 is expected to replace the Rockot and Dnepr while the Angara A5 is expected to replace the Proton M within 5-7 years. The Universal Rocket Module (URM-1) forms the modular core of every Angara vehicle, with a URM-2 used as a second stage. A Breeze-M upper stage serves as an optional third stage.

The baseline Angara A5 has a greater capacity than the Proton M and burns a cleaner propellant mix that the Proton's UDMH. However, it is worth noting that the Angara A5 performance is reduced because it will launch from Plestesk Cosmodrome, which is further north than the Baikonur Cosmodrome, home of the Proton. This means the Angara A5 will have a similar geosynchronous orbit (GEO) capacity to the Proton M.

The first flight of Angara A5 took place in December 2014 carrying a test payload and was successful.

A launch complex is being developed at Russia's new Vostochny Cosmodrome to accommodate the Angara A5. Launches from this complex are expected to begin sometime after 2025.

Launch Service Provider
VKS/Roscosmos/ILS

Organization Headquarters
Russia

Manufacturer
Khrunichev

Mass, kg (lb)
773,000 (1,704,173)

Length, m (ft)
64 (210)

Diameter, m (ft)
8.9 (29.2)

Year of First Launch
2014

Number of Orbital Launches
1

Reliability
100%

Launch Sites
Plesetsk (LS-35)
Vostochny (LS-1A)

GTO Capacity, kg (lb)
5,400-7,500 (11,905-16,535)

LEO Capacity, kg (lb)
24,000 (52,911)

SSO Capacity, kg (lb)
Undisclosed

Estimated Price per Launch
$100M

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Launch Vehicle Fact Sheet

Angara A5

The inaugural Angara A5 vehicle being prepared for its first launch, which took place in 2014 from Plesetsk Cosmodrome. (Source: Khrunichev)

Fairing	Length, m (ft)	Diameter, m (ft)
Short Fairing	13.3 (43.6)	4.4 (14.4)
Long Fairing	15.3 (50.2)	4.4 (14.4)

	Liquid Boosters*	1st Stage	2nd Stage	3rd Stage
Stage designation	4 x URM-1	URM-1	URM-2	Breeze-M
Length, m (ft)	25.6 (84)	25.6 (84)	6.9 (22.6)	2.7 (8.9)
Diameter, m (ft)	2.9 (9.5)	2.9 (9.5)	3.6 (11.8)	4 (13)
Manufacturer	Khrunichev	Khrunichev	Khrunichev	Khrunichev
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene	N_2O_4/UDMH
Propellant mass, kg (lb)	127,362 (280,785)	127,362 (280,785)	35,222 (77,651)	19,800 (43,651)
Total thrust, kN (lbf)	7,688 (1,728,331)	1,922 (432,083)	294.3 (66,161)	19.6 (4,406)
Engine(s)	1 x RD-191	1 x RD-191	1 x RD-0124A	1 x 14D30
Engine manufacturer	NPO Energomash	NPO Energomash	DB Khimmash	DB Khimmash
Engine thrust, kN (lbf)	1,922 (432,083)	1,922 (432,083)	294.3 (66,161)	19.6 (4,406)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Antares

In 2013, Orbital Sciences Corporation (now Orbital ATK) began offering its Antares, a two-stage vehicle designed to launch government and commercial satellites to low Earth orbit (LEO), Cygnus cargo modules to the International Space Station (ISS), and missions requiring Earth escape trajectories. The Antares is also available under the NASA Launch Services (NLS) II contract for future science missions.

The Antares is the first cryogenically fueled vehicle produced by Orbital ATK. The first version of the vehicle family, the Antares 100 series powered by AJ26 engines, has been discontinued in favor of the Antares 200 series powered by RD-181 engines.

The Antares 200 series consists of a first stage produced by Ukrainian Yuzhnoye Design Office (Yuzhnoye) powered by twin NPO Energomash RD-181 engines, each of which produces about 400 kN more thrust than a single AJ26. A CASTOR-30XL is used for the second stage. Orbital ATK also offers an optional Bi-Propellant Third Stage (BTS) for high-energy performance needs. The vehicle is topped off with a payload adapter and a 4-meter (13-foot) diameter fairing. In 2008, NASA selected the Antares/Cygnus system to receive funding under the Commercial Orbital Transportation Services (COTS) program. NASA ultimately selected Orbital and its competitor SpaceX to provide cargo transportation to the ISS under a Commercial Resupply Services (CRS) contract.

The fifth launch of Antares, which took place in October 2014, ended in a launch failure. Following the accident, Orbital ATK preceded with development of the 200 series. An Antares 230 successfully launched almost exactly two years later in October 2016.

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
530,000 (1,168,450)

Length, m (ft)
40.5 (132.9)

Diameter, m (ft)
3.9 (12.8)

Year of First Launch
2013

Number of Orbital Launches
7

Reliability
86%

Launch Site
MARS (Pad 0-A)

GTO Capacity, kg (lb)
Undisclosed

LEO Capacity, kg (lb)
6,200-6,600 (13,669-14,551)

SSO Capacity, kg (lb)
2,100-3,400 (4,630-7,496)

Estimated Price per Launch
$80M-$85M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Antares

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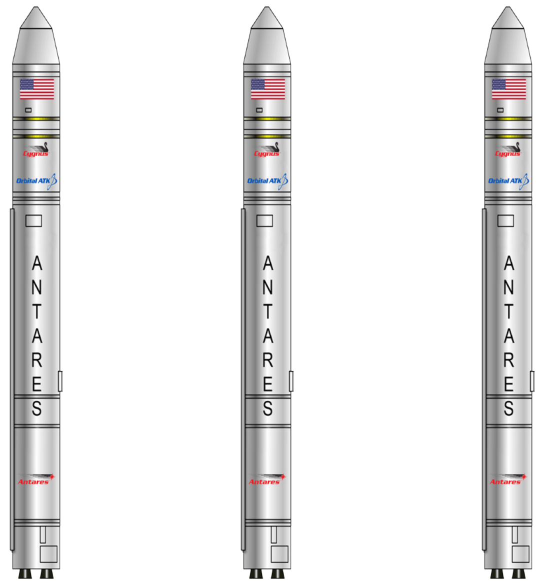

Antares 230 **Antares 231** **Antares 232**

The Antares is offered in three variants. The first stage, which is common to all variants, is outfitted with a CASTOR 30XL solid motor upper stage. The vehicle can have no third stage, or an option between a Bi-Propellant Third Stage (BTS) or a STAR 48. The same fairing is used for all six versions.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	9.9 (32.5)	3.9 (12.8)

	1st Stage	2nd Stage	3rd Stage Option	3rd Stage Option
Stage designation	N/A	CASTOR-30XL	STAR-48V	Bi-Propellant Third Stage (BTS)
Length, m (ft)	25 (82)	30B: 4.17 (13.7) 30XL: 5.99 (19.7)	2 (6.6)	1.8 (5.9)
Diameter, m (ft)	3.9 (12.8)	2.34 (7.7)	1.2 (3.9)	1.7 (5.6)
Manufacturer	KB Yuzhnoye	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	LOX/Kerosene	Solid	Solid	N_2O_4/UDMH
Propellant mass, kg (lb)	240,000 (529,109)	24,196 (53,343)	2,010 (4,431)	–
Total thrust, kN (lbf)	3,648 (820,000)	396.3 (89,092)	77.8 (17,490)	–
Engine(s)	2 x RD-181	–	–	–
Engine manufacturer	NPO Energomash	–	–	Orbital ATK
Engine thrust, kN (lbf)	1,824 (410,000)	396.3 (89,092)	77.8 (17.490)	–

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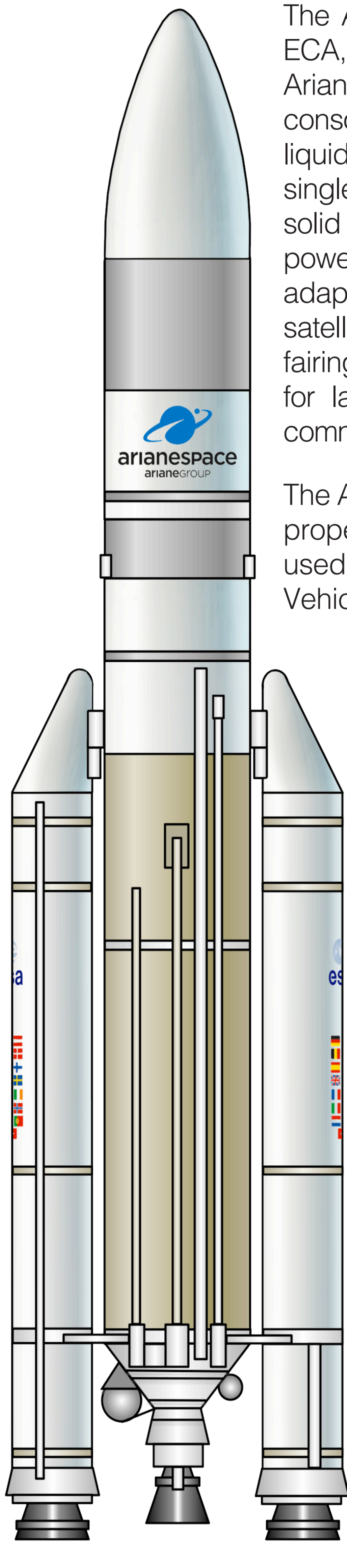
Launch Vehicle Fact Sheet

Ariane 5 ECA



The Ariane 5, technically the Ariane 5 ECA, is the workhorse of France-based Arianespace, a European launch consortium. The Ariane 5 consists of a liquid-fueled core stage powered by a single Vulcain 2 engine, two strap-on solid boosters, a cryogenic upper stage powered by an HM7B engine, a payload adapter that can accommodate two satellites (called SYLDA), and a payload fairing. The Ariane 5 ECA is optimized for launches of two geosynchronous communications satellites.

The Ariane 5 ES version with a storable propellant upper stage engine was used to launch the Automated Transfer Vehicle (ATV) to the International Space Station (ISS) and very large satellites like Envisat. This vehicle will also be used for some launches of the Galileo global navigation satellite system.

Arianespace oversees the procurement, quality control, launch operations, and marketing of the Ariane 5. A new joint venture, called ArianeGroup and established in 2015, is the prime contractor for Ariane 5 manufacturing. The Ariane 5 has launched 83 times since its introduction in 1996, with 69 consecutive successes since 2003. The Ariane 5 ECA variant has flown 53 times.

In December 2014, the European Space Agency (ESA) authorized development of the Ariane 6 vehicle as an eventual replacement for the Ariane 5. The new vehicle will be offered in two variants beginning in 2020. The Ariane 5 ECA will be phased out by 2023.

Launch Service Provider
Arianespace

Organization Headquarters
France

Manufacturer
ArianeGroup

Mass, kg (lb)
780,000 (1,719,606)

Length, m (ft)
54.8 (179.8)

Diameter, m (ft)
5.4 (17.7)

Year of First Launch
1996

Number of Orbital Launches
71 (ECA and ES versions)

Reliability
99%

Launch Site
Guiana Space Center (ELA-3)

GTO Capacity, kg (lb)
10,500 (23,149)

LEO Capacity, kg (lb)
20,000 (44,092)

SSO Capacity, kg (lb)
10,000+ (22,046+)

Estimated Price per Launch
$178M

The new vehicle will be offered in two variants beginning in 2020. The Ariane 5 ECA will be phased out by 2023.

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Launch Vehicle Fact Sheet

Ariane 5 ECA

An Ariane 5 ECA sends SGDC and KOREASAT-7 into orbit on May 4, 2017. (Source: Arianespace)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	17 (55.8)	5.4 (17.7)

	SRB*	1st Stage	2nd Stage
Stage designation	EAP	EPC	ESC-A
Length, m (ft)	31.6 (103.7)	30.5 (100.1)	4.7 (15.4)
Diameter, m (ft)	3.1 (10.2)	5.4 (17.7)	5.4 (17.7)
Manufacturer	ArianeGroup	ArianeGroup	ArianeGroup
Propellant	Solid	LOX/LH$_2$	LOX/LH$_2$
Propellant mass, kg (lb)	240,000 (529,109)	170,000 (374,786)	14,900 (32,849)
Total thrust, kN (lbf)	7,080 (1,591,647)	960 (215,817)	67 (15,062)
Engine(s)	—	1 x Vulcain 2	1 x HM-7B
Engine manufacturer	—	Airbus Safran Launchers	Airbus Safran Launchers
Engine thrust, kN (lbf)	—	960 (215,817)	67 (15,062)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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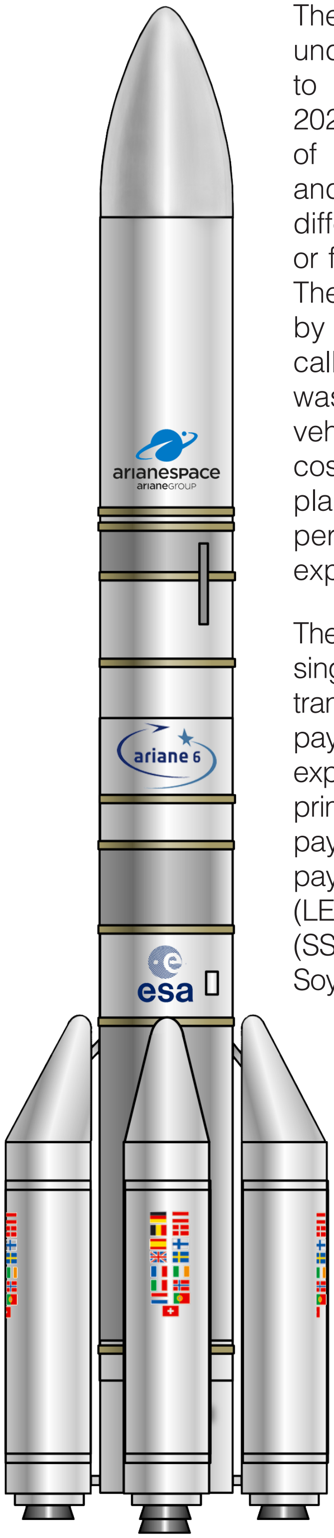
Launch Vehicle Fact Sheet

Ariane 6



The Ariane 6 family currently under development is expected to replace the Ariane 5 ECA by 2023. The family will be composed of two variants, the Ariane 62 and the Ariane 64, with the main differentiator being the use of two or four solid boosters, respectively. The vehicle will be manufactured by a newly established consortium called ArianeGroup. ArianeGroup was formed to streamline launch vehicle manufacturing and reduce costs. The maximum throughput planned is 12 Ariane 6 launches per year, an operational tempo also expected to reduce launch costs.

The Ariane 62 will primarily be used for single launches to geosynchronous transfer orbit (GTO) and for some payloads destined for deep space exploration. The Ariane 64 will primarily be used for dual-manifested payloads to GTO. Small and medium payloads destined for low Earth orbit (LEO) or Sun-synchronous orbits (SSO) will be handled using the Soyuz 2 or Vega vehicles also offered by Arianespace.

The decision to move forward on the Ariane 6 was made in December 2014. In August 2015, the European Space Agency (ESA) signed contracts for the development of the Ariane 6, its launch infrastructure, and a new variant of the Vega called Vega C. The Vega C is a related development program because the first stage of that vehicle, the P120C, will serve as the solid booster for Ariane 6.

Launch Service Provider
Arianespace

Organization Headquarters
France

Manufacturer
ArianeGroup

Mass, kg (lb)
530,000–860,000
(1,168,450-1,895,975)

Length, m (ft)
63 (207)

Diameter, m (ft)
5.4 (18)

Year of Planned First Launch
2020

Launch Site
Guiana Space Center (ELA-3)

GTO Capacity, kg (lb)
4,500-10,500 (9,921-23,149)

LEO Capacity, kg (lb)
20,000 (44,000) *est.*

SSO Capacity, kg (lb)
4,500 (9,921)

Estimated Price per Launch
$94M-$117M

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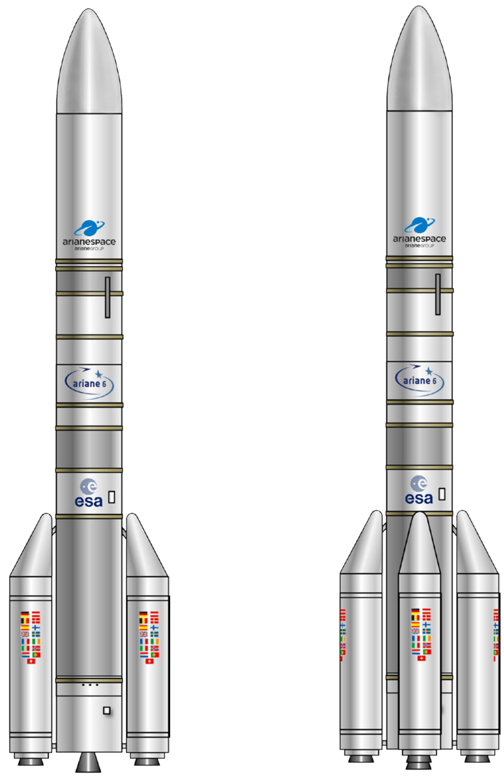
Launch Vehicle Fact Sheet

Ariane 6



Ariane 62 Ariane 64

Two variants of the Ariane 6 will be available. The Ariane 62 will primarily be used for singular missions to GTO, whereas the Ariane 64 will be used for dual-manifested payloads to GTO.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	15 (49) *est.*	5.4 (18)

	Ariane 62 SRB*	Ariane 64 SRB*	1st Stage	2nd Stage
Stage designation	P120C	P120C	2nd Stage	3rd Stage
Length, m (ft)	11.7 (38.4)	11.7 (38.4)	40 (131) *est*	15 (49) *est*
Diameter, m (ft)	3.4 (11.2)	3.4 (11.2)	5.4 (18)	5.4 (18)
Manufacturer	ArianeGroup	ArianeGroup	ArianeGroup	ArianeGroup
Propellant	Solid	Solid	LOX/H_2	LOX/H_2
Propellant mass, kg (lb)	240,000 (529,109)	480,000 (1,058,219)	140,000 (308,647)	31,000 (68,343)
Total thrust, kN (lbf)	9,000 (2,023,280)	18,000 (4,046,561)	1,370 (307,988)	180 (40,466)
Engine(s)	—	—	1 x Vulcain 2.1	1 x Vinci
Engine manufacturer	—	—	ArianeGroup	ArianeGroup
Engine thrust, kN (lbf)	—	—	1,370 (310,000)	180 (40,466)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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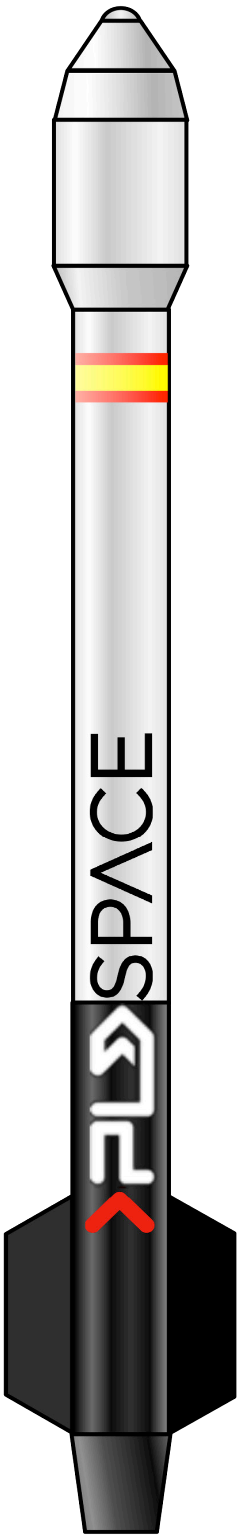
Launch Vehicle Fact Sheet

Arion 2



PLD Space, based in Spain, is developing a small, 3-stage orbital launch vehicle called Arion 2. The Arion 2 is designed to be reusable and the company is hoping to manage up to 10 launch campaigns per year. The Arion 2 is also marketed as “ITAR-free,” meaning that the vehicle is devoid of components falling under the U.S. International Traffic in Arms Regulations (ITAR) regulations. The vehicle will be launched from El Arenosillo test center in the southern part of Spain. The Arion 2 is based upon the single-stage Arion 1, a suborbital variant also under development. Though neither vehicle has flown, the company has conducted 30 hot fire tests of the first stage engine. Details provided in the tables refer to the Arion 2 vehicle.

In 2017, PLD Space was awarded a $7M investment round by satellite ground systems company GMV to support development of the Arion 1. In 2016, PLD Space received $1.56M from the Spanish government for continued development of the Arion’s liquid rocket engines. In April 2016, the company disclosed that it has signed $45M in pre-sales with a variety of payload customers. In December 2015, PLD Space was awarded $334,000 by the European Commission for propulsion research and development.

The first flight of the suborbital Arion 1 is expected in 2018. The first flight of Arion 2 is planned for 2020.

PLD Space is also offering the option to use Arion 2 vehicle to launch 5-kilogram (11-pound) payloads to the Moon. The company plans to conduct its first mission to the Moon in 2023.

Launch Service Provider
PLD Space

Organization Headquarters
Spain

Manufacturer
PLD Space

Mass, kg (lb)
7,000 (15,432)

Length, m (ft)
19.2 (63)

Diameter, m (ft)
1.2 (3.9)

Year of Planned First Launch
2020

Launch Sites
El Arenosillo
Canary Islands

LEO Capacity, kg (lb)
150 (331)

Estimated Price per Launch
$4.8M-$5.5M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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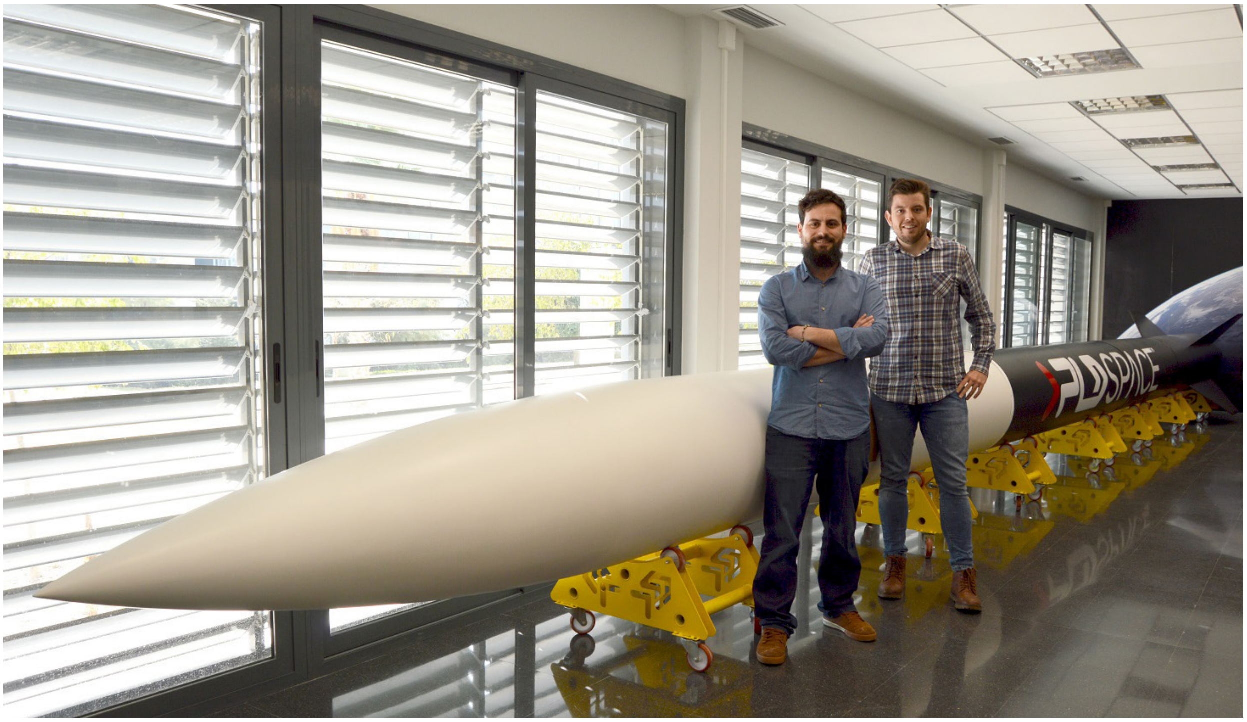
Launch Vehicle Fact Sheet

Arion 2



Raúl Verdú and Raúl Torres, founders of the company PLD Space, based in Alicante. (Source: PLD Space)

Fairing	Length, m (ft)	Diameter, m (ft)
Classic Fairing	1.4 (4.6)	1.2 (3.9)
Enhanced Fairing	3.6 (11.8)	1.4 (4.6)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	10.8 (35.4)	4.8 (15.7)	1.2 (3.9)
Diameter, m (ft)	1.2 (3.9)	1.2 (3.9)	1.2 (3.9)
Manufacturer	PLD Space	PLD Space	PLD Space
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	60 (13,489)	Undisclosed	Undisclosed
Engine(s)	2 x Neton 1	1 x TBD	1 x TBD
Engine manufacturer	PLD Space	PLD Space	PLD Space
Engine thrust, kN (lbf)	30 (6,744)	Undisclosed	Undisclosed

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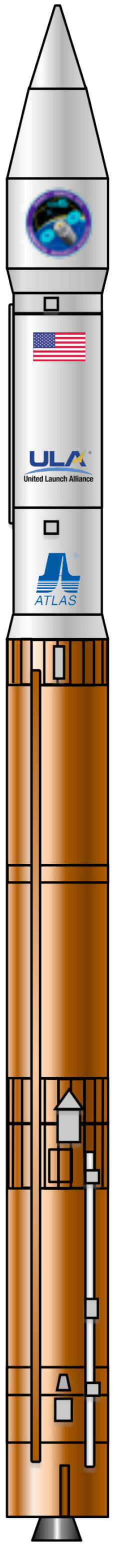
Launch Vehicle Fact Sheet

Atlas V



The Atlas V family is a product of the U.S. Air Force's Evolved Expendable Launch Vehicle Program (EELV), begun in 1995. Lockheed Martin originally developed the Atlas V, but manufacturing and operations are now conducted by United Launch Alliance (ULA), a joint company between Lockheed Martin and Boeing. ULA markets the vehicle to the U.S. Government and Lockheed Martin Commercial Launch Services markets to commercial clients worldwide. In 2010, ULA began the process of certifying Atlas V for human missions, to launch NASA astronauts to low Earth orbit (LEO). ULA has an agreement to launch Boeing's CST-100 Starliner, a crewed vehicle designed to service the International Space Station (ISS).

Atlas V consists of the Common Core Booster (CCB) powered by a Russian RD-180 engine, a combination of up to five solid rocket boosters, a Centaur upper stage powered by either one or two Pratt & Whitney Rocketdyne (PWR) RL10A-4-2 engines, a payload adapter, and a payload fairing. The vehicle variants are described in two groups: Atlas V 400 series and Atlas V 500 series. The first number of the three-digit designator indicates the diameter of the fairing in meters, the second number indicates the number of Aerojet solid rocket boosters used (zero to five), and the third number indicates the number of RL10A-4-2 engines employed by the Centaur upper stage (one or two).

The Atlas V family debuted in 2002 with the successful launch of an Atlas V 401 from Cape Canaveral Air Force Station (CCAFS) and can launch payloads to any desired orbit. It will be replaced with ULA's Vulcan family beginning in 2019, with full replacement expected shortly after 2023.

In 2015, ULA selected Orbital ATK as the provider of solid motors for the Atlas V, replacing the AJ-60A motors. First flight of an Atlas V with the new GEM-63 motors is expected in 2018.

Launch Service Provider
ULA/LMCLS

Organization Headquarters
USA

Manufacturer
ULA

Mass, kg (lb)
401: 333,731 (734,208)
551: 568,878 (1,251,532)

Length, m (ft)
60.6-75.5 (198.7-247.5)

Diameter, m (ft)
3.8 (12.5)

Year of First Launch
2002

Number of Orbital Launches
74

Reliability
100%

Launch Sites
CCAFS (SLC-40)
VAFB (SLC-3E)

GTO Capacity, kg (lb)
2,690-8,900 (5,930-19,621)

LEO Capacity, kg (lb)
8,123-18,814 (17,908-41,478)

SSO Capacity, kg (lb)
6,424-15,179 (14,163-33,464)

Estimated Price per Launch
$109M-$179M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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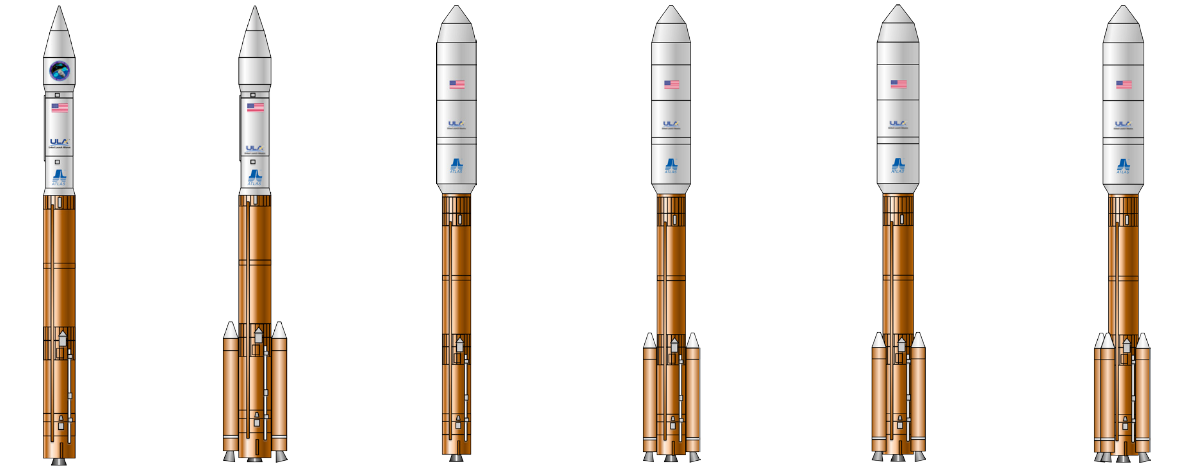
Launch Vehicle Fact Sheet

Atlas V

The Atlas V family consists of 18 variants, though only nine variants have flown to date. The Atlas V variants are defined by the number of solid rocket boosters attached to the CCB (between zero and 5), the type of Centaur upper stage employed (either a single or dual engine), and the type of fairing (4-meter or 5-meter diameter).



Atlas V 401/411 | **Atlas V 421/431** | **Atlas V 501/511** | **Atlas V 521/531** | **Atlas V 541** | **Atlas V 551**

Fairing	Length, m (ft)	Diameter, m (ft)
4m Large Payload Fairing	12 (39.3)	4 (13)
4m Extended Payload Fairing	12.9 (42.3)	4 (13)
4m Extra Extended Payload Fairing	13.8 (45.3)	4 (13)
5m Large Payload Fairing	20.7 (68)	5 (16.4)
5m Extended Payload Fairing	23.5 (77)	5 (16.4)
5m Extra Extended Payload Fairing	26.5 (87)	5 (16.4)

	1st Stage	SRB*	2nd Stage Option	2nd Stage Option
Stage designation	Common Core Booster	AJ-60A	Single Engine Centaur	Dual Engine Centaur
Length, m (ft)	32.5 (106.6)	20 (65.6)	12.7 (41.7)	12.7 (41.7)
Diameter, m (ft)	3.8 (12.5)	1.6 (5.2)	3.1 (10.2)	3.1 (10.2)
Manufacturer	ULA	Aerojet Rocketdyne	ULA	ULA
Propellant	LOX/Kerosene	Solid	LOX/LH_2	LOX/LH_2
Propellant mass, kg (lb)	284,089 (626,309)	46,697 (102,949)	20,830 (45,922)	20,830 (45,922)
Total thrust, kN (lbf)	3,827 (860,309)	1,688 (379,550)	99.2 (22,300)	198.4 (44,600)
Engine(s)	1 x RD-180	—	1 x RL10A-4-2	2 x RL10A-4-2
Engine manufacturer	RD AMROSS	—	Aerojet Rocketdyne	Aerojet Rocketdyne
Engine thrust, kN (lbf)	3,827 (860,309)	1,688 (379,550)	99.2 (22,300)	99.2 (22,300)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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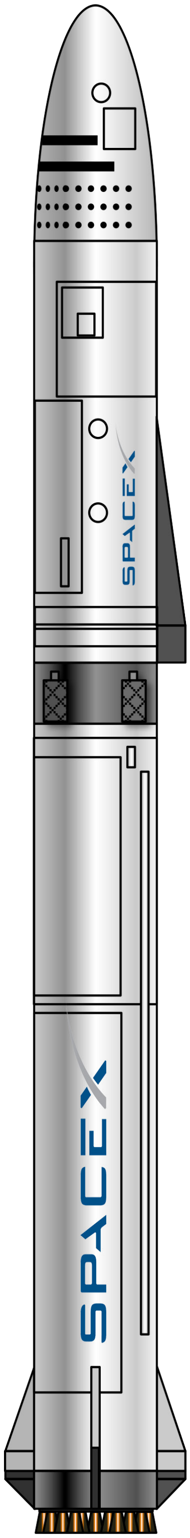
Launch Vehicle Fact Sheet

BFR



Space Exploration Technologies (SpaceX) is developing a much larger vehicle system than the Falcon 9 and Falcon Heavy the company currently offers.

In November 2016, SpaceX Founder and CEO announced plans to develop a massive vehicle called the Interplanetary Transport System (ITS). A year later, the company announced a revised plan consisting of a smaller vehicle called the BFR. For years prior to these announcements, the industry was aware SpaceX had been working on a large engine called Raptor that burns liquid oxygen (LOX) and liquified natural gas (LNG, or methane).

The vehicle's primary purpose is to transport passengers and cargo to Mars,. In late 2017, SpaceX President Gwynne Shotwell mentioned that the company will not replace the Falcon 9 and Falcon Heavy with BFR; SpaceX will continue to fly those vehicles for as long as customers want to use them.

BFR will be composed of two completely reusable components, the Booster and the Spaceship. Plans for the Spaceship show it will be produced in three versions: Passenger, Cargo, and Tanker.

SpaceX plans to conduct its first BFR mission to Mars in 2024.

BFR supercedes the Red Dragon program previously announced by the company in 2011.

Launch Service Provider
SpaceX

Organization Headquarters
USA

Manufacturer
SpaceX

Mass, kg (lb)
4,400,00 (9,700,000)

Length, m (ft)
106 (348)

Diameter, m (ft)
9 (30)

Year of Planned First Launch
2022

Launch Sites
KSC (LC-39A)
Brownsville (TBD)

GTO Capacity, kg (lb)
Undisclosed

LEO Capacity, kg (lb)
250,000 (550,000)

SSO Capacity, kg (lb)
Undisclosed

Estimated Price per Launch
Undisclosed

Unless otherwise noted, this fact sheet reflects data for the expendable version of the BFR.

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Launch Vehicle Fact Sheet

BFR

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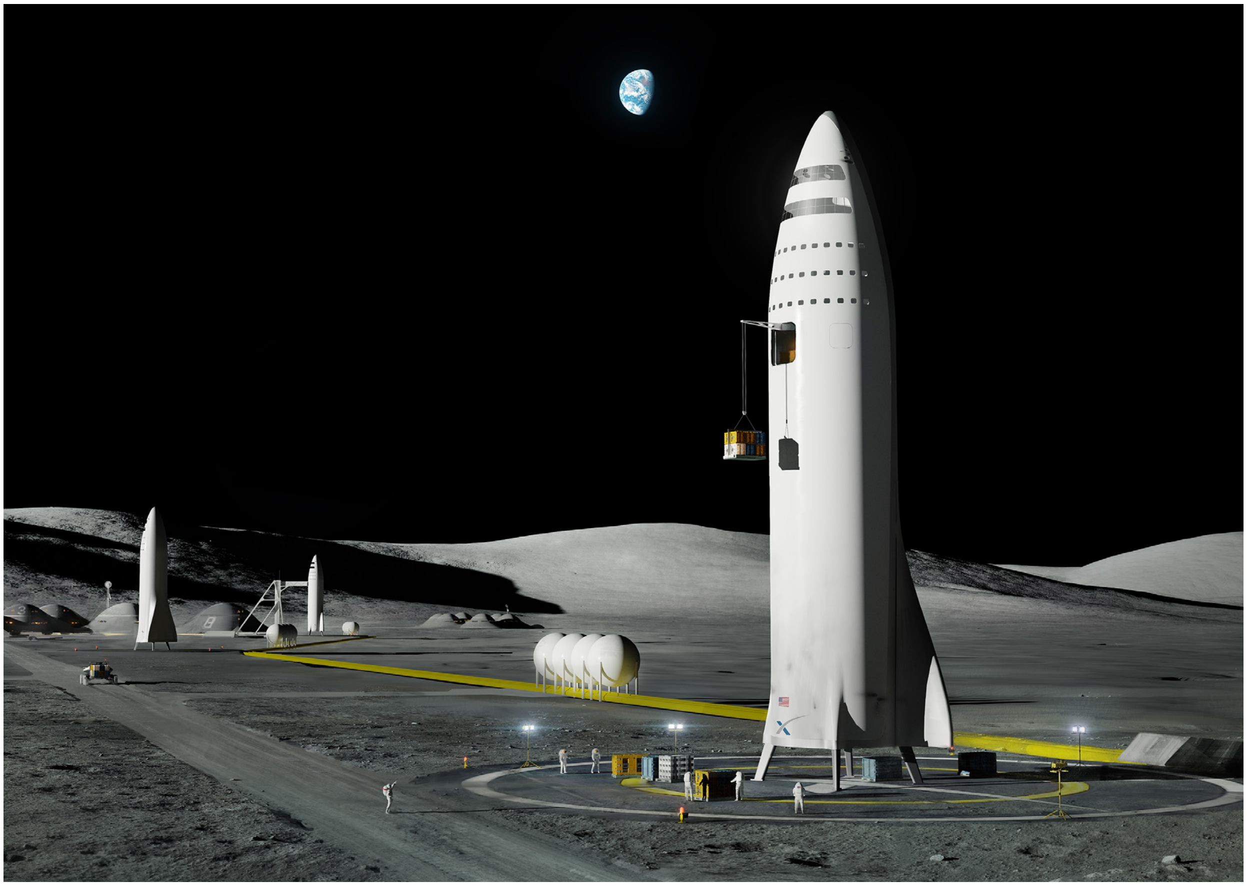

A BFR Spaceship being unloaded on the Moon's surface. (Source: SpaceX)

	1st Stage	SRB*
Stage designation	Booster	Spaceship
Length, m (ft)	58 (190)	48 (157)
Diameter, m (ft)	9 (30)	9 (30)
Manufacturer	SpaceX	SpaceX
Propellant	LOX/CH_4	LOX/CH_4
Propellant mass, kg (lb)	Undisclosed	1,100,000 (2,400,000)
Total thrust, kN (lbf)	52,700 (11,780,000)	13,300 (3,010,000)
Engine(s)	31 x Raptor	7 x Raptor
Engine manufacturer	SpaceX	SpaceX
Engine thrust, kN (lbf)	1,700 (380,000)	1,900 (430,000)

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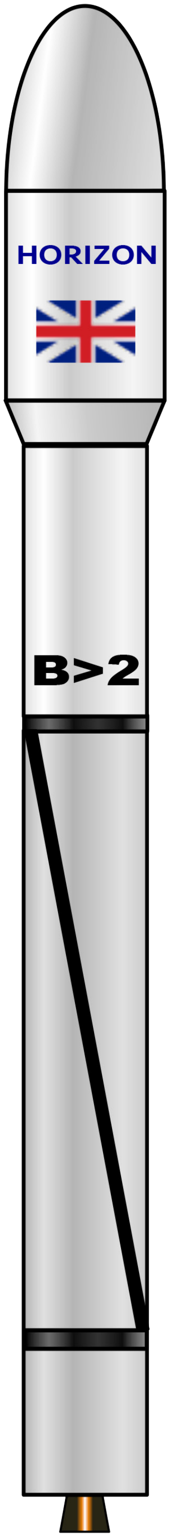
Launch Vehicle Fact Sheet

Black Arrow 2



Horizon Space Technologies, located to the northwest of London, is developing the 2-stage Black Aroow 2 orbital launch vehicle. The name of the vehicle honors the Black Arrow 1, a British rocket built and launched during the 1960s. Black Arrow 2 is first orbital launch vehicle system to be made in the UK since the Black Arrow 1 was cancelled 1971.

The company plans to conduct commercial flights at a rate of four per year from a launch site in Northern Scotland or from a floating platform at sea.

The company plans an extensive ground test program for the vehicle's upper stage combustion chambers, turbopumps, injectors, and reaction control thrusters using facilities at Westcott, near Aylesbury in Buckinghamshire. Engine hot-fire testing was scheduled to begin there in 2016, but it is unclear if these have taken place. Black Arrow 2 will feature at least 30 parts produced using additive manufacturing.

The first flights are planned to be suborbital tests of the first stage alone along west-bound trajectories over the Atlantic Ocean. Later flights will fly on north-bound trajectories, as as the company builds experience designed to support polar missions.

Horizon Space Technologies is exploring options to partner with the European Space Agency (ESA) for use of the Guiana Space Center and the Australian government for use of the launch site at Woomera. Australian launch site at Woomera where s utilise the extensive tracking facilities. The company is also investigating the possibility of launching from Cape Canaveral Air Force Station (CCAFS), but restrictions related to the International Trade in Arms Regulations (ITAR) appear to be a complicating a factor.

Horizons is planning to begin a 10-flight suborbital test program in 2017, with operational flights beginning in 2018.

Launch Service Provider
Horizon Space Technologies

Organization Headquarters
UK

Manufacturer
Horizon Space Technologies

Mass, kg (lb)
Undisclosed

Length, m (ft)
25 (82)

Diameter, m (ft)
1.8 (5.9)

Year of Planned First Launch
2019

Launch Sites
Northern Scotland
Possible ocean platform

LEO Capacity, kg (lb)
500 (1,102)

SSO Capacity, kg (lb)
350 (772)

Estimated Price per Launch
$6.12M

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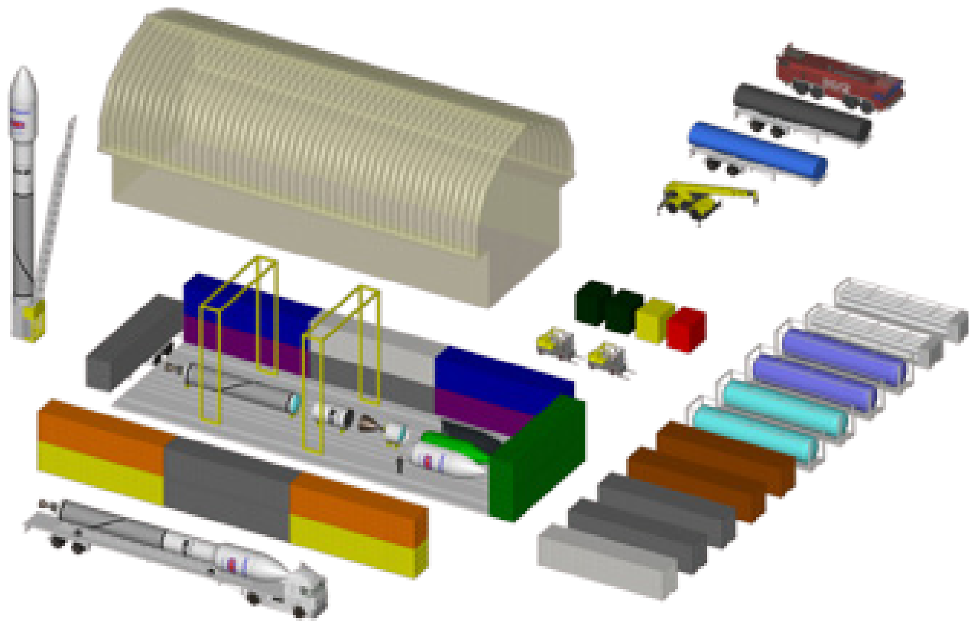
Launch Vehicle Fact Sheet

Black Arrow 2



The Black Arrow 2 launch facility is unique in that it is designed to be transported to various launch sites depending on customer needs. All the facilities can be stowed in 26 standard ISO cargo-containers and can be relocated to a new launch site in less than 30 days. (Source: Horizon Space Technologies)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	6.1 (20)	2.4 (7.9)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	14 (46) *est*	3.9 (12.8) *est*
Diameter, m (ft)	1.8 (5.9)	1.8 (5.9)
Manufacturer	Horizon Space Technologies	Horizon Space Technologies
Propellant	LOX/CH_4	LOX/CH_4
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	500 (112,404)	45 (10,116)
Engine(s)	Undisclosed	Undisclosed
Engine manufacturer	Horizon Space Technologies	Horizon Space Technologies
Engine thrust, kN (lbf)	500 (112,404)	45 (10,116)

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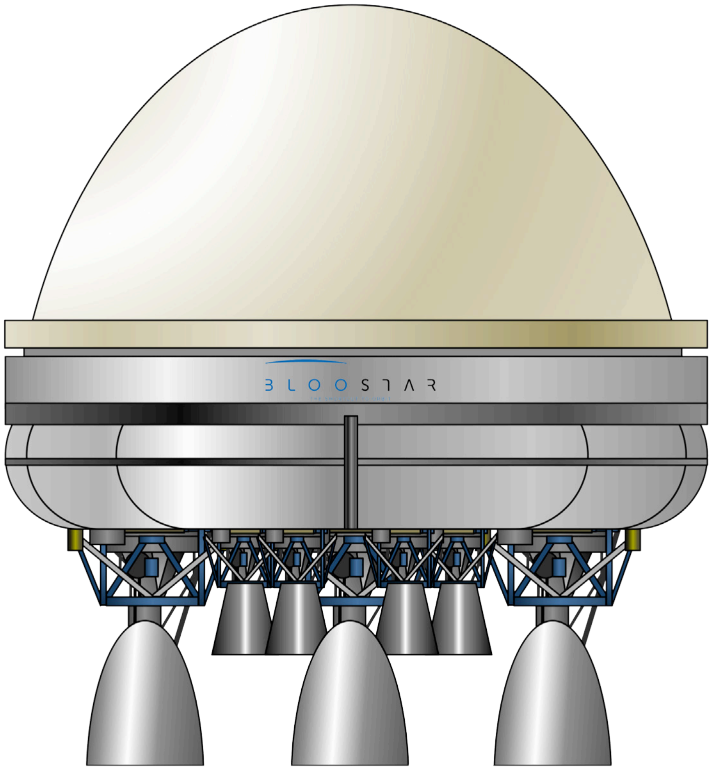
Launch Vehicle Fact Sheet

Bloostar



Launch Service Provider
Zero2Infinity

Organization Headquarters
Spain

Manufacturer
Zero2Infinity

Mass, kg (lb)
Undisclosed

Length, m (ft)
Undisclosed

Diameter, m (ft)
Undisclosed

Year of Planned First Launch
2019

Launch Site
Undisclosed

LEO Capacity, kg (lb)
Undisclosed

SSO Capacity, kg (lb)
75 (165)

Estimated Price per Launch
$4M

Spain-based Zero2Infinity is a company specializing in stratospheric balloon platforms that serve customers interested in operating payloads in "near space," or an altitude of between 30 kilometers and 100 kilometers (18.6 miles to 62 miles). The stratospheric balloons offered by Zero2Infinity loiter at the lower end of this zone, which is above 99% of the Earth's atmosphere.

In 2016, Zero2Infinity lofted Aistech-1 for Barcelona-based Aistech, a company that aims to operate a balloon-born constellation of 25 nanosatellites by 2022 to support asset tracking services and thermal imaging of the planet's surface.

Zero2Infinity is also working on a more ambitious capability designed to leverage its balloon experience as a basis for orbital launch services. It seeks to develop a vehicle that will launch from a balloon-based platform. The launch vehicle consists of a unique toroidal design featuring three nested stages and a voluminous payload shroud. One of the key advantages of such a shroud is that payloads need not necessarily be folded up.

Though the key advantage to a balloon-based launch is avoiding 99% of the Earth's atmosphere during powered ascent, weather and azimuth control remain challenges because balloons can be difficult to control.

As of March 2017, Zero2infinity has $266.4M in pre-sales frim nanosatellite operators. In March 2017, the company conducted its first successful test flight of Bloostar, with more tests planned through 2019.

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Launch Vehicle Fact Sheet

Bloostar

Artist's rendering of Bloostar after release from its balloon. Note the three nested stages and the payload in the center. (Source: Zero2Infinity)

Fairing	Length, m (ft)	Diameter, m (ft)
Fairing	1.2 (3.9)	2 (6.6)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	Balloon	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Manufacturer	Zero2Infinity	Zero2Infinity	Zero2Infinity	Zero2Infinity
Propellant	--	N_2O_4/HNO_3	N_2O_4/HNO_3	N_2O_4/HNO_3
Propellant mass, kg (lb)	--	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	--	Undisclosed	Undisclosed	Undisclosed
Engine(s)	--	6 x TBD	6 x TBD	1 x TBD
Engine manufacturer	Zero2Infinity	Zero2Infinity	Zero2Infinity	Zero2Infinity
Engine thrust, kN (lbf)	--	Undisclosed	Undisclosed	Undisclosed

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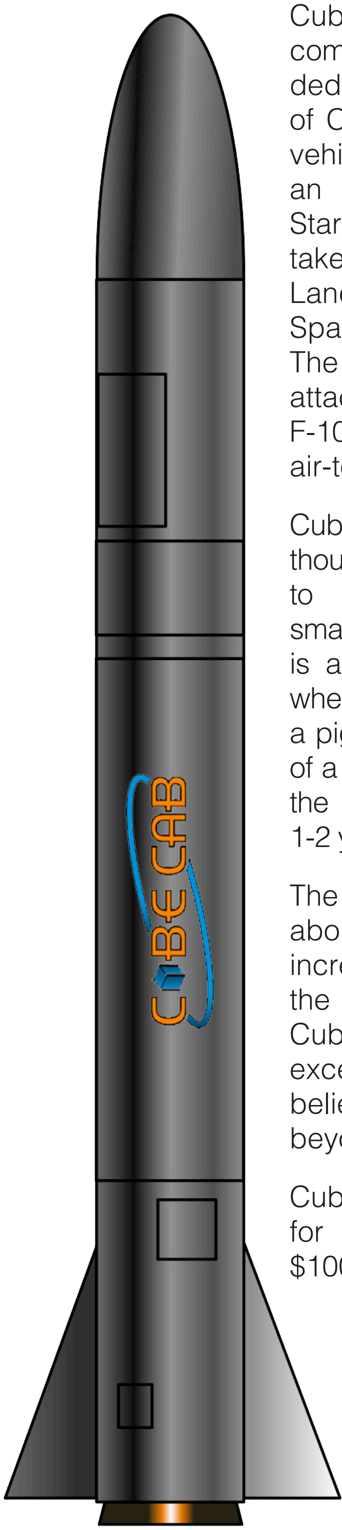
Launch Vehicle Fact Sheet

Cab-3A



CubeCab is a U.S.-based company seeking to provide dedicated launches for operators of CubeSats. The relatively small vehicle will be launched from an F-104 Starfighter offered by Starfighters Aerospace that will take off from NASA's Shuttle Landing Facility at Kennedy Space Center (KSC) in Florida. The CubeCab vehicle will be attached below the wing of the F-104 in a similar manner to an air-to-air missile.

CubeCab believes that even though it is technically less efficient to launch small payloads on small launch vehicles, the cost is actually less than experienced when arranging for a rideshare as a piggyback payload. An example of a cost-saving benefit is trimming the launch scheduling time from 1-2 years to just a few months.

The company expects to launch about 100 times per year, further increasing efficiencies. Though the number of 1U and 3U CubeSats launched per year first exceeded 100 in 2014, CubeCab believes this market will grow beyond that number per year.

CubeCab is targeting $250,000 for a 3U CubeSat launch, or $100,000 for a 1U CubeSat.

Launch Service Provider
CubeCab

Organization Headquarters
USA

Manufacturer
CubeCab

Mass, kg (lb)
13,000 (28,660) *est*

Length, m (ft)
16.8 (55)

Wingspan, m (ft)
6.6 (21.8)

Year of Planned First Launch
2018

Launch Site
KSC (Runway)

LEO Capacity, kg (lb)
5 (11)

Estimated Price per Launch
$250,000

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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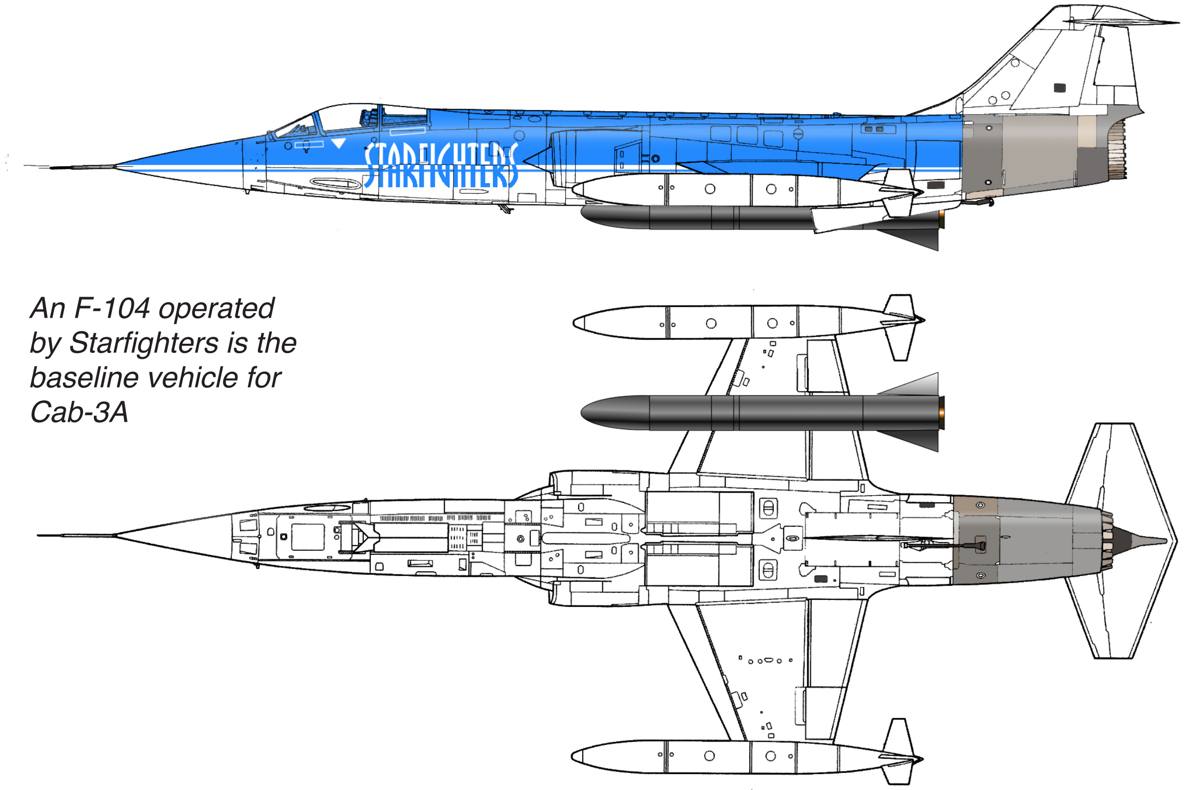
Launch Vehicle Fact Sheet

Cab-3A

FAA AST



An F-104 operated by Starfighters is the baseline vehicle for Cab-3A

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	0.5 (1.7) *est*	0.5 (1.7) est

	1st Stage	2nd Stage
Stage designation	F-104	CubeCab
Length, m (ft)	16.8 (55)	5.3 (17.4) *est*
Diameter/Wingspan, m (ft)	6.6 (21.8)	0.5 (1.7) *est*
Manufacturer	Lockheed	CubeCab
Propellant	Kerosene (JP-4)	Undisclosed
Propellant mass, kg (lb)	8,727 (19,240)	Undisclosed
Total thrust, kN (lbf)	79.3 (17,835)	Undisclosed
Engine(s)	1 x J79-GE-11A	Undisclosed
Engine manufacturer	General Electric	CubeCab
Engine thrust, kN (lbf)	79.3 (17,835)	Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Delta II

McDonnell Douglas (now The Boeing Company) introduced the Delta II series in 1989 building upon a legacy that can be traced to the Air Force's Thor missile from 1960. The vehicle has since performed exceptionally well, having been used on 153 successful missions. One failure did occur in 1997 during a Navstar GPS mission. United Launch Alliance (ULA) took over manufacturing and launch of the Delta II following establishment of the joint Boeing-Lockheed Martin Company in 2006.

When introduced, the vehicle was offered in three sub-families: 7300 series, 7400 series, and 7900 series. The first digit refers to the RS-27A engine used on the first stage, the second digit refers to the number of solid motors used, the third digit refers to the AJ10 second stage engine, and the fourth digit refers to the type of third stage. Following the four-digit number is a designator for the type of fairing used.

The penultimate launch of the Delta II took place in November 2017 with the launch of the first satellite of the Joint Polar Satellite System (JPSS). The Delta II will retire in 2018 with the launch of ICESat-2.

Launch Service Provider
ULA

Organization Headquarters
USA

Manufacturer
ULA

Mass, kg (lb)
228,000 (502,654)

Length, m (ft)
38.9 (127.6)

Diameter, m (ft)
2.4 (7.9)

Year of First Launch
1989

Number of Orbital Launches
155

Reliability
99%

Launch Sites
VAFB (SLC-2W)

LEO Capacity, kg (lb)
2,036-3,755 (4,548-8,277)

SSO Capacity, kg (lb)
1,579-3,123 (3,481-6,886)

Estimated Price per Launch
$137.3M

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Launch Vehicle Fact Sheet

Delta II

FAA AST

A Delta II 7920-10C vehicle sends JPSS-1 into a Sun-synchronous orbit from Vandenburg Air Force Base, California on November 9, 2017. (Source: Kim Shiflett/NASA)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	8.5 (27.9)	2.9 (9.5)
Composite Fairing	8.9 (29.2)	3 (9.8)
Long Composite Fairing	9.3 (30.5)	3 (9.8)

	SRB*	1st Stage	2nd Stage
Stage designation	Up to 9 x GEM-40	1st Stage	2nd Stage
Length, m (ft)	11.1 (36.4)	26.1 (85.6)	6 (19.7)
Diameter, m (ft)	1 (3.3)	2.4 (7.9)	2.4 (7.9)
Manufacturer	Orbital ATK	ULA	ULA
Propellant	Solid	LOX/Kerosene	N_2O_4/Aerozine-50
Propellant mass, kg (lb)	11,766 (25,940)	96,120 (211,908)	6,000 (13,228)
Total thrust, kN (lbf)	5,794 (1,302,543)	890 (200,080)	43.4 (9,757)
Engine(s)	—	1 x RS-27A	1 x AJ10-118K
Engine manufacturer	—	Aerojet Rocketdyne	Aerojet Rocketdyne
Engine thrust, kN (lbf)	643.8 (144,732)	890 (200,080)	43.4 (9,757)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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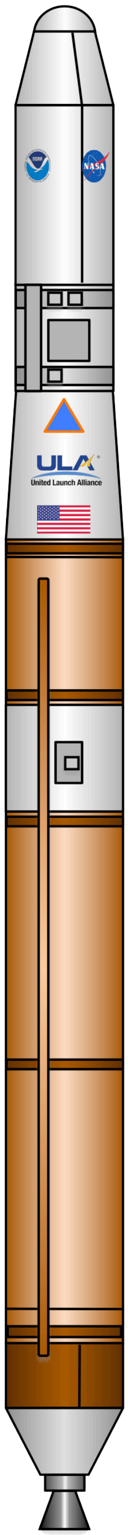
Launch Vehicle Fact Sheet
Delta IV



The Delta IV family is a product of the U.S. Air Force's Evolved Expendable Launch Vehicle Program (EELV), begun in 1995. Boeing originally developed the Delta IV, but manufacturing and operations are now conducted by United Launch Alliance (ULA), a joint company between Lockheed Martin and Boeing. ULA markets the vehicle to the U.S. Government.

The Delta IV is composed of a Common Booster Core (CBC) powered by an Aerojet Rocketdyne RS-68A main engine, one of two different types of cryogenic upper stages (varying in propellant tank volume and diameter) powered by a single Aerojet Rocketdyne RL10B-2 engine, a payload adapter, and a choice between three fairings. The vehicle may also feature two or four Orbital ATK GEM-60 motors. The Delta IV is available in five variants.

The Delta IV family debuted in 2002 with the successful launch of a Delta IV Medium+ (4,2) from Cape Canaveral Air Force Station (CCAFS).

With the exception of the Delta IV Heavy, the Delta IV has been slated for retirement in 2018 as ULA prepares to introduce the Vulcan launch vehicle family in 2019. The Delta IV Heavy will continue to fly until the Vulcan's Centaur upper stage is replaced with the Advanced Cryogenic Evolved Stage (ACES), boosting the Vulcan's payload capacity dramatically, effectively making the Delta IV Heavy obsolete. The Delta IV Heavy is expected to be retired by 2023.

Launch Service Provider
ULA

Organization Headquarters
USA

Manufacturer
ULA

Mass, kg (lb)
D-IVM: 249,500 (549,559)
D-IVH: 733,000 (1,615,416)

Length, m (ft)
62.8-71.6 (206-234.9)

Diameter, m (ft)
5 (16.4)

Year of First Launch
2002

Number of Orbital Launches
35

Reliability*
100%

Launch Sites
CCAFS (SLC-37B)
VAFB (SLC-6)

GTO Capacity, kg (lb)
4,210-14,210 (9,281-31,328)

LEO Capacity, kg (lb)
9,420-28,790 (20,768-63,471)

SSO Capacity, kg (lb)
7,690-23,560 (16,954-51,941)

Estimated Price per Launch
$164M-$400M

** The December 21, 2004 partial launch success of a Delta IV Heavy is counted as a success in this reliability calculation*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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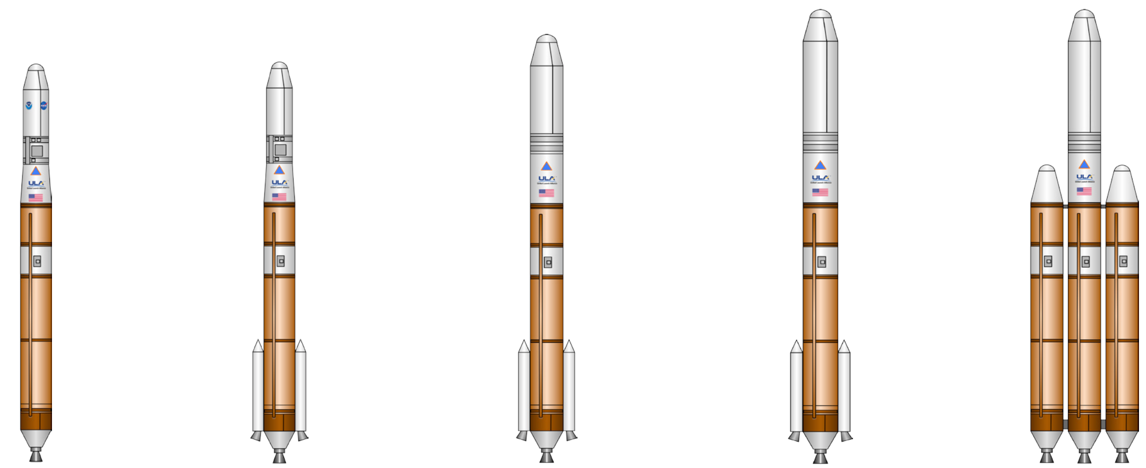
Launch Vehicle Fact Sheet

Delta IV

The Delta IV family consists of five variants. The Delta IV Medium features a CBC and a 4-meter fairing, but no solid motors. Three versions of the Delta IV Medium+ are available, using either a 4-meter or 5-meter fairing, and a combination of solid motors. Finally, the Delta IV Heavy is composed of three CBCs and a 5-meter fairing.



Delta IV Medium | **Delta IV Medium+(4,2)** | **Delta IV Medium+(5,2)** | **Delta IV Medium+(5,4)** | **Delta IV Heavy**

Fairing	Length, m (ft)	Diameter, m (ft)
11.7-Meter Fairing	11.7 (38.5)	4 (13)
14.3-Meter Fairing	14.3 (47)	5 (16.4)
19.1-Meter Fairing	19.1 (62.7)	5 (16.4)
Metallic Fairing	19.8 (65)	5 (16.4)

	1st Stage*	SRB**	2nd Stage Option	2nd Stage Option
Stage designation	Common Booster Core	2 or 4 GEM-60	4-Meter Cryogenic Upper Stage	5-Meter Cryogenic Upper Stage
Length, m (ft)	41.6 (136.4)	16.2 (53)	12.2 (40)	13.1 (43)
Diameter, m (ft)	5 (16.4)	1.6 (5.3)	4 (13.1)	5 (16.4)
Manufacturer	ULA	Orbital ATK	ULA	ULA
Propellant	LOX/LH_2	Solid	LOX/LH_2	LOX/LH_2
Propellant mass, kg (lb)	199,640 (439,735)	58,967-117,934 (130,000-260,000)	20,410 (45,000)	27,200 (60,000)
Total thrust, kN (lbf)	2,891 (650,000)	2,491-4,982 (560,000-1,120,000)	110 (24,750)	110 (24,750)
Engine(s)	1 x RS-68A	—	1 x RL10B-2	1 x RL10B-2
Engine manufacturer	Aerojet Rocketdyne	—	Aerojet Rocketdyne	Aerojet Rocketdyne
Engine thrust, kN (lbf)	3,136 (705,000)	1,245.5 (280,000)	110 (24,750)	110 (24,750)

** Delta IV Heavy uses 3 CBC units*
*** Propellant mass and total thrust is sum of 2 to 4 boosters.*

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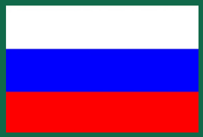
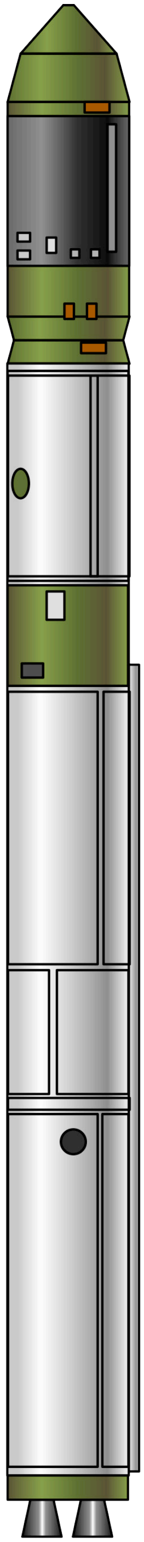
Launch Vehicle Fact Sheet

Dnepr





The Dnepr, introduced in 1999, is developed from surplus Soviet R-36 (SS-18) intercontinental ballistic missiles (ICBM). About 150 missiles were made available for conversion into launch vehicles. The missiles, with components built during the Soviet era, are refurbished by PA Yuzhmash located in Ukraine. The three-stage, liquid fueled vehicle is designed to address medium-class payloads or clusters of small- and micro-class satellites. It was marketed by the Russian-based company ISC Kosmotras from 1999 until 2016; in 2017, marketing of the Dnepr was taken over by a new company called GK Launch Services, a joint company between Glavkosmos (a subsidiary of the Russian state corporation Roscosmos) and LLC Kosmotras.

The Dnepr has launched 21 times, with one failure. The Dnepr is launched from Pad 109 and Pad 95 at the Baikonur Kosmodrome in Kazakhstan and the Dombarovsky missile base in Western Russia.

Due to increasing political tensions between Russia and Ukraine during 2014, and the resulting international sanctions against Russia, PA Yushmash, a key supplier of missiles and other hardware to the Russian military, has experienced considerable financial difficulties that may impact its product line. Despite this, GK Launch Services has reassured existing and potential customers that the Dnepr will be available.

Launch Service provider
GK Launch Services

Organization Headquarters
Russia

Manufacturer
PA Yuzhmash

Mass, kg (lb)
201,000 (462,971)

Length, m (ft)
34.3 (112.5)

Diameter, m (ft)
3 (9.8)

Year of First Launch
1999

Number of Orbital Launches
22

Reliability
95%

Launch Sites
Baikonur (LC-109, LC-95)
Dombarovsky (LC-13)

LEO Capacity, kg (lb)
3,200 (7,055)

SSO Capacity, kg (lb)
2,300 (5,071)

Estimated Price per Launch
$29M

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Launch Vehicle Fact Sheet

Dnepr

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Satellites integrated on the Dnepr vehicle prior to launch in June 2004. (Source: GAUSS)

Fairing	Length, m (ft)	Diameter, m (ft)
Sandard Fairing	5.3 (17.4)	3 (9.8)
Extended Fairing	6.1 (20)	3 (9.8)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	22 (72.2)	6 (19.7)	1.5 (4.9)
Diameter, m (ft)	3 (9.8)	3 (9.8)	3 (9.8)
Manufacturer	PA Yuzhmash	PA Yuzhmash	PA Yuzhmash
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	147,900 (326,064)	36,740 (80,998)	1,910 (4,211)
Total thrust, kN (lbf)	4,520 (1,016,136)	755 (169,731)	18.6 (4,181)
Engine(s)	4 x RD-264	1 x RD-0255	1 x RD-869
Engine manufacturer	OKB-456 (NPO Energomash)	OKB-154 (KB Khimavtomatika)	OKB-586 (Yuzhnoye)
Engine thrust, kN (lbf)	1,130 (254,034)	755 (169,731)	18.6 (4,181)

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Launch Vehicle Fact Sheet
Electron

Founded in New Zealand in 2007 by entrepreneur Peter Beck, Rocket Lab is now headquartered in the United States with a subsidiary in New Zealand.

Rocket Lab aims to provide its Electron vehicle to tap the microsatellite market, offering rapid scheduling and dedicated launch services to operators that have historically been dependent on piggyback rides with primary payloads. These piggyback rides mean the microsatellite operator does not have much say in scheduling or orbital trajectory.

The two-stage Electron features a simple construction using low-mass composite materials capable of handling cryogenic liquids like liquid oxygen (LOX). In addition, the company's Rutherford engine is designed to be produced quickly, as ten total engines are used for each Electron and Rocket Labs plans to launch the vehicle frequently. To enable this, and to keep costs down, all primary components of the Rutherford are produced using additive manufacturing, commonly refered to as 3D printing.

The Electron will be marketed primarilly for customers whose satellites are bound for Sun-synchronous orbits (SSO).

In 2015, Rocket Lab was awarded a NASA Venture Class Launch Services contract. The $6.95M ontract is for the launch of a NASA payload to low-Earth orbit (LEO) between 2016 and 2017. Moon Express announced in 2015 that it will purchase three Rocket Lab launches for its lunar lander spacecraft as part of the former's bid to win the Google Lunar X Prize competition. Rocket Lab has indicated it has other customers in the queue, but has not released their names publicly. Also in 2015, Rocket Lab announced it selected Alaska Aerospace Corporation to provide range safety support for their upcoming Electron launches in 2016 from the Pacific Spaceport Complex – Alaska (PSCA).

Launch Service Provider
Rocket Lab

Organization Headquarters
USA

Manufacturer
Rocket Lab

Mass, kg (lb)
10,500 (23,149)

Length, m (ft)
16 (52.5)

Diameter, m (ft)
1.2 (3.9)

Year of First Launch
2017

Number of Orbital Launches
1

Reliability
0%

Launch Sites
Kaitorete (LC-1)
KSC (LC-39C)

LEO Capacity, kg (lb)
225 (496)

SSO Capacity, kg (lb)
150 (331)

Estimated Price per Launch
$4.9M

Rocket Lab conducted its first orbital launch test on May 24, 2017 from its launch site at Mahia in New Zealand. The vehicle failed to reach orbit, but the company announced that the issue was easily identified and corrected.

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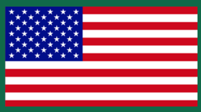
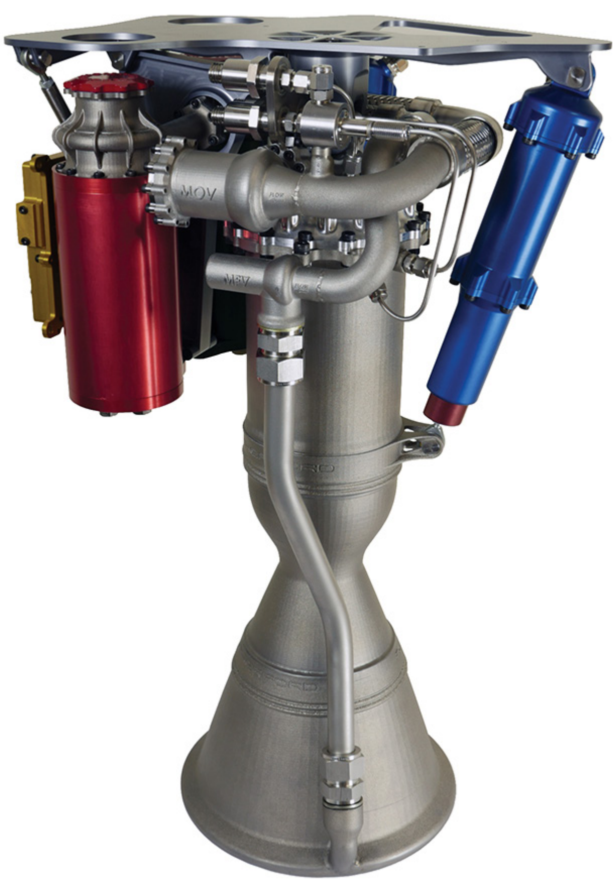
Launch Vehicle Fact Sheet

Electron





Rocket Lab's Rutherford engine. All its primary components are produced using additive manufacturing, or 3D printing. (Source: Rocket Lab)

Rocket Lab's launch price for a 1U CubeSat is $50,000. For a 3U, it is $180,000.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2 (6.6) *est*	1.2 (3.9)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	12.8 (42) *est*	1.6 (5.2) *est*
Diameter, m (ft)	1.2 (3.9)	1.2 (3.9)
Manufacturer	Rocket Lab	Rocket Lab
Propellant	LOX/kerosene	LOX/kerosene
Propellant mass, kg (lb)	6,900 (15,212) *est*	2,300 (5,071) *est*
Total thrust, kN (lbf)	183 (41,500)	22 (5,000)
Engine(s)	9 x Rutherford	1 x Rutherford Vacuum
Engine manufacturer	Rocket Lab	Rocket Lab
Engine thrust, kN (lbf)	22 (5,000)	22 (5,000)

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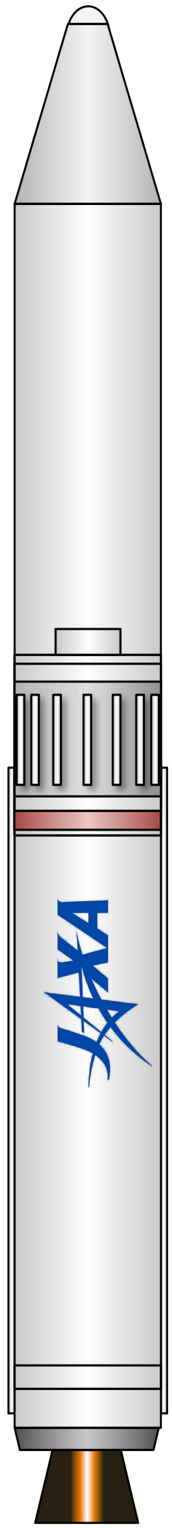
Launch Vehicle Fact Sheet

Epsilon



The Epsilon is a vehicle under development by the Japan Aerospace Exploration Agency (JAXA), derived from the Nissan-built M-V discontinued in 2006. The vehicle will be used to send small payloads to low Earth orbits and polar orbits. The first launch of Epsilon took place during 2013, successfully placing a small payload into low Earth orbit (LEO).

The Epsilon comes in both a Standard Configuration and an Optional Configuration. The first stage of the Standard Configuration Epsilon is a solid motor similar to those on the H-IIA. An M-34c solid motor constitutes the second stage, and a KM-2Vb represents the third stage. A payload adapter and fairing complete the system. The Optional Configuration features an additional compact Post Boost Stage integrated with the third stage for Sun-synchronous orbits (SSO).

The vehicle is launched from Uchinoura Space Center, formerly called Kagoshima Space Center.

Launch Service Provider
JAXA

Organization Headquarters
Japan

Manufacturer
IHI

Mass, kg (lb)
90,800 (200,180)

Length, m (ft)
24.4 (80.1)

Diameter, m (ft)
2.5 (8.2)

Year of First Launch
2013

Number of Orbital Launches
2

Reliability
100%

Launch Site
Uchinoura Space Center

LEO Capacity, kg (lb)
700 -1,200 (1,543-2,646)

SSO Capacity, kg (lb)
450 (992)

Estimated Price per Launch
$39M

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Launch Vehicle Fact Sheet

Epsilon

The Epsilon launch vehicle at the launch site just prior to its inaugural mission in 2013. (Source: JAXA)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	10 (32.8)	2.5 (8.2)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	SRB-A3	M-34c	KM-V2b	Post Boost Stage
Length, m (ft)	15 (49.2)	5 (16.4)	3 (9.8)	0.5 (1.6)
Diameter, m (ft)	2.5 (8.2)	2.5 (8.2)	2.5 (8.2)	2 (6.6)
Manufacturer	Nissan	Nissan	Nissan	Nissan
Propellant	Solid	Solid	Solid	Hydrazine
Propellant mass, kg (lb)	66,000 (145,505)	10,800 (23,800)	2,500 (5,512)	100 (220)
Total thrust, kN (lbf)	1,580 (355,198)	377.2 (84,798)	81.3 (18,277)	< 1 (225)
Engine(s)	--	--	--	3 units
Engine manufacturer	--	--	--	Nissan
Engine thrust, kN (lbf)	1,580 (355,198)	377.2 (84,798)	81.3 (18,277)	<0.33 (74)

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Launch Vehicle Fact Sheet

Falcon 9

FAA AST

Space Exploration Technologies (SpaceX), founded in 2002, launched its first Falcon 9 in 2010 from Cape Canaveral Air Force Station (CCAFS). The Falcon 9 has been certified under the Evolved Expendable Launch Vehicle (EELV) program to fly national security space missions. Falcon 9 is also used to transport SpaceX's Dragon spacecraft to the International Space Station (ISS). Dragon has made 13 trips to the ISS to deliver cargo, and as early as 2018 will begin its first crewed missions to carry astronauts to the ISS.

The vehicle consists of a first stage powered by nine SpaceX Merlin-1D engines, a seoncd stage powered by a single Merlin-1D Vacuum engine, a payload adapter, and a large payload fairing. Launches of the company's Dragon spacecraft do not require a fairing. Falcon 9 is the only orbital launch vehicle capable of reflight. Depending on the mission profile, the first stage returns to a landing pad near the launch site or to one of SpaceX's autonomous droneships located in the Pacific and Atlantic oceans. The first stage represents the majority of the cost of the vehicle; as such, reusability of the first stage is key in bringing down the cost of access to space. SpaceX is also working on recovering the payload fairing as well as the Falcon 9 second stage.

The first version of the Falcon 9 (v1.0) launched successfully five times since its introduction in 2010. An upgraded version of the Falcon 9 (v1.1) was introduced in September 2013. SpaceX then introduced the current version of the Falcon 9 (Falcon 9 Full Thrust) in 2015, featuring 20 percent greater capacity than the Falcon 9 v1.1. The company is working on the final version of the Falcon 9, called "Block 5," due for introduction in 2018. The vehicle's upgrade is designed to meet all U.S. government requirements, increasing lift capability, simplifying manufacturability, and enhancing reusability.

As of December 31, 2017, the Falcon 9 has flown 46 times. The first stage of the Falcon 9 has been recovered 20 times, 8 via land and 12 via a droneship. SpaceX has reflown the Falcon 9 first stage 5 times since the first successful stage landing in December 2015.

Launch Service Provider
SpaceX

Organization Headquarters
USA

Manufacturer
SpaceX

Mass, kg (lb)
549,054 (1,210,457)

Length, m (ft)
70 (229.7)

Diameter, m (ft)
3.7 (12)

Year of First Launch
2010 (Falcon 9 family)

Number of Orbital Launches
46 (Falcon 9 family)

Reliability
98%

Launch Sites
CCAFS (SLC-40)
VAFB (SLC-3E)
Brownsville (TBD)

GTO Capacity, kg (lb)
8,300 (18,300)

LEO Capacity, kg (lb)
22,800 (50,265)

Estimated Price per Launch
$62M expendable/$49M reused

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Launch Vehicle Fact Sheet

Falcon 9

Falcon 9 FT
with fairing

Falcon 9 FT
with Dragon

A Falcon 9 first stage returns to Cape Canaveral Air Force Station during a mission conducted in 2017. (Source: SpaceX)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	13.2 (43.3)	5.2 (17.1)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	42.6 (139.8)	12.6 (41.3)
Diameter, m (ft)	3.7 (12)	3.7 (12)
Manufacturer	SpaceX	SpaceX
Propellant	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	Sea Level: 7,607 (1,710,122) Vacuum: 8,227 (1,849,503)	Vacuum: 934 (210,000)
Engine(s)	9 x Merlin-1D	1 x Merlin-1D (vacuum)
Engine manufacturer	SpaceX	SpaceX
Engine thrust, kN (lbf)	845 (190,000)	934 (210,000)

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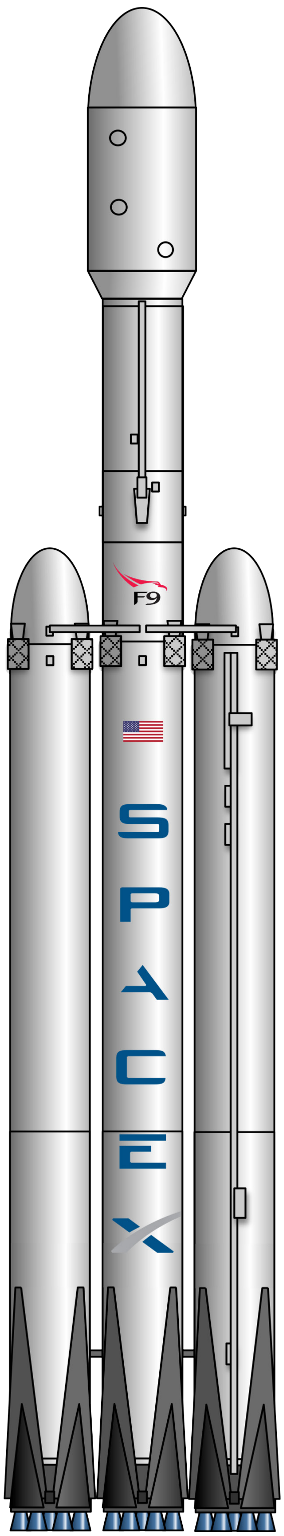
Launch Vehicle Fact Sheet

Falcon Heavy



Space Exploration Technologies (SpaceX), founded in 2002, is developing the Falcon Heavy. This vehicle leverages the same components used to manufacture the Falcon 9.

The first stage of Falcon Heavy essentially consists of three Falcon 9 first stages linked together. The center core and side boosters are each powered by 9 Merlin-1D engines. Each booster is designed to be reused and will return to either a landing pad or one of SpaceX's autonomous droneships located in the Pacific and Atlantic oceans. The second stage is similar to the Falcon 9 second stage, powered by a single Merlin-1D vacuum engine.

The lift capacity of the Falcon Heavy is 63,800 kg (140,655 lb) to low Earth orbit (LEO), making it the most powerful U.S.-built launch vehicle since the Saturn V.

The first launch of Falcon Heavy is scheduled to take place in 2018 from Launch Complex 39A (LC-39A) at the Kennedy Space Center (KSC) in Florida. The mission will be a test demonstration. Customers who have signed contracts for a Falcon Heavy flight include the Department of Defense, Arabsat, Intelsat, Inmarsat, and ViaSat.

SpaceX lists $90M for a launch of a payload at or below 8,000 kg (17,637 lb) to geosynchronous transfer orbit (GTO). With a GTO capacity of 26,700 kg (58,863 lb), this means the vehicle will be able to send up multiple payloads to this orbit.

Launch Service Provider
SpaceX

Organization Headquarters
USA

Manufacturer
SpaceX

Mass, kg (lb)
1,420,788 (3,125,735)

Length, m (ft)
70 (229.6)

Width, m (ft)
12.2 (39.9)

Year of Planned First Launch
2018

Launch Sites
KSC (LC-39A)
VAFB (SLC-4E)

GTO Capacity, kg (lb)
26,700 (58,860)

LEO Capacity, kg (lb)
63,800 (140,660)

Estimated Price per Launch
$90M

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Launch Vehicle Fact Sheet

Falcon Heavy

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An artist's rendering of the Falcon Heavy at KSC's LC-39A. (Source: SpaceX)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	13.2 (43.3)	5.2 (17.1)

	1st Stage	2nd Stage
Stage designation	1st Stage (3 cores)	2nd Stage
Length, m (ft)	42.6 (139.8)	12.6 (41.3)
Diameter, m (ft)	12.2 (39.9)	3.7 (12)
Manufacturer	SpaceX	SpaceX
Propellant	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	Sea Level: 22,819 (5,129,915) Vacuum: 24,681 (5,548,510)	Vacuum: 934 (210,000)
Engine(s)	27 x Merlin-1D	1 x Merlin-1D (vacuum)
Engine manufacturer	SpaceX	SpaceX
Engine thrust, kN (lbf)	845 (190,000)	934 (210,000)

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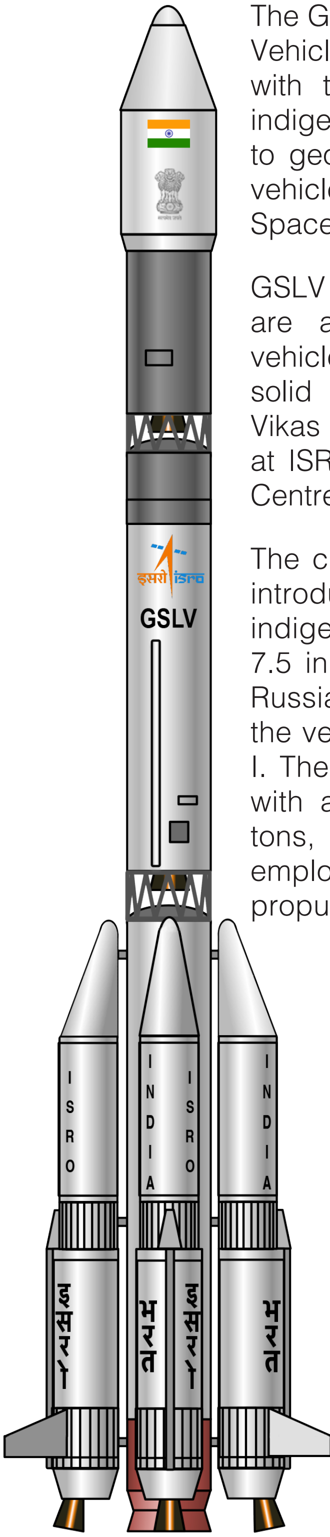
Launch Vehicle Fact Sheet

GSLV



The Geosynchronous Satellite Launch Vehicle (GSLV) project began in 1990 with the objective of achieving an indigenous satellite launch capability to geosynchronous orbit (GEO). The vehicle was developed by the Indian Space Research organization (ISRO).

GSLV uses major components that are already proven in the PSLV vehicles in the form of the S125/S139 solid booster and the liquid-fueled Vikas engine. Engines are developed at ISRO's Liquid Propulsion Systems Centre (LPSC).

The current variant, GSLV Mk.II was introduced in 2010 and uses an indigenous cryogenic engine, the CE-7.5 in the third stage instead of the Russian cryogenic engine used by the vehicle's older version, GSLV Mk I. The 49.1 meter (161 ft) tall GSLV, with a lift-off mass of 414.8 metric tons, is a three-stage vehicle that employs solid, liquid and cryogenic propulsion technologies. The payload fairing is 7.8 meter (26 ft) long and 3.4 meters (11.2 ft) in diameter. The GSLV can place approximately 5,000 kg (11,023 lb) into low earth orbit (LEO). GSLV can place 2,500 kg (5,516 lb) into geosynchronous transfer orbit (GTO).

After experiencing four failures and one partially successful mission, the vehicle is not considered reliable. ISRO is working to replace the GSLV with the LVM3, which was successfully launched on a suborbital test mission in early 2015. India's objective is to develop a fully indigenous launch capability, no longer relying on Arianespace for missions to GTO.

Launch Service Provider
ISRO/Antrix

Organization Headquarters
India

Manufacturer
ISRO

Mass, kg (lb)
414,750 (914,637)

Length, m (ft)
49.13 (161.2)

Wingspan, m (ft)
2.8 (9.2)

Year of First Launch
2001

Number of Orbital Launches
11

Reliability
73%

Launch Site
Satish Dhawan (FLP, SLP)

GTO Capacity, kg (lb)
2,500 (5,516)

LEO Capacity, kg (lb)
5,000 (11,023)

Estimated Price per Launch
$47M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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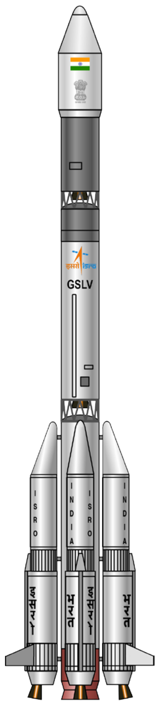
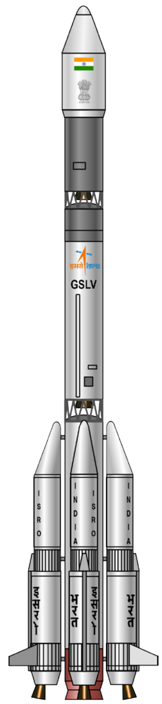
Launch Vehicle Fact Sheet

GSLV



GSLV
Mk I



GSLV
Mk II

The GSLV Mk I has flown six times, while the GSLV Mk II hjas flown three times. There were three variants of the GSLV Mk I, each distinguished by differences in propellant capacity and quality across stages and solid boosters. Only one variant, the GSLV Mk I(c) remains in service. The GSLV Mk II differs from the Mk I primarily because of the third stage, which is built by ISRO. Upper stages used for the Mk I were built in Russia.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	7.8 (26)	3.4 (11.2)

	Liquid Boosters*	1st Stage	2nd Stage	3rd Stage
Stage designation	Strap-on Motors	GS1	GS2	CUS
Length, m (ft)	19.7 (64.6)	20.3 (66.7)	11.6 (38)	8.7 (28.6)
Diameter, m (ft)	2.1 (6.8)	2.8 (9.1)	2.8 (9.1)	2.8 (9.1)
Manufacturer	ISRO	ISRO	ISRO	ISRO
Propellant	N_2O_4/UDMH	Solid	N_2O_4/UDMH	LOX/H_2
Propellant mass, kg (lb)	40,000 (88,200)	129,000 (284,400)	37,500 (82,600)	12,400 (27,300)
Total thrust, kN (lbf)	680 (152,870)	4,700 (1,056,602)	800 (179,847)	75 (16,861)
Engine(s)	L40H Vikas 2	S139	Vikas	CE-7.5
Engine manufacturer	ISRO/LPSC	ISRO/LPSC	ISRO/LPSC	ISRO/LPSC
Engine thrust, kN (lbf)	170 (38,218)	4,700 (1,056,602)	800 (179,847)	75 (16,861)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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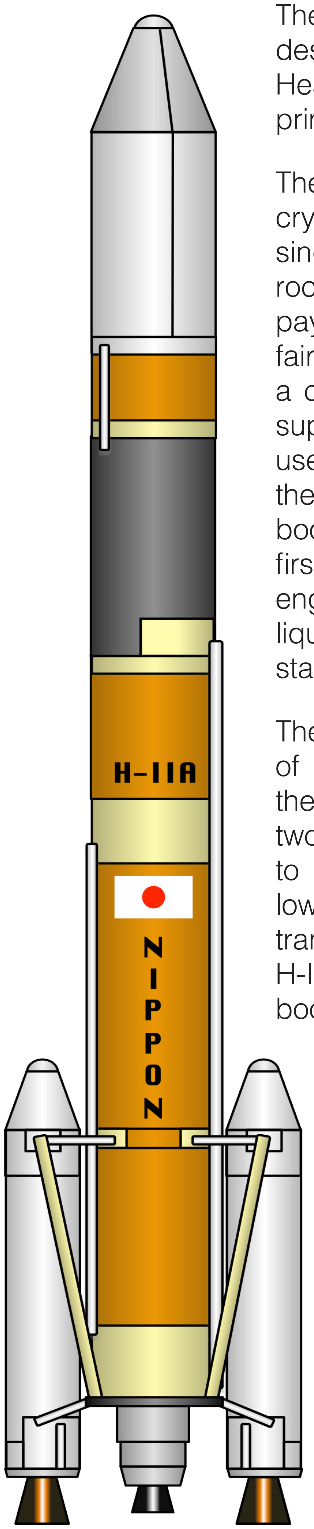
Launch Vehicle Fact Sheet

H-IIA/B

FAA AST



The two-stage H-IIA and H-IIB, designed and built by Mitsubishi Heavy Industries (MHI), are Japan's primary launch vehicles.

The H-IIA vehicle features a cryogenic core stage powered by a single LE-7A engine, two large liquid rocket boosters, an upper stage, a payload adapter, and a payload fairing. The vehicle may also employ a combination of solid boosters to supplement thrust. The H-IIA 202 uses two solid rocket boosters, and the H-IIA 204 uses four solid rocket boosters. The H-IIB features a large first stage powered by two LE-7A engines and supplemented by four liquid rocket boosters and a second stage powered by an LE-5B engine.

There are currently two versions of the H-IIA and one version of the H-IIB available. The H-IIA (with two or four solid boosters) is used to launch a variety of satellites to low Earth orbit, geosynchronous transfer orbits, and beyond. The H-IIB (with four upgraded solid boosters) is currently used to launch the H-II Transfer Vehicle (HTV) to the International Space Station (ISS), and has recently been offered as an option for commercial satellite customers.

The H-II vehicle family can trace its lineage through the H-I, the N-1, and ultimately the U.S. Thor intermediate range ballistic missile.

In 2014, the Japan Aerospace Exploration Agency (JAXA) requested the MHI begin development of the H3, a replacement for the H-IIA/B expected by 2020.

Launch Service Provider
MHI Launch Services

Organization Headquarters
Japan

Manufacturer
Mitsubishi Heavy Industries

Mass, kg (lb)
89,000-530,000
(637,136-1,168,450)

Length, m (ft)
53-57 (173.9-187)

Diameter, m (ft)
4 (13.1)

Year of First Launch
H-IIA: 2001, H-IIB: 2009

Number of Orbital Launches
H-IIA: 37, H-IIB: 6

Reliability
H-IIA: 97%, H-IIB: 100%

Launch Site
Tanegashima (LA-Y)

GTO Capacity, kg (lb)
4,000-6,000 (8,818-13,228)

LEO Capacity, kg (lb)
10,000-16,500 (22,046-36,376)

SSO Capacity, kg (lb)
3,600-4,400 (7,937-9,700)

Estimated Price per Launch
$90M-$112.5M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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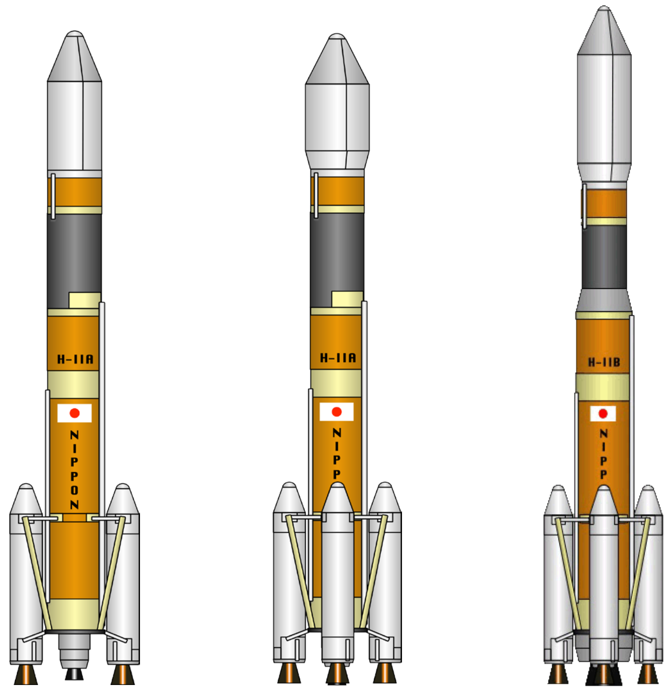
Launch Vehicle Fact Sheet

H-IIA/B



The H-IIA is used for a variety of missions and represents the workhorse launch vehicle for Japan. The H-IIB has been used exlusively to send cargo to the ISS, but recently MHI Launch Services has made the vehicle avalabile for commercial use.

The first commercial mission using the H-IIA took place in 2015 with the launch of Telstar-12 Vantage.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	12 (39.4)	4.07 (13.4)

	Solid Boosters (H-IIA 202)*	Solid Boosters (H-IIA 204)*	Solid Boosters (H-IIB)*	1st Stage	2nd Stage
Stage designation	SRB-A	SRB-A	SRB-A3	1st Stage	2nd Stage
Length, m (ft)	15 (49.2)	15 (49.2)	15.1 (49.5)	37 (121.4)	11 (36.1)
Diameter, m (ft)	2.5 (8.2)	2.5 (8.2)	2.5 (8.2)	4 (13.1)	4 (13.1)
Manufacturer	Nissan	Nissan	Nissan	Mitsubishi	Mitsubishi
Propellant	Solid	Solid	Solid	LOX/LH_2	LOX/LH_2
Propellant mass, kg (lb)	130,000 (293,215)	260,000 (586,430)	264,000 (582,020)	101,000 (222,667)	17,000 (37,479)
Total thrust, kN (lbf)	4,520 (1,016,136)	9,040 (2,032,272)	6,320 (1,420,793)	1,098 (246,840)	137 (30,799)
Engine(s)	—	—	—	LE-7A	LE-5B
Engine manufacturer	—	—	—	Mitsubishi	Mitsubishi
Engine thrust, kN (lbf)	2,260 (508,068)	2,260 (508,068)	1,580 (355,198)	1,098 (246,840)	137 (30,799)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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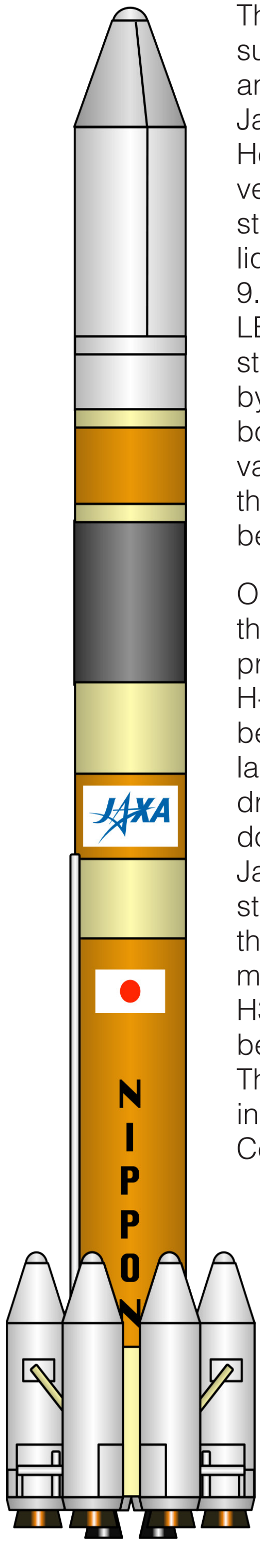
Launch Vehicle Fact Sheet

H3



The H3 launch vehicle is the successor to the H-IIA launch vehicle, and is currently in development by the Japanese government and Mitsubishi Heavy Industries. This 60-meter-tall vehicle will be powered by a core stage that includes a liquid hydrogen/liquid oxygen engine, named the LE-9. The second stage will use a single LE-5B engine. In addition to the core stage engine, the H3 will be powered by two, four, or six solid rocket boosters. There are three proposed variants to the H3. Total capacity for the new launch vehicle is projected to be 6.5 metric tons of payload to GTO.

One of the key differentiators between the H3 and its predecessor is a lower price point. The typical cost of an H-IIA is $100 million, which has not been competitive in the commercial launch industry. Japan intends to drive launch costs for the new vehicle down to $50-70 million. Whereas the Japanese government would like to strengthen its competitive posture in the international commercial launch market through development of the H3, the primary use of the vehicle will be to lift government payloads to orbit. The first launch is estimated to occur in 2020 from the Tanegashima Space Center in Japan.

Launch Service Provider
MHI Launch Services

Organization Headquarters
Japan

Manufacturer
Mitsubishi Heavy Industries

Mass, kg (lb)
Undisclosed

Length, m (ft)
63 (206.7)

Diameter, m (ft)
5.2 (17.1)

Year of Planned First Launch
2020

Launch Site
Tanegashima (LA-Y)

GTO Capacity, kg (lb)
6,500 (14,330)

LEO Capacity, kg (lb)
10,000 (22,046)

SSO Capacity, kg (lb)
4,000 (8,818)

Estimated Price per Launch
$50M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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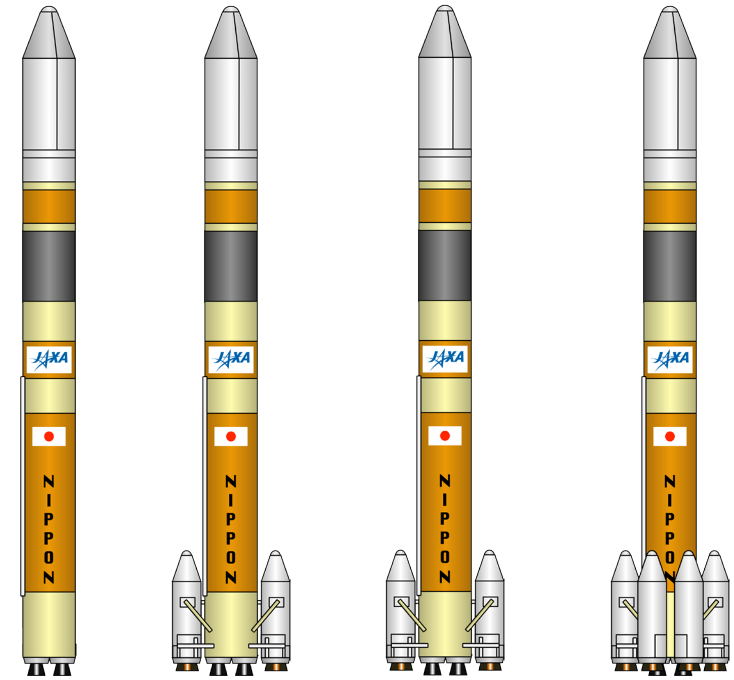
Launch Vehicle Fact Sheet
H3



H3-30S H3-22S H3-32L H3-24L

MHI anticipates developing four variants of the H3 family.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	12 (39.4) *est*	4.07 (13.4) *est*

	Solid Boosters*	1st Stage	2nd Stage
Stage designation	SRB-A3 derivative	1st Stage	2nd Stage
Length, m (ft)	Undisclosed	Undisclosed	11 (36.1)
Diameter, m (ft)	Undisclosed	Undisclosed	4 (13.1)
Manufacturer	Nissan	Mistubishi	Mitsubishi
Propellant	Solid	LOX/LH_2	LOX/LH_2
Propellant mass, kg (lb)	Undisclosed	Undisclosed	17,000 (37,479)
Total thrust, kN (lbf)	Undisclosed	2,896 (652,000)	137 (30,799)
Engine(s)	—	2 x LE-9	LE-5B
Engine manufacturer	—	Mitsubishi	Mitsubishi
Engine thrust, kN (lbf)	Undisclosed	1,448 (326,000)	137 (30,799)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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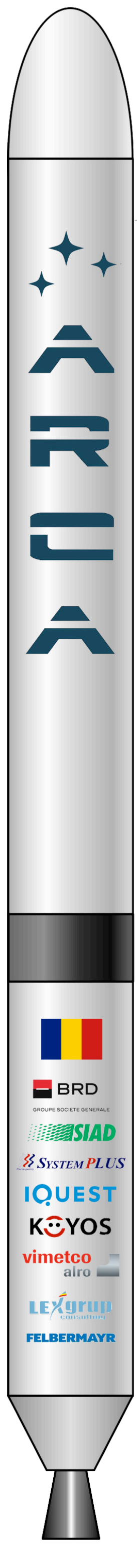
Launch Vehicle Fact Sheet
Haas 2C



Developed by the Aeronautics and Cosmonautics Romanian Association (ARCA) as part of its bid to win the Google Lunar X Prize, the Haas 2C is a 2-stage orbital launch vehicle. The vehicle is named after Transylvanian Conrad Haas, an engineer that explored staged rockets during the 16th century, well before Konstantin Tsiolkovsky published his rocket equation in 1903. In addition to rocket technology, ARCA develops aeronautical and ground transportation systems.

Having withdrawn from the Google Lunar X Prize, ARCA decided to reassess its business plan. This effort resulted in a development schedule focused on two vehicles, the Haas 2B and the Haas 2C. The Haas 2B is a single stage suborbital vehicle designed to carry 5 people to an apogee above 100 kilometers (62 miles). The Haas 2C is designed to tap anticipated demand from operators of very small satellites.

ARCA is relying on the use of composite materials for strength, durability, and low mass. The use of composites in the propulsion system is particularly notable. The Executor and Venator engines feature an internal layer made of silica fiber and phenolic resin, with an external layer made of carbon fiber and epoxy resin.

Launch Service Provider
ARCA Space Corporation

Organization Headquarters
USA

Manufacturer
ARCA Space Corporation

Mass, kg (lb)
16,000 (35,274)

Length, m (ft)
18 (59)

Diameter, m (ft)
1.2 (3.9)

Year of Planned First Launch
2018

Launch Site
TBD

LEO Capacity, kg (lb)
400 (882)

SSO Capacity, kg (lb)
Undisclosed

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Haas 2C

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The Haas 2C on its transporter. (Source: ARCA Space Corporation)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	Undisclosed	1.2 (3.9)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	Undisclosed	Undisclosed
Diameter, m (ft)	1.2 (3.9)	1.2 (3.9)
Manufacturer	ARCA Space Corporation	ARCA Space Corporation
Propellant	LOX/kerosene	LOX/kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	231.3 (52,000)	24.5 (5,500)
Engine(s)	1 x Executor	1 x Venator
Engine manufacturer	ARCA Space Corporation	ARCA Space Corporation
Engine thrust, kN (lbf)	231.3 (52,000)	24.5 (5,500)

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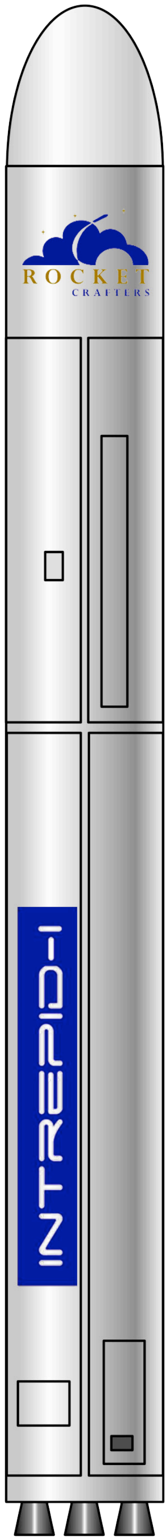
Launch Vehicle Fact Sheet

Intrepid 1



U.S.-based Rocket Crafters, Inc. is developing the Intrepid family of vehicles with the primary aim of lowering cost. According to the company, performance is a secondary consideration.

The company plans to launch the first version in this family, Intrepid 1, in 2018. It then plans to develop the XL and XL+ variants to support a broader base of customers. The vehicles will be powered by hybrid liquid-solid engines produced through additive manufacturing and using a proprietary propellant mixture. In addition to the anticipated lower costs, Rocket Crafters is designing the vehicles with a 6-month lead time from order to launch.

Though investment details have not been made public, Rocket Crafters has successfully tested its hybrid engine more than two dozen times with its partner Utah State University, indicating the company is making progress.

By 2018, Rocket Crafters hopes to launch its vehicles from Cape Canaveral, Florida. It hopes to launch several times per week by 2020.

Launch Service Provider
Rocket Crafters, Inc.

Organization Headquarters
USA

Manufacturer
Rocket Crafters, Inc.

Mass, kg (lb)
24,200 (53,352)

Length, m (ft)
16.2 (53.1)

Diameter, m (ft)
1.7 (5.6)

Year of Planned First Launch
2018

Launch Site
CCAFS

LEO Capacity, kg (lb)
Undisclosed

SSO Capacity, kg (lb)
376 (829)

Estimated Price per Launch
$5.4M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Intrepid 1

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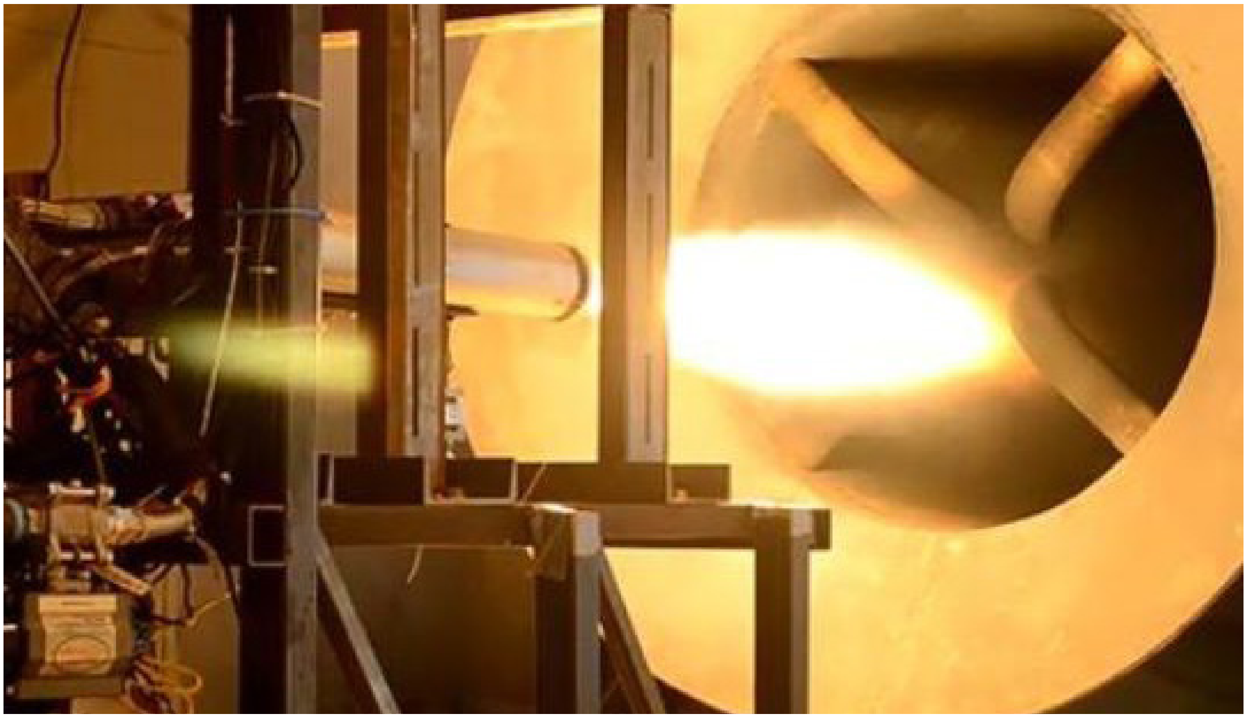

Rocket Crafters test fires its patented fuel system at an indoor testing facility in Utah. (Source: Rocket Crafters, Inc.)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	Undisclosed	1.7 (5.6)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	Undisclosed	Undisclosed
Diameter, m (ft)	1.7 (5.6)	1.7 (5.6)
Manufacturer	Rocket Crafters, Inc.	Rocket Crafters, Inc.
Propellant	Liquid/Solid Hybrid	Liquid/Solid Hybrid
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	328 (73,737)	12 (2,698)
Engine(s)	4 x Sparta-82B	4 x Sparta-3V
Engine manufacturer	Rocket Crafters, Inc.	Rocket Crafters, Inc.
Engine thrust, kN (lbf)	82 (18,434)	3 (674)

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Launch Vehicle Fact Sheet

Kaituozhe 2

The China Aerospace Science & Industry Corporation (CASIC) has been working on the Kaitouzhe line of vehicles since before 2002. The first variant, Kaitouzhe 1, was flown successfully twice, in 2002 and again in 2003. That particular vehicle had an estimated capacity to low Earth orbit (LEO) of 100 kilograms (220.4 pounds). This flights were not considered successful. No further activity took place with this vehicle, and it was assumed by many industry observers that the Kaitouzhe effort had stalled or was terminated.

However, in early 2017, a new Kaitouzhe vehicle was launched, this time an apparent second variant, the Kaitouzhe 2. The specifications reported in the Chinese press differed from some earlier literature regarding a follow on to Kaitouzhe 1.

CASIC is also working on a variant of the Kaitouzhe 2 called the Kaitouzhe 2A. This vehicle will employ two strap-on solid boosters and is expected to launch in 2018. It's LEO capacity is expected to be between 1,000 to 2,000 kilograms.

It is assumed that the Kaitouzhe line will be offered commercially by the China Space Sanjiang Group Corporation (EXPACE). The China Academy of Launch Vehicle Technology (CALT), a subordinate organization within the China Aerospace Science and Technology Corporation (CASC), is a contributor to the program.

Launch Service Provider
EXPACE/PLA

Organization Headquarters
China

Manufacturer
CASIC

Mass, kg (lb)
40,000 (88,185)

Length, m (ft)
35 (115)

Diameter, m (ft)
2.7 (8.9)

Year of First Launch
2017

Number of Orbital Launches
1

Reliability
100%

Launch Site
Jiuquan (SLS-E2)

LEO Capacity, kg (lb)
350 (772)

SSO Capacity, kg (lb)
250 (551)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Kaituozhe 2

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The inaugural launch of a Kaitouzhe 2 vehicle takes place from jiuquan Satellite Launch Center on March 3, 2017. (Source: CN)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	Undisclosed	1.2 (3.9)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	2.7 (8.9)	2.7 (8.9)	2.7 (8.9)
Manufacturer	CASIC	CASIC	CASIC
Propellant	Solid	Solid	Solid
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	Undisclosed	Undisclosed	Undisclosed
Engine(s)	—	—	—
Engine manufacturer	—	—	—
Engine thrust, kN (lbf)	—	—	—

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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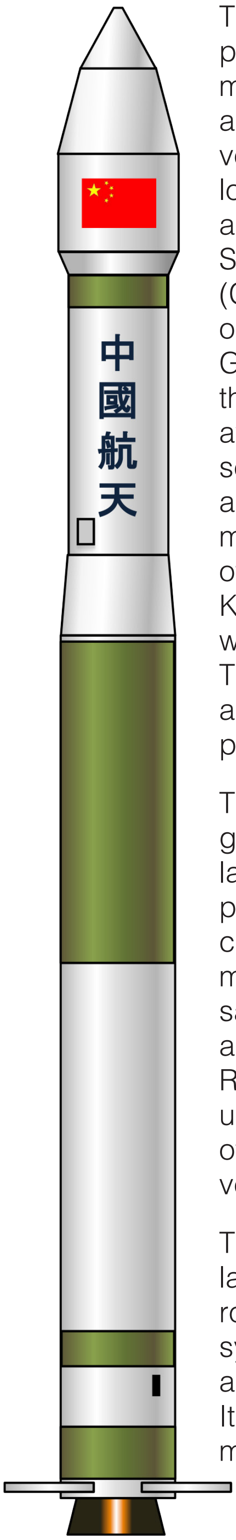
Launch Vehicle Fact Sheet
Kuaizhou 1/1A



The Kuaizhou series of vehicles is possibly based on the mobile DF-21 missile. The Kuaizhou 1A, previously also called Feitian 1 and the commercial version of the military Kuaizhou 1, is a low cost solid launch vehicle developed and built by the China Aerospace Science and Technology Corporation (CASIC) and offered as a commercial option by the China Space Sanjiang Group Corporation (EXPACE). There are three variants of the Kuaizhou currently available (the Kuaizhou 1 for national security missions, and the Kuaizhou 1A and a larger Kuaizhou 1A for commercial missions). Third and fourth versions of the vehicle, called Kuaizhou 21 and Kuaizhou 31, may be in development, with introduction planned in 2025. These vehicles will have LEO capacities approaching 70,000 kilograms (150,000 pounds).

The Kuaizhou seems to have found its genesis as a rapidly deployable orbital launch system that can be stored with payloads already integrated. Upon being called up to support national security missions, the system could launch satellites within hours or days. This approach is not unlike the Operationally Responsive Space (ORS) program undertaken by the U.S. Department of Defense. “Kuaizhou” means “fast vessel” in Chinese.

The 2-stage vehicle requires a mobile launch platform (towable on conventional roads). The platform includes all the systems needed to manage the vehicle and payload during ground operations. It also contains launc control and range management systems.

Launch Service Provider
EXPACE/PLA

Organization Headquarters
China

Manufacturer
CASIC

Mass, kg (lb)
30,000 (66,139)

Length, m (ft)
19.4 (63.6)

Diameter, m (ft)
1.4 (4.6)

Year of First Launch
2013

Number of Orbital Launches
3

Reliability
100%

Launch Site
Jiuquan (mobile)

LEO Capacity, kg (lb)
300 (661)

SSO Capacity, kg (lb)
250 (551)

Estimated Price per Launch
$3M *est*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Kuaizhou 1/1A

FAA AST

The first commercial variant of the Kuaizhou 1A is launched on January 10, 2017. (Source: CN)

Fairing	Length, m (ft)	Diameter, m (ft)
Small Fairing	Undisclosed	1.2 (3.9)
Large Fairing	Undisclosed	1.4 (4.6)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	1st Stage	2nd Stage	3rd Stage	4th Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	1.4 (4.6)	1.4 (4.6)	1.2 (3.9)	1.2 (3.9)
Manufacturer	CASIC	CASIC	CASIC	CASIC
Propellant	Solid	Solid	Solid	Liquid
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Engine(s)	—	—	—	Undisclosed
Engine manufacturer	—	—	—	Undisclosed
Engine thrust, kN (lbf)	—	—	—	Undisclosed

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Launch Vehicle Fact Sheet

Kuaizhou 11

The Kuaizhou series of vehicles is possibly based on the mobile DF-21 missile. The Kuaizhou 1A, previously also called Feitian 1 and the commercial version of the military Kuaizhou 1, is a low cost solid launch vehicle developed and built by the China Aerospace Science and Technology Corporation (CASIC) and offered as a commercial option by the China Space Sanjiang Group Corporation (EXPACE). There are three variants of the Kuaizhou currently available (the Kuaizhou 1 for national security missions, and the Kuaizhou 1A and a larger Kuaizhou 1A for commercial missions). Two other versions, called Kuaizhou 21 (20,000 kg to LEO) and Kuaizhou 31 (70,000 kg to LEO) are apparently in development, with introduction planned in 2025.

The Kuaizhou seems to have found its genesis as a rapidly deployable orbital launch system that can be stored with payloads already integrated. Upon being called up to support national security missions, the system could launch satellites within hours or days. This approach is not unlike the Operationally Responsive Space (ORS) program undertaken by the U.S. Department of Defense. “Kuaizhou” means “fast vessel” in Chinese.

The 2-stage vehicle requires a mobile launch platform (towable on conventional roads). The platform includes all the systems needed to manage the vehicle and payload during ground operations. It also contains launc control and range management systems.

Launch Service Provider
EXPACE/PLA

Organization Headquarters
China

Manufacturer
CASIC

Mass, kg (lb)
78,000 (171,961)

Length, m (ft)
20 (65.6)

Diameter, m (ft)
2.2 (7.2)

Year of Planned First Launch
2018

Launch Site
Jiuquan (mobile)

LEO Capacity, kg (lb)
1,500 (3,307)

SSO Capacity, kg (lb)
1,000 (2,205)

Estimated Price per Launch
$15M *est*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Kuaizhou 11

A model of the Kuaizhou 11 on display at a convention. (Source: Weapon Magazine)

Fairing	Length, m (ft)	Diameter, m (ft)
Small Fairing	Undisclosed	2.2 (7.2)
Large Fairing	Undisclosed	2.6 (8.5)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	1st Stage	2nd Stage	3rd Stage	4th Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	2.2 (7.2)	2.2 (7.2)	1.2 (3.9)	1.2 (3.9)
Manufacturer	CASIC	CASIC	CASIC	CASIC
Propellant	Solid	Solid	Solid	Liquid
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Engine(s)	—	—	—	Undisclosed
Engine manufacturer	—	—	—	Undisclosed
Engine thrust, kN (lbf)	—	—	—	Undisclosed

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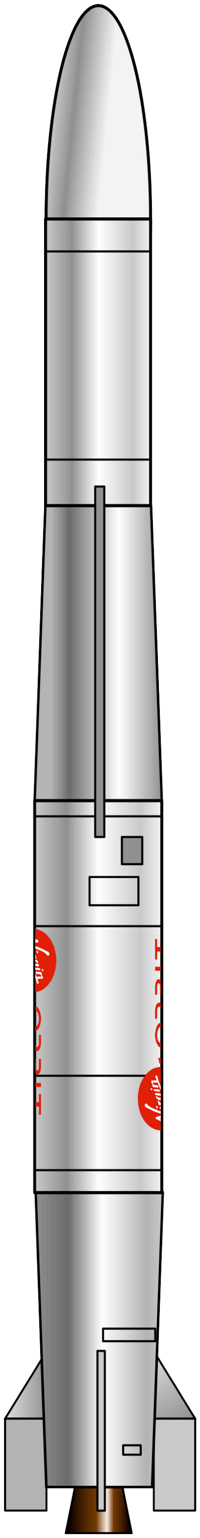
Launch Vehicle Fact Sheet

LauncherOne



Virgin Orbit is currently testing air-launched, two-stage LauncherOne vehicle in preparation for the start of commercial service. Virgin Orbit is a privately-funded, US company based in Long Beach, California.

LauncherOne is designed to address the growing demand for microsatellites by providing dedicated microsatellite services, including rapid scheduling and fast constellation replenishment.

Originally conceived as a vehicle capable of sending 225 kg to low Earth orbit (LEO), the company has since increased that capacity to 400 kg to address the diverse needs of the microsatellite market. This meant that the original carrier aircraft, the WhiteKnightTwo, was no longer able to lift LauncherOne. As a result, Virgin Orbit has secured a Boeing 747-400 aircraft, repurposed from its former role as a Virgin Atlantic airliner.

Virgin Orbit has been selected by NASA, the Department of Defense's Space Test Program (via Virgin Orbit's subsidiary, VOX Space), SITAEL, Cloud Constellation Corporation, Sky and Space Global, Planet, and OneWeb as a launch provider. Many of these contracts represent multiple launches; for example, Cloud Constellation has purchased a dozen launches, Sky and Space Global has purchased four, and OneWeb has purchased launches for as any as 39 of their microsatellites.

The first launch of LauncherOne is planned for 2017. It will carry a test package rather than a payload for a paying customer.

Launch Service Provider
Virgin Orbit

Organization Headquarters
USA

Manufacturer
Virgin Orbit

Mass, kg (lb)
25,000 (55,116) *est.*

Length, m (ft)
25 (82) est.

Diameter, m (ft)
1.8 (5.9)

Year of Planned First Launch
2018

Launch Sites
Mojave Air and Space Port
Others TBA

LEO Capacity, kg (lb)
500 (1,102)

SSO Capacity, kg (lb)
300 (661)

Estimated Price per Launch
$12M

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Launch Vehicle Fact Sheet

LauncherOne

An artist's impression of the LauncherOne vehicle integrated with a Boeing 747-400 carrier aircraft. (Source: Virgin Orbit)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	3.6 (11.8)	1.4 (4.6)

	1st Stage	2nd Stage	3rd Stage
Stage designation	747-400 *Cosmic Girl*	1st Stage	2nd Stage
Length, m (ft)	70.6 (232)	Undisclosed	Undisclosed
Diameter/Wingspan, m (ft)	64.4 (211)	1.8 (5.9)	1.5 (4.9)
Manufacturer	Boeing	Virgin Orbit	Virgin Orbit
Propellant	Kerosene (Jet-A1)	LOX/kerosene	LOX/kerosene
Propellant mass, kg (lb)	175,652 (387,247)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	1,097 (246,615)	335 (75,000)	22.2 (5,000)
Engine(s)	4 x GE CF6-80C2B5F	1 x NewtonThree	1 x NewtonFour
Engine manufacturer	General Electric	Virgin Orbit	Virgin Orbit
Engine thrust, kN (lbf)	274.2 (61,500)	335 (73,500)	22.2 (5,000)

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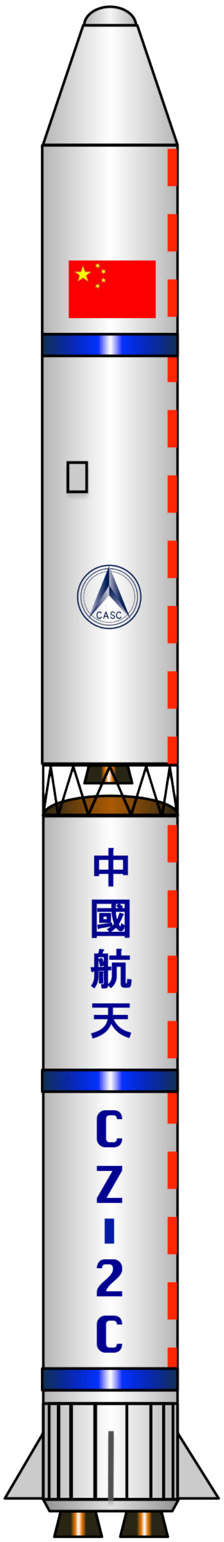
Launch Vehicle Fact Sheet

Long March 2C



First launched from Jiuquan Space Launch Center in 1975, the Long March 2C launch vehicle has been a workhorse. The rocket is part of the Long March 2 family and is the successor to the Long March 2A launch vehicle. As of December 31, 2015, China has successfully launched 43 Long March 2C vehicles. There has only been one reported launch failure during its operational life.

There exist six variants of the Long March C launch vehicle, and these variants range from 2-stage to 3-stage designs, and are considered medium-capacity vehicles, capable of lifting payloads to low Earth orbit (LEO), geostationary transfer orbit (GTO), or direct to geosynchronous orbit (GEO), depending on the variant. Launches to LEO polar orbit are conducted from Taiyuan Satellite Launch Center, whereas launches to GTO and GEO are conducted from Xichang Satellite Launch Center.

The Long March 2C is expected to be retired before 2020 as China introduces several new Long March vehicles. A proposed variant of the Long March 5 may be pursued to fulfill the capability offered by the Long March 2C, since the new Long March 6 and Long March 11 are much smaller.

The China Academy of Launch Vehicle Technology (CALT) is the systems integrator for the Long March 2C. Major support is provided by the Shanghai Academy of Spaceflight Technology (SAST).

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
CALT

Mass, kg (lb)
233,000 (513,677)

Length, m (ft)
42 (138)

Diameter, m (ft)
3.4 (11)

Year of First Launch
1982

Number of Orbital Launches
44

Reliability
98%

Launch Sites
Jiuquan (LA-2, LA-4)
Taiyuan (LA-7, LA-9)
Xichang (LA-3)

GTO Capacity, kg (lb)
1,250 (2,758)

LEO Capacity, kg (lb)
3,850 (8,488)

SSO Capacity, kg (lb)
1,900 (4,189)

Estimated Price per Launch
$30M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet
Long March 2C

A Long March 2C carrying Shijian-11 07 is launched from Jiuquan Satellite Launch Center in 2014. (Source: www.news.cn)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	7 (22.9)	3.4 (11.2)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	2804
Length, m (ft)	25.7 (84.3)	7.8 (25.6)	1.5 (4.9)
Diameter, m (ft)	3.4 (11.2)	3.4 (11.2)	2.7 (8.9)
Manufacturer	CALT	CALT	CALT
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	Solid
Propellant mass, kg (lb)	162,706 (358,705)	54,667 (120,520)	125 (275.6)
Total thrust, kN (lbf)	2,961.6 (665,794)	741.3 (166,651)	10.8 (2,428)
Engine(s)	4 x YF-21C	1 x YF-24E	—
Engine manufacturer	SAST	SAST	—
Engine thrust, kN (lbf)	740.4 (166,449)	741.3 (166,651)	10.8 (2,428)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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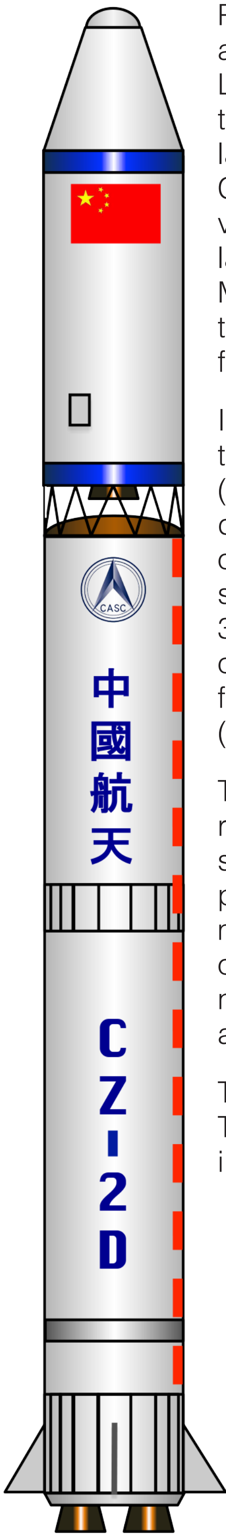
Launch Vehicle Fact Sheet

Long March 2D



Primarily used to lift payloads to LEO and SSO, the 41-meter-tall, two-stage Long March 2D launch vehicle is part of the Long March 2 family of rockets. First launched from Jiuquan Satellite Launch Center in 1992, this Chinese launch vehicle has completed 25 successful launches. Two variants of the Long March 2D are known, and both are two-stage rockets that employ engines fueled by N_2O_4/UDMH.

In addition, this launch vehicle can use two different types of payload fairings (Type A: 2.9-m diameter, Type B: 3.35-m diameter). The launch vehicle is capable of lifting a 1,300 kg payload to a 645 km sun synchronous orbit (SSO) orbit and 3,500 kg payload to a 200 km low Earth orbit (LEO) orbit. The vehicle is not used for missions to geosynchronous orbit (GEO).

The Long March 2D is expected to be retired before 2020 as China introduces several new Long March vehicles. A proposed variant of the Long March 5 may be pursued to fulfill the capability offered by the Long March 2D, since the new Long March 6 and Long March 11 are much smaller.

The Shanghai Academy of Spaceflight Technology (SAST) is the systems integrator for the Long March 2D.

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
SAST

Mass, kg (lb)
232,250 (512,024)

Length, m (ft)
41 (134.5)

Diameter, m (ft)
3.4 (11)

Year of First Launch
1992

Number of Orbital Launches
33

Reliability
100%

Launch Site
Jiuquan (LA-2, LA-4)

LEO Capacity, kg (lb)
3,500 (7,716)

SSO Capacity, kg (lb)
1,300 (2,866)

Estimated Price per Launch
$30M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Long March 2D

FAA AST

A Long March 2D carrying Tianhui-1C is launched from Jiuquan Satellite Launch Center in 2015. (Source: Xinghua)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	7 (22.9)	3.4 (11.2)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	27.9 (91.5)	10.9 (35.8)
Diameter, m (ft)	3.4 (11.2)	3.4 (11.2)
Manufacturer	SAST	CALT
Propellant	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	182,000 (401,241)	52,700 (116,184)
Total thrust, kN (lbf)	2,961.6 (665,794)	742 (166,808)
Engine(s)	4 x YF-21C	1 x YF-24C
Engine manufacturer	SAST	SAST
Engine thrust, kN (lbf)	740.4 (166,449)	742 (166,808)

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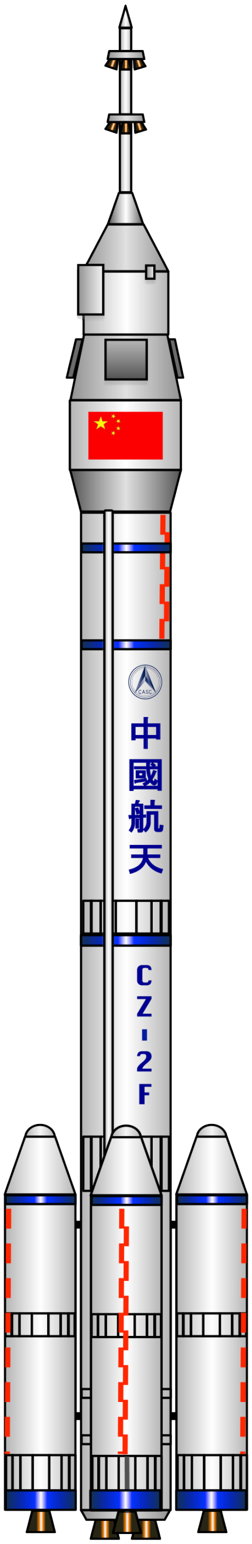
Launch Vehicle Fact Sheet

Long March 2F



The Long March 2F, introduced in 1999, is China's only vehicle designed to transport astronauts. The two-stage vehicle is ultimately derived from the Long March 2C via the Long March 2E, a retired vehicle that was used to send payloads to geosynchronous orbit (GEO).

The Long March 2F carried the Shenzhou spacecraft, which consists of an orbital module, a descent module, and a service module. Shenzhou is partly derived from Soviet/Russian Soyuz hardware, which was purchased by the Chinese government in 1995. However, the Shenzhou is significantly different than the Soyuz in terms of dimensions, internal arrangement, and subsystems.

There have been eleven launches of the Long March 2F. Ten of these supported Shenzhou missions, six of which carried crews. The eleventh launch was of Tiangong-1 in 2011, China's first space station with a design not unlike the early Salyut/Almaz systems launched by the Soviet Union in the 1970s.

China's Tiangong-2 is scheduled for launch in 2016, followed by the crewed Shenzhou-11, which will dock with the station. Both of these missions will be launched by separate Long March 2F vehicles. Crewed missions are expected to be launched by the Long March 5 vehicle, introduced in 2016.

Launch Service Provider
PLA/CNSA

Organization Headquarters
China

Manufacturer
CALT

Mass, kg (lb)
464,000 (1,022,945)

Length, m (ft)
62 (203.4)

Diameter, m (ft)
3.4 (11)

Year of First Launch
1999

Number of Orbital Launches
13

Reliability
100%

Launch Site
Jiuquan (LC-43/921)

LEO Capacity, kg (lb)
8,400 (18,519)

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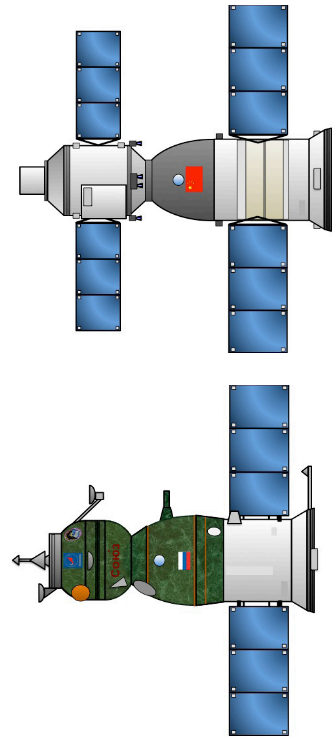
Launch Vehicle Fact Sheet

Long March 2F

The Long March 2F carrying Shenzhou 9 is rolled to the launch pad in jiuquan in 2012. (Source: SinoDefence)



The Shenzhou spacecraft (above) is similar to the Russian Soyuz (below). China had purchased Soyuz hardware from Russia in 1995 to support China's 921-1 human spaceflight program begun in 1992.

	Liquid Boosters*	1st Stage	2nd Stage
Stage designation	Liquid Boosters (4)	1st Stage	2nd Stage
Length, m (ft)	15.3 (50.2)	23.7 (77.8)	13.5 (44.3)
Diameter, m (ft)	2.3 (7.5)	3.4 (11)	3.4 (11)
Manufacturer	CALT	CALT	CALT
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	37,800 (83,335)	187,000 (412,264)	86,000 (189,598)
Total thrust, kN (lbf)	3,256 (731,978)	3,256 (731,978)	831 (186,816)
Engine(s)	1 x YF-20B	4 x YF-20B	1 x YF-24B
Engine manufacturer	CALT	CALT	CALT
Engine thrust, kN (lbf)	814 (182,994)	814 (182,994)	831 (186,816)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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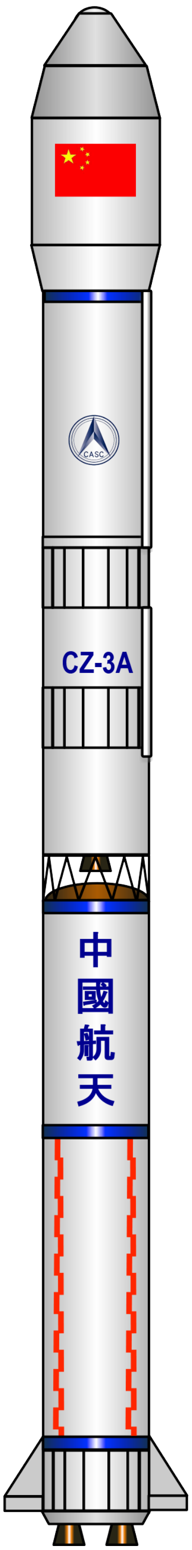
Launch Vehicle Fact Sheet

Long March 3A



This operational launch vehicle has been launched successful 24 times since its first launch in 1994. Developed by the China Academy of Launch Vehicle Technology (CALT), Long March 3A is part of the Long March 3 rocket family and is considered an intermediate-capacity launch vehicle. Long March 3A is capable of lifting a 2,600 kg payload to geostationary transfer orbit (GTO) and a 6,000 kg payload to a 200 km low Earth orbit (LEO). The Chinese launch the three-stage Long March 3A from Xichang Satellite Launch Center, primarily to place communications and navigation satellites into GTO.

The Long March 3A divides into three stages. The first and second stages use a N_2O_4/UDMH fuel whereas the third stage uses a liquid oxygen (LOX) oxidizer and liquid hydrogen (LH_2) fuel. This launch vehicle is the predecessor to a higher-capacity launch vehicle in the Long March 3 family, the Long March 3B.

The Long March 3A is expected to be retired before 2020 as China introduces several new Long March vehicles, particularly the Long March 5 series.

The China Academy of Launch Vehicle Technology (CALT) is the systems integrator for the Long March 3A. Major support is provided by the Shanghai Academy of Spaceflight Technology (SAST).

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
CALT

Mass, kg (lb)
241,000 (531,314)

Length, m (ft)
52.5 (172.2)

Diameter, m (ft)
3.4 (11)

Year of First Launch
1994

Number of Orbital Launches
25

Reliability
100%

Launch Site
Xichang (LA-2, LA-3)

GTO Capacity, kg (lb)
2,600 (5,732)

LEO Capacity, kg (lb)
8,500 (18,739)

Estimated Price per Launch
$70M

FAA AST

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Launch Vehicle Fact Sheet

Long March 3A

FAA AST

A Long March 3A carrying Fengyun 2G is launched from Xichang in 2014. (Source: ChinaNews)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	8.9 (29.2)	3.4 (11)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	23.3 (76.4)	11.3 (37.1)	12.4 (40.7)
Diameter, m (ft)	3.4 (11)	3.4 (11)	3 (9.8)
Manufacturer	SAST	SAST	CALT
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	LOX/LH_2
Propellant mass, kg (lb)	171,800 (378,754)	32,600 (71,871)	18,200 (40,124)
Total thrust, kN (lbf)	3,265 (734,001)	742 (166,808)	167 (37,543)
Engine(s)	4 x YF-21C	1 x YF-24E	1 x YF-75
Engine manufacturer	SAST	SAST	CALT
Engine thrust, kN (lbf)	816.3 (183,512)	742 (166,808)	167 (37,543)

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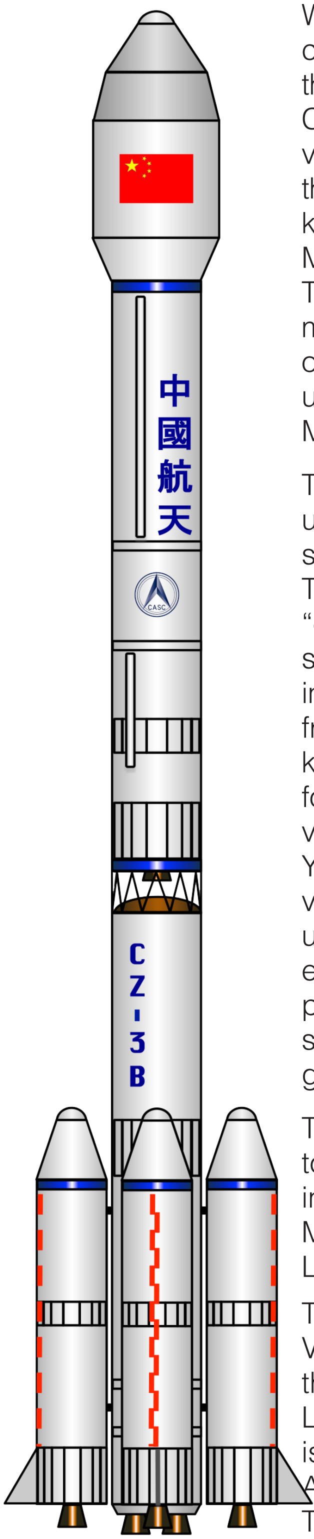
Launch Vehicle Fact Sheet

Long March 3B/E



With a low Earth orbit (LEO) capacity of 12,000 kg (26,456 lb), the Long March 3B is currently China's most powerful launch vehicle. The vehicle is derived from the Long March 3A vehicle, with the key difference being that the Long March 3B uses four liquid boosters. The vehicle is primarily used for missions to a geostationary transfer orbit (GTO), but can be used for uncrewed science missions to the Moon (Chang'e-3).

The Long March 3B has been upgraded on a few occassions since its introduction in 1996. The Long March 3B/E ("E" for "enhanced") featured a larger first stage and liquid rocket boosters, increasing its capacity to GTO from 5,100 kg (11,244 lb) to 5,500 kg (12,125 lb). This variant flew for the first time in 2007. Another variant, called the Long March 3B/YZ-1, was introduced in 2015. This vehicle features a new, restartable upper stage called Yuanzheng-1, enabling the vehicle to send payloads to high energy orbits, such as a direct insertion to a geostationary orbit (GSO).

The Long March 3B is expected to be retired before 2020 as China introduces several new Long March vehicles, particularly the Long March 5 series.

The China Academy of Launch Vehicle Technology (CALT) is the systems integrator for the Long March 3B. Major support is provided by the Shanghai Academy of Spaceflight Technology (SAST).

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
CALT

Mass, kg (lb)
458,970 (1,011,856)

Length, m (ft)
56.3 (184.7)

Diameter, m (ft)
3.4 (11)

Year of First Launch
1996 (3B), 2007 (3B/E)

Number of Orbital Launches
42

Reliability
98%

Launch Site
Xichang (LA-2, LA-3)

GTO Capacity, kg (lb)
5,500 (12,125)

LEO Capacity, kg (lb)
12,000 (26,456)

SSO Capacity, kg (lb)
5,700 (12,566)

Estimated Price per Launch
$70M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Long March 3B/E

A Long March 3B/YZ-1 carrying BDS I2-S is launched from Xichang Satellite Launch Center in 2015. (Source: CNS/XNA)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	8.9 (29.2)	4 (13.1)

	Liquid Boosters*	1st Stage	2nd Stage	3rd Stage	4th Stage Option
Stage designation	Liquid Boosters (4)	1st Stage	2nd Stage	3rd Stage	Yuanzheng-1
Length, m (ft)	16.1 (52.8)	24.8 (81.4)	12.9 (42.3)	12.4 (40.7)	Undisclosed
Diameter, m (ft)	2.3 (7.5)	3.4 (11)	3.4 (11)	3 (9.8)	Undisclosed
Manufacturer	CALT	SAST	SAST	CALT	CALT
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	41,100 (90,610)	186,200 (410,501)	49,400 (108,908)	18,200 (40,124)	Undisclosed
Total thrust, kN (lbf)	740.4 (166,449)	3,265 (734,001)	742 (166,808)	167 (37,543)	6.5 (1,500)
Engine(s)	1 x YF-25	4 x YF-21C	1 x YF-24E	1 x YF-75	1 x YF-50D
Engine manufacturer	CALT	SAST	SAST	CALT	CALT
Engine thrust, kN (lbf)	740.4 (166,449)	816.3 (183,512)	742 (166,808)	167 (37,543)	6.5 (1,500)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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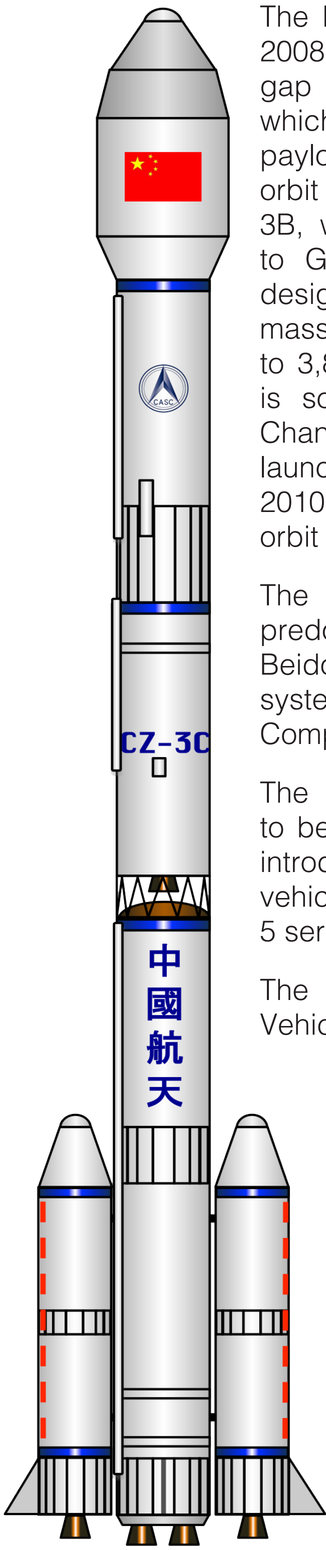
Launch Vehicle Fact Sheet

Long March 3C



The Long March 3C, introduced in 2008, is designed to fill a capacity gap between the Long March 3A, which handles relatively small payloads to geostationary transfer orbit (GTO) and the Long March 3B, which handles large payloads to GTO. The Long March 3C is designed to send payloads with a mass of between 3,000 kg (6,614 lb) to 3,800 kg (8,378 lb). The vehicle is sometimes used for uncrewed Chang'e science missions, having launched Chang'e-2 to the Moon in 2010 and Chang'e-T1 to a high lunar orbit in 2014.

The Long March 3C has been predominantly used to support the Beidou global navigation satellite system, having sent seven Beidou Compass satellites to GTO.

The Long March 3C is expected to be retired before 2020 as China introduces several new Long March vehicles, particularly the Long March 5 series.

The China Academy of Launch Vehicle Technology (CALT) is the systems integrator for the Long March 3C. Major support is provided by the Shanghai Academy of Spaceflight Technology (SAST).

Launch Service Provider
PLA/CNSA

Organization Headquarters
China

Manufacturer
CALT

Mass, kg (lb)
345,000 (760,595)

Length, m (ft)
54.8 (179.8)

Diameter, m (ft)
3.4 (11)

Year of First Launch
2008

Number of Orbital Launches
15

Reliability
100%

Launch Site
Xichang (LA-2, LA-3)

GTO Capacity, kg (lb)
3,800 (8,378)

Estimated Price per Launch
$70M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Long March 3C

A Long March 3C stands poised for launch from Xichang Satellite Launch Center in 2011. (Source: ChinaDailyMail.com)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	8.9 (29.2)	4 (13.1)

	Liquid Boosters*	1st Stage	2nd Stage	3rd Stage	4rd Stage Option
Stage designation	Liquid Boosters (2)	1st Stage	2nd Stage	3rd Stage	Yuanzheng-1
Length, m (ft)	16.1 (52.8)	24.8 (81.4)	12.9 (42.3)	12.4 (40.7)	Undisclosed
Diameter, m (ft)	2.3 (7.5)	3.4 (11)	3.4 (11)	3 (9.8)	Undisclosed
Manufacturer	CALT	SAST	SAST	CALT	CALT
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	41,100 (90,610)	186,200 (410,501)	49,400 (108,908)	18,200 (40,124)	Undisclosed
Total thrust, kN (lbf)	740.4 (166,449)	3,265 (734,001)	742 (166,808)	167 (37,543)	6.5 (1,500)
Engine(s)	1 x YF-25	4 x YF-21C	1 x YF-24E	1 x YF-75	1 x YF-50D
Engine manufacturer	CALT	SAST	SAST	CALT	CALT
Engine thrust, kN (lbf)	740.4 (166,449)	816.3 (183,512)	742 (166,808)	167 (37,543)	6.5 (1,500)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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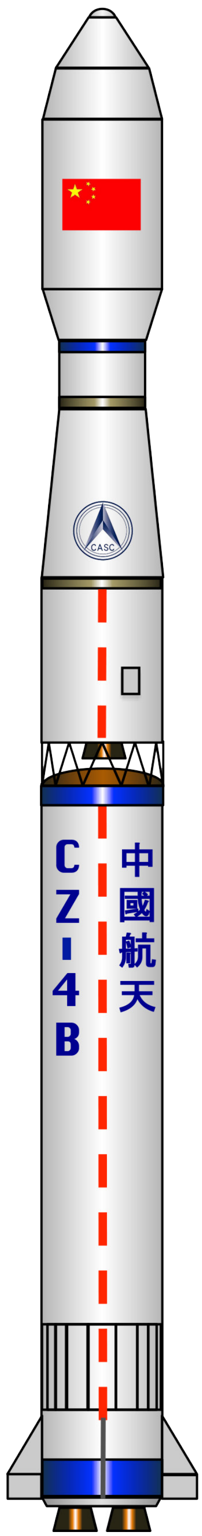
Launch Vehicle Fact Sheet

Long March 4B



The Long March 4B, like the similar Long March 4C, is a workhorse launch vehicle used by the Chinese since 1999 to send payloads into polar orbits from the Taiyuan Satellite Launch Center near Beijing. On only one occasion, the vehicle was launched from Jiuquan. The Long March 4 series was originally conceived as a backup for the Long March 3 series in support of missions to geostationary transfer orbit (GTO). However, the vehicle proved more capable for polar orbiting missions. The vehicle is manufactured by the Shanghai Academy of Spaceflight Technology (SAST).

The vehicle is based on the Long March 4 vehicle, conceived in the late 1980s but never built. The Long March 4B was an improvement to that original design, featuring a larger payload fairing; improved telemetry, tracking, control, and self-destruction systems; and new propulsion elements designed to increase the vehicle's capacity to orbit.

The Long March 4B is expected to be retired before 2020 as China introduces several new Long March vehicles, particularly the Long March 5 series.

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
SAST

Mass, kg (lb)
249,200 (549,392)

Length, m (ft)
45.8 (150.3)

Diameter, m (ft)
3.4 (11)

Year of First Launch
1999

Number of Orbital Launches
29

Reliability
97%

Launch Sites
Jiuquan (LA-4)
Taiyuan (LA-7)

GTO Capacity, kg (lb)
1,500 (3,307)

LEO Capacity, kg (lb)
4,200 (9,259)

SSO Capacity, kg (lb)
2,800 (6,173)

Estimated Price per Launch
$30M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Long March 4B

A Long March 4B carrying Ziyuan 3 and VesselSat-2 is launched from Taiyuan in 2012. (Source: Xinghua)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	8.5 (27.9)	3.4 (11.2)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	27.9 (91.5)	10.9 (35.8)	14.8 (48.6)
Diameter, m (ft)	3.4 (11.2)	3.4 (11)	2.9 (9.5)
Manufacturer	SAST	SAST	SAST
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	182,000 (401,241)	52,700 (116,184)	14,000 (30,865)
Total thrust, kN (lbf)	3,265 (734,001)	741.3 (166,651)	206 (46,311)
Engine(s)	4 x YF-21C	1 x YF-24C	2 x YF-40
Engine manufacturer	SAST	SAST	SAST
Engine thrust, kN (lbf)	816.3 (183,512)	741.3 (166,651)	103 (23,155)

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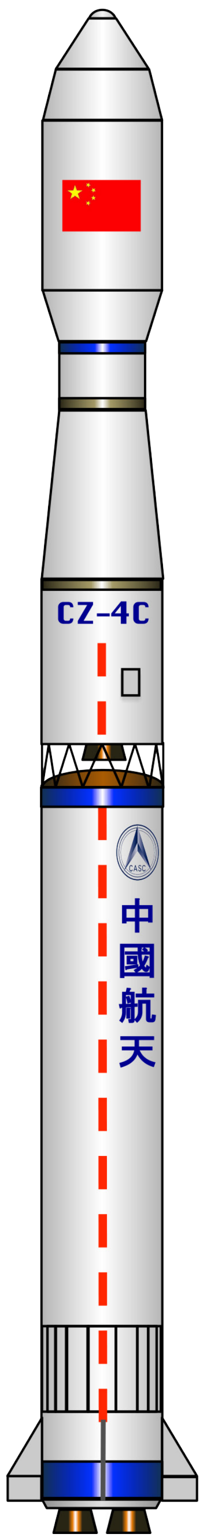
Launch Vehicle Fact Sheet

Long March 4C



The Long March 4C is derived from the Long March 4B, but both vehicles are used to support missions to low Earth orbit (LEO) and sun synchronous orbits (SSO). Unlike the Long March 4B, which is primarily launched from the Taiyuan Satellite Launch Center, the Long March 4C is also frequently launched from the Jiuquan Satellite Launch Center. Launches from Taiyuan typically support meteorology missions, whereas those from Jiuquan support image intelligence missions. The vehicle is manufactured by the Shanghai Academy of Spaceflight Technology (SAST).

The Long March 4C differs from the Long March 4B in that it features a larger volume payload fairing and a restartable third stage.

The Long March 4C is expected to be retired before 2020 as China introduces several new Long March vehicles, particularly the Long March 5 series.

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
SAST

Mass, kg (lb)
250,000 (551,156)

Length, m (ft)
45.8 (150)

Diameter, m (ft)
3.4 (11)

Year of First Launch
2006

Number of Orbital Launches
21

Reliability
95%

Launch Sites
Jiuquan (LA-4)
Taiyuan (LA-7, LA-9)

GTO Capacity, kg (lb)
1,500 (3,307)

LEO Capacity, kg (lb)
4,200 (9,259)

SSO Capacity, kg (lb)
2,800 (6,73)

Estimated Price per Launch
$30M

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Launch Vehicle Fact Sheet

Long March 4C

A Long March 4C carrying Yaogan 15 is launched from Taiyuan in 2012. (Source: ChinaNews)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	8.5 (27.9)	3.4 (11.2)
Large Fairing	Undisclosed	Undisclosed

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	27.9 (91.5)	10.9 (35.8)	14.8 (48.6)
Diameter, m (ft)	3.4 (11.2)	3.4 (11)	2.9 (9.5)
Manufacturer	SAST	SAST	SAST
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	182,000 (401,241)	52,700 (116,184)	14,000 (30,865)
Total thrust, kN (lbf)	3,265 (734,001)	741.3 (166,651)	201.8 (45,366)
Engine(s)	4 x YF-21C	1 x YF-24C	2 x YF-40A
Engine manufacturer	SAST	SAST	SAST
Engine thrust, kN (lbf)	816.3 (183,512)	741.3 (166,651)	100.9 (22,683)

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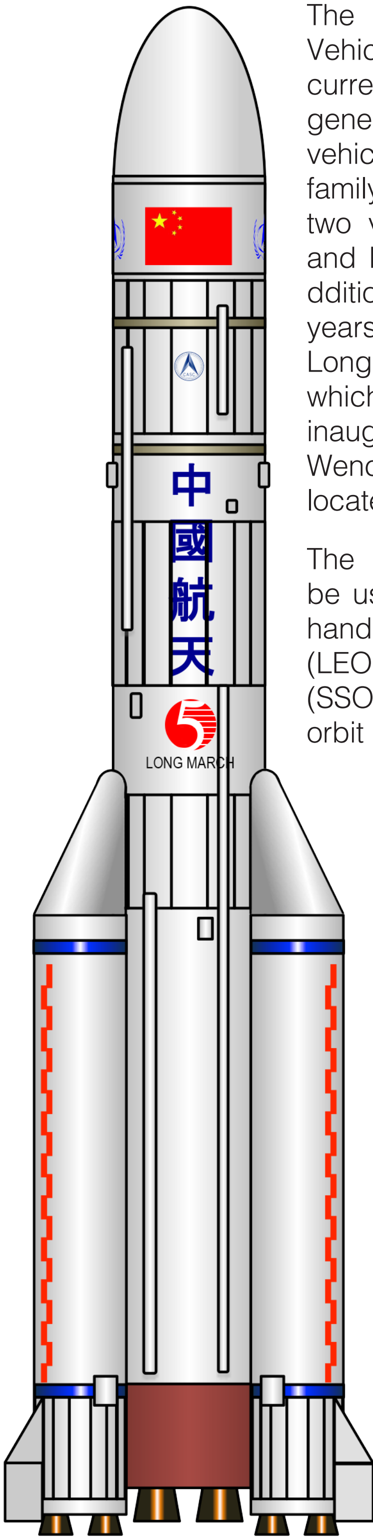
Launch Vehicle Fact Sheet

Long March 5



The China Academy of Launch Vehicle Technology (CALT) is currently developing the next generation of Chinese launch vehicles, the Long March 5 family. The effort is focused on two versions, the Long March 5 and Long March 5B, with several dditional variants expected in the years to follow. The first launch of a Long March 5 is expected in 2016, which will apparently represent the inaugural launch from China's new Wencheng Satellite Launch Center located on Hainan Island.

The Long March 5 series may be used for the bulk of launches, handling missions to low Earth orbit (LEO), sun synchronous orbits (SSO), and geostationary transfer orbit (GTO).

While CALT is the systems integrator for Long March 5, the Academy of Aerospace Propulsion Technology (AAPT) is developing the new engines.

Since the Long March 5 will replace the Long March 3B/E for GTO launches, it is likely the vehicle will be marketed as an option for satellite operators worldwide.

The first launch of the Long March 5 took place on November 3, 2016 from China's newly built Wenchang Spacecraft Launch Site. The launch was successful. The second launch, which took place in July 2017, ended in failure.

Launch Service Provider
PLA/CNSA/CGWIC

Organization Headquarters
China

Manufacturer
CALT

Mass, kg (lb)
879,000 (1,937,863)

Length, m (ft)
57 (187)

Diameter, m (ft)
5 (16.4)

Year of First Launch
2016

Number of Orbital Launches
2

Reliability
50%

Launch Sites
Wenchang (LC-1)

GTO Capacity, kg (lb)
14,000 (30,865)

LEO Capacity, kg (lb)
25,000 (55,116)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Long March 5

The Long March 5 takes shape at CALT. (Source: Xinghua)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	12.5 (41)	5.2 (17.1)

	Liquid Boosters*	1st Stage	2nd Stage Option	2nd Stage Option	3rd Stage
Stage designation	Liquid Boosters (4)	1st Stage	2nd Stage	2nd Stage	3rd Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	3.4 (11)	5 (16.4)	5 (16.4)	5 (16.4)	Undisclosed
Manufacturer	CALT	CALT	CALT	CALT	CALT
Propellant	LOX/Kerosene	LOX/H_2	LOX/H_2	LOX/H_2	LOX/H_2
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	2,358 (530,100)	1,018 (228,856)	44.2 (9,937)	176.6 (39,701)	78.5 (17,648)
Engine(s)	2 x YF-100	2 x YF-77	1 x YF-73	2 x YF-75D	1 x YF-75
Engine manufacturer	AAPT	AAPT	AAPT	AAPT	AAPT
Engine thrust, kN (lbf)	1,179 (265,050)	509 (114,428)	44.2 (9,937)	88.3 (19,851)	78.5 (17,648)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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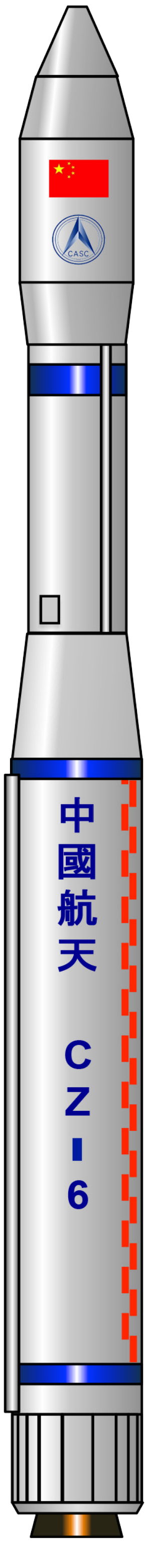
Launch Vehicle Fact Sheet

Long March 6



The Long March 6 is a cooperative effort between China Aerospace Science and Technology Corporation (SAST) and the China Academy of Launch Vehicle Technology (CALT). It is a small, liquid-fueled vehicle that has a low Earth orbit (LEO) payload capacity less than that provided by the currently available small-class Long March 2C, meaning the vehicle serves a niche previously not directly addressed.

Pursuit of a small-class launch vehicle started in the late 1990s and resulted in the Kaitouzhe (launched in 2002 and 2003). The vehicle used solid propellant and was easily transported using a trailer. Following a failure in 2003, the Kaitouzhe program ended. The Long March 6, Long March 11, and Kuaizhou vehicles have been under development since, each vehicle offering small capacity options for the government and, potentially, commercial satellite oeprators. Of these vehicles, the Long March 6 has the highest capacity to LEO at 1,500 kg (3,307 kg).

The vehicle is easily transported via a mobile trailer from the manufacturing and systems integration site to the launch site. This, combined with public statements from the Chinese government, indicate that the vehicle will be used to support rapid deployment missions for the People's Liberation Army (PLA).

Its inaugural launch from the Taiyuan Satellite Launch Center in 2015 was notable because it carried 20 microsatellites, some of which were built in China using the CubeSat standard (10 cm cubic form factor). For this reason, it is possible the vehicle will be offered as a commercial option.

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
SAST/CALT

Mass, kg (lb)
103,217 (227,555)

Length, m (ft)
29 (95.1)

Diameter, m (ft)
3.4 (11)

Year of First Launch
2015

Number of Orbital Launches
2

Reliability
100%

Launch Site
Taiyuan (LA-16)

LEO Capacity, kg (lb)
1,500 (3,307)

SSO Capacity, kg (lb)
1,080 (2,381)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Long March 6

The Long March 6 and its trailer. (Source: China Space Report)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	5.7 (18.7)	2.3 (7.5)
Large Fairing	5.7 (18.7)	2.6 (8.5)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	15 (49.2)	7.3 (24)	1.8 (5.9)
Diameter, m (ft)	3.4 (11)	2.3 (7.5)	2.3 (7.5)
Manufacturer	CALT	SAST	SAST
Propellant	LOX/Kerosene	LOX/Kerosene	H_2O_2/Kerosene
Propellant mass, kg (lb)	76,000 (167,551)	15,000 (33,069)	Undisclosed
Total thrust, kN (lbf)	1,179 (265,050)	175 (39,342)	16 (3,597)
Engine(s)	1 x YF-100	1 x YF-115	4 x YF-85
Engine manufacturer	AAPT	AAPT	AAPT
Engine thrust, kN (lbf)	1,179 (265,050)	175 (39,342)	4 (899)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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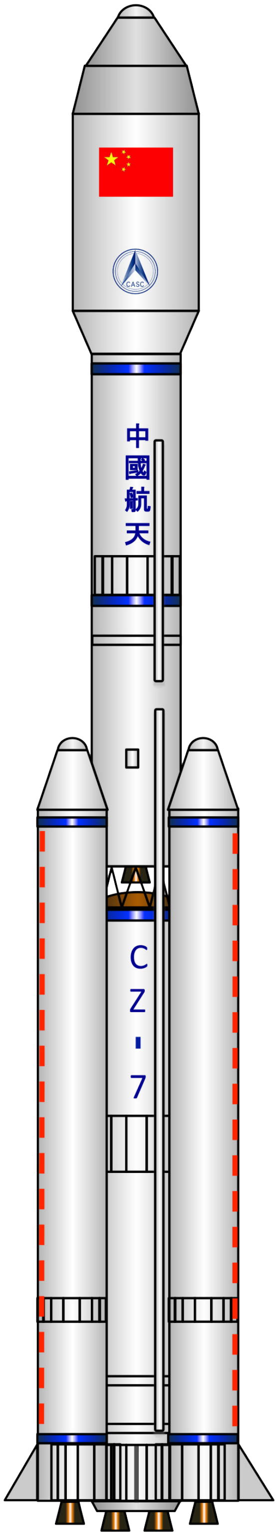
Launch Vehicle Fact Sheet

Long March 7



The China Academy of Launch Vehicle Technology (CALT) is currently developing the next generation of Chinese launch vehicles, the Long March 7 family. The first launch of a Long March 7 is expected in 2016 from China's new Wencheng Satellite Launch Center located on Hainan Island.

The Long March 7 series is being designed to handle missions to low Earth orbit (LEO) and sun synchronous orbits (SSO). It will apparently not be used for missions destined for geostationary transfer orbit (GTO). The vehicle will replace the Long March 2F as a means to send astronauts into space.

While CALT is the systems integrator for Long March 7, the Academy of Aerospace Propulsion Technology (AAPT) is developing the new engines.

The first launch of the Long March 7 took place on June 25, 2016 from China's newly built Wenchang Spacecraft Launch Site. The launch was successful.

Launch Service Provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
CALT/SAST

Mass, kg (lb)
594,000 (1,309,546)

Length, m (ft)
53.1 (174.2)

Diameter, m (ft)
3.4 (11)

Year of First Launch
2016

Number of Orbital Launches
2

Reliability
100%

Launch Site
Wenchang (LC-2)

LEO Capacity, kg (lb)
13,500 (29,762)

SSO Capacity, kg (lb)
5,500 (12,125)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Long March 7

The first Long March 7 launch vehicle prior to launch from Wenchang on Hainan Island. (Source: CNS)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	Undisclosed	Undisclosed

	Liquid Boosters*	2nd Stage	3rd Stage
Stage designation	K2 Liquid Boosters (4)	K3 1st Stage	2nd Stage
Length, m (ft)	Undisclosed	15 (49.2)	7.3 (24)
Diameter, m (ft)	2.3 (7.5)	3.4 (11)	2.3 (7.5)
Manufacturer	CALT	CALT	SAST
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	76,000 (167,551)	15,000 (33,069)
Total thrust, kN (lbf)	4,716 (1,060,199)	2,358 (530,100)	700 (157,366)
Engine(s)	1 x YF-100	2 x YF-100	4 x YF-115
Engine manufacturer	AAPT	AAPT	AAPT
Engine thrust, kN (lbf)	1,179 (265,050)	1,179 (265,050)	175 (39,342)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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Launch Vehicle Fact Sheet

Long March 11

The solid-fueled Long March 11 first flew in 2015, just days after China had successfully introduced the liquid-fueled Long March 6. Whereas the Long March 6 can send payloads with a mass of 1,500 kg (3,307 lb) to low Earth orbit (LEO), the Long March 11 can only send payloads of up to 530 kg (1,168 lb) to LEO. Like the Long March 6, the Long March 11 can be transported relatively easily between a storage facility and the launch site, enabling rapid deployment of satellites. The fact that the Long March 11 is storable is notable.

Little else is publicly known about the vehicle, but it may have benefited from development of the Kaitouzhe launch vehicle that flew twice; once successfully in 2002 and once unsuccessfully in 2003. It appears the vehicle is transported within a protective shroud. While a photograph indicates it is erected upon the launch pad within the shroud, it is unclear if the shroud is removed prior to launch or falls away during launch.

A commercial variant called LandSpace-1 (LS 1) is now being offered by LandSpace Technology, having been introduced in 2016. The price is expected to be about $5.3M per launch.

Launch Service Provider
PLA/LandSpace

Organization Headquarters
China

Manufacturer
CALT

Mass, kg (lb)
58,000 (127,868) *est*

Length, m (ft)
20.8 (68.2) est

Diameter, m (ft)
2 (6.6) *est*

Year of First Launch
2015

Number of Orbital Launches
2

Reliability
100%

Launch Site
Jiuquan

LEO Capacity, kg (lb)
530 (1,168)

SSO Capacity, kg (lb)
400 (882)

Estimated Price per Launch
$5.3M

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Launch Vehicle Fact Sheet

Long March 11

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The Long March 11 is apparently transported and erected within a protective shroud. (Source: CCTV)

Few clear images of the Long March 11 exist. This photo shows the vehicle being prepared for launch. (Source: Weibo.com)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2 (6.6) *est*	1.6 (5.2) *est*

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	1st Stage	2nd Stage	3rd Stage	4th Stage
Length, m (ft)	9 (29.5) *est*	3 (9.8) *est*	1 (3.3) *est*	Undisclosed
Diameter, m (ft)	2 (6.6) *est*	2 (6.6) *est*	1.4 (4.6) *est*	Undisclosed
Manufacturer	CALT	CALT	CALT	CALT
Propellant	Solid	Solid	Solid	Undisclosed
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Engine(s)	—	—	—	1 x YF-50
Engine manufacturer	—	—	—	CALT
Engine thrust, kN (lbf)	—	—	—	Undisclosed

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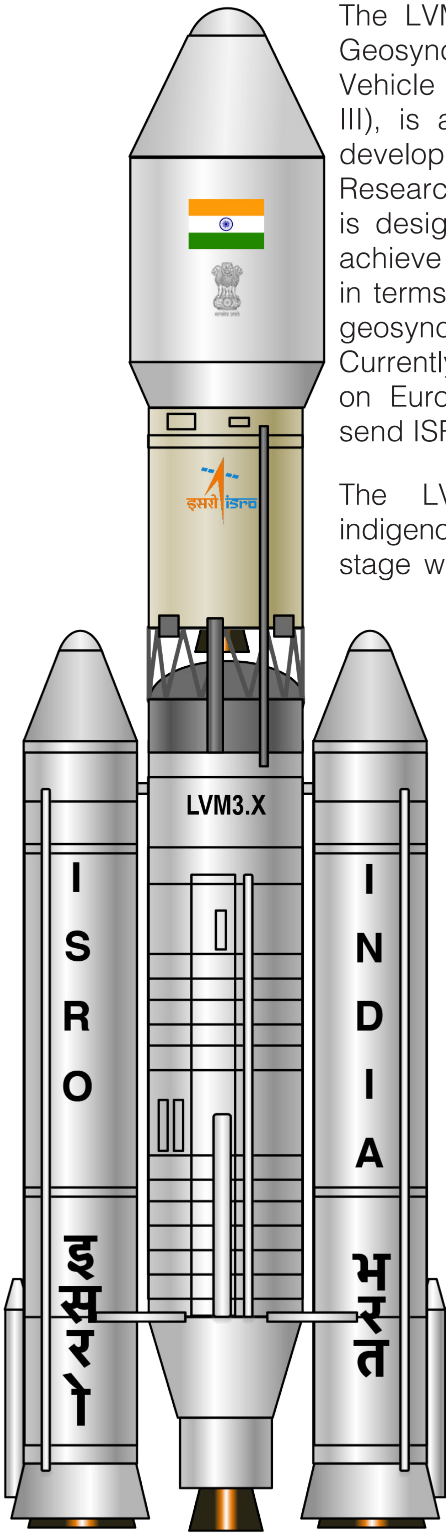
Launch Vehicle Fact Sheet

LVM3



The LVM3, formally called the Geosynchronous Space Launch Vehicle Mark III (GSLV Mk III), is a launch vehicle being developed by the Indian Space Researc organization (ISRO). It is designed to enable India to achieve complete self reliance in terms of sending satellites to geosynchronous orbits (GEO). Currently, India largely depends on Europe's Ariane 5 ECA to send ISRO payloads to GEO.

The LVM3 will feature an indigenously built cryogenic stage with higher capacity than GSLV. The GSLV Mk I used a Russian-build engine for the cryogenic upper stage. The engines are developed by ISRO's Liquid Propulsion Systems Centre (LPSC).

The first experimental flight of LVM3 was a suborbital launch of the Crew Module Atmospheric Re-entry Experiment (CARE) reentry test capsule. The successful launch took place from the Satish Dhawan Space Center on December 18, 2014. The capsule reentered, deployed its parachutes as planned, and splashed down in the Bay of Bengal.

Launch Service Provider
ISRO/Antrix

Organization Headquarters
India

Manufacturer
ISRO

Mass, kg (lb)
640,000 (1,410,000)

Length, m (ft)
43.4 (142.5)

Diameter, m (ft)
4 (13.1)

Year of First Launch
2014

Number of Orbital Launches
2

Reliability
100%

Launch Site
Satish Dhawan (SLP)

GTO Capacity, kg (lb)
4,000 (8,818)

LEO Capacity, kg (lb)
8,000 (17,637)

SSO Capacity, kg (lb)
Undisclosed

Estimated Price per Launch
$60M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

LVM3

FAA AST

The LVM3 on the pad at Satish Dhawan Space Center prior to its inaugural launch in December 2014. (Source: ISRO)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	6 (19.7)	5 (16.4)

	Liquid Boosters*	1st Stage	2nd Stage
Stage designation	S200 (2)	L110	C25
Length, m (ft)	25 (82)	17 (55.8)	13.5 (44.3)
Diameter, m (ft)	3.2 (10.5)	4 (13.1)	4 (13.1)
Manufacturer	ISRO	ISRO	ISRO
Propellant	Solid	N_2O_4/UDMH	LOX/H_2
Propellant mass, kg (lb)	207,000 (456,357)	110,000 (242,508)	27,000 (59,525)
Total thrust, kN (lbf)	5,150 (1,157,766)	1,598 (359,245)	186 (41,815)
Engine(s)	—	2 x Vikas	1 x CE-20
Engine manufacturer	—	ISRO/LPSC	ISRO/LPSC
Engine thrust, kN (lbf)	—	799 (179,622)	186 (41,815)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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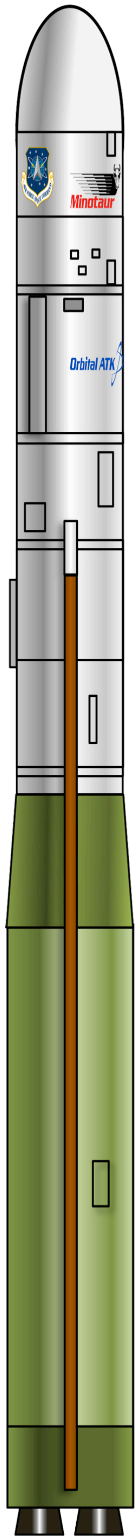
Launch Vehicle Fact Sheet

Minotaur I



Orbital ATK provides the Minotaur I as a responsive and cost-effective launch solution for U.S. Government spacecraft. The launch vehicle is composed of residual 1960s era Minuteman II first and second stage solid rocket motors integrated with Orion upper stages.

Because it leverages retired ballistic missile components that were designed to be stored for long periods of time, the Minotaur I requires little in the way of launch infrastructure and processing. This makes it an attractive choice for small military payloads in particular.

The M55 first stage is powered by four individual nozzles that can be gimbaled for attitude control. When launched from Virginia's Mid-Atlantic Regional Spaceport (MARS), the first stage is protected from cold weather by an insulative blanket that peels away as the vehicle clears the tower. An optional Hydrazine Auxiliary Propulsion Stage (HAPS) is also available as a fifth stage, though this has not been used on previous missions. Eleven successful launches of the Minotaur I placed 62 satellites into orbit.

Minotaur I missions are provided under the Orbital/Suborbital Program (OSP) managed by the U.S. Air Force Space and Missile Systems Center (SMC), Advanced Systems and Development Directorate, Rocket Systems Launch Program.

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
36,200 (79,807)

Length, m (ft)
19.2 (63)

Diameter, m (ft)
1.7 (5.6)

Year of First Launch
2000

Number of Orbital Launches
11

Reliability
100%

Launch Sites
VAFB (SLC-8)
MARS (LP-0B)

LEO Capacity, kg (lb)
580 (1,279)

SSO Capacity, kg (lb)
440 (970)

Estimated Price per Launch
$40M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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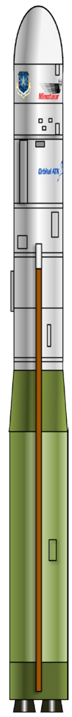
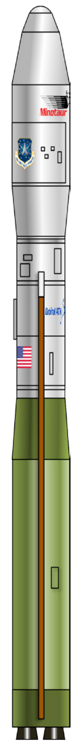
Launch Vehicle Fact Sheet

Minotaur I



Minotaur I
Standard Fairing



Minotaur I
61” Fairing

A Minotaur I lifts off from MARS on November 20, 2013 carrying 29 payloads. At the time, this was a U.S. record for number of payloads launched at once. Note the insulative blanket, which peels away seconds after lift off. (Source: Orbital ATK)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	3.8 (12.5)	1.3 (4.3)
61” Fairing	6.1 (20)	1.6 (5.2)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	M55 A1	SR19	Orion-50XL	Orion-38
Length, m (ft)	7 (22.9)	2.6 (8.4)	2.3 (7.2)	1.8 (5.8)
Diameter, m (ft)	1.7 (5.5)	1.3 (4.3)	1.2 (4.1)	1.2 (4.1)
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Solid
Propellant mass, kg (lb)	20,785 (45,823)	6,237 (13,750)	3,930 (8,664)	770 (1,698)
Total thrust, kN (lbf)	935 (210,000)	268 (60,000)	118.2 (26,600)	34.8 (7,800)

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Launch Vehicle Fact Sheet

Minotaur IV

The Minotaur IV is an orbital launch vehicle offered by Orbital ATK. The vehicle is derived from the Peacekeeper intercontinental ballistic missile (ICBM).

The four-stage vehicle is exclusively provided for U.S. Government customers. Though designed primarily for orbital launches, the Minotaur IV is also periodically used for suborbital missions. Most notably, the vehicle was used to deploy Hypersonic Technology Vehicles (HTV) for the Defense Advanced Research Projects Agency (DARPA).

There are three versions of the Minotaur IV. The Minotaur IV Lite is a three-stage version used for suborbital missions. The Minotaur IV+ uses a more powerful Star-48V upper stage instead of the Orion-38 used by the standard Minotaur IV.

Minotaur IV missions are provided under the Orbital/Suborbital Program (OSP) managed by the U.S. Air Force Space and Missile Systems Center (SMC), Advanced Systems and Development Directorate, Rocket Systems Launch Program.

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
86,300 (190,259)

Length, m (ft)
23.9 (78.4)

Diameter, m (ft)
2.3 (7.5)

Year of First Launch
2010

Number of Orbital Launches
4

Reliability
100%

Launch Site
CCAFS (SLC-46)
VAFB (SLC-8)
MARS (LP-0B)
PSCA (LP-1)

LEO Capacity, kg (lb)
1,600 (3,527)

SSO Capacity, kg (lb)
1,190 (2,624)

Estimated Price per Launch
$46M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Minotaur IV

Minotaur IV Lite
Suborbital

Minotaur IV
Orion-38
as 4th Stage

Minotaur IV+
STAR-48V
as 4th Stage

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	4.11 (13.5)	2.1 (6.7)

	1st Stage	2nd Stage	3rd Stage	4th Stage Option	4th Stage Option	5th Stage Option
Stage designation	SR-118	SR-119	SR-120	Orion-38	STAR-48BV	Orion-38
Length, m (ft)	8.5 (27.9)	7.9 (25.9)	2.4 (7.9)	1.8 (5.8)	2 (6.6)	1.8 (5.8)
Diameter, m (ft)	2.3 (7.5)	2.3 (7.5)	2.3 (7.5)	1.2 (4.1)	1.2 (3.9)	1.2 (4.1)
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Solid	Solid	Solid
Propellant mass, kg (lb)	45,400 (100,090)	24,500 (54,013)	7,080 (15,609)	770 (1,698)	2,010 (4,431)	770 (1,698)
Total thrust, kN (lbf)	1,607 (361,000)	1,365 (307,000)	329 (74,000)	34.8 (7,800)	64 (14,000)	34.8 (7,800)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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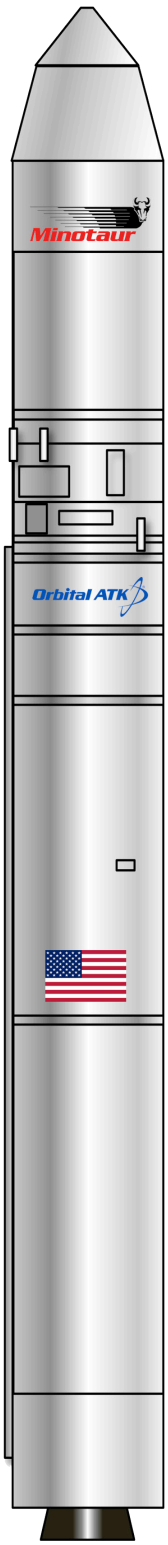
Launch Vehicle Fact Sheet
Minotaur V



Orbital ATK is the manufacturer and launch service provider of the Minotaur V. The vehicle is used primarily for payloads destined for geosynchronous transfer orbit (GTO) or orbital trajectories to the Moon and beyond. The U.S. Government is the primary customer for this vehicle.

The first, second, and third stages of the Minotaur V are legacy systems - they are former Peacekeeper solid rocket motors re-purposed for orbital launch. Though the Minotaur V has flown only once, each Peacekeeper stage has a record of 50 flights.

As of December 2015, the Minotaur V has only been used once. It successfully launched NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) on September 7, 2013 from Virginia's Mid-Atlantic Regional Spaceport (MARS).

Minotaur V missions are provided under the Orbital/Suborbital Program (OSP) managed by the U.S. Air Force Space and Missile Systems Center (SMC), Advanced Systems and Development Directorate, Rocket Systems Launch Program.

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
89,373 (197,034)

Length, m (ft)
24.5 (80.6)

Diameter, m (ft)
2.3 (7.5)

Year of First Launch
2013

Number of Orbital Launches
1

Reliability
100%

Launch Sites
VAFB (SLC-8)
MARS (LP-0B)
PSCA (LP-1)
CCAFS

GTO Capacity, kg (lb)
532 (1,173)

Estimated Price per Launch
$55M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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FAA AST

Launch Vehicle Fact Sheet

Minotaur V

The Minotaur V with NASA's LADEE probe poised for launch in 2015. (Source: NASA)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	4.11 (13.5)	2.1 (6.7)

	1st Stage	2nd Stage	3rd Stage	4th Stage	5th Stage
Stage designation	SR-118	SR-119	SR-120	STAR-48BV	STAR-37FMV
Length, m (ft)	8.5 (27.9)	7.9 (25.9)	2.4 (7.9)	2 (6.6)	1.7 (5.5)
Diameter, m (ft)	2.3 (7.5)	2.3 (7.5)	2.3 (7.5)	1.2 (3.9)	0.9 (3.1)
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Solid	Solid
Propellant mass, kg (lb)	45,400 (100,090)	24,500 (54,013)	7,080 (15,609)	2,010 (4,431)	1,066 (2,350)
Total thrust, kN (lbf)	1,607 (361,000)	1,365 (307,000)	329 (74,000)	64 (14,000)	47.3 (10,633)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Minotaur VI

The Minotaur VI, offered by Orbital ATK, is derived from the Minotaur IV+. The five-stage vehicle is essentially identical to the Minotaur IV, except that it features an additional SR-118 solid motor stage. The only new piece of hardware is the interstage assembly that separates the two SR-118 stages.

The vehicle is designed to leverage flight-proven hardware in the Minotaur IV and V vehicles, but adding additional low Earth orbit (LEO) capacity and increasing capability for geosynchronous transfer orbit (GTO) and Earth escape trajectories.

As of publication, no Minotaur VI vehicles have flown, and a contract for a Minotaur VI mission has not yet been signed.

Minotaur VI missions are provided under the Orbital/Suborbital Program (OSP) managed by the U.S. Air Force Space and Missile Systems Center (SMC), Advanced Systems and Development Directorate, Rocket Systems Launch Program.

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
89,373 (197,034)

Length, m (ft)
32.6 (107)

Diameter, m (ft)
2.3 (7.5)

Year of Planned First Launch
TBD

Launch Sites
VAFB (SLC-8)
MARS (LP-0B)
PSCA (LP-1)

GTO Capacity, kg (lb)
860 (1,896)

LEO Capacity, kg (lb)
2,600 (5,732)

SSO Capacity, kg (lb)
2,250 (4,960)

Estimated Price per Launch
$60M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Minotaur VI

FAA AST

Minotaur VI
Standard Fairing

Minotaur VI
Large Fairing

Though the Minotaur VI has been available to customers for a few years, none have flown.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	5.3 (17.4)	2 (0.6)
Large Fairing	5.3 (17.4)	2.5 (8.2)

	1st Stage	2nd Stage	3rd Stage	4th Stage	5th Stage Option	5th Stage Option	6th Stage Option
Stage designation	SR-118	SR-118	SR-119	SR-120	STAR-48BV	Orion-38	STAR-37FMV
Length, m (ft)	8.5 (27.9)	8.5 (27.9)	7.9 (25.9)	2.4 (7.9)	2 (6.6)	1.8 (5.8)	1.7 (5.5)
Diameter, m (ft)	2.3 (7.5)	2.3 (7.5)	2.3 (7.5)	2.3 (7.5)	1.2 (3.9)	1.2 (4.1)	0.9 (3.1)
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Solid	Solid	Solid	Solid
Propellant mass, kg (lb)	45,400 (100,090)	45,400 (100,090)	24,500 (54,013)	7,080 (15,609)	2,010 (4,431)	770 (1,698)	1,066 (2,350)
Total thrust, kN (lbf)	1,607 (361,000)	1,607 (361,000)	1,365 (307,000)	329 (74,000)	64 (14,000)	34.8 (7,800)	47.3 (10,633)

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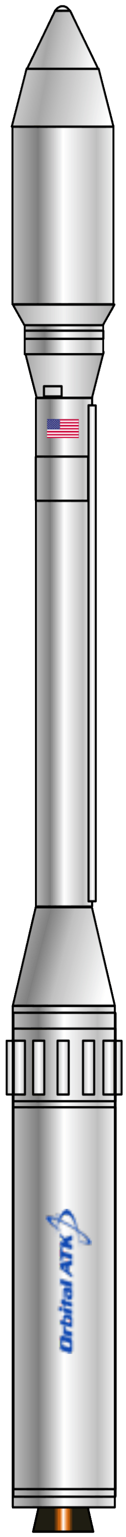
Launch Vehicle Fact Sheet

Minotaur C



Orbital ATK offers the four-stage small-class vehicle, Minotaur C, as an option for satellite customers. The Minotaur C is an upgraded version of the Taurus first introduced in 1994 and developed under sponsorship of the Defense Advance Research Projects Agency (DARPA). The Minotaur C features upgraded avionics and other enhancements as compared to the Taurus vehicle. Several variants of the Minotaur C are available, allowing Orbital ATK to mix and match different stages and fairings to address customer needs.

The Minotaur C launches from SLC-376E at Vandenberg Air Force Base (VAFB), though it may also be launched from SLC-46 at Cape Canaveral Air Force Station (CCAFS) and Pad 0-B at Virginia's Mid-Atlantic Regional Spaceport (MARS).

Terra Bella (then Skybox Imaging and recently acquired by Planet) signed a contract with Orbital ATK in 2014 for the launch of six SkySat satellites on a single Minotaur C. The launch successfully took place in November 2017.

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
77,000 (170,000)

Length, m (ft)
32 (104)

Diameter, m (ft)
1.6 (5.2)

Year of First Launch
1994 (as Taurus)

Number of Orbital Launches
10

Reliability
70%

Launch Sites
CCAFS (SLC-46)
VAFB (LC-576E)
MARS (LP-0B)
PSCA (LP-1)

LEO Capacity, kg (lb)
1,278-1,458 (2,814-3,214)

SSO Capacity, kg (lb)
912-1,054 (2,008-2,324)

Estimated Price per Launch
$40M-$50M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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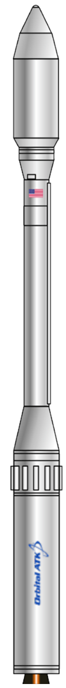
Launch Vehicle Fact Sheet

Minotaur C

3110 Minotaur C

3113 Minotaur C



3210 Minotaur C

The Minotaur C is essentially and upgraded version of the flight proven Taurus vehicle once offered by Orbital Sciences Corporation (now Orbital ATK).

Fairing	Length, m (ft)	Diameter, m (ft)
2.3-Meter Fairing	1.6 (5.2)	2.3 (7.5)
1.6-Meter Fairing	2.2 (7.2)	1.6 (5.2)

	1st Stage	2nd Stage	3rd Stage	4th Stage Option	4th Stage Option	5h Stage Option
Stage designation	CASTOR-120	Orion-50S XLG	Orion-50 XLT	Orion-38	STAR-37	STAR-37
Length, m (ft)	9.1 (29.9)	8.9 (29.2)	1.3 (4.3)	1.3 (4.3)	2.3 (7.5)	2.3 (7.5)
Diameter, m (ft)	2.4 (7.9)	1.3 (4.3)	1 (3.3)	1 (3.3)	0.7 (2.3)	0.7 (2.3)
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Solid	Solid	Solid
Propellant mass, kg (lb)	48,960 (107,939)	15,023 (33,120)	770 (1,697)	770 (1,697)	1,066 (2,350)	1,066 (2,350)
Total thrust, kN (lbf)	1,904 (428,120)	704 (157,729)	36 (8,062)	36 (8,062)	47.3 (10,625)	47.3 (10,625)

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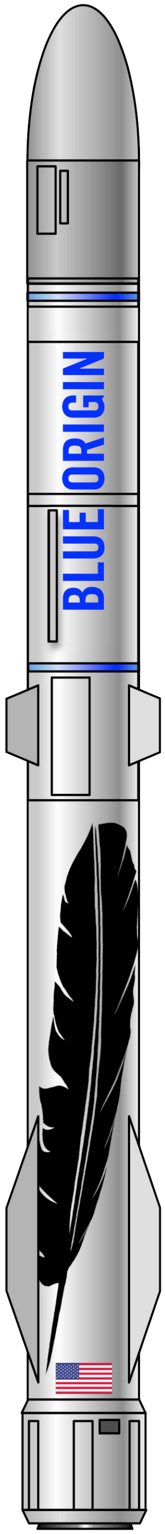
Launch Vehicle Fact Sheet

New Glenn



In the summer of 2015, Blue Origin publicly announced its plan to develop an orbital launch vehicle. Details regarding the vehicle's design remained close-hold until 2016, when the company introduced its New Glenn family of vehicles. The New Glenn family will feature a reusable first stage with six landing struts, and will burn liquid oxygen (LOX) and liquified natural gas (LNG). The tanks will be pressuraized without helium, a rare characteristic for launch vehicles employing liquid propellants.

The New Glenn vehicles will launch from SLC-36 located at Cape Canaveral Air Force Station (CCAFS), Florida. The reusable first stage will be powered by seven of the company's BE-4 engines. The BE-4 is also being developed for the first stage of the Vulcan, which will be provided by United Launch Alliance (ULA) beginning in 2019. This stage also appears to feature four extendable landing struts. The expendable second stage will be powered by a single BE-4. For the 3-stage New Glenn version, a smaller BE-3U engine will be used. The BE-3 is also used to power Blue Origin's reusable New Shepard crewed suborbital vehicle.

The BE-4, which will be flight ready by 2017, is fed a LOX-LNG mix. The LNG, essentially methane, is considered by Blue Origin and ULA to be an affordable and efficient propellant than rocket grade kerosene (RP-1). The key difference is that LNG is a cleaner burning fuel, ideal for a reusable engine, and is 1/4 as expensive than RP-1. There is also a plentiful supply of LNG.

SLC-36 was once used by NASA to launch Mariner, Surveyor, and Pioneer probes during the 1960s and 1970s, as well as national security payloads for the Department of Defense (DoD). The last mission from this pad took place in 2005 with the launch of an Atlas III. Blue Origin is leasing the pad from Space Florida and is currently developing the facility in preparation for an inaugural launch around 2020. The company plans to open its manufacturing facility at the Kennedy Space Center (KSC) Exploration Park in early 2018.

Launch Service Provider
Blue Origin

Organization Headquarters
USA

Manufacturer
Blue Origin

Mass, kg (lb)
Undisclosed

Length, m (ft)
82-95 (269-312)

Diameter, m (ft)
8 (26.2)

Year of Planned First Launch
2020

Launch Site
CCAFS (SLC-36)

GTO Capacity, kg (lb)
13,000 (28,660)

LEO Capacity, kg (lb)
45,000 (99,208)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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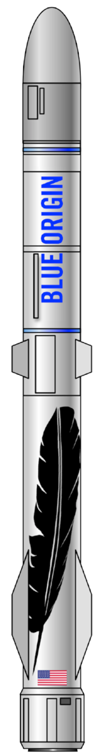
Launch Vehicle Fact Sheet

New Glenn

New Glenn 2-Stage



New Glenn 3-Stage

Blue Origin intends to develop two variants of the New Glenn family.

Fairing	Length, m (ft)	Diameter, m (ft)
2-Stage Fairing	Undisclosed	7 (23)
3-Stage Fairing	Undisclosed	7 (23)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	8 (26.2)	8 (26.2)	8 (26.2)
Manufacturer	Blue Origin	Blue Origin	Blue Origin
Propellant	LOX/CH_4	LOX/CH_4	LOX/H_2
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	17,100 (3,844,233)	2,400 (539,542)	670 (150,622)
Engine(s)	7 x BE-4	1 x BE-4	1 x BE-3U
Engine manufacturer	Blue Origin	Blue Origin	Blue Origin
Engine thrust, kN (lbf)	2,442 (549,176)	2,400 (539,542)	670 (150,622)

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Launch Vehicle Fact Sheet

New Line 1

China-based Link Space, founded in 2014, is developing a two-stage, small orbital launch vehicle called New Line 1 (Xin Gan Xian 1) with a reusable first stage. The vehicle is based on a successfully tested suborbital rocket called KC-SA-TOP.

The company has been testing the reusable first stage using a similar approach to that employed by U.S.-based Masten Space Systems. Using several tethered testbed vehicles, Link Space has conducted over 200 vertical takeoff/vertical landing (VTVL) flight tests using three test articles. Testing with an untethered vehicle will begin in 2018.

Long-term plans include a reusable second stage as well as larger variants of the vehicle.

The New Line 1 is one of several small launch vehicles being developed in China for commercial use. Others include OneSpace's OS-M1, LandSpace's LandSpace 1, and EXPACE's Kuaizhou series.

Launch Service Provider
Link Space

Organization Headquarters
China

Manufacturer
LinkSpace

Mass, kg (lb)
33,000 (72,753)

Length, m (ft)
20.1 (66)

Diameter, m (ft)
1.8 (5.9)

Year of Planned First Launch
2021

Launch Site
Undisclosed

LEO Capacity, kg (lb)
Undisclosed

SSO Capacity, kg (lb)
200 (441)

Estimated Price per Launch
$4.5M expendable/
$2.3M reused

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

New Line 1

FAA AST

Link Space conducts a hover test in 2016 using a tethered testbed vehicle. (Source: Link Space)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	3 (9.8) *est.*	1.8 (5.9)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	15.1 (49.5) *est.*	2 (6.6) *est.*
Diameter, m (ft)	1.8 (5.9)	1.8 (5.9)
Manufacturer	LinkSpace	LinkSpace
Propellant	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	400 (89,924)	Undisclosed
Engine(s)	4 x TBD	Undisclosed
Engine manufacturer	LinkSpace	LinkSpace
Engine thrust, kN (lbf)	100 (22,481)	Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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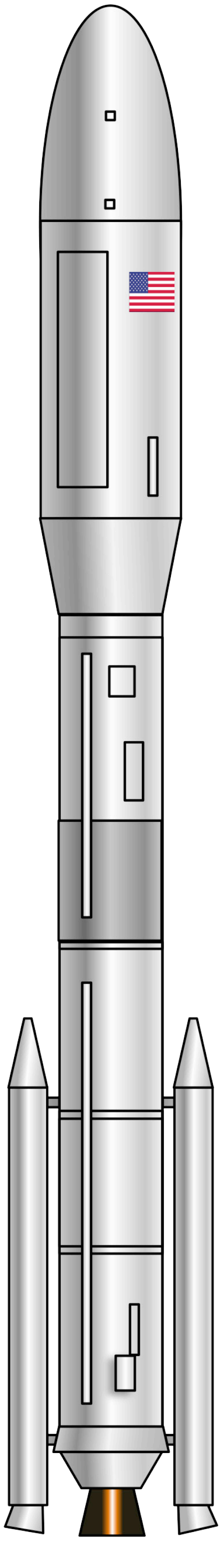
Launch Vehicle Fact Sheet
NGL



Leveraging technologies proven for the Space Transportation System (STS), Orbital ATK is developing its Next Generation Launch (NGL) System. NGL emerges from similar post-STS programs, the Ares I and Liberty vehicle systems, which did not result in operational vehicles.

The NGL is composed of multi-segmented solid motors derived from the Solid Rocket Boosters (SRB) used for STS. The NGLS Intermediate Series will use the CASTOR 600 motor as a first stage, which is essentially a 2-segment SRB. The NGL Heavy Series will use a larger, 4-segment motor called CASTOR 1200. Both vehicles will employ up to six GEM-36 or GEM-36XL strap-on boosters and a CASTOR 300 second stage (a 1-segment motor). The stack is rounded out with a cryogenic upper stage.

The primary customer for the NGL is expected to be the U.S. Air Force, but Orbital ATK will offer the vehicle to commercial customers after the it is introduced in 2021.

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
Undisclosed

Length, m (ft)
59.8 (196.3)

Diameter, m (ft)
5.3 (17)

Year of Planned First Launch
2021

Launch Site
KSC (LC-39B)
VAFB (SLC-2)

GTO Capacity, kg (lb)
5,500-8,500 (12,125-18,739)

LEO Capacity, kg (lb)
Undisclosed

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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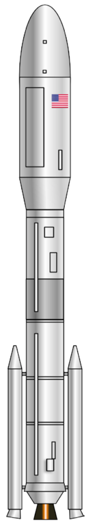
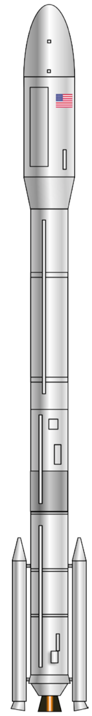
Launch Vehicle Fact Sheet

NGL



NGL Intermediate



NGL Heavy

Orbital ATK intends to develop two variants of the NGL.

Fairing	Length, m (ft)	Diameter, m (ft)
50 Series Fairing	15 (49.2)	5 (16.4)
500XL Series Fairing	20 (65.6)	5 (16.4)

	SRB*	1st Stage	1st Stage	2nd Stage	3rd Stage
Stage designation	GEM-63	CASTOR 600	CASTOR 1200	CASTOR 300	3rd Stage
Length, m (ft)	2.2 (6)	22 (72.2)	37.5 (123)	12.7 (41.7)	Undisclosed
Diameter, m (ft)	1.6 (5.3)	3.7 (12.2)	3.7 (12.2)	5.3 (17.2)	Undisclosed
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Solid	LOX/H_2
Propellant mass, kg (lb)	88,400 (195,000)	280,775 (619,003)	505,372 (1,114,155)	152,512 (336,231)	Undisclosed
Total thrust, kN (lbf)	4,004 (900,000)	6,661 (1,497,451)	9,996 (2,247,233)	3,572 (802,989)	534 (120,000)
Engine(s)	—	—	—	—	BE-3U
Engine manufacturer	—	—	—	—	Blue Origin
Engine thrust, kN (lbf)	2,002 (450,000)	—	—	—	534 (120,000)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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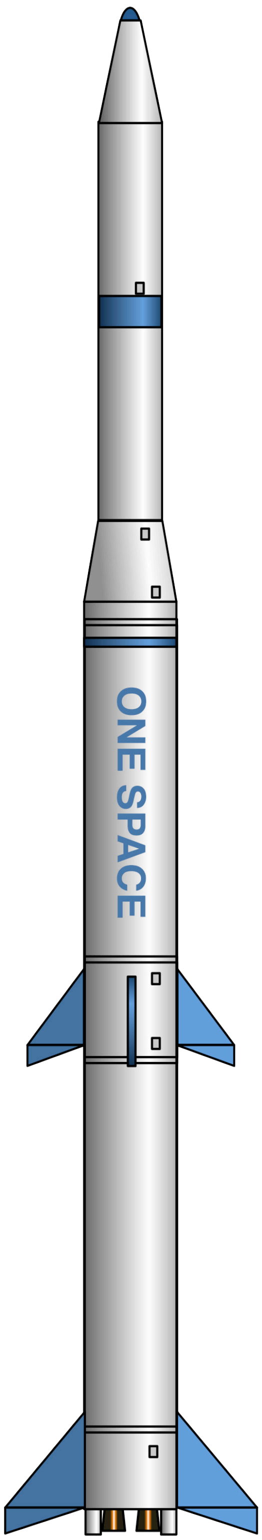
Launch Vehicle Fact Sheet

OS-M1



OneSpace is a Chinese company developing the OS line of vehicles. OneSpace is receiving support from the State Administration for Science, Technology, and Industry for National Defense (SASTIND) and has received financing from Qianhai Wutong Mergers and Acquisitions Funds, China Merchants Capital, Zhengxuan Investment, and others. By the end of 2017, OneSpace announced it had a backlog of ten launches.

The company's OS-X1 is a suborbital variant largely being used for flight testing and microgravity research. The OS-M1 is an orbital version with a LEO capacity of 205 kg (452 lb). The company plans to develop larger, reusable versions of the OS-M1 featuring between two and four solid boosters and two types of fairings. OneSpace expects its vehicles can launch once per week, on average, with a two-day preparation time.

The OS-M1 is one of several small launch vehicles being developed in China for commercial use. Others include Link Space's New Line 1, LandSpace's LandSpace 1, and EXPACE's Kuaizhou series.

Launch Service Provider
OneSpace

Organization Headquarters
China

Manufacturer
OneSpace

Mass, kg (lb)
Undisclosed

Length, m (ft)
14.8 (49) *est.*

Diameter, m (ft)
1 (3.3) *est.*

Year of Planned First Launch
2019

Launch Site
TBD

LEO Capacity, kg (lb)
205 (452)

SSO Capacity, kg (lb)
143 (315)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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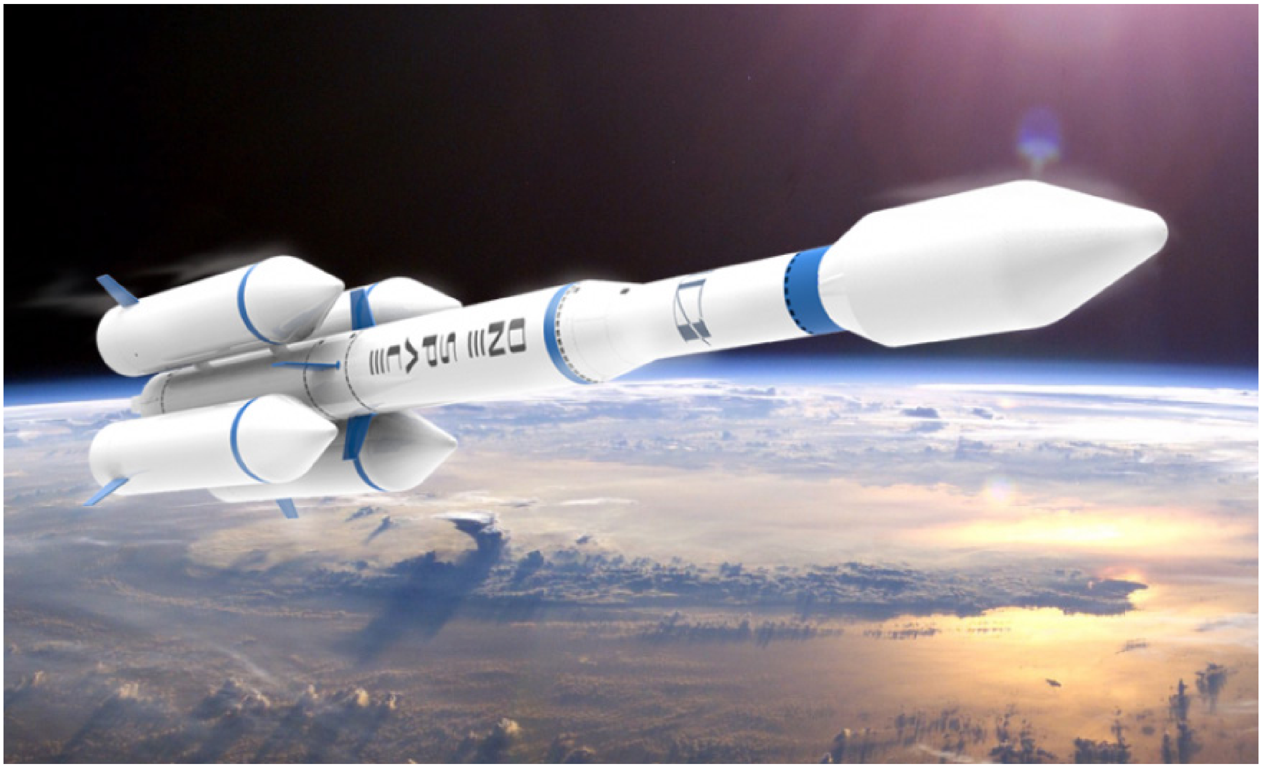
Launch Vehicle Fact Sheet

OS-M1



An artist's impression of OneSpace's OS-M4 vehicle configuration. (Source: OneSpace)

Fairing	Length, m (ft)	Diameter, m (ft)
0.7m Fairing	1.3 (4.3)	0.7 (2.3)
1-m Fairing	1.3 (4.3)	1 (3.3)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	5 (16.4) *est.*	4.5 (14.8) *est.*	4 (13.1) *est.*
Diameter, m (ft)	1 (3.3) *est.*	0.8 (2.6) *est.*	0.8 (2.6) *est.*
Manufacturer	OneSpace	OneSpace	OneSpace
Propellant	Solid	Solid	Solid
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	Undisclosed	Undisclosed	Undisclosed

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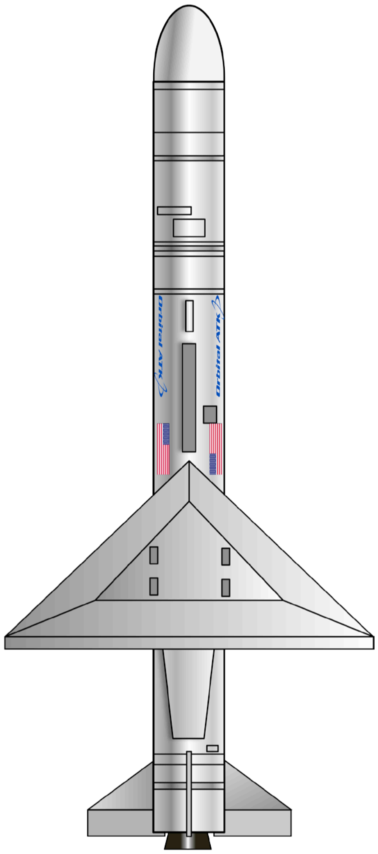
Launch Vehicle Fact Sheet

Pegasus XL



Orbital ATK's Pegasus XL is a small-class, air-launched vehicle. Orbital ATK offers the Pegasus XL as a means to launch small satellites to low Earth orbits (LEO).

The vehicle is derived from the first generation Standard Pegasus first launched in 1990. It is normally composed of three solid propellant stages manufactured by Orbital ATK, but it may also include a Hydrazine Auxiliary Propulsion System (HAPS) as a fourth stage. The vehicle uses a 1.2-meter (3.9-foot) payload fairing. The first, second, and third stages are also manufactured by Orbital ATK and include Orion-50SXL, Orion-50XL, and Orion-38 motors, respectively. The Orion-50SXL is also integrated with a wing, enabling aerodynamic flight during the launch phase. The vehicle is air-launched from a Lockheed-built L-1011 aircraft.

The Pegasus XL has flown 29 consecutive successful missions since 1997.

LEO capacity figures are for the Pegasus XL without a HAPS fourth stage from Cape Canaveral Air Force Station (CCAFS). Sun-synchronous orbit (SSO) figures are for the same vehicle configuration launched from Vandenberg Air Force Base (VAFB).

Launch Service Provider
Orbital ATK

Organization Headquarters
USA

Manufacturer
Orbital ATK

Mass, kg (lb)
23,130 (50,993)

Length, m (ft)
16.9 (55.4)

Diameter, m (ft)
1.3 (4.2)

Year of First Launch
1994

Number of Orbital Launches
33

Reliability
97%

Launch Sites
CCAFS, KSC, Gran Canaria, Reagan Test Site, VAFB, WFF

LEO Capacity, kg (lb)
450 (992)

SSO Capacity, kg (lb)
325 (717)

Estimated Price per Launch
$40M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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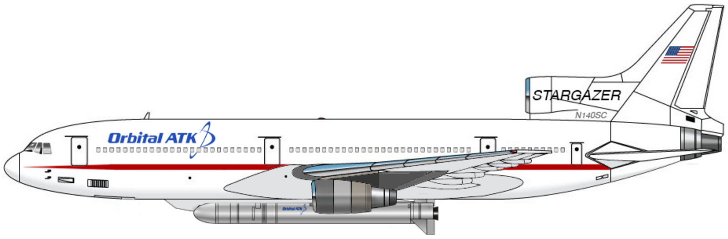
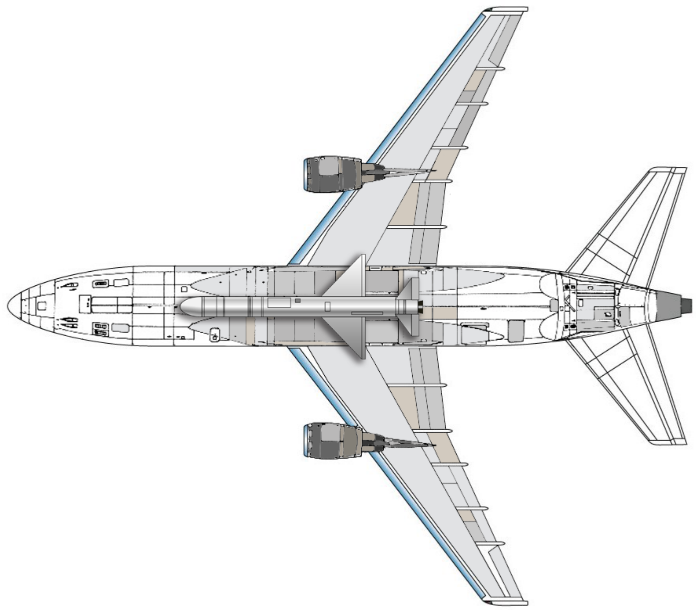
Launch Vehicle Fact Sheet

Pegasus XL





Orbital ATK uses a modified L-1011 aircraft to carry and launch the Pegasus XL vehicle. The ground equipment necessary to launch the system is minimal, and the combination can be launched from almost any conventional runway.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2.1 (6.9)	1.2 (3.9)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	Orion-50SXL	Orion-50XL	Orion-38	HAPS
Length, m (ft)	10.27 (33.7)	3.1 (10.2)	1.3 (4.3)	0.7 (2.3)
Diameter, m (ft)	1.3 (4.3)	1.3 (4.3)	1 (3.3)	1 (3.3)
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Hydrazine
Propellant mass, kg (lb)	15,014 (33,105)	3,925 (8,655)	770 (1,697)	73 (161)
Total thrust, kN (lbf)	726 (163,247)	196 (44,171)	36 (8,062)	0.6 (135)
Engine(s)	—	—	—	3 x Rocket Engine Assemblies
Engine manufacturer	—	—	—	Orbital ATK
Engine thrust, kN (bf)	—	—	—	0.2 (45)

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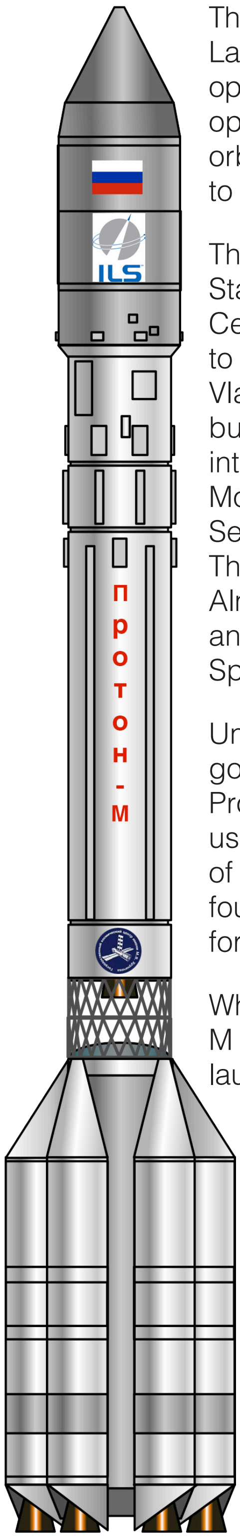
Launch Vehicle Fact Sheet

Proton M



The Proton M is provided by International Launch Services (ILS) as a launch option for government and commercial operators of satellites in geosynchronous orbit. It is typically not used for missions to low Earth orbit (LEO).

The Proton M is built by the Khrunichev State Research and Production Space Center. The vehicle traces its lineage to the UR500 system developed by Vladimir Chelomei's OKB-52 design bureau in 1965. The Proton was originally intended to send cosmonauts to the Moon until Soviet leadership selected Sergei Korolov's N-1 vehicle instead. The Proton launched the Soviet Union's Almaz (Salyut) and Mir space stations, and two modules of the International Space Station (ISS).

Until December 2012, the Russian government used an earlier version of the Proton, often called the Proton K. It now uses the Proton M with either versions of the Block DM or the Breeze-M as the fourth stage or as a three-stage vehicle for LEO missions.

When introduced in 2001, the Proton M maintained a flawless record of 13 launches before a failure was encountered in 2006. Since then, there has been a Proton M failure each year except in 2009, 2016, and 2017.

Khrunichev has also proposed developing two versions of the Proton M. The Proton Lite have a GTO capacity of 3,600 kilograms (7,937 pounds) and the Proton Medium will have a GTO capacity of 5,000 kilograms (11,023 pounds). It is unclear if these variants will actually be produced.

Launch Service Provider
VKS/Roscosmos/ILS

Organization Headquarters
Russia

Manufacturer
Khrunichev

Mass, kg (lb)
705,000 (1,554,259)

Length, m (ft)
58.2 (191)

Diameter, m (ft)
7.4 (24)

Year of First Launch
2001

Number of Orbital Launches
102

Reliability
91%

Launch Site
Baikonur (LC-81, LC-200)

GTO Capacity, kg (lb)
6,270 (13,823)

LEO Capacity, kg (lb)
23,000 (50,706)

Estimated Price per Launch
$65M

The Khrunichev-designed and built Angara series of vehicles is expected to gradually replace the Proton M beginning in 2015.

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet
Proton M

FAA AST

A Proton M is poised from launch from Baikonur Cosmodrome. (Source: ILS)

Fairing	Length, m (ft)	Diameter, m (ft)
PLF-BR-13305 Fairing	13.3 (43.6)	4.4 (14.4)
PLF-BR-15255 Fairing	15.3 (50.2)	4.4 (14.4)
Long Fairing (2020)	16.3 (53.5)	5 (16.4)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	1st Stage	2nd Stage	3rd Stage	Breeze-M
Length, m (ft)	21.2 (69.6)	17.1 (56.1)	4.1 (13.5)	2.7 (8.9)
Diameter, m (ft)	7.4 (24.3)	4.1 (13.5)	4.1 (13.5)	4 (13)
Manufacturer	Khrunichev	Khrunichev	Khrunichev	Khrunichev
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	428,300 (944,239)	157,300 (346,787)	46,562 (102,651)	19,800 (43,651)
Total thrust, kN (lbf)	10,000 (2,248,089)	2,400 (539,541)	583 (131,063)	19.2 (4,411)
Engine(s)	6 x RD-276	3 x RD-0210	1 x RD-0123	1 x 14D30
Engine manufacturer	NPO Energomash	KB Khimavtomatika	KB Khimavtomatika	DB Khimmash
Engine thrust, kN (lbf)	1,667 (374,682)	800 (179,847)	583 (131,063)	19.6 (4,411)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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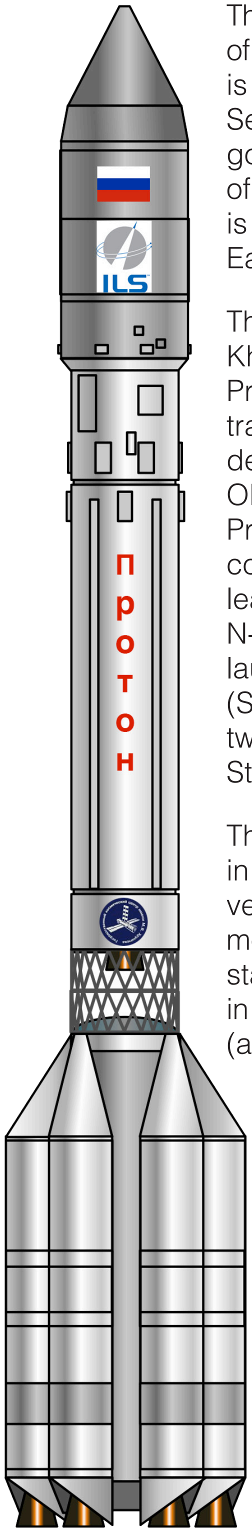
Launch Vehicle Fact Sheet

Proton Medium



The Proton Medium, a 2-stage version of the venerable Proton M vehicle, is provided by International Launch Services (ILS) as a launch option for government and commercial operators of satellites in geosynchronous orbit. It is typically not used for missions to low Earth orbit (LEO).

The Proton Medium is built by the Khrunichev State Research and Production Space Center. The vehicle traces its lineage to the UR500 system developed by Vladimir Chelomei's OKB-52 design bureau in 1965. The Proton was originally intended to send cosmonauts to the Moon until Soviet leadership selected Sergei Korolov's N-1 vehicle instead. The Proton launched the Soviet Union's Almaz (Salyut) and Mir space stations, and two modules of the International Space Station (ISS).

The vehicle differs from the Proton M in that the third stage used in the latter version is removed and the interstage modified. An optional Breeze M upper stage is also offered. It was introduced in 2016 along with the Proton Light (apparently no longer being developed).

The first launch of the Proton Medium is anticipated in 2018. Pricing information for the Proton Medium has not been published, but it is designed to be competitive with the SpaceX Falcon 9, among other vehicles.

Launch Service Provider
VKS/Roscosmos/ILS

Organization Headquarters
Russia

Manufacturer
Khrunichev

Mass, kg (lb)
655,000 (1,444,028) *est.*

Length, m (ft)
53 (173) *est.*

Diameter, m (ft)
7.4 (24)

Year of Planned First Launch
2018

Launch Site
Baikonur (LC-81, LC-200)

GTO Capacity, kg (lb)
5,000 (11,023)

Estimated Price per Launch
<$65M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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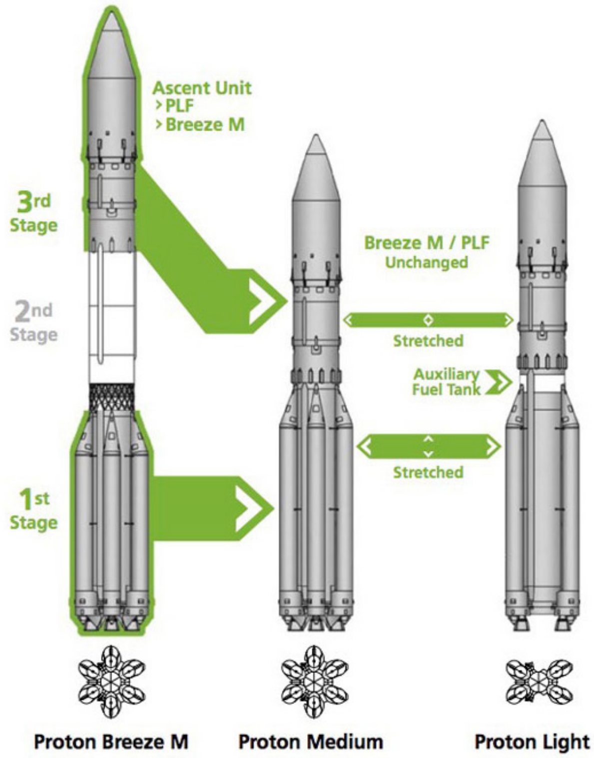
Launch Vehicle Fact Sheet

Proton Medium



An ILS graphic showing the differences between the Proton M, the Proton Medium, and the Proton Light. The latter version is apparently no longer being developed. (Source: ILS)

Fairing	Length, m (ft)	Diameter, m (ft)
PLF-BR-13305 Fairing	13.3 (43.6)	4.4 (14.4)
PLF-BR-15255 Fairing	15.3 (50.2)	4.4 (14.4)
Long Fairing (2020)	16.3 (53.5)	5 (16.4)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	Breeze-M
Length, m (ft)	21.2 (69.6)	17.1 (56.1)	2.7 (8.9)
Diameter, m (ft)	7.4 (24.3)	4.1 (13.5)	4 (13)
Manufacturer	Khrunichev	Khrunichev	Khrunichev
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	428,300 (944,239)	157,300 (346,787)	19,800 (43,651)
Total thrust, kN (lbf)	10,000 (2,248,089)	2,400 (539,541)	19.2 (4,411)
Engine(s)	6 x RD-276	3 x RD-0210	1 x 14D30
Engine manufacturer	NPO Energomash	KB Khimavtomatika	DB Khimmash
Engine thrust, kN (lbf)	1,667 (374,682)	800 (179,847)	19.6 (4,411)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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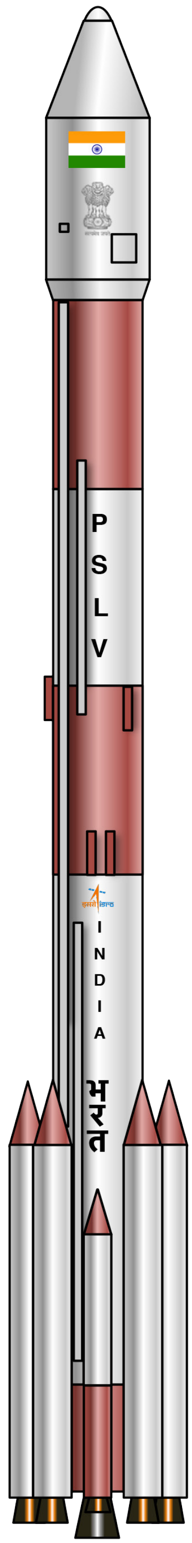
Launch Vehicle Fact Sheet

PSLV



The Indian Space Research Organization (ISRO) has offered the Polar Satellite Launch Vehicle (PSLV) since 1993. The vehicle is used to launch small and medium payloads to low Earth orbit and, on occasion, to send small satellites to geosynchronous orbit. For missions to LEO, it is not uncommon for the PSLV to launch several satellites at a time.

The PSLV is available in three variants. The basic version is known as the PSLV-CA, for "Core Alone." The PSLV-G, or standard PSLV, is teh more common variant and features six solid strap-on motors attached to the first stage core. The PSLV-XL is similar to the standard PSLV, but the six solid boosters are longer to accomodate greater propellant mass and thus increasing buring time.

The PSLV has been used for four commercial launches. The latest was a 2014 launch that carried payloads for France (SPOT 7), Canada (Can-X4 and X5), Germany (AISAT), and Singapore (VELOX-1). SPOT 7 was sold to the government of Azerbaijan several moths later.

A PSLV suffered a launch failure on August 31, 2017, destroying the vehicle and its payload, IRNSS-1H. This was the first failure for the PSLV since 1993, when the first launch ended in failure. The 2017 failure was traced to the payload fairing, which did not separate as planned.

Launch Service Provider
ISRO/Antrix

Organization Headquarters
India

Manufacturer
ISRO

Mass, kg (lb)
PSLV-G: 295,000 (650,000)
PSLV-CA: 230,000 (510,000)
PSLV-XL: 320,000 (710,000)

Length, m (ft)
44 (144)

Diameter, m (ft)
2.8 (9.2)

Year of First Launch
1993

Number of Orbital Launches
41

Reliability
95%

Launch Site
Satish Dhawan (FLP, SLP)

GTO Capacity, kg (lb)
1,425 (3,142)

LEO Capacity, kg (lb)
3,250 (7,165)

SSO Capacity, kg (lb)
1,750 (3,858)

Estimated Price per Launch
$21M-$31M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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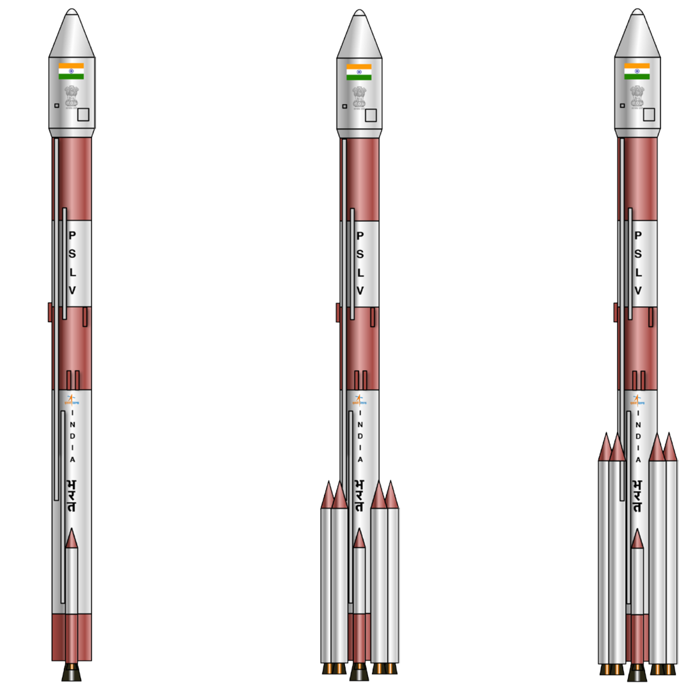
Launch Vehicle Fact Sheet

PSLV



PSLV-CA PSLV-G PSLV-XL

Notable PSLV payloads include Chandrayaan-1, Mars Orbiter Mission (MOM), Space Capsule Recovery Experiment, and the Indian Regional Navigation Satellite System (IRNSS).

Fairing	Length, m (ft)	Diameter, m (ft)
PSLV Fairing	8.3 (27.2)	3.2 (10.5)

	Solid Boosters*	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	PSOM	PS1	PS2	PS3	PS4
Length, m (ft)	G: 10 (32.8) XL: 13.5 (44.3)	20.34 (66.7)	12.8 (42)	3.54 (11.6)	2.6 (8.5)
Diameter, m (ft)	1 (3.3)	2.8 (9.2)	2.8 (9.2)	2.02 (6.6)	2.02 (6.6)
Manufacturer	ISRO	ISRO	ISRO	ISRO	ISRO
Propellant	Solid	Solid	N_2O_4/UDMH	Solid	Solid
Propellant mass, kg (lb)	G: 9,000 (19,842) XL: 12,000 (26,455)	138,000 (304,238)	40,700 (89,728)	6,700 (14,771)	2,000 (4,409)
Total thrust, kN (lbf)	4,314 (969,828)	4,800 (1,079,082)	799 (179,622)	240 (53,954)	14.6 (3,282)
Engine(s)	—	—	1 x Vikas	—	2 x PS-4
Engine manufacturer	—	—	ISRO	—	ISRO
Engine thrust, kN (lbf)	—	—	799 (179,622)	—	7.3 (1,641)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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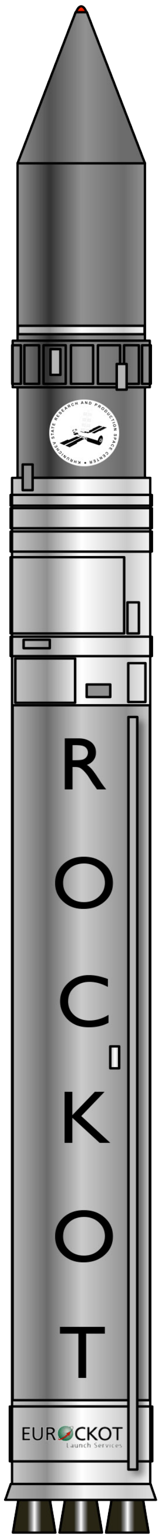
Launch Vehicle Fact Sheet

Rockot



The three-stage Rockot is developed using refurbished missile components. The missile used as the basis for the commercially available vehicle is the UR100N (SS-19) intercontinental ballistic missile (ICBM) built by Soviet-era OKB-52. Production and launch of the Rockot is managed by Eurockot Launch Services GmbH, a joint company between Russia's Khrunichev State Research and Production Space Center and EADS Astrium.

The Rockot consists of three stages. The first two stages are composed of SS-19 booster segments. The first stage is powered by an RD-244 engine and the second by an RD-235 engine. The third stage is a newly manufactured Khrunichev Breeze-KM upper stage. A payload adapter and fairing complete the vehicle system.

Since 1990, the vehicle has launched 24 times, with 2 failures. The first three launches were with the initial version, the Rockot-K. In May 2000, the vehicle was upgraded to accommodate a larger payload, it became the Rockot-KM, which has launched 21 times with 2 failures. The Rockot-KM launches from Plesetsk Kosmodrome in Russia.

The Rockot is predominantly used for scientific Earth observation and climate research missions in LEO. Eleven flights have been performed by Eurockot Launch Services for international customers. Rockot-KM currently has a backlog of commercial customers until 2015 and Russian government flights to the end of the decade.

Launch Service Provider
VKS/Eurockot

Organization Headquarters
Russia

Manufacturer
Khrunichev

Mass, kg (lb)
107,000 (235,895)

Length, m (ft)
29.2 (95.8)

Diameter, m (ft)
2.5 (8.2)

Year of First Launch
2000

Number of Orbital Launches
28

Reliability
93%

Launch Site
Plesetsk (LC-133)

LEO Capacity, kg (lb)
1,820-2,150 (4,012-4,740)

SSO Capacity, kg (lb)
1,180-1,600 (2,601-3,527)

Estimated Price per Launch
$41.8M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Rockot

FAA AST

A Rockot vehicle is launched from Plestesk Cosmodrome on October 13, 2017 carrying Europe's Sentinel-5P Earth observing satellite. (Source: ESA)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2.6 (8.5)	2.5 (8.2)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	Breeze-KM
Length, m (ft)	17.2 (56.4)	3.9 (12.8)	2.5 (8.2)
Diameter, m (ft)	2.5 (8.2)	2.5 (8.2)	2.5 (8.2)
Manufacturer	OKB-52 (Khrunichev)	OKB-52 (Khrunichev)	Khrunichev
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	71,455 (157,531)	10,710 (23,612)	4,975 (10,968)
Total thrust, kN (lbf)	1,870 (420,393)	240 (53,954)	19.6 (4,406)
Engine(s)	3 x RD-0233 1 x RD-0234	1 x RD-235	1 x S5.98M
Engine manufacturer	OKB-154 (KB Khimavtomatika)	OKB-154 (KB Khimavtomatika)	Khrunichev
Engine thrust, kN (lbf)	520 (116,901)	240 (53,954)	19.6 (4,406)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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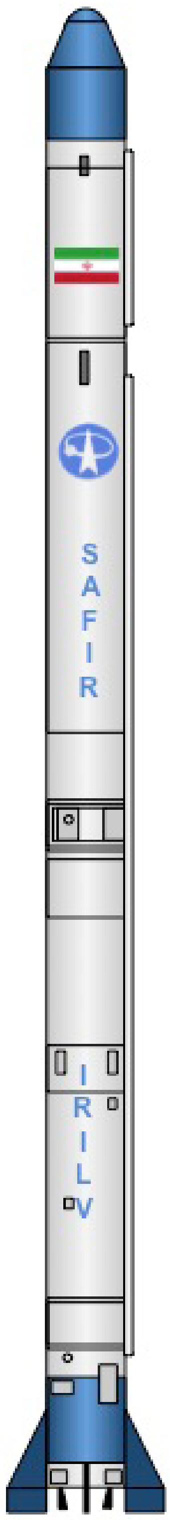
Launch Vehicle Fact Sheet

Safir



Iran's Safir launch vehicle is based on the Shahab 3 ballistic missile. The Shahab 3, based on the North Korean Nodong-1 ballistic missile, was in service from 1998 through 2003. Though the Safir may have been launched during an attempt in 2007 (there is confusion on what vehicle was used during the flight test), the first confirmed launch of Safir occured in 2008. This suborbital flight was followed by six orbital launch attempts, four of which have been considered successful.

Four variants have been introduced. These variants appear to be evolutionary stages, rather than availabile options. The Safir 1 was used on a suborbital flight and the first orbital flight in 2009. The Safir 1A was used on only one occasion, when it successfully launched the Rasad satellite into orbit in 2011. The Safir 1B also flew once. This version featured a new second stage with greater thrust, and placed Navid into orbit in 2012. The latest version, Safir 1B+ features a new third stage that can maneuver in orbit using cold gas thrusters. Two of three launch attempts using this version ended in failure. The most recent launch, that of the Fajr satellite in 2015, was successful.

It is believed that the third stage of North Korea's Unha vehicle uses a Safir third stage. Both Iran and North Korea have cooperated on missile and launch vehicle development since at least the 1990s.

Launch Service Provider
Iranian Space Agency

Organization Headquarters
Iran

Manufacturer
Iranian Space Agency

Mass, kg (lb)
26,000 (57,320)

Length, m (ft)
22 (72)

Diameter, m (ft)
1.3 (4.3)

Year of First Launch
2009

Number of Orbital Launches
6

Reliability
67%

Launch Site
Semnan

LEO Capacity, kg (lb)
50 (110)

SSO Capacity, kg (lb)
< 50 (< 110)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Safir

A Safir launch vehicle is being prepared for launch in February 2015. (Source: ISA)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	1.8 (5.9)	1.4 (4.6)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	17 (55.8)	3.2 (10.5)	Undisclosed
Diameter, m (ft)	1.4 (4.6)	1.4 (4.6)	Undisclosed
Manufacturer	ISA	ISA	ISA
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	Solid
Propellant mass, kg (lb)	21,400 (47,179)	2,700 (5,952)	Undisclosed
Total thrust, kN (lbf)	333.4 (74,951)	19.6 (4,406)	Undisclosed
Engine(s)	ISA	ISA	—
Engine manufacturer	1 x TBD	1 x TBD	—
Engine thrust, kN (lbf)	333.4 (74,951)	19.6 (4,406)	—

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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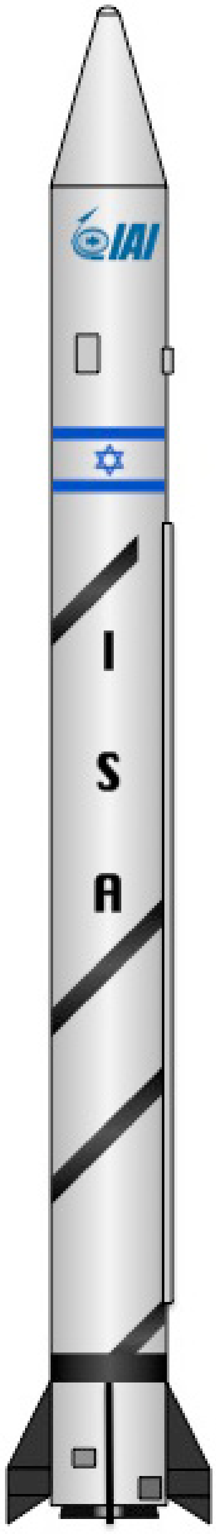
Launch Vehicle Fact Sheet
Shavit 2



The Shavit 2 is an orbital launch vehicle developed by Israel. The Shavit 1, launched for the first time in 1988, was based on the Jericho II missile. The more powerful Shavit 2 vehicle was introduced in 2007 and is the current version being used.

The Shavit is manufactured by Israel Aerospace Industries (IAI) and though it has been exclusively used to launch Ofeq reconnaissance satellites for the Israel Defense Forces (IDF), the Shavit program is managed by the Israel Space Agency (ISA). ISA manages the space launch facilities at IDF's Palmachim Air Force Base.

The Shavit 2 is launched in a retrograde fashion, flying westward over the Mediterranean Sea to avoid flying over hostile territories and prevent possible debris from falling above populated areas across the Middle East. This requirement imposes a penalty of roughly 30 percent of the vehicle's performance.

A version of this vehicle was acquired by South Africa in partnership with the ISA during the 1990s. The resulting RSA 1 vehicle system did not become operational as the program was cancelled in 1994.

Launch Service Provider
Israel Space Agency/IDF

Organization Headquarters
Israel

Manufacturer
IAI

Mass, kg (lb)
70,000 (154,324)

Length, m (ft)
26.4 (86.6)

Diameter, m (ft)
1.4 (4.6)

Year of First Launch
1988

Number of Orbital Launches
10

Reliability
90%

Launch Site
Palmachim AFB

SSO Capacity, kg (lb)
500 (1,102)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Shavit 2

The launch of Israel's Ofeq 9 satellite with the Shavit launch vehicle on June 22, 2010. (Source: Israeli Aerospace Industries)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2.8 (9.2)	1.3 (4.3)

	1st Stage	2nd Stage	3rd Stage
Stage designation	ATSM 13	ATSM 13	AUS 51
Length, m (ft)	7.5 (24.6)	7.5 (24.6)	2.6 (8.5)
Diameter, m (ft)	1.4 (4.6)	1.4 (4.6)	1.3 (4.3)
Manufacturer	IAI/Ta'as	IAI/Ta'as	IAI/Rafael Advanced Defense Systems
Propellant	Solid	Solid	Solid
Propellant mass, kg (lb)	12,750 (28,109)	12,750 (28,109)	1,890 (4,167)
Total thrust, kN (lbf)	564 (126,792)	564 (126,792)	60.4 (13,579)

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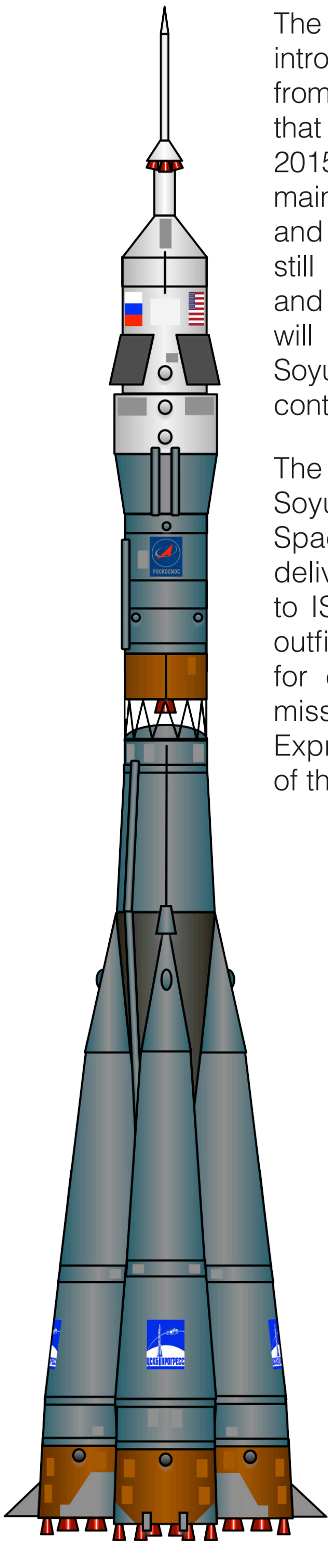
Launch Vehicle Fact Sheet

Soyuz FG



The Soyuz FG vehicle (11A511FG), introduced in 2001, is an improvement from the Soyuz U (11A511U) vehicle that was in service from 1973 to 2015. The improvements focused mainly on upgrades to the RD-108 and RD-107 engines. The vehicle still uses an analog control system, and it is anticipated that the vehicle will ultimately be replaced by the Soyuz 2 series, which has a digital control system.

The vehicle is used for crewed Soyuz missions to the International Space Station (ISS). It is also used to deliver the Progress cargo modules to ISS. The Soyuz FG can also be outfitted with a Fregat upper stage for certain missions; examples of missions using Fregat include Mars Express and some replenishments of the Globalstar constellation.

Launch Service Provider
VKS/Glavkosmos

Organization Headquarters
Russia

Manufacturer
JSC SRC Progress

Mass, kg (lb)
305,000 (672,410)

Length, m (ft)
49.5 (162.4)

Diameter, m (ft)
10.3 (33.8)

Year of First Launch
2001

Number of Orbital Launches
62

Reliability
100%

Launch Site
Baikonur (LC-1, LC-31)

LEO Capacity, kg (lb)
7,800 (17,196)

SSO Capacity, kg (lb)
4,500 (9,921)

Estimated Price per Launch
$50M-$213M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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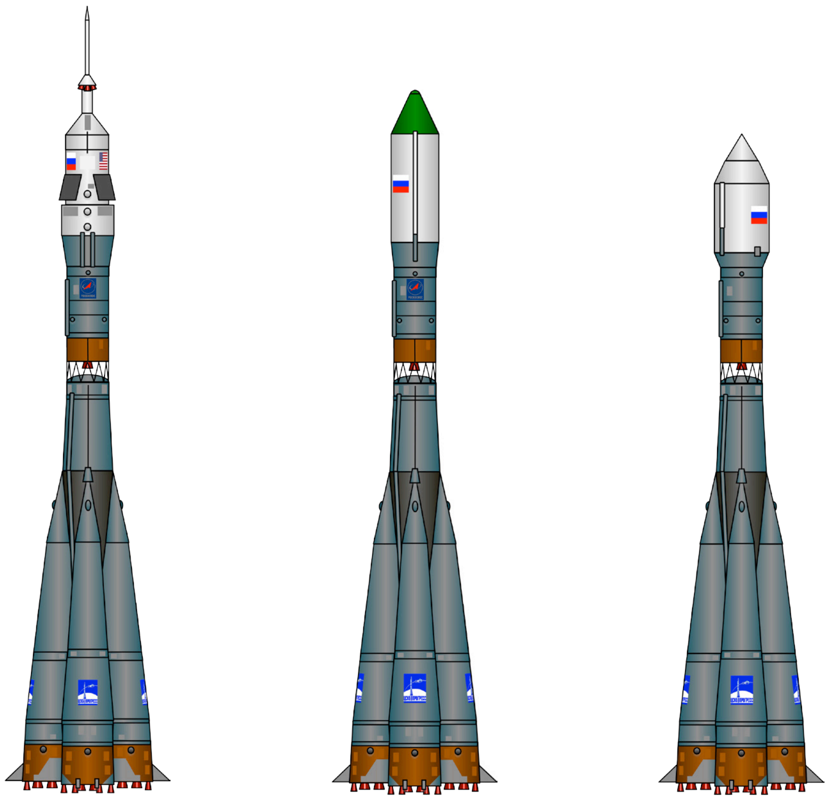
Launch Vehicle Fact Sheet

Soyuz FG

FAA AST



Soyuz FG Crewed

Soyuz FG Progress

Soyuz FG Fregat

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	11.4 (37.4)	4.1 (13.5)

	1st Stage	4 x Liquid Boosters	2nd Stage	3rd Stage
Stage designation	Core Stage	1st Stage	2nd Stage	Fregat
Length, m (ft)	27.1 (88.9)	19.6 (64.3)	6.7 (22)	1.5 (4.9)
Diameter, m (ft)	3 (9.8)	2.7 (8.9)	2.7 (8.9)	3.4 (11)
Manufacturer	JSC SRC Progress	JSC SRC Progress	JSC SRC Progress	NPO Lavochkin
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene	N_2O_4/UDMH
Propellant mass, kg (lb)	90,100 (198,636)	39,160 (86,333)	25,400 (55,997)	5,350 (11,795)
Total thrust, kN (lbf)	838.5 (188,502)	792.5 (178,161)	297.9 (66,971)	19.6 (4,406)
Engine(s)	1 x RD-108A	1 x RD-107A	2.1a: 1 x RD-0110 2.1b: 1 x RD-0124	1 x S5.92
Engine manufacturer	AO Motorostroitel	AO Motorostroitel	KB Khimavtomatika	KB KhIMMASH
Engine thrust, kN (lbf)	838.5 (188,502)	792.5 (178,161)	2.1a: 297.9 (66,971) 2.1b: 297.9 (66,971)	19.6 (4,406)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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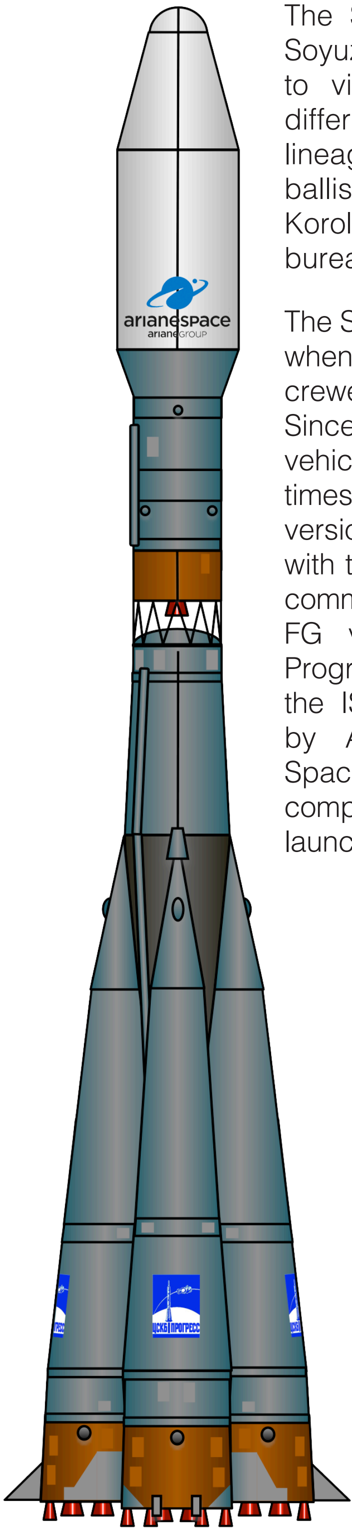
Launch Vehicle Fact Sheet

Soyuz 2.1a/b



The Soyuz 2 (also referred to as Soyuz ST) is used to launch satellites to virtually any orbit from three different launch sites. It can trace its lineage to the R-7 intercontinental ballistic missile designed by Sergei Korolov and his OKB-1 design bureau in the mid-1950s.

The Soyuz received its current name when it was selected to launch crewed Soyuz spacecraft in 1966. Since that year, the R-7-derived vehicles have launched almost 1,800 times. There have been several versions of the Soyuz, culminating with the Soyuz 2 currently providing commercial service. The older Soyuz FG version continues to launch Progress and Soyuz missions to the ISS. The Soyuz 2 is operated by Arianespace at the Guiana Space Center. Arianespace's sister company, Starsem, manages Soyuz launches from Baikonur.

The Soyuz 2 is manufactured by JSC SRC Progress at the Samara Space Center and NPO Lavotchkin (the upper stage). The vehicle consists of a core stage powered by an RD-108A, four liquid strap on boosters powered by RD-107A engines, a second stage powered by an RD-0124 engine, and a Lavotchkin Fregat upper stage powered by an S5.92 engine. A payload adapter and standard 4-meter (13-foot) diameter fairing complete the vehicle system. TsSKB-Progress can produce about 20 Soyuz vehicles per year.

Launch Service Provider
VKS/Arianespace/VKS/GK Launch Services

Organization Headquarters
Russia/France

Manufacturer
JSC SRC Progress

Mass, kg (lb)
305,000 (672,410)

Length, m (ft)
49.5 (162.4)

Diameter, m (ft)
10.3 (33.8)

Year of First Launch
2.1a (2004), 2.1b (2006)

Number of Orbital Launches
2.1a (32), 2.1b (37)

Reliability
2.1a (97%), 2.1b (94%)

Launch Sites
Plesetsk (LC-133)
Guiana Space Center (ELS)

GTO Capacity, kg (lb)
3,250 (7,165)

LEO Capacity, kg (lb)
4,850 (10,692)

SSO Capacity, kg (lb)
4,400 (9,700)

Estimated Price per Launch
$80M

The Soyuz 2 variant has flown 38 times, with three failures. The 2014 failure, due to a fault in the Fregat upper stage, resulted in the loss of two Galileo navigation satellites.

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Soyuz 2.1a/b

A Soyuz 2.1b launches two Galileo navigation satellites from the Guiana Space Center in 2015. (Source: Arianespace)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	7.7 (25.3)	3.7 (12.1)
Long Fairing	11.4 (37.4)	4.1 (13.5)

	1st Stage	4 x Liquid Boosters	2nd Stage	3rd Stage
Stage designation	Core Stage	1st Stage	3rd Stage	Fregat
Length, m (ft)	27.1 (88.9)	19.6 (64.3)	6.7 (22)	1.5 (4.9)
Diameter, m (ft)	3 (9.8)	2.7 (8.9)	2.7 (8.9)	3.4 (11.2)
Manufacturer	JSC SRC Progress	JSC SRC Progress	JSC SRC Progress	NPO Lavotchkin
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene	N_2O_4/UDMH
Propellant mass, kg (lb)	90,100 (198,636)	39,160 (86,333)	25,400 (55,997)	6,638 (14,634)
Total thrust, kN (lbf)	838.5 (188,502)	792.5 (178,161)	297.9 (66,971)	19.9 (4,474)
Engine(s)	1 x RD-108A	1 x RD-107A	2.1a: 1 x RD-0110 2.1b: 1 x RD-0124	1 x S5.92
Engine manufacturer	AO Motorostroitel	AO Motorostroitel	KB Khimavtomatika	NPO Lavotchkin
Engine thrust, kN (lbf)	838.5 (188,502)	792.5 (178,161)	2.1a: 297.9 (66,971) 2.1b: 297.9 (66,971)	19.9 (4,474)

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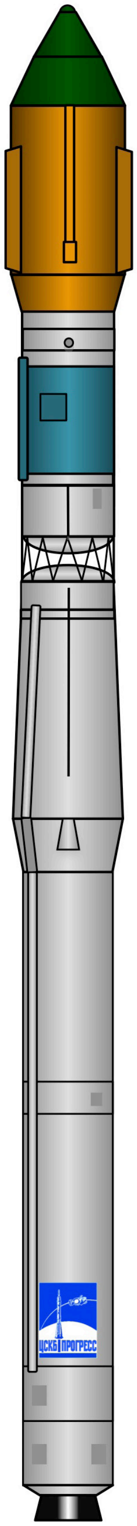
Launch Vehicle Fact Sheet

Soyuz 2.1v



The Soyuz 2.1v (formerly described as the Soyuz 1) is similar to the Soyuz, but without the liquid strap-on boosters.

The first stage diameter is 2.7 meters, compared to 2 meters of a Soyuz. It is powered by a single engine, a modified version of the NK-33 once designated for use on the N-1 lunar rocket from the 1970s. In the long-term, the first stage will be powered by the RD-191 manufactured by NPO Energomash. The second stage is the same as that used for the Soyuz 2.1a/b.

A Volga upper stage may be employed for certain missions, such as insertion in orbits as high as 1,500 kilometers (932 miles) in altitude.

The vehicle was originally conceived as a replacement for the small-class Rockot. It is expected to be available for launch from Russia's newest launch site, Vostochny, sometime after 2018.

The second launch of the Soyuz 2.1v, which took place in December 2015, is considered a success. According to Russian press reports, the Kanopus Earth observing satellite failed shortly after separation from the vehicle's upper stage. A classified military payload was launched on the vehicle's third flight during the summer of 2017.

Launch Service Provider
VKS/GK Launch Services

Organization Headquarters
Russia

Manufacturer
JSC SRC Progress

Mass, kg (lb)
157,000 (346,126)

Length, m (ft)
44 (144)

Diameter, m (ft)
2.95 (9.7)

Year of First Launch
2013

Number of Orbital Launches
3

Reliability
100%

Launch Sites
Baikonur (LC-31 or LC-6)
Plesetsk (LC-43)

LEO Capacity, kg (lb)
3,000 (6,614)

SSO Capacity, kg (lb)
1,400 (3,086)

Estimated Price per Launch
$40M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Soyuz 2.1v

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A Soyuz 2.1v is prepared for launch in December 2015. The launch, carrying a Kanopus remote sensing satellite, did not go entirely as planned - the payload did not fully separate from the upper stage due to a second stage latching problem. (Source: Russian MoD)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	7.7 (25.3)	3.7 (12.1)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	Volga
Length, m (ft)	27.8 (91.2)	6.7 (22)	1.03 (3.4)
Diameter, m (ft)	2.95 (9.7)	2.7 (8.9)	3.1 (10.2)
Manufacturer	JSC SRC Progress	JSC SRC Progress	JSC SRC Progress
Propellant	LOX/Kerosene	LOX/Kerosene	UDMH
Propellant mass, kg (lb)	119,700 (263,893)	25,400 (55,997)	900 (1,984)
Total thrust, kN (lbf)	1,510 (339,462)	297.9 (66,971)	2.94 (661)
Engine(s)	1 x 14D15 (NK-33)	1 x RD-0124	1 x main engine
Engine manufacturer	NK Engines Company	KB Khimavtomatika	JSC SRC Progress
Engine thrust, kN (lbf)	1,510 (339,462)	297.9 (66,971)	2.94 (661)

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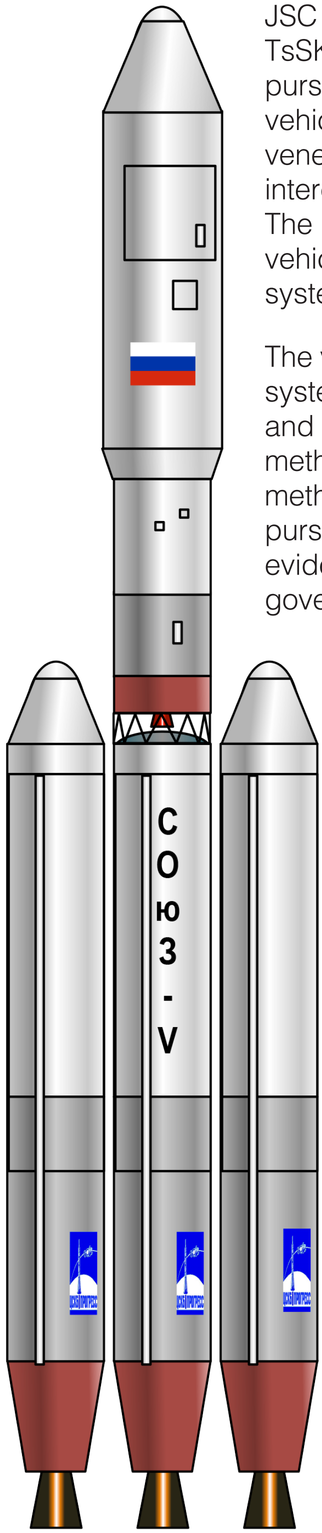
Launch Vehicle Fact Sheet

Soyuz 5



JSC SRC Progress (formerly TsSKB Progress) is currently pursuing the Soyuz 5, a family of vehicles designed to replace the venerable R-7 derived from the R-7 intercontinental ballistic missile. The Soyuz 5 is an entirely different vehicle, being a wholly new vehicle system.

The vehicle will feature a propulsion system burning liquid oxygen (LOX) and liquified natural gas (LNG), or methane. This marks the first time a methane-burning vehicle has been pursued by Russia. There is some evidence indicating that the Russian government sought development of this vehicle in part because of similar efforts underway by SpaceX and Blue Origin to build LOX-LNG vehicles.

The Soyuz 5 is also being pursued as the base vehicle for Russia's replacement to its Soyuz crewed spacecraft, the "New Generation Piloted Transport Ship (PTK NP)," or Federatsiya.

Interestingly, the capability of Soyuz 5 overlaps that of the new Angara family. The justification behind pursuing development of Soyuz 5 appears to focus on demonstrating the use of LOX-LNG for future space transportation and the potential for reusability.

To compete with the Falcon 9 FT and similar vehicles, the price for the smallest variant, the Soyuz 5.1, is expected to be about $50M.

Launch Service Provider
VKS/GK Launch Services

Organization Headquarters
Russia

Manufacturer
JSC SRC Progress

Mass, kg (lb)
200,000-690,000 (440,925-1,521,190)

Length, m (ft)
50-57 (164-187)

Diameter, m (ft)
3.6 (11.8)

Year of Planned First Launch
2022

Launch Site
Vostochny

GTO Capacity, kg (lb)
Undisclosed

LEO Capacity, kg (lb)
3,000-26,000 (6,614-57,320)

SSO Capacity, kg (lb)
Undisclosed

Estimated Price per Launch
$50M+

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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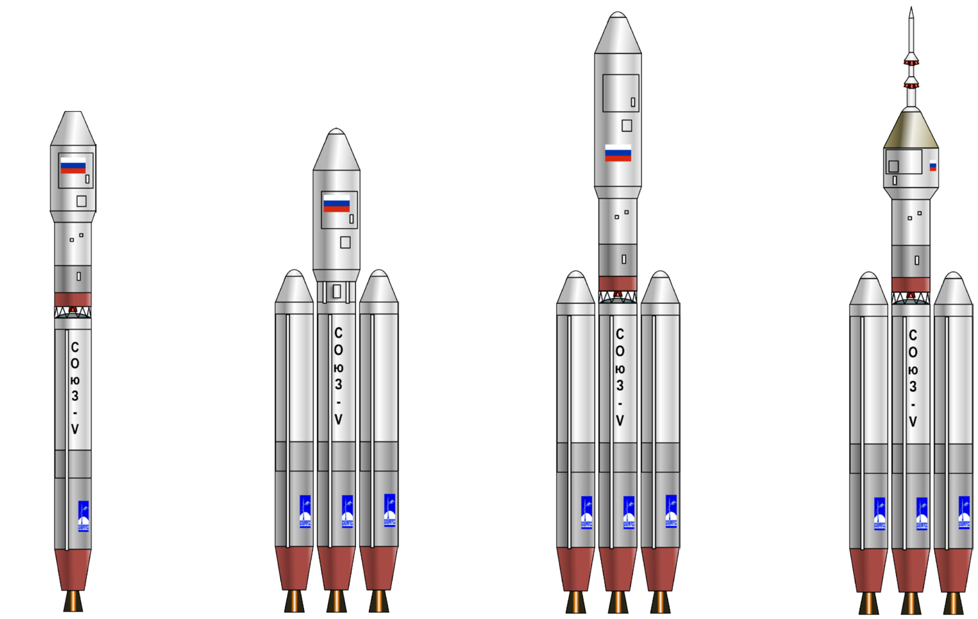
Launch Vehicle Fact Sheet
Soyuz 5



Soyuz 5.1 | Soyuz 5.2 | Soyuz 5.3 | Soyuz 5.3 PTK NP

The Soyuz 5 is expected to be available in at least three variants, with a fifth configured to carry Russia's newest spacecraft capable of carrying a crew, the PTK NP.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	8.4 (27.6) *est.*	4.1 (13.5)
Medium Fairing	11.7 (38.4) *est.*	4.4 (14.4)
Long Fairing	14 (46) *est.*	4.4 (14.4)

	1st Stage	2nd Stage	Optional 3rd Stage
Stage designation	1st Stage	2nd Stage	Fregat
Length, m (ft)	Undisclosed	Undisclosed	1.5 (4.9)
Diameter, m (ft)	3.6 (11.8)	3.6 (11.8)	3.4 (11.2)
Manufacturer	JSC SRC Progress	JSC SRC Progress	NPO Lavotchkin
Propellant	LOX/CH_4	LOX/CH_4	N_2O_4/UDMH
Propellant mass, kg (lb)	184,000 (405,651)	50,000 (110,231)	6,638 (14,634)
Total thrust, kN (lbf)	3,330 (750,000)	737 (166,000)	19.9 (4,474)
Engine(s)	RD-0164	RD-0169	1 x S5.92
Engine manufacturer	KB Khimavtomatika	KB Khimavtomatika	NPO Lavotchkin
Engine thrust, kN (lbf)	3,330 (750,000)	737 (166,000)	19.9 (4,474)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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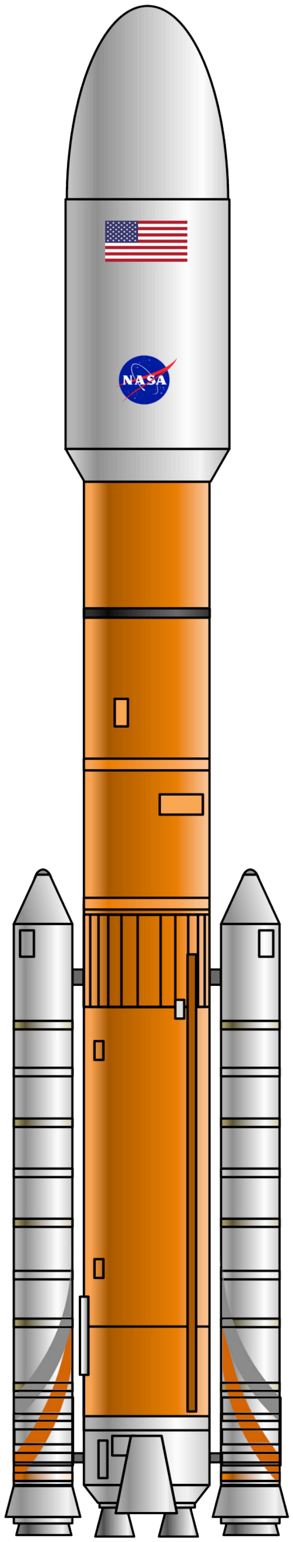
Launch Vehicle Fact Sheet

Space Launch System



Launch Service Provider
NASA

Organization Headquarters
USA

Manufacturer
Boeing/ULA/Orbital ATK

Mass, kg (lb)
2,650,000 (5,842,250)

Length, m (ft)
111.3 (365)

Diameter, m (ft)
8.4 (27.8)

Year of Planned First Launch
2019

Launch Site
KSC (LC-39B)

LEO Capacity, kg (lb)
70,000-130,000
(154,324-286,601)

The Space Launch System (SLS) is a launch vehicle system being developed by NASA for the next era of human exploration beyond Earth's orbit. The vehicle will be used to send crews of up to four astronauts in an Orion spacecraft, cargo, or large robotic scientific missions to Mars, Saturn and Jupiter. Boeing is the prime contractor for SLS. Orbital ATK will provide the solid rocket boosters (SRB), United Launch Alliance (ULA) will provide the Interim Cryogenic Propulsion Stage (ICPS), and Aerojet Rocketdyne is the provider of liquid rocket engines.

SLS is designed to evolve into increasingly more powerful configurations using the same core stage throughout. The first SLS vehicle, called Block 1, has a maximum capacity of 70,000 kg (154,323 lb) to low Earth orbit (LEO). It will be powered by four RS-25 engines and two five-segment SRBs and include a modified version of an existing upper stage. The next versions, the Block 1B, will use a new, more powerful Exploration Upper Stage (EUS) to deliver 105,000 kg (231,485 lb) to LEO. A later evolution, the Block 2, would replace the SRBs with a pair of advanced solid or liquid propellant boosters to provide a LEO capacity of 130,000 kg (286,601 lb).

Two missions are envisioned for the SLS Block 1, including a 3-week uncrewed flight test of Orion in 2019 (EM-1) and a crewed mission to the vicinity of the Moon in 2021 (EM-2). The SLS Block 1B will be used to send astronauts and equipment on increasingly complex mission in cislunar space. Finally, the SLS Block 2 will be used for crewed missions to Mars by the 2030s.

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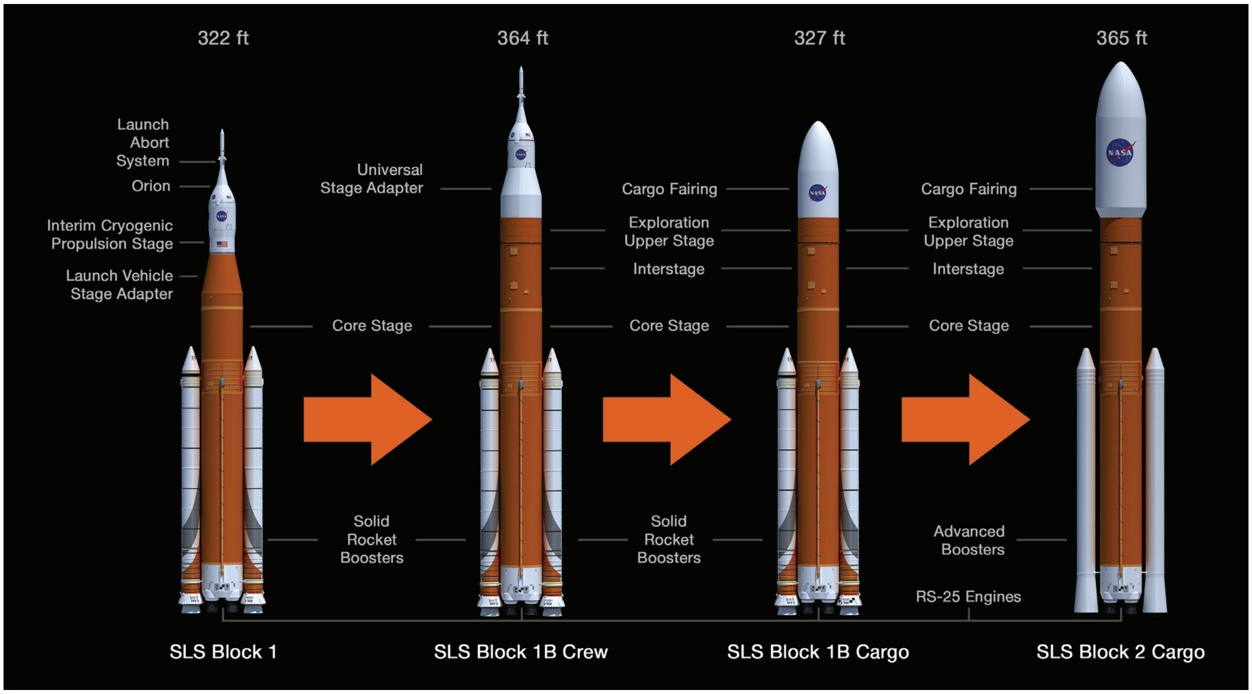
Launch Vehicle Fact Sheet
Space Launch System



A NASA diagram showing the evolution of the Space Launch System. (Source: NASA)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	12.5 (41)	8.4 (27.6)
Large Fairing	25 (82)	8.4 (27.6)

	Solid Boosters*	1st Stage	2nd Stage Option	2nd Stage Option
Stage designation	SRB	1st Stage	Interim Cryogenic Propulsion Stage	Exploration Upper Stage
Length, m (ft)	53.9 (177)	64.6 (212)	13.7 (45)	23 (75.5)
Diameter, m (ft)	3.7 (12)	8.4 (27.6)	5 (16.4)	8.4 (27.8)
Manufacturer	Orbital ATK	Boeing	ULA	Boeing
Propellant	Solid	LOX/H_2	LOX/H_2	LOX/H_2
Propellant mass, kg (lb)	631,495 (1,392,208)	894,181 (1,971,332)	26,853 (59,201)	206,020 (454,196)
Total thrust, kN (lbf)	16,014 (3,600,000)	1,859 (418,000)	110 (24,751)	110 (24,751)
Engine(s)	—	4 x RS-25E	1 x RL10B-2	4 x RL10B-2
Engine manufacturer	—	Aerojet Rocketdyne	Aerojet Rocketdyne	Aerojet Rocketdyne
Engine thrust, kN (lbf)	—	7,436 (1,671,679)	110 (24,751)	440 (98,916)

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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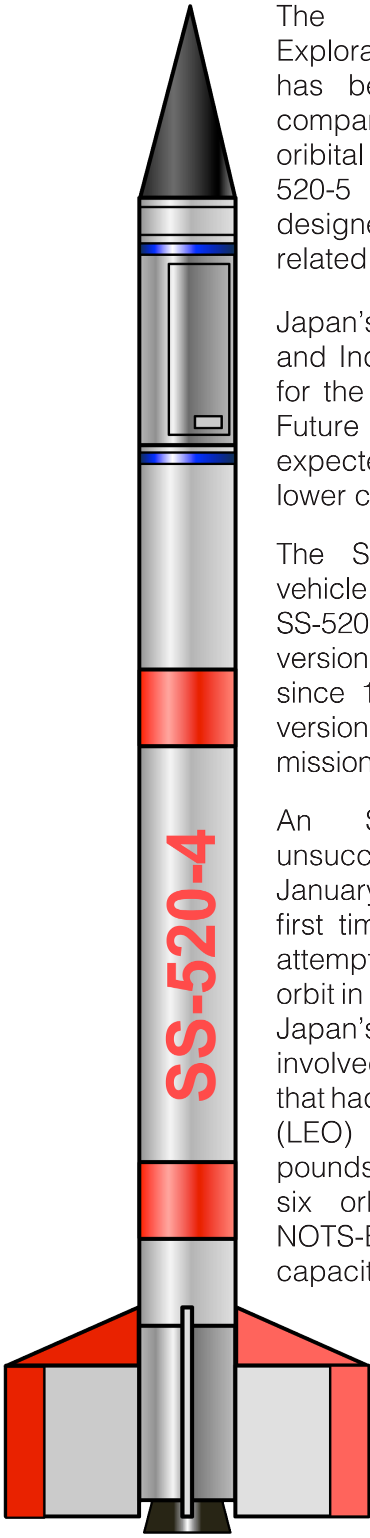
Launch Vehicle Fact Sheet

SS-520-5



The Japan Aerospace and Exploration Agency (JAXA) has been working with several companies to develop a very small oribital launch vehicle. The SS-520-5 is a development vehicle designed to gather data for use in related future programs.

Japan's Ministry of Economy, Trade, and Industry provided $3.5 million for the SS-520-5 vehicle program. Future operational launches are expected to be conducted at much lower costs.

The SS-520-5 is a three-stage vehicle derived from the two-stage SS-520 sounding rocket. Early versions of this vehicle flew 30 times since 1980, though a three stage version has flown twice on suborbital missions.

An SS-520-4 vehicle flew unsuccessfully for the first time in January 2017. It represented the first time a small vehicle like this attempted to send a payload into orbit in nearly five decades. Indeed, Japan's first ever orbital launch involved the Lambda 4S, a vehicle that had a capacity to low Earth orbit (LEO) of about 25 kilograms (55 pounds). The U.S. Navy attempted six orbital launches using the NOTS-EV-1 Pilot, which had a LEO capacity of just 2 kilograms (4.4 pounds). None of those missions were successful.

JAXA has not announced any plans for future launch attempts using the SS-520-4, but did launch an upgraded version called the SS-520-5 in January 2018. This flight carried the 4-kg TRICOM-1R, and the vehicle became the smallest ever to launch a payload into orbit.

Launch Service Provider
Canon/JAXA

Organization Headquarters
Japan

Manufacturer
Canon/JAXA

Mass, kg (lb)
2,600 (5,732)

Length, m (ft)
9.5 (31)

Diameter, m (ft)
0.5 (1.6)

Year of First Launch
2017

Number of Orbital Launches
1

Reliability
0%

Launch Site
Uchinoura

LEO Capacity, kg (lb)
4 (8.8)

SSO Capacity, kg (lb)
< 4 (8.8)

Estimated Price per Launch
Undisclosed

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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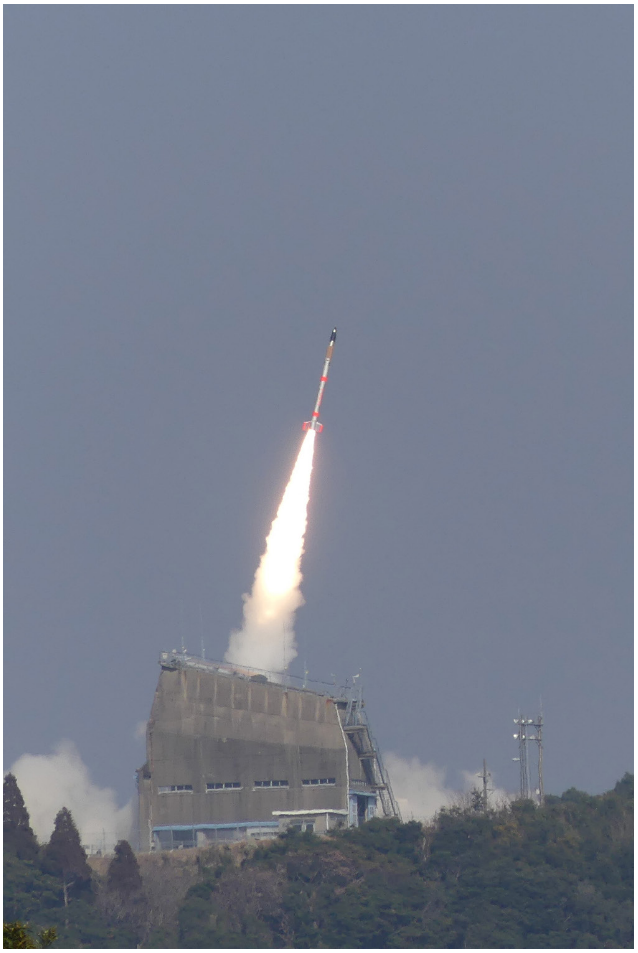
Launch Vehicle Fact Sheet

SS-520-5

FAA AST



The SS-520-5 is launched in January 2018 ccarrying a student-built CubeSat called TRICOM-1R. On this flight, the vehicle became the smallest ever to launch a payload into orbit. (Source: NVS)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	Undisclosed	0.5 (1.6)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	0.5 (1.6)	0.5 (1.6)	0.5 (1.6)
Manufacturer	Canon	Canon	Canon
Propellant	Solid	Solid	Solid
Propellant mass, kg (lb)	1,587 (3,499)	325 (717)	78 (172)
Total thrust, kN (lbf)	143 (32,148)	Undisclosed	Undisclosed

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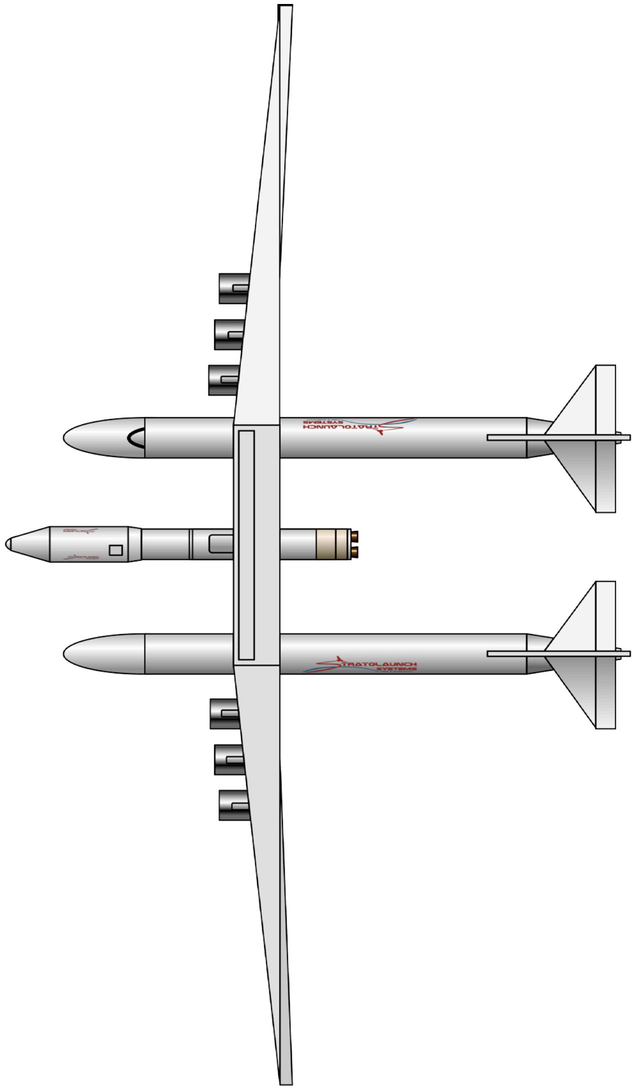
Launch Vehicle Fact Sheet

Stratolaunch



Launch Service Provider
Stratolaunch Systems

Organization Headquarters
USA

Manufacturer
Scaled Composites/Dynetics

Mass, kg (lb)
589,671 (1,300,000)

Length, m (ft)
72.5 (238)

Wingspan, m (ft)
117 (385)

Year of Planned First Launch
2018

Launch Sites
Mojave Air and Space Port
KSC (Runaway)

LEO Capacity, kg (lb)
1,350 (2,976)*

SSO Capacity, kg (lb)
975 (2,150)*

Estimated Price per Launch
Undisclosed

Stratolaunch is a system under development by Stratolaunch Systems and funded by owning company Vulcan Aerospace. The system will employ the largest airplane ever built to be a carrier vehicle for an orbital rocket. Initial plans called for a twin-boom Boeing 747, but this has been replaced with an original design by Scaled Composites. In 2016, Stratolaunch partnered with Orbital ATK, which will provide its Pegasus XL air-launched vehicle for the system. Stratolaunch Systems is also reportedly working with Sierra Nevada Corporation (SNC) to consider plans for deploying SNC's Dream Chaser from the carrier aircraft.

Stratolaunch aims to be fully operational by 2020, delivering payloads to multiple orbits and inclinations in a single mission. A test flight of the carrier aircraft is expected during the next several years from Mojave Air and Space Port in California.

** This capacity reflects Stratolaunch capability to carry 3 Pegasus XL vehicles at one time.*

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Stratolaunch

FAA AST

Stratolaunch makes its first rollout to begin fueling tests in May 2017. (Source: Stratolaunch Systems)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2.1 (6.9)	1.2 (3.9)

	1st Stage	2nd Stage	3rd Stage	4th Stage	5th Stage
Stage designation	StratoLauncher	Orion-50SXL	Orion-50XL	Orion-38	HAPS
Length, m (ft)	72.5 (238)	10.27 (33.7)	3.1 (10.2)	1.3 (4.3)	0.7 (2.3)
Wingspan/Diameter, m (ft)	117 (385)	1.3 (4.3)	1.3 (4.3)	1 (3.3)	1 (3.3)
Manufacturer	Boeing/Scaled Composites/Dynetics	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Kerosene (JP-4)	Solid	Solid	Solid	Hydrazine
Propellant mass, kg (lb)	Undisclosed	15,014 (33,105)	3,925 (8,655)	770 (1,697)	73 (161)
Total thrust, kN (lbf)	2,616 (588,100)	726 (163,247)	196 (44,171)	36 (8,062)	0.6 (135)
Engine(s)	6 x PW4056	—	—	—	3 x Rocket Engine Assemblies
Engine manufacturer	Pratt & Whitney	—	—	—	Orbital ATK
Engine thrust, kN (lbf)	436 (98,017)	—	—	—	0.2 (45)

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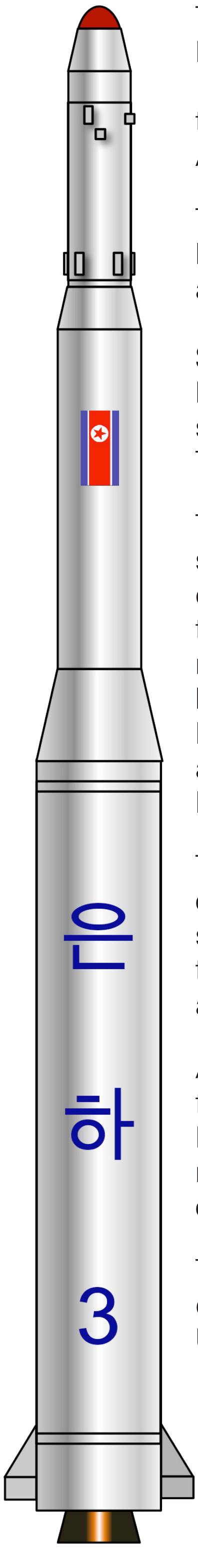
Launch Vehicle Fact Sheet

Unha



The Unha family of vehicles represent North Korea's current orbital launch capability. It was developed and is operated by the National Aerospace Development Administration (NADA).

The origin of the Unha can be traced to the Paektusan-1 missile, which was used for an unsuccessful orbital launch attempt in 1998. The Paektusan-1 used elements of the Soviet Scud missile, but also the indigenous Nodong-1 missile. Experience with these systems informed development of the Taepodong-1.

The Taepodong-1 ballistic missile is a system that was never deployed and is considered a technology demonstrator for the two- or three-stage Taepodong-2 long-range ballistic missile. The Taepodong-2 has yet to be operationally deployed, leading some to suspect the Taepodong-2 is a developmental stage leading to the Unha launch vehicle.

The Unha first stage consists of a cluster of motors from the Nodong-1. The second stage is likely derived from the Scud. The third stage may have come from technology associated with Iran's Safir vehicle.

An Unha was successfully launched from Sohae on February 7, 2016 carrying Kwangmyŏngsŏng-4 satellite into orbit. This represents only the second successful flight out of four for this vehicle.

There is some evidence that NADA is developing a larger vehicle based on the Unha.

Launch Service Provider
NADA

Organization Headquarters
North Korea

Manufacturer
NADA

Mass, kg (lb)
90,000 (198,416)

Length, m (ft)
30 (98.4)

Diameter, m (ft)
2.4 (7.9)

Year of First Launch
2009

Number of Orbital Launches
4

Reliability
50%

Launch Site
Tonghae (Musudan-ri)
Sohae (Pongdong-ri)

LEO Capacity, kg (lb)
100 (220)

SSO Capacity, kg (lb)
< 100 (< 220)

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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Launch Vehicle Fact Sheet

Unha

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North Korea's Unha is prepared for launch in 2016, this time carrying Kwangmyŏngsŏng-4. Source: Korea Herald.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2 (6.6)	1.3 (4.3)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	15 (49)	9.3 (31)	5.7 (19)
Wingspan/Diameter, m (ft)	2.4 (7.9)	1.5 (4.9)	1.3 (4.3)
Manufacturer	NADA	NADA	NADA
Propellant	RFNA/UDMH	RFNA/UDMH	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	1,100 (247,290)	250 (56,202)	54 (12,140)
Engine(s)	4 x Nodong	Undisclosed	Undisclosed
Engine manufacturer	NADA	NADA	NADA
Engine thrust, kN (lbf)	275 (61,823)	250 (56,202)	54 (12,140)

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Launch Vehicle Fact Sheet

Vector H

Vector (formerly Vector Space Systems), founded in 2016, seeks to provide dedicated options for operators of payloads with masses of 110 kilograms (243 pounds) or less. The genesis of the company depended on acquiring Garvey Space Corporation, itself founded in 2000. Garvey Spacecraft Corporation provided engineering, technical support, project management and hardware prototyping services to U.S. government and commercial customers with the long-term objective being the development and operation of the Nanosat Launch Vehicle (NLV). The NLV is the foundation for the development of two three-stage vehicles, the Vector H and the smaller Vector R.

The company received $1M in seed funding immediately following its founding. This, combined with the legacy research and development from Garvey Spacecraft Corporation, provides a solid basis to continue development of the Vector vehicle family.

Several months later, Finland-based Iceye, which aims to deploy up to 20 remote sensing satellites, signed a contract with Vector Space Systems for 21 launches beginning in 2018. Financial terms of the contract were not publicly released, but the contract is estimated to have a value of about $60M.

Launch Service Provider
Vector

Organization Headquarters
USA

Manufacturer
Vector

Mass, kg (lb)
8,700 (19,180)

Length, m (ft)
16 (52.5)

Diameter, m (ft)
1.1 (3.6)

Year of Planned First Launch
2019

Launch Sites
CCAFS (LC-46)
PSCA

LEO Capacity, kg (lb)
160 (353)

SSO Capacity, kg (lb)
75 (165)

Estimated Price per Launch
$3.5M

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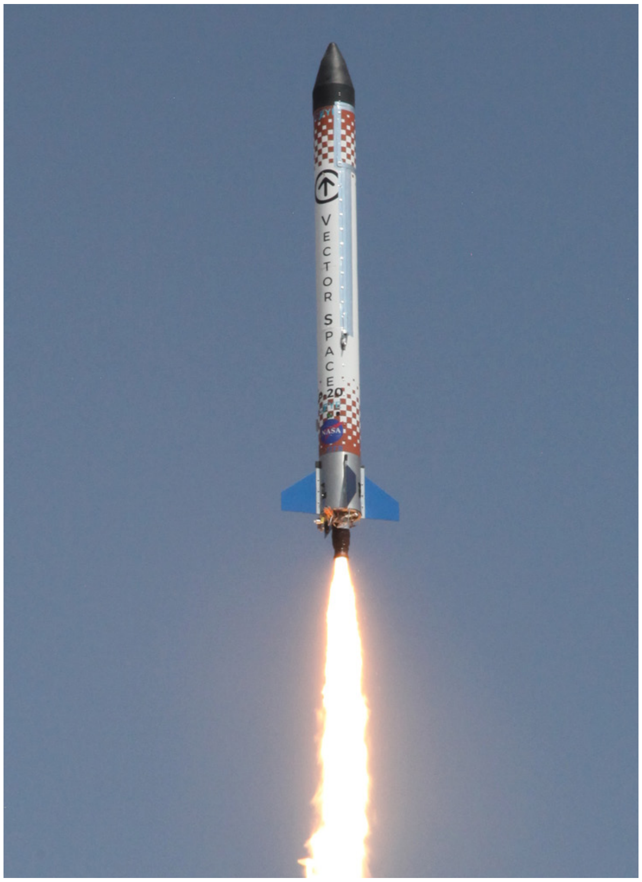
Launch Vehicle Fact Sheet

Vector H



Vector Space Systems tests a 3.7-meter (12-foot) prototype vehicle. Source: Vector Space Systems.

Fairing	Length, m (ft)	Diameter, m (ft)
Fairing	0.6 (2)	0.6 (2)

	1st Stage	2nd Stage	3rd Stage Option
Stage designation	1st Stage	2nd Stage	EUS
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	1.1 (3.6)	1.1 (3.6)	< 1.1 (3.6)
Manufacturer	Vector	Vector	Vector
Propellant	LOX/Propylene	LOX/Propylene	
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	150 (33,721)	2.2 (500)	Undisclosed
Engine(s)	6 x TBD	1 x TBD	1 x TBD
Engine manufacturer	Vector	Vector	Vector
Engine thrust, kN (lbf)	25 (5,620)	2.2 (500)	Undisclosed

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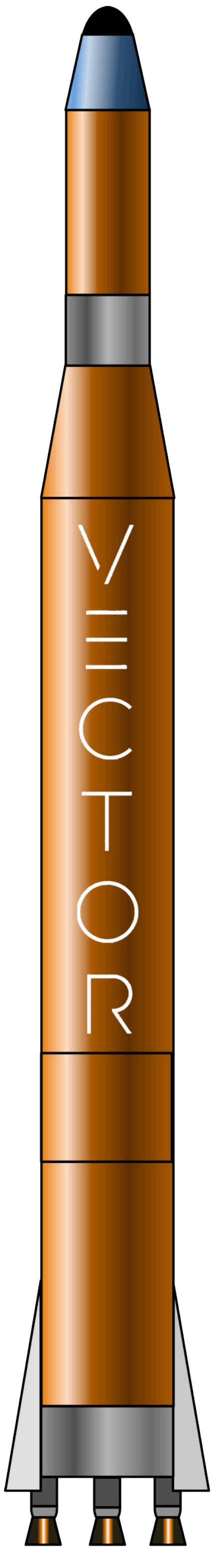
Launch Vehicle Fact Sheet

Vector R (Rapide)



Vector (formerly Vector Space Systems), founded in 2016, seeks to provide dedicated options for operators of payloads with masses of 110 kilograms (243 pounds) or less. The genesis of the company depended on acquiring Garvey Space Corporation, itself founded in 2000. Garvey Spacecraft Corporation provided engineering, technical support, project management and hardware prototyping services to U.S. government and commercial customers with the long-term objective being the development and operation of the Nanosat Launch Vehicle (NLV). The NLV is the foundation for the development of two three-stage vehicles, the Vector H and the smaller Vector R.

The company received $1M in seed funding immediately following its founding. This, combined with the legacy research and development from Garvey Spacecraft Corporation, provides a solid basis to continue development of the Vector vehicle family.

Several months later, Finland-based Iceye, which aims to deploy up to 20 remote sensing satellites, signed a contract with Vector Space Systems for 21 launches beginning in 2018. Financial terms of the contract were not publicly released, but the contract is estimated to have a value of about $60M.

Two successful suborbital flight tests of the Vector R have taken place, both during 2017.

Launch Service Provider
Vector

Organization Headquarters
USA

Manufacturer
Vector

Mass, kg (lb)
6,000 (13,228)

Length, m (ft)
12 (39.4)

Diameter, m (ft)
1.2 (3.9)

Year of Planned First Launch
2018

Launch Sites
CCAFS (LC-46)
PSCA

LEO Capacity, kg (lb)
66 (146)

SSO Capacity, kg (lb)
40 (88)

Estimated Price per Launch
$1.5M

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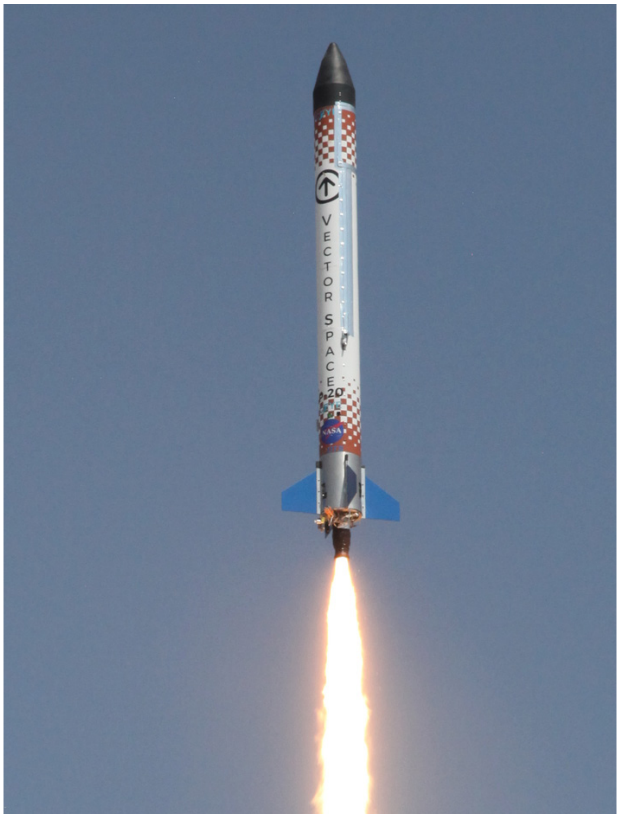
Launch Vehicle Fact Sheet

Vector R (Rapide)



Vector Space Systems tests a 3.7-meter (12-foot) prototype vehicle. Source: Vector Space Systems.

Fairing	Length, m (ft)	Diameter, m (ft)
Basic Fairing	0.7 (2.4)	0.64 (2.1)
Optional Expanded Fairing	1.2 (3.9)	0.64 (2.1)

	1st Stage	2nd Stage	3rd Stage Option
Stage designation	1st Stage	2nd Stage	EUS
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	1.1 (3.6)	1.1 (3.6)	< 1.1 (3.6)
Manufacturer	Vector	Vector	Vector
Propellant	LOX/Propylene	LOX/Propylene	
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	75 (16,861)	4.1 (922)	Undisclosed
Engine(s)	3 x TBD	1 x TBD	1 x TBD
Engine manufacturer	Vector	Vector	Vector
Engine thrust, kN (lbf)	25 (5,620)	4.1 (922)	Undisclosed

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Launch Vehicle Fact Sheet

Vega

The Vega launch vehicle, named after the second brightest star in the northern hemisphere, is operated by Arianespace and targets payloads to polar and low Earth orbits used by scientific and Earth observation satellites. It is manufactured by ELV SpA, a joint venture between Italy-based Avio SpA and the Italian Space Agency (ISA).

Development of the Vega began in 2003 led by the European Space Agency (ESA) with contributions from ISA, the French space agency CNES, and Avio SpA.

The Vega consists of four stages: a first stage P80 solid motor, a second stage Zefiro-23 solid motor, a third stage Zefiro-9 solid motor, and a liquid-fueled fourth stage called the Attitude and Vernier Upper Module (AVUM). The AVUM, powered by the RD-869, is produced by Yuzhnoye in the Ukraine. The payload adapter is affixed to the fourth stage and covered in a fairing during launch.

In December 2014, the European Space Agency agreed to pursue a replacement for the first stage called P120C, which will power an upgraded vehicle called Vega-C. As part of this objective, in 2017 ELV SpA, ESA, and Thales Alenia Space signed a contract designed to lower the Vega cost and offer regular ride-share opportunities for owners of small satellites. A second contract was also signed to pursue a third version of Vega called Vega-E, which would be operational by around 2024. It is expected to be more powerful be even less expensive than the Vega-C.

The P120C will also serve as a strap-on booster for the Ariane 6 vehicle expected to be introduced in 2020. The inaugural flight of the Vega-C is planned for 2018.

Launch Service Provider
Arianespace

Organization Headquarters
France

Manufacturer
ELV SpA

Mass, kg (lb)
133,770 (294,912)

Length, m (ft)
29.9 (98.1)

Diameter, m (ft)
3 (9.8)

Year of First Launch
2012

Number of Orbital Launches
10

Reliability
100%

Launch Site
Guiana Space Center (ZLA)

LEO Capacity, kg (lb)
1,963 (4,328)

SSO Capacity, kg (lb)
1,430 (3,153)

Estimated Price per Launch
$37M

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Launch Vehicle Fact Sheet

Vega

The second Vega mission, carrying the European Space Agency's (ESA) Proba-V and Vietnam's VNREDSat-1A, is prepared for launch from the Guiana Space Center in 2013. (Source: Arianespace)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	7.9 (25.9)	2.6 (8.5)

	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	P80FW	Zefiro 23	Zefiro 9	AVUM
Length, m (ft)	11.2 (36.7)	8.4 (27.6)	4.1 (13.5)	2 (6.6)
Diameter, m (ft)	3 (9.8)	1.9 (6.2)	1.9 (6.2)	2.2 (7.2)
Manufacturer	Europropulsion	Avio	Avio	Avio
Propellant	Solid	Solid	Solid	N_2O_4 (UDMH)
Propellant mass, kg (lb)	88,365 (194,811)	23,906 (52,704)	10,115 (22,300)	367 (809)
Total thrust, kN (lbf)	2,261 (508,293)	1,196 (268,871)	225 (50,582)	2.5 (562)
Engine(s)	—	—	—	1 x RD-869
Engine manufacturer	—	—	—	Yuzhnoye
Engine thrust, kN (lbf)	—	—	—	2.5 (562)

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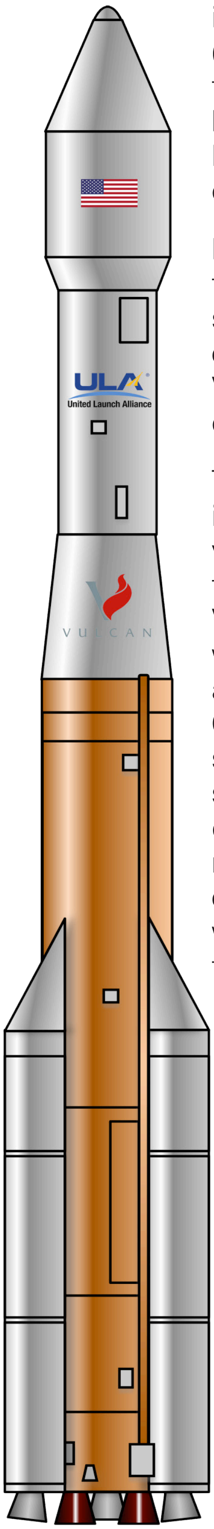
Launch Vehicle Fact Sheet
Vulcan



The Vulcan family of launch vehicles was introduced by United Launch Alliance (ULA) in 2015 as an eventual replacement for the company's Atlas V and Delta IV. Formerly called the Next Generation Launch System (NGLS), the vehicle is expected to be introduced in 2020.

Leveraging technologies and processes from the Atlas V and Delta IV programs since 2002, and even earlier in terms of reach and development time, the Vulcan will nevertheless feature greater capability.

The development strategy will take place in phases. First, the Delta IV Medium vehicle will be retired in 2019, except for the Delta IV Heavy. The first launch of Vulcan Centaur is expected in 2020 and will fly concurrently with the Atlas V for an undisclosed period of time. Vulcan Centaur consists of single booster stage, the high-energy Centaur second stage, and either a 4-meter or 5-meter-diameter payload fairing. Up to four solid rocket boosters (SRBs) augment the lift off power of the 4-meter configuration, while up to six SRBs can be added to the 5-meter.

In step two, further upgrades to the Centaur upper stage will dramatically increase the vehicle's capacity to orbit, exceeding the current capability of the Delta IV Heavy. The Delta IV Heavy and the Atlas V will be retired following successfully deployment of this variant of the Vulcan Centaur system.

Separately, ULA is developing the Advanced Cryogenic Evolved Stage (ACES) upper stage. A derivative of the Centaur upper stage, ACES will be refuelable. This will allow the stage to be reused in space, enabling long-duration missions not currently possible.

Launch Service Provider
ULA

Organization Headquarters
USA

Manufacturer
ULA

Mass, kg (lb)
432,000-1,280,000
(952,397-2,821,917) *est*

Length, m (ft)
58.3-69.5 (191-228)

Diameter, m (ft)
3.8-5.4 (12.5-17.7)

Year of Planned First Launch
2020

Launch Sites
CCAFS (SLC-41)
VAFB (SLC-3E)

GTO Capacity, kg (lb)
4,750-16,300 (10,500-35,900)

LEO Capacity, kg (lb)
9,400-31,400 (20,700-69,300)

SSO Capacity, kg (lb)
7,700-27,900 (17,000-61,500)

Estimated Price per Launch
Undisclosed

The ACES upper stage is currently under development. The final design and selection of an engine provider has not yet been decided.

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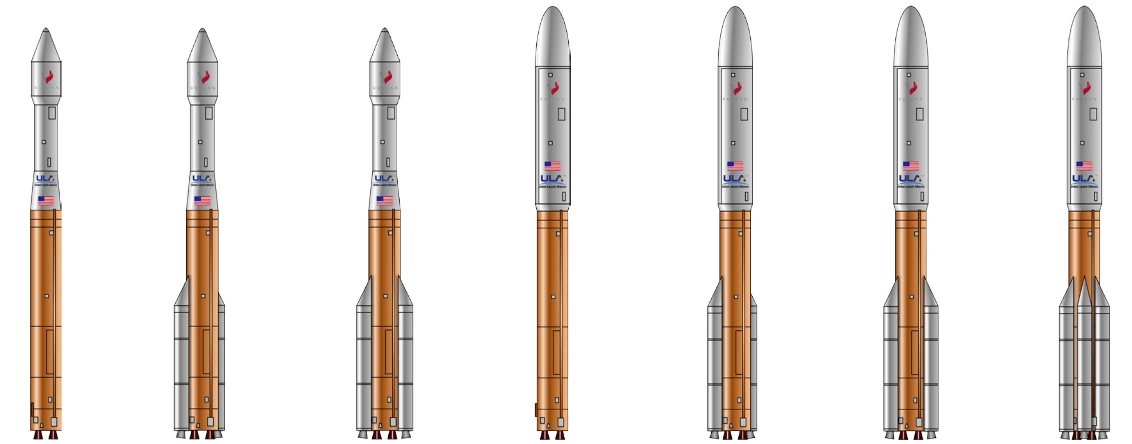
Launch Vehicle Fact Sheet

Vulcan



Vulcan 401 | Vulcan 421 | Vulcan 441 | Vulcan 501 | Vulcan 521 | Vulcan 541 | Vulcan 561

The Vulcan will feature a core stage and a combination of up to six solid rocket boosters, two Centaur upper stage options (and later ACES), and a 4- or 5-meter fairing. There will be three versions of the 400 series and four versions of the 500 series.

Fairing	Length, m (ft)	Diameter, m (ft)
4m Large Payload Fairing	12 (39.3)	4 (13)
4m Extended Payload Fairing	12.9 (42.3)	4 (13)
4m Extra Extended Payload Fairing	13.8 (45.3)	4 (13)
5m Short Fairing	15.5 (51)	5.4 (17.7)
5m Long Fairing	21.3 (70)	5.4 (17.7)

	SRB*	1st Stage	2nd Stage Option	2nd Stage Option	2nd Stage Option
Stage designation	GEM-63XL	1st Stage	Single Engine Centaur	Dual Engine Centaur	Upgraded Centaur
Length, m (ft)	21.9 (71.8)	33.3 (109.2)	12.7 (41.7)	11.6 (38) *est*	TBD
Diameter, m (ft)	1.6 (5.3)	5.4 (17.7)	3.1 (10.2)	5.4 (17.7)	5.4 (17.7)
Manufacturer	Orbital ATK	ULA	ULA	ULA	ULA
Propellant	Solid	LOX/CH_4	LOX/LH_2	LOX/LH_2	LOX/H_2
Propellant mass, kg (lb)	48,000 (105,900)	368,000 (811,301) *est*	20,830 (45,922)	54,431 (120,000)	77,111 (170,000) *est*
Total thrust, kN (lbf)	2,000 (450,000)	4,800 (1,079,083)	101.8 (22,890)	204 (45,860) *est*	TBD
Engine(s)	—	TBD	1 x RL10C	TBD	TBD
Engine manufacturer	—	TBD	Aerojet Rocketdyne	TBD	TBD
Engine thrust, kN (lbf)	—	TBD	101.8 (22,890)	TBD	TBD

** Figures are for each booster. Propellant mass and total thrust is sum of all boosters.*

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Launch Vehicle Fact Sheet

XS-1

In 2013, the Defense Advanced Research Projects Agency (DARPA) announced it is pursuing development of a reusable spaceplan concept called Experimental Spaceplane-1 (XS-1). The primary objective of this program is to produce a vehicle capable of sending 2,267 kg to low Earth orbit (LEO). The XS-1 is being designed to handle a launch rate of 10 missions within ten days, with each launch costing about $5M.

DARPA selected three teams in 2014 to compete for the final development and manufacturing contract. The teams included Northrop Grumman (with Scaled Composites and Virgin Galactic), Masten Space Systems (with XCOR Aerospace, which has since filed for bankruptcy), and Boeing (with Blue Origin). In August 2015, each company was awarded $6.5M under what is called Phase 1, in which XS-1 designs are matured further to include demonstration tasks. Completion of these tasks is expected in 2016. DARPA plans to select one of the three teams to move on to Phase 2 in 2017.

Initial flights of the XS-1 are expected to take place in 2019-2020.

Launch Service Provider
DARPA

Organization Headquarters
USA

Manufacturer
TBD

Mass, kg (lb)
TBD

Length, m (ft)
TBD

Diameter, m (ft)
TBD

Year of Planned First Launch
2019-2020

Launch Sites
TBD

LEO Capacity, kg (lb)
1,361 (3,000)

SSO Capacity, kg (lb)
TBD

Estimated Price per Launch
$5M

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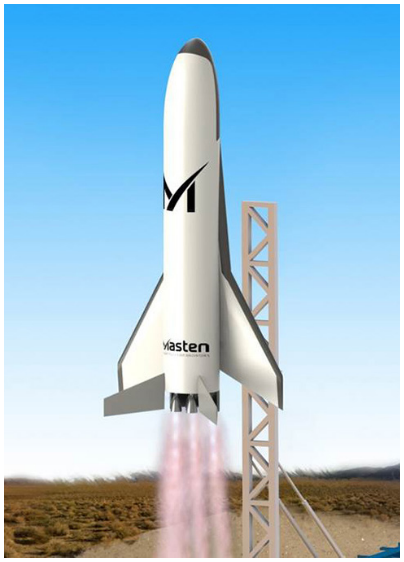
Launch Vehicle Fact Sheet

XS-1



Masten Space Systems has been working on vertical takeoff, vertical landing (VTVL) technologies for about a decade. This effort has lead to the development of several test vehicles, including Xombie, Xoie, and Xaero. On several occassions, these systems have met DARPA's 10 flights within 10 days objective. Masten is developing the XS-1 design, including guidance, navigation, and control (GNC) systems. It's partner XCOR Aerospace, now defunct, was focusing on propulsion. (Source: Masten Space Systems)

Northrop Grumman's subsidiary, Scaled Composites, is developing this team's XS-1 concept. The concept includes a clean-pad approach using a transporter erector launcher with minimal infrastructure and ground crews, highly autonomous flight operations, and horizontal landing and recovery on standard runways. Virgin Galactic would manage operational missions. (Source: Northrop Grumman)

Boeing is the lead on the development of this team's XS-1 concept. Boeing is leveraging its extensive spaceflight experience, perhaps with emphasis on its X-37B spaceplane, which is owned and operated by the U.S. Air Force. Its concept is to deploy the XS-1 via an aircraft. The spaceplane would then deploy the payload and return to Earth as an airplane. Blue Origin is focusing on the propulsion system. (Source: Boeing)

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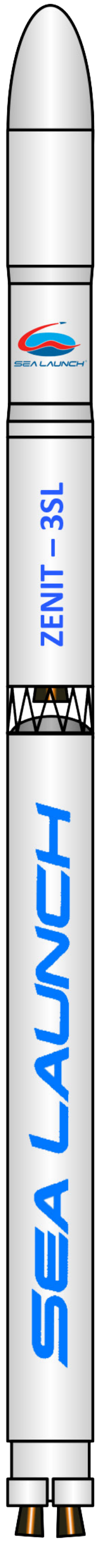
Launch Vehicle Fact Sheet

Zenit



The Zenit 3SL can be traced to the 1980s when the Soviet government pursued a system that could be used as both a booster for the Energia launch vehicle and as a stand-alone vehicle. The first-generation Zenit 2 was introduced in 1985 and has been launched 37 times. The Zenit 3SL represents a second generation vehicle. It is provided by Sea Launch, a conglomerate entity with four major component providers: RSC Energia, PA Yuzhmash/Yuzhnoye, Aker Solutions, and Boeing.

The Zenit 3SL is a three-stage vehicle. Yuzhnoye provides both the first and second stages, which are powered by the RD-171M and the RD-120 engines, respectively. A specially modified Block-DM third stage is supplied by S.P. Korolev Rocket and Space Corporation Energia (RKK Energia). Boeing provides the payload fairing.

The Zenit 3SLB is a modernized version of the earlier generation of the two-stage Zenit featuring a Block-DM third stage, but marketed by Land Launch, a subsidiary of Sea Launch. Land Launch also includes the Zenit 2SLB, which is essentially the same as the Zenit 3SLB but without a third stage.

Due to increasing political tensions between Russia and Ukraine during 2014, and the resulting international sanctions against Russia, PA Yushmash, a key supplier of missiles and other hardware to the Russian military, has experienced considerable financial difficulties that may impact its product line.

Launch Service Provider
VKS/Sea Launch AG

Organization Headquarters
Russia

Manufacturer
PA Yuzhmash

Mass, kg (lb)
470,000 (1,036,173)

Length, m (ft)
59 (193.6)

Diameter, m (ft)
3.9 (12.8)

Year of First Launch
1985

Number of Orbital Launches
84

Reliability
88%

Launch Sites
3SL: Pacific Ocean/*Odyssey*
2/3F/3SLB: Baikonur (LC-45/1)

GTO Capacity, kg (lb)
3SL: 6,160 (13,580)
3SLB: 3,750 (8,267)

Estimated Price per Launch
$85M-$95M

Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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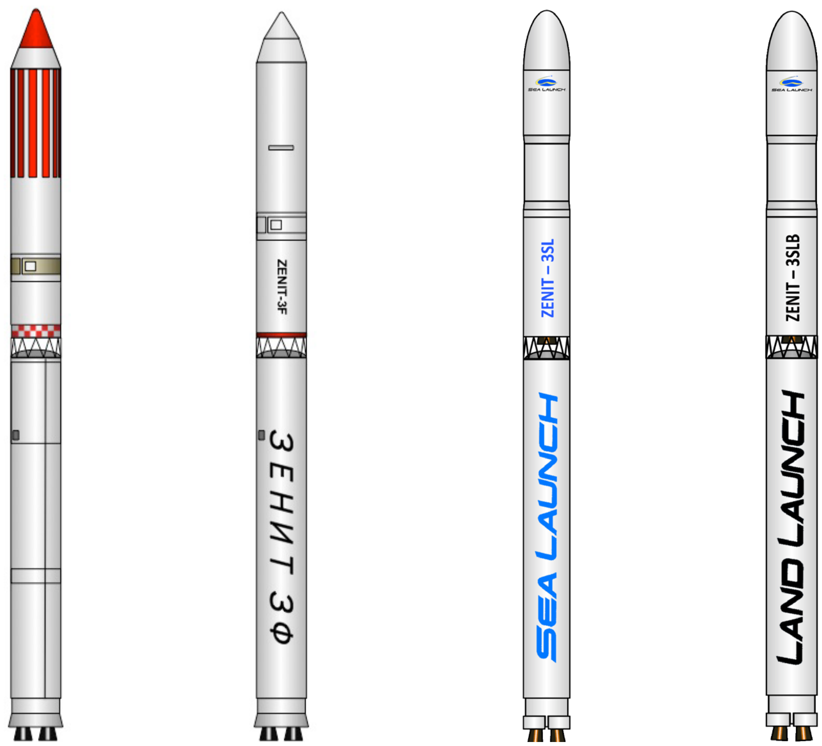
Launch Vehicle Fact Sheet
Zenit

FAA AST



Zenit 2 | Zenit 3F | Zenit 3SL | Zenit 3SLB

The Zenit 3SL and Zenit 3SLB are provided commercially. The Zenit 2 was used for government missions, and has since retired. The Zenit 3F was used for a short period of time for government missions beginning in 2011.

The Zenit vehicles, which are built in Ukraine, appear unlikely to fly again.

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	11.4 (37.4)	3.9 (12.8)

	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	Block DM-SL
Length, m (ft)	32.9 (108)	10.4 (34)	4.9 (16.1)
Diameter, m (ft)	3.9 (12.8)	3.9 (12.8)	3.7 (12.1)
Manufacturer	Yuzhnoye	Yuzhnoye	RSC Energia
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	322,280 (710,505)	81,740 (180,205)	15,850 (34,943)
Total thrust, kN (lbf)	7,256 (1,631,421)	992 (223,026)	79.5 (17,864)
Engine(s)	1 x RD-171M	1 x RD-120 1 x RD-8	1 x 11D58M
Engine manufacturer	NPO Energomash	NPO Energomash	RSC Energia
Engine thrust, kN (lbf)	7,117 (1,631,421)	RD-120: 912 (205,026) RD-8: 80 (18,000)	79.5 (17,864)

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