Federal Aviation Administration

The Annual Compendium of Commercial Space Transportation: 2017

January 2017

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

Cover art: Phil Smith, The Tauri Group (2017)

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

Revised August 2017

NOTICE

GENERAL CONTENTS

DETAILED CONTENTS

EXECUTIVE SUMMARY

The size of the global space industry, which combines satellite services and ground equipment, government space budgets, and global navigation satellite services (GNSS) equipment, is estimated to be about $335 billion. At $98 billion in revenues, or about 29 percent, satellite television represents the largest segment of activity. Following satellite television are services enabled by global navigation satellite systems (GNSS), which represent about $81 billion in revenues, or 24 percent. Government space budgets represent $77 billion, or 23 percent. Other satellite services (fixed and mobile satellite services, broadband, and remote sensing) generated about $30 billion in revenues, and ground equipment represents $28 billion in revenues. Satellite manufacturing generated nearly $17 billion.

All of this activity would not be possible without orbital launch services. Global launch services is estimated to account for $5.4 billion of the $335 billion total, or only about 2 percent. Most of this launch activity is captive; that is, the majority of payload operators have existing agreements with launch service providers or do not otherwise “shop around” for a launch. About a third of the $5.4 billion represents internationally competed, or commercial, transactions.

An Orbital ATK Antares is prepared for the OA 5 cargo mission to the International Space Station (ISS). (Source: NASA/Bill Ingalls)

In 2016, service providers conducted a total of 85 orbital launches in seven countries. While this figure is elaborated upon in greater detail later in this report, there are some interesting events worthy of noting here. 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 and Falcon Heavy vehicles to the global market at low prices, is attracting significant business. In addition, launch failures, quality control problems, and supply chain issues have plagued the Russian space industry, leading some customers to seek alternatives like SpaceX. Meanwhile, Europe’s Arianespace remains a steadfast provider, offering reliable 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 PSLV vehicles, respectively.

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.

Perhaps the most notable in terms of government launch activity is China. The number of orbital launches conducted by China has steadily increased each year since 2010, with a peak of 22 launches in 2016. The China Great Wall Industry Corporation (CGWIC) has also been aggressively pursuing international clients via package deals that include satellite manufacturing and launch. These launches are not considered commercial since the launch contract is not internationally competed. In 2015, China introduced two new small-class launch vehicles, the Long March 6 and the Long March 11. In 2016, China successfully launched the Long March 5 and Long March 7, both of which were launched from a new launch site on Hainan Island. Finally, China's human spaceflight program continues in a deliberate fashion, with the 2016 launch of its Tiangong 2 space station. 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.

Rocket Lab's Electron is prepared for launch in 2017. (Source: Rocket Lab)

Meanwhile, the commercial launch pie has not grown significantly during the past decade; instead, the slices of the pie have changed size. Yet, there are signs the commercial launch pie may be expanding. 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. Consequently, 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 are in advanced stages of development, like the Electron by

Rocket Lab and LauncherOne from Virgin Galactic, with some expected to start launching payloads in 2017 and 2018. There are almost 50 proposed small launch vehicles being developed worldwide, though most are in conceptual stages.

Two launch failures occurred in 2016. In August, a Long March 4C carrying a government-owned meteorological satellite called Gaofen 10 was destroyed late in the launch trajectory. The second launch failure took place in December, when a Soyuz U failed to deliver Progress MS-4 to the ISS. Only one Soyuz U remains to be launched; all further flights will take place using the upgraded Soyuz 2, which has been commercially available since 2004.

There were some notable activities in 2016 relating to suborbital reusable vehicles. Blue Origin's New Shepard vehicle successfully flew four times, launching from the company's site in western Texas. The fourth flight, which took place on October 5, 2016, featured a test of a capsule abort and separation, and both the capsule and the booster returned to the site intact. Virgin Galactic resumed glide tests of its second SpaceShipTwo vehicle. The company received a licence from AST in July 2016 and is planning to conduct powered flights in 2017.

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 on both the orbital and suborbital front, with orbital test flights of commercial orbital and suborbital vehicles expected to begin taking place in 2017.

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 ensure public health and safety 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 as the FAA's only space-related line of business. FAA AST was established to:

- Regulate 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.

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

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 licensed over 230 launches. 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 space transportation industry.

General Description

The body of the document is composed of three parts, supplemented by introductory matter and appendices. The first part provides narrative detail on the space transportation industry, covering topics such as launch vehicles, payloads, and launch and reentry sites. The second part summarizes worldwide space activities during the previous calendar year and integrates this review with space transportation activities that have taken place during the past five years. The third part covers policies and regulations relevant to commercial space transportation. In addition, the third part also highlights activities conducted by the Commercial Space Transportation Advisory Committee (COMSTAC) during the previous calendar year. Future editions of the Compendium will include a fourth part capturing the annually updated 10-year commercial space transportation forecast.

The appendices include definitions and acronyms, a list of tables and figures, 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.

Compendium and Supplemental Fact Sheets

To maintain clarity, a good deal of technical information is omitted from the body of the Compendium and carried over into fact sheets. These fact sheets, which are included in the Compendium Appendix and provided on the FAA AST website, relate to major sections of the Compendium, as shown by Figure 1. While the Compendium is updated annually and provides context, the fact sheets are designed to be updated as necessary to reflect real world developments.

Future editions will include fact sheets on policy and regulations, as well as a section and supporting fact sheets on the annual 10-year commercial space transportation forecast.

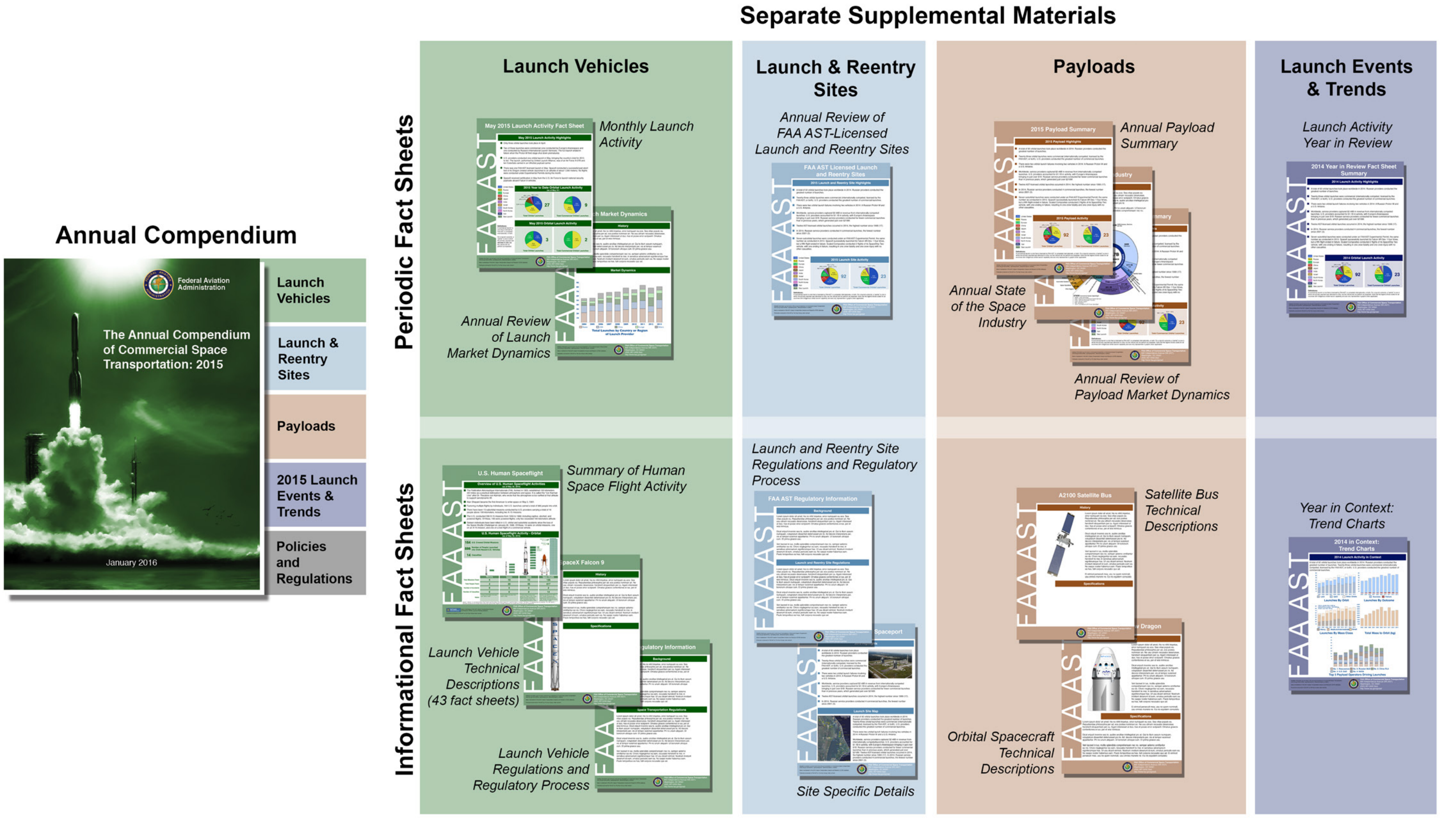


Figure 1. The general structure of the Annual Compendium and its various supporting fact sheets. The fact sheets represented in the graphic are for illustration only.

An Atlas V 421 vehicle carrying Mexico's Morelos 3 satellite is prepared for launch from Cape Canaveral Air Force Station (CCAFS). Source: ULA.

THE SPACE TRANSPORTATION INDUSTRY

At $5.4B in revenues in 2015, the global space transportation industry is a relatively small part of the overall $335B global space industry. 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

For context, the global space industry is estimated to have been $335B in 2015. About $208B (62%) 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 $127B (38%) constitutes government space budgets and global navigation satellite system (GNSS) chipsets and services.

The U.S. space industry was approximately $126B in 2015. This figure includes $89B in revenues generated by satellite services, satellite manufacturing, satellite ground equipment, and launch services, as well as $37B spent on space programs by the U.S. government. U.S. launch service providers accounted for about $1.8B in total revenues or 34% of global launch services. FAA AST-licensed launches accounted for $839M of the $1.8B.

LAUNCH VEHICLES

The story of space transportation reaches back 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. In 1903, Russian mathematician, Konstantin Tsiolkovsky, published details on his plans for a multi-stage, liquid-fueled rocket. 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 nascent 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 cash-strapped

[1] $5.4B is an estimate that includes all orbital launch contracts in which financial transaction occurred between two or more organizations and revenue estimates for all launches licensed by FAA AST. For example, payload operators typically acquire launches through another organization. The Indian Space Research Organization (ISRO) is an obvious exception, because payloads are built, operated, and launched by ISRO itself. Of the $5.4B, approximately $1.9B was revenue generated by internationally competed launches, in which a customer “shopped around” for a launch. Sources: 2015 State of the Satellite Industry (Satellite Industry Association), The Tauri Group, and publicly available data.

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 large 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. By 2015, the world was launching between 70 and 100 rockets into orbit annually.

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.

Rocket engines are generally grouped according to the type of propellant being used: solid or liquid. There are also examples of hybrid engines that feature both solid and liquid propellants.

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 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.

Solid Motors

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

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

- 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 37 inches (94 centimeters). 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 40-inch 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-centimeter (62-inch) diameter boosters burn HTPB. One 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.


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)

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 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.


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

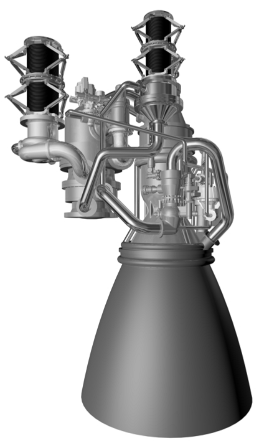
Liquid rocket engines are complex and expensive for a variety of reasons. Often, the propellants used are cryogenic, meaning the liquid is several hundred degrees below zero celsius. The engine can be throttled, necessitating an engine controller and associated hardware. These rocket engines can use 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

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

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.

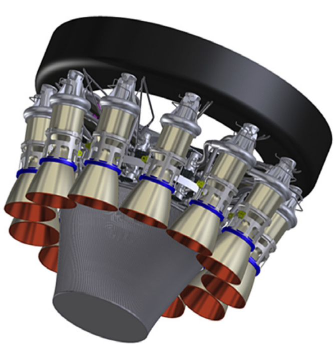
The following liquid rocket engines are used in currently available U.S. launch vehicles. Also included are engines designated for use on vehicles under development.

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

- FRE-1 and FRE-2: Firefly Space has developed the FRE line of engines to power the first and second stages of its Alpha launch vehicle. The FRE-2 is an aerospike engine that, if successful, may prove to be the first aerospike engine employed in an operational launch system. An aerospike does not feature a traditional bell-shaped nozzle, which reduces weight but also reduces exhaust pressure (specific impulse). Aerodynamic design is used to counter this loss of pressure and increase efficiency. The engine burns LOX and kerosene to produce a thrust of about 443 kN (99,600 lbf). The FRE-1 is a conventional nozzle engine burning the same propellant mixture to produce 28 kN (6,200 lbf) of thrust.

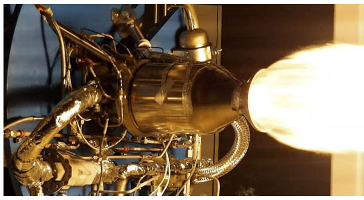


The FRE-2 aerospike engine (Firefly Space Systems)

- 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 v1.1 vehicle. The more powerful Falcon 9 Full Thrust (Falcon 9 FT) will feature a higher thrust capability, giving the vehicle a 30 percent increase in performance from the Falcon 9 v1.1. This upgraded vehicle was introduced in late 2015.

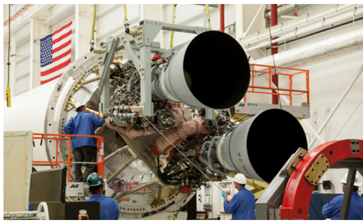
- Newton: The Newton series of engines being developed by Virgin Galactic will power the company's air-launched LauncherOne vehicle. These engines use LOX and kerosene as propellants. The NewtonThree, which produces 327 kN (73,500 lbf) of thrust, will power the LauncherOne first stage. A NewtonFour engine, producing 22 kN (5,000 lbf) of thrust, will power the second stage to orbit. First flight of LauncherOne is expected in 2017.
- 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-25E: The RS-25E, built by Aerojet Rocketdyne, is an expendable version of the RS-25, 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

A Merlin-1D engine (SpaceX)

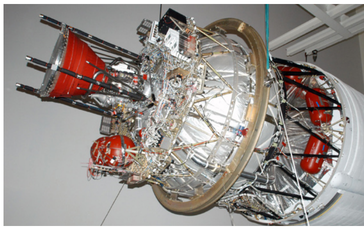


A NewtonOne engine undergoing a test (Virgin Galactic)

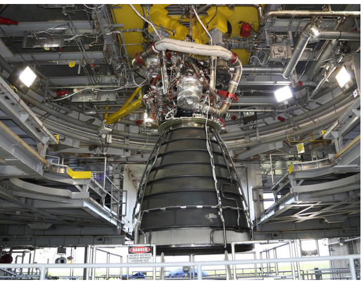
An RD-180 engine installed ont he first stage of an Atlas V (ULA)



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



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

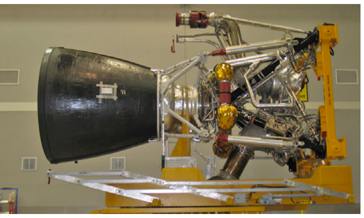


An RS-25 being prepared for a test firing (Aerojet Rocketdyne)

System (STS) Program have been refurbished and stored for use on four SLS missions, which begin in late 2018. The RS-25E will be used on subsequent SLS vehicles. Each RS-25E 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 RS-25E designed to increase performance while at the same time reduce the per-unit cost.

- 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.
- XR Series: XCOR Aerospace has been developing engines since 2000, when the company fully integrated the XR-3A2 and XR-4A3 into an EZ-Rocket test aircraft. Currently, XCOR is developing the XR-5K18 engine for the company's Lynx suborbital vehicle. The XR-5K18 burns a LOX and kerosene propellant mixture, producing a thrust of about 13 kN (2,900 lbf). The Lynx will be powered by four XR-5K18 engines. The company is a partner with ULA on the development of a LOX-liquid hydrogen upper stage engine, capable of producing up to 130 kN (30,000 lbf) of thrust. This effort leverages technologies developed for the XR-5K18.

An RS-27A undergoing ground testing (ULA)



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

The Rutherford engine (Rocket Lab)

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 XR-5K18 being test fired (XCOR Aerospace)

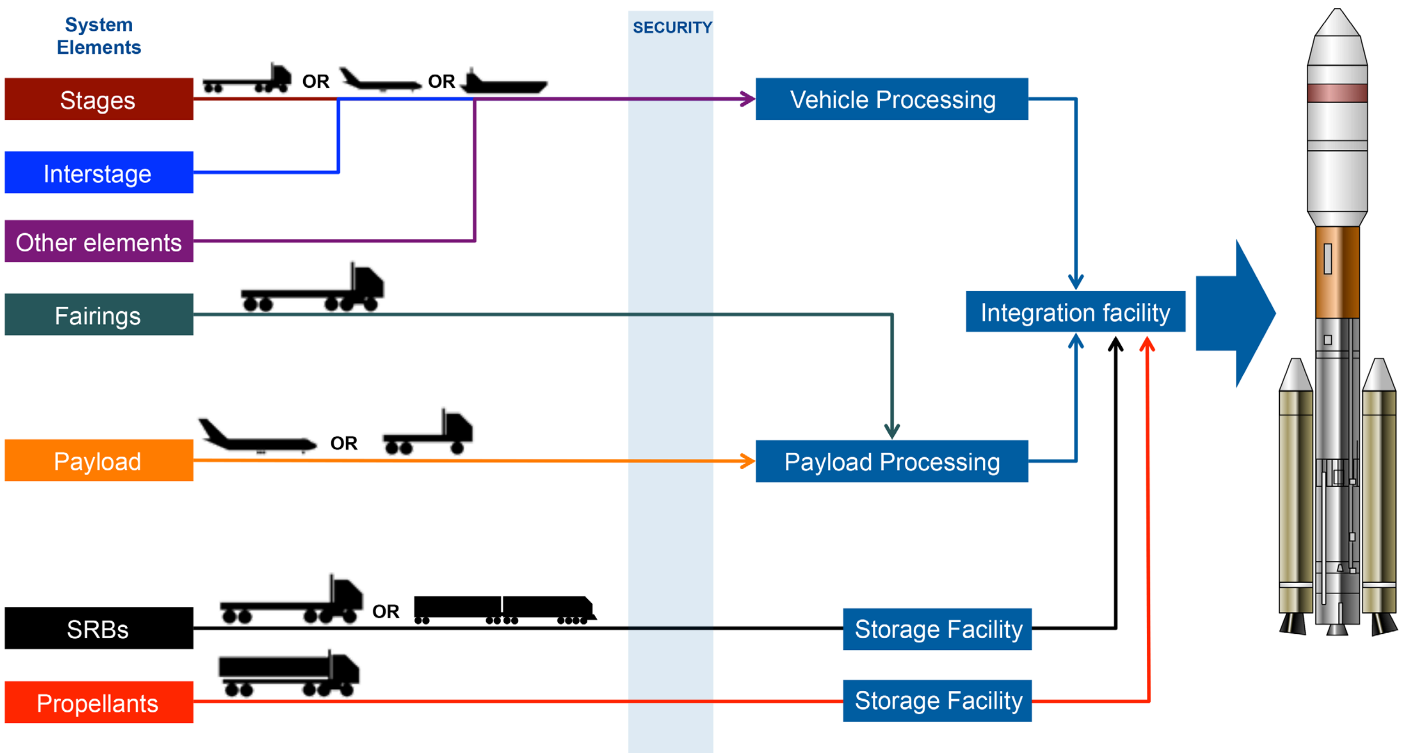


Figure 2. A typical launch vehicle integration and processing scheme.

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 handled by a launch range, which is tasked with ensuring that the launch is conducted efficiently and safely. Typically, the range arranges for the the appropriate control or warnings necessary to protect aircraft, waterborne 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 2016, there were 82 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.

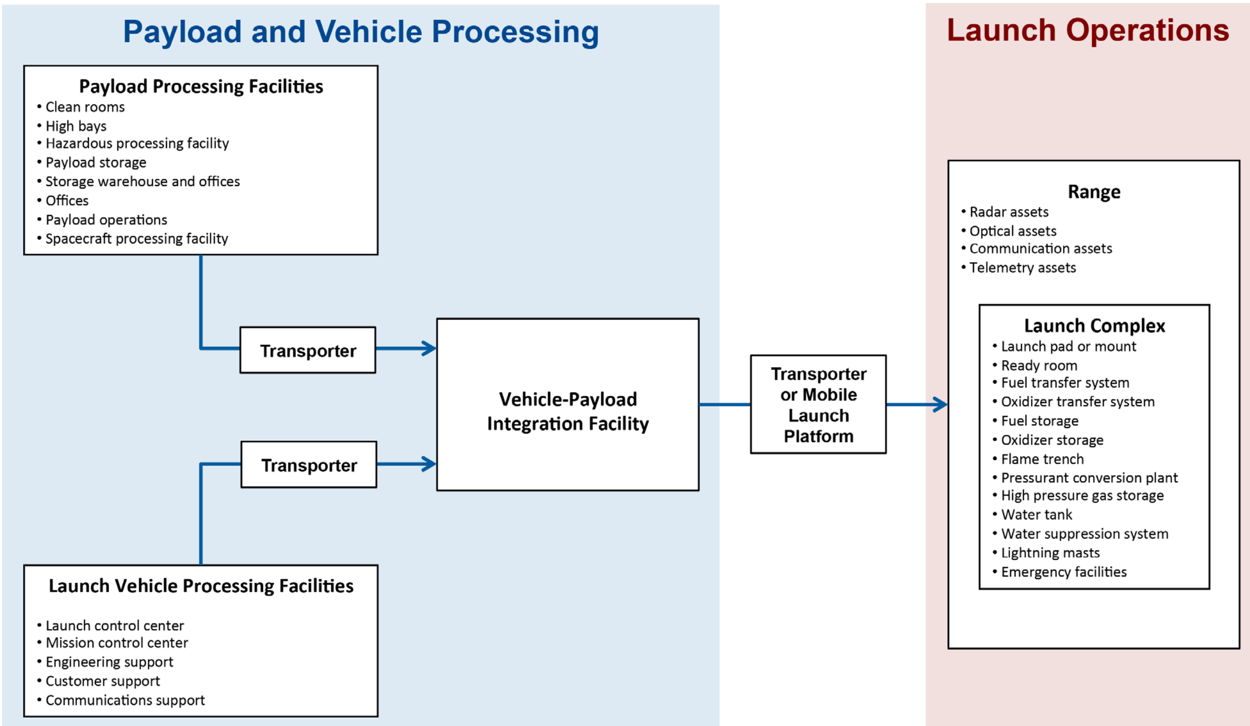


Figure 3. A typical arrangement for a launch site and range.

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 two more times (JPSS-1 and 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, Delta IV, and future Vulcan vehicles for international competition. Another U.S. vehicle, the Super Strypi, developed and built by the University of Hawaii (UH), Sandia National Laboratory, and Aerojet Rocketdyne, was launched for the first time in 2015; however, the vehicle was destroyed shortly after launch. The availability of this vehicle for commercial use in the future remains uncertain.

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, Generation Orbit'a GOLauncher-2, 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 15 expendable launch vehicle types available for commercial use outside the United States: Angara, Ariane 5, Dnepr, GSLV, H-IIA/B, Kuaizhou 1 and 11, Long March 2D, Long March 3A, Long March 3B, Proton M, PSLV, Rockot, Soyuz 2, and Vega.

Vehicle	Operator	Year of First Launch	Total 2016 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	8	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
Delta IV	ULA	2002	4	CCAFS VAFB	9,420-28,790 (20,768-63,471)	7,690-23,560 (16,954-51,941)	3,060-14,220 (6,746-31,350)	$164M-$400M
Falcon 9	SpaceX	2010	8	CCAFS VAFB KSC	13,150 (28,991)	Undisclosed	4,850 (10,692)	$61.2M
Minotaur-C	Orbital ATK	2017	0	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	1	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	TBD	TBD	400 (882)	200 (441)	N/A	$8M
Orbital Launch Vehicle	Blue Origin	2020	CCAFS	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Cab-3A	CubeCab	2017	TBD	5 (11)	Undisclosed	N/A	$250K
Electron	Rocket Lab	2017	PSCA Mahia, NZ	Undisclosed	150 (331)	N/A	$4.9M
Falcon Heavy	SpaceX	2017	KSC VAFB	53,000 (116,845)	Undisclosed	21,200 (46,738)	$270M
LauncherOne	Virgin Galactic	2017	Spaceport America	400 (882)	225 (496)	N/A	$10M
Stratolaunch	Stratolaunch Systems	2018	Mojave KSC	3,000 (6,614)	1,400 (3,086)	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 two 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.

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.

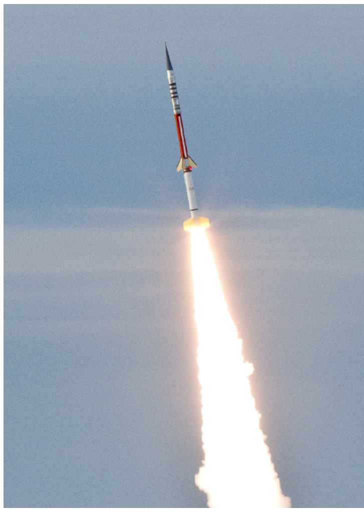
NASA's SRPO conducts sounding rocket launches for NASA, universities, and other customers. Supplied vehicles include Bristol Aerospace's Black Brant series in several vehicle configurations, from a single-stage vehicle to a four-stage vehicle stack (described in a previous section); the Improved Orion; 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 description of major U.S. sounding rockets is provided below:

A Black Brant sounding rocket launched in 2011 (NASA)

- 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, some will carry people, and one (Lynx Mark III) will be able to launch small satellites. 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	Xaero Xombie Xogdor	N/A	12 (26) 20 (44) 25 (55)	TBD	TBD
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*

Recovered Falcon 9 first stage after a drone ship landing following SpaceX launch of JCSAT-14 on May 6, 2016 from Space Launch Complex 40 at Cape Canaveral Air Force Station, Florida. Source: SpaceX.

LAUNCH AND REENTRY SITES

Launch sites are sites 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 site, a launch vehicle travels through an area called the launch range, which typically includes tracking and telemetry assets. These range assets 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 2016, FAA AST 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	2016 FAA AST-Licensed or Permitted Flights
California Spaceport, CA	Harris Corporation	1996	9/19/2021	1
Mid-Atlantic Regional Spaceport, VA	Virginia Commercial Space Flight Authority	1997	12/18/2017	1
Pacific Spaceport Complex Alaska, AK	Alaska Aerospace Corporation	1998	9/23/2018	0
Florida Spaceport, FL	Space Florida	1999	6/30/2020	9
Mojave Air and Space Port, CA	East Kern Airport District	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, nine 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. The Odyssey Launch Platform exclusively supports Sea Launch's Zenit 3SL vehicles on the Central Pacific Ocean. SpaceX conducts flight tests of its Falcon 9R vehicle at its McGregor, Texas site. 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	Orbital	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

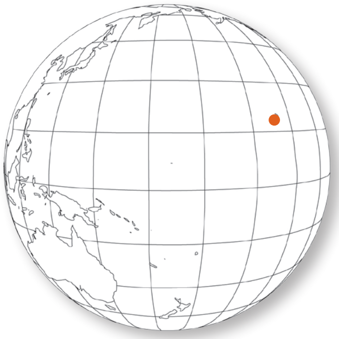
CCAFS is an installation of Air Force Space Command's 45th Space Wing and the primary launch head of America's Eastern Range, with three active launch pads, Space Launch Complexes (SLC) 37, 40, and 41. CCAFS is located on Merritt Island, south of NASA's Kennedy Space Center, and has a 10,000-foot-long 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.

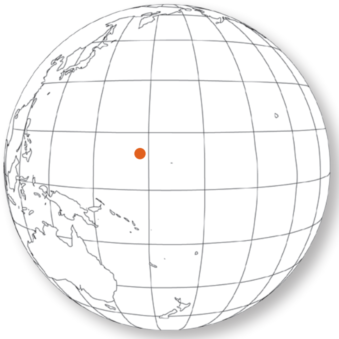
Kennedy Space Center

Kennedy Space Center (KSC) is NASA's Launch Operations Center. KSC supports Launch Complex 39 (LC-39), originally built for the Saturn V, the largest and most powerful operational launch vehicle 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 Launch Complex 39A for the Falcon Heavy, and the company began modifying the facility in 2014. The Falcon Heavy is currently set to launch in 2016. 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 42,000 square miles of controlled airspace, with its base covering nearly 2,400 acres, with a 6,000-foot 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

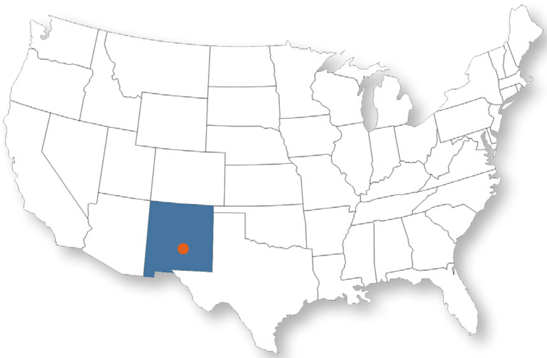
The Ronald Reagan Ballistic Missile Defense Test Site (Reagan Test Site), formerly the Kwajalein Missile Range, is a test range in the Pacific Ocean on the Republic of Marshall Islands (RMI). The Reagan Test Site includes several rocket launch sites spread across the Kwajalein Atoll, Wake Island, and 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 centimeters.

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 100 miles 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.

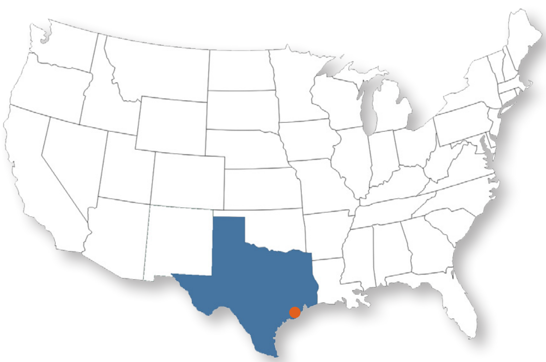
FAA AST-LICENSED SITES

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 53,000-square-foot 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, $60 million 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 August 2014, XCOR Aerospace, which is moving its headquarters from Mojave Air and Space Port to Midland, kicked off construction of its new hangar. The XCOR hangar will become the home of the first XCOR Lynx suborbital spacecraft, XCOR's corporate headquarters, and its research and development facilities. In October 2014, they were followed by Orbital Outfitters, a company that specializes in space suits and space vehicle mockups. Orbital Outfitters has 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 Scaled Composites, XCOR Aerospace, Masten, Orbital ATK, and Interorbital Systems. Companies are currently designing, building, and testing small suborbital reusable vehicles on site.

In October 2014, Virgin Galactic's SpaceShipTwo VSS Enterprise, which was tested at Mojave Air and Space Port, was destroyed shortly after it was launched from the WhiteKnightTwo carrier aircraft. The pilot survived serious injuries and the copilot was killed. The National Transportation Safety Board (NTSB) has performed an investigation of the accident with the support of FAA AST, and it was determined that the crash was caused by co-pilot error.

Oklahoma Spaceport

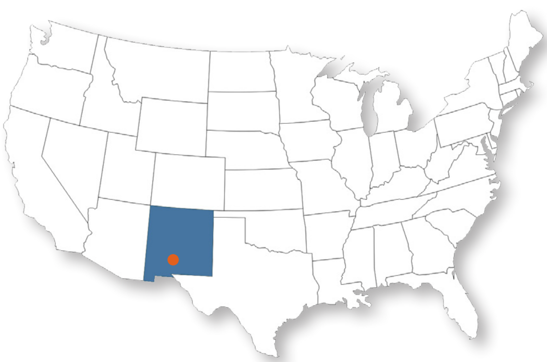
Oklahoma Spaceport is managed by the Oklahoma Space Industry Development Authority (OSIDA), created in 1999, and was granted a license to the site by the FAA in June 2006. The site is located near the community of Burns Flat, Oklahoma and is part of what is also known as the Clinton-Sherman Industrial 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 13,503-foot by 300-foot 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 (PSC) Alaska (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 PSC.



Spaceport America

Spaceport America, formerly the Southwest Regional Airport, 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.

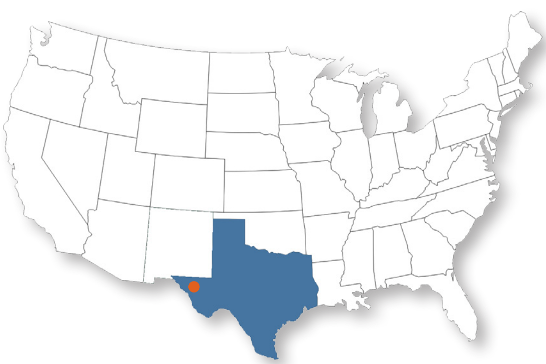
Delays experienced by launch service providers like Virgin Galactic have inspired the New Mexico Spaceport Authority to explore alternative means of generating revenue at the spaceport until flight operations begin. Negotiations with several potential tenants took place in 2014. The Spaceport hired a 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 $209 million. 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.

SpaceX signed a three-year lease with Spaceport America in 2013 and to date has spent over $2 million in infrastructure improvements. SpaceX hopes to use the site to launch, recover, and reuse its Falcon 9 v1.1 booster. Thus far, several tests have been performed in preparation for launch and recovery. SpaceX successfully tested flyback and landing of an operational Falcon 9 first stage in December 2015. The vehicle was used to deploy 11 ORBCOMM satellites.

NON-LICENSED U.S. SITES

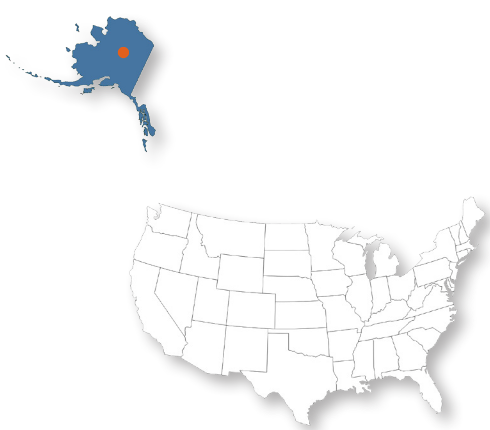
SpaceX McGregor Rocket Development and Test Facility

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 high-altitude, high-velocity 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. The facility is currently permitted by FAA AST for flights up to a maximum altitude of 66 miles, with no more than one flight per week.



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 three primary 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; and Dombarovsky Air Base near the western Kazakh border. 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. The Russian government is also completing construction of a new site in the eastern part of the country called Vostochny Cosmodrome. This site, which is expected to launch Soyuz and possibly Angara vehicles, was inaugurated in 2016.

China is home to three 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 Chinese government is building a site on Hainan Island called Wencheng Satellite Launch Center; the first orbital launch from this site took place in 2016.

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, provided by Arianespace.

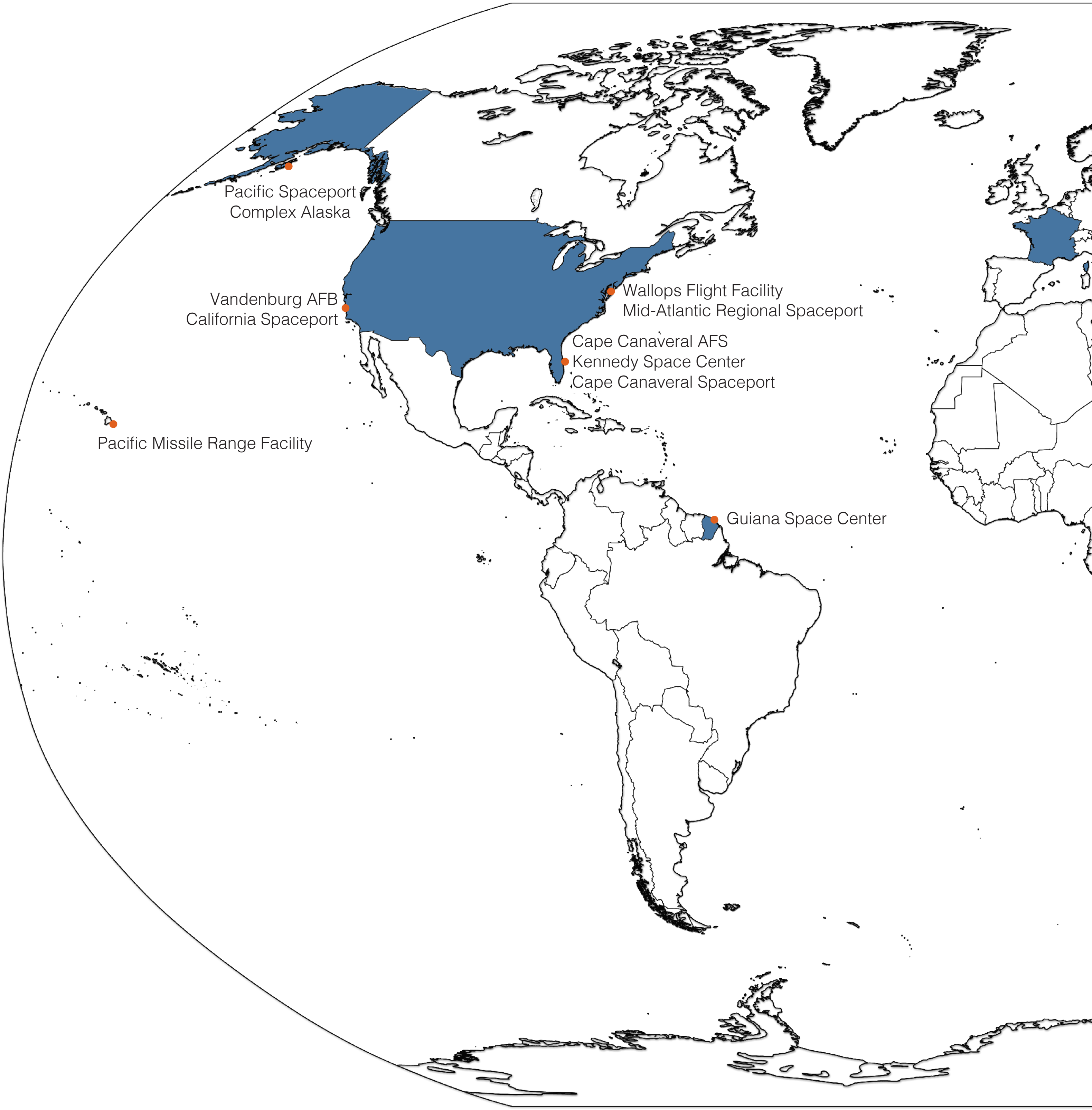
Japan has two active launch sites: The Tanegashima Space Center and the Uchinoura Space Center. The Tanegashima Space Center is the larger of the two and where the H-IIA and H-IIB vehicles are launched. Previously known as Kagoshima Space Center, the Uchinoura Space Center is the launch site for the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

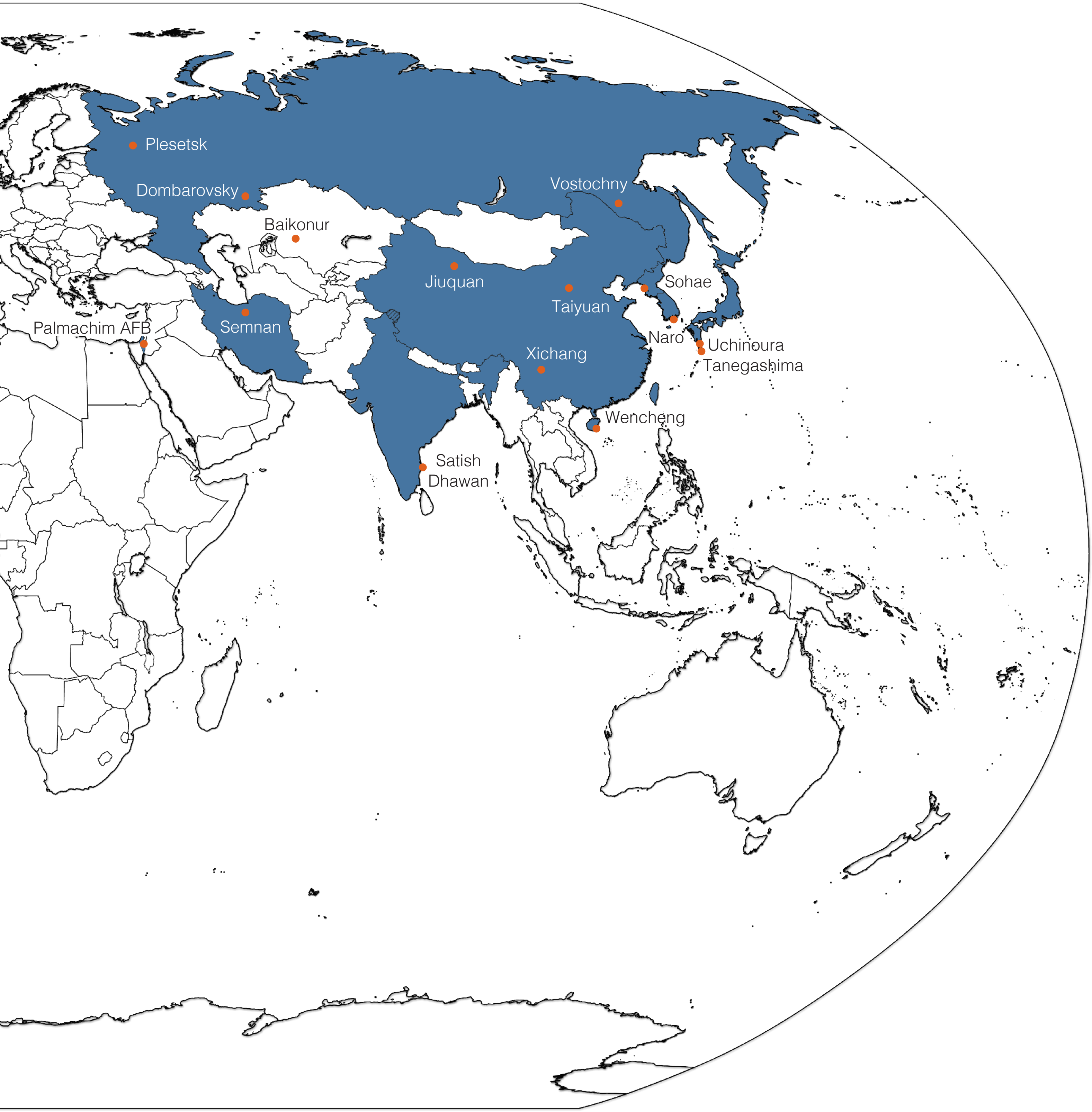
The Indian Space Research Organization (ISRO) operates India's sole launch site, the Satish Dhawan Space Center located near Sriharikota. Inaugurated in 1971, this is the launch site for ISRO's Polar Satellite Launch Vehicle (PSLV) and the Geosynchronous Satellite Launch Vehicle (GSLV). ISRO's next vehicle,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

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

A SpaceX Dragon orbits the Earth on the Spx-8 mission to the ISS, launched on April 8, 2016. Source: NASA.

PAYLOADS IN 2016

In the case of an orbital launch, the payload can be a satellite, a space probe, an on-orbit vehicle, or a platform that carries humans, animals, or cargo. Such satellites, probes, or on-orbit vehicles and platforms, often generally referred to as spacecraft, are usually separated from a launch vehicle (or its 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.

State of the Payload Industry

TThe first orbital payloads were satellites launched into LEO. These satellites were followed by on-orbit vehicles and platforms launched into other orbits and to different destinations. Space stations carrying humans and satellites carrying Earth observation, communications, and scientific sensors, telescopes, and transponders launched into not only LEO but also sun-synchronous (SSO), highly elliptical, and geosynchronous orbit (GEO). Scientific probes traveled to such destinations as the Moon, planets, and other destinations within and beyond our solar system.

Space industry companies and organizations worldwide, sometimes the same as launch vehicle manufacturers but also those specifically dedicated to spacecraft manufacturing, produce these spacecraft. Commercially launched payloads 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;
- Technology test and demonstration missions, usually new types of payloads undergoing test or used to test new launch vehicle technology; and
- Other commercially launched payloads, usually satellites launched for various purposes by governments of countries not having indigenous orbital launch capability.

All orbital payloads are divided into mass classes, described in Appendix 1 on Page 94.

GLOBAL PAYLOAD INDUSTRY

Countries and jurisdictions worldwide that possess functional and operating indigenous payload manufacturing sectors are China, the European Union, India, Japan, Russia, and the United States. Countries that have developed and built their own spacecraft include Argentina, Iran, Israel, North Korea, South

Korea, and Ukraine. 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, built from pre-fabricated kits by universities and government and non-profit organizations.

Table 6 presents civil, military, and commercial orbital payloads, by country of manufacturer, in 2016. In 2016, 55 CubeSats, most of them commercial, were launched as cargo for subsequent deployment from the ISS. Twenty Planet CubeSats were launched aboard a Cygnus for the OA-6 mission in March and 12 were launched directly into orbit by an Indian PSLV vehicle in June. Spire Global began its constellation deployment in 2016, with 13 CubeSats launched aboard Atlas V and Antares vehicles supporting cargo missions to the International Space Station (ISS).

Country of Manufacturer	Civil	Military	Non-Profit	Commercial	Total
Argentina	0	0	0	2	***2***
Canada	1	0	1	1	***3***
China	16	4	8	3	***31***
Europe	15	2	2	1	***20***
India	8	0	4	0	***12***
Indonesia	1	0	0	0	***1***
Israel	0	1	0	0	***1***
Japan	4	0	3	0	***7***
North Korea	0	1	0	0	***1***
Philippines	1	0	0	0	***1***
Russia	10	3	2	0	***15***
USA	11	8	0	72	***91***
TOTALS	***67***	***19***	***20***	***79***	***185***

Table 6. Number of civil, military, non-profit, and commercial, payloads launched in 2016 by country of manufacturer.

U.S. PAYLOAD INDUSTRY

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

- Ball Aerospace
- The Boeing Company
- Lockheed Martin Corporation
- 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 five 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. 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. In 2016, NASA awarded a second cargo resupply services contract to SpaceX, Orbital ATK, and Sierra Nevada Corporation (which is still developing a cargo system) to cover the period 2019 through 2024. Crewed vehicles made many advances in 2016 but are not expected to become operational before 2018.

On-orbit vehicle and platform development by commercial companies conducted in 2016 included the missions:

- Two cargo missions were conducted as part of NASA's ISS Commercial Resupply Services (CRS) contracts with SpaceX. A non-launch pad accident of a Falcon 9 vehicle in September grounded SpaceX missions until January 2017.
- The Orbital ATK OA-5 and OA-6 missions were conducted using Antares (OA-5) and Atlas V (OA-6) launch vehicles. Orbital ATK has completed upgrades to its Antares vehicle following a 2014 launch failure, including new RD-181 engines provided by NPO Energomash.

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 continues work on its New Shepard suborbital vehicle, and announced in 2016 more detailed plans to develop its New Glenn launch vehicle.

Table 7 lists on-orbit vehicles and platforms 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	2017
Orbital ATK	Cygnus	Antares	3,500 (7,716)	0	2013
Boeing	CST-100 Starliner	Atlas V Falcon 9	TBD	7	2017
Sierra Nevada Corp.	Dream Chaser	Atlas V	TBD	TBD	TBD
Blue Origin	Space Vehicle	Atlas V Blue Origin	TBD	7	TBD

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

An Orbital ATK Antares vehicle launches a Cygnus cargo spacecraft to ISS on the OA-5 mission, October 17, 2016. Source: NASA.

2016 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 2016, 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 launch industries are the United States, Russia, China, European Union, India, Japan, Israel, Iran, North Korea, and South Korea. 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 2016.

Country/Region	Civil	Military	Commercial	Total
USA	4	7	11	**22**
China	18	4	0	**22**
Russia	12	3	2	**17**
Europe	3	0	8	**11**
India	7	0	0	**7**
Japan	4	0	0	**4**
Israel	0	1	0	**1**
North Korea	0	1	0	**1**
TOTALS	***48***	***16***	***21***	***85***

Table 8. Total orbital launches in 2015 by country and type.

In 2016, the United States, Russia, Europe, China, Japan, India, Israel, and North Korea conducted a total of 85 orbital launches, 21 of which were commercial (see Figure 5). In 2015 there were 86 launches, including 22 commercial launches.

Two of the 85 launches failed. These included two government launches: a Soyuz U carrying the Progress MS-4 cargo mission to the International Space Station (ISS) and a Long March 4C carrying the Gaofen 10 remote sensing mission. Two

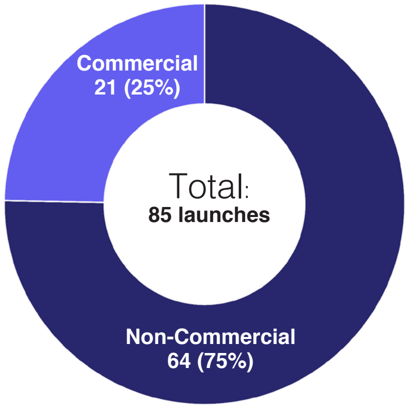


Figure 5. 2016 total worldwide launch activity.

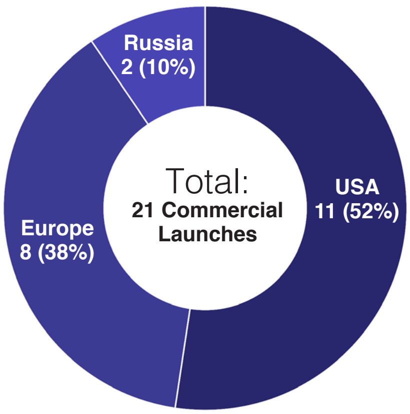


Figure 6. 2016 total worldwide commercial launch activity.

launches resulted in partial success. The Atlas V carrying OA-6 to the ISS in March experienced first stage booster shutdown several seconds ahead of schedule that did not affect the success of the mission. China's Long March 2D launch in December represents the second partial success, having deployed three satellites into an incorrect (lower) orbit. The September 1 launch pad explosion of a Falcon 9 FT during a static-fire test did not present a launch attempt and is not counted as such in this report.

Highlights of 2016 in the orbital space launch industry:

- The United States performed 11 commercial orbital launches;
- NASA continued its ISS CRS program, with the launch of four resupply missions;
- SpaceX continued to launch payloads for commercial clients with five commercial launches to geosynchronous transfer orbit (GTO). Falcon 9 FT launches were suspended following a launch pad explosion during a static-fire test on September 1. Falcon 9 FT returned to flight in January 2017, launching ten Iridium-NEXT satellites;
- United Launch Alliance (ULA) performed 12 missions, launching eight Atlas V and four Delta IV; and
- One new orbital launch vehicle was successfully tested. The Chinese Long March 7 launched a test reentry capsule to demonstrate capability of launching human rated spacecraft.

Revenues from the 21 commercial orbital launches in 2016 were estimated to be $2.5B, a healthy increase from $2.2B in 2015. The estimated commercial orbital launch revenues of $1.2B for U.S. providers, compared to $617M in 2015, reflects 7 Falcon 9 FT flights, 3 Atlas V flights, and the return to flight of the Antares (See Figure 7). These 11 missions were licensed by FAA AST.

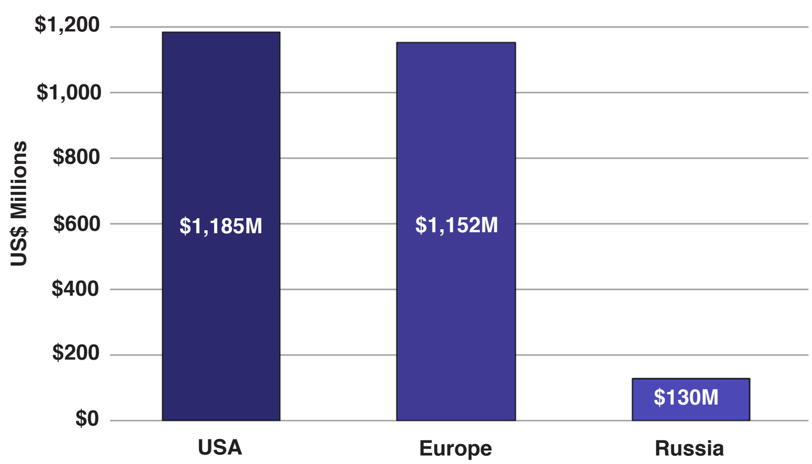


Figure 7. 2016 estimated revenues for commercial launches by country of service provider.

AST 2016 ORBITAL LAUNCH ACTIVITY

AST licensed eleven commercial orbital launches in 2016, compared to eight licensed launches in 2015 (Table 9). SpaceX's Falcon 9 vehicle was used in seven licensed launches: two in April and July under NASA's CRS program and five for commercial satellite operators SES, Sky Perfect JSAT (twice), Thaicom, and a dual manifest launch for ABS and Eutelsat. ULA's Atlas V vehicles successfully launched a Cygnus cargo module to ISS on behalf of Orbital ATK and a communications satellite for Echostar, a Worldview 4 commercial Earth observation satellite. Orbital ATK returned to flight with its modified Antares 230 vehicle successfully launching another Cygnus spacecraft to ISS.

Date	Vehicle	Primary Payload	Orbit	Launch Outcome
3/4/16	Falcon 9 FT	SES 9	GEO	Success
3/22/16	Atlas V 401	OA 6	LEO	Partial
4/8/16	Falcon 9 FT	Spx 8	LEO	Success
5/6/16	Falcon 9 FT	JCSAT 14	GEO	Success
5/27/16	Falcon 9 FT	Thaicom 8	GEO	Success
6/15/16	Falcon 9 FT	Eutelsat 117 West B	GEO	Success
7/18/16	Falcon 9 FT	Spx 9	LEO	Success
8/14/16	Falcon 9 FT	JCSAT 16	GEO	Success
10/17/16	Antares 230	OA 5	LEO	Success
11/11/16	Atlas V 401	WorldView 4	SSO	Success
12/18/16	Atlas V 431	EchoSat XIX	GEO	Success

Table 9. 2016 FAA AST-licensed orbital launch events.

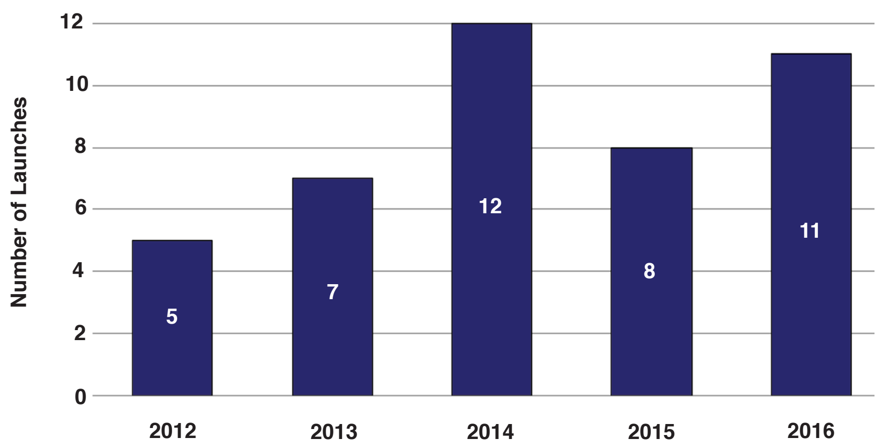
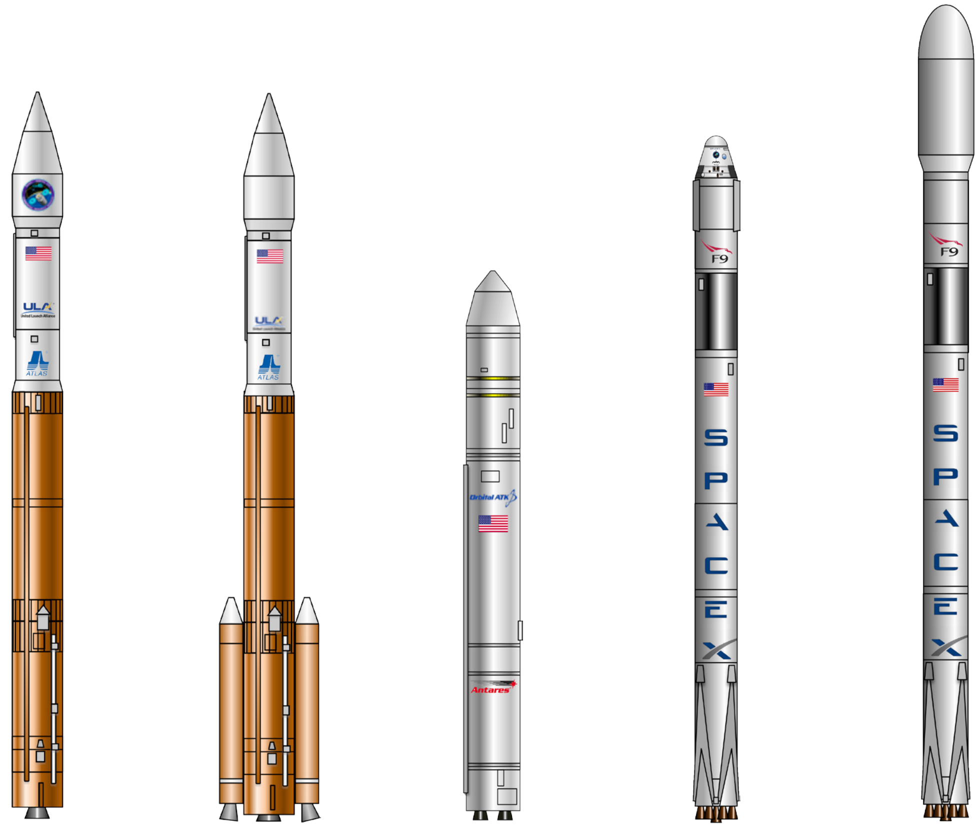


Figure 8. FAA AST-licensed orbital launch events, 2012-2016.

Figure 8 shows the number of FAA AST-licensed orbital launches for 2012 through 2016.



Vehicle	Atlas V 401	Atlas V 431	Antares 230	Falcon 9 FT (Dragon)	Falcon 9 FT
2016 Total Launches	3	1	1	2	5
2016 Licensed Launches	2	1	1	2	5
Launch Reliability (2016)	3/3 100%	1/1 100%	1/1 100%	2/2 67%	5/5 100%
Launch Reliability (Last 10 Years)	33/33 100%	3/3 100%	1/1 100%	2/2 100%	6/6 100%
Year of First Launch*	2002	2005	2016	2016	2015
Active Launch Sites	CCAFS, VAFB	CCAFS, VAFB	MARS	CCAFS	CCAFS, VAFB
LEO kg (lbs)	9,797 (21,598)	15,718 (34,653)	6,600 (14,551)	22,800 (50,265)	22,800 (50,265)
GTO kg (lbs)	4,750 (10,470)	7,700 (16,970)	--	--	8,300 (18,300)

Table 10. U.S. and FAA AST-licensed launch vehicles active in 2016.

Table 10 provides specifications for the five vehicle types that were launched during 2016 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 2016 REENTRY LICENSE SUMMARY

There were two reentries conducted under an FAA AST reentry license in 2016. Two SpaceX Dragon spacecraft performed the licensed reentries, in May and August, completing its eighth and ninth CRS missions to the ISS.

FAA AST 2016 SUBORBITAL LAUNCH SUMMARY

Four suborbital test flights were conducted under an FAA Experimental Permit by Blue Origin’s New Shepard vehicle, in January, April, June, and October. No suborbital flights were conducted under an FAA AST license during calendar year 2016.

An Atlas V 401 provided by United Launch Alliance stands poised to send DigitalGlobe's WorldView-4 into orbit. Source: ULA.

2017 COMMERCIAL SPACE TRANSPORTATION FORECAST

Executive Summary

The Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST) and the Commercial Space Transportation Advisory Committee (COMSTAC) have prepared this forecast of global demand for commercial space launch services in 2017 through 2026.

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, and
- 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 41.2 commercial launches per year for 2017 through 2026 for all commercial launch industry segments.

By orbital destination, the projection is 19.8 commercial GSO launches per year and 21.4 NGSO launches per year for 2017 through 2026. Table 11 shows the number of payloads and launches projected from 2017 through 2026, by industry segment and by orbital destination.

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Total	Avg.
Payloads												
GSO Forecast (COMSTAC)	25	25	26	21	22	22	22	22	22	22	229	22.9
NGSO Forecast (FAA)	242	300	300	244	256	249	206	252	206	135	2,390	239.0
Total Payloads	***267***	***325***	***326***	***265***	***278***	***271***	***228***	***274***	***228***	***157***	***2,619***	***261.9***
Launches												
GSO Medium-to-Heavy	19	21	24	19	20	18	20	18	19	20	198	19.8
NGSO Medium-to-Heavy	16	25	15	17	16	16	11	15	11	9	151	15.1
NGSO Small	5	10	13	11	5	4	5	4	5	1	63	6.3
Total Launches	***40***	***56***	***52***	***47***	***41***	***38***	***36***	***37***	***35***	***30***	***412***	***41.2***

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 22.9 satellites per year. Figure 12 shows the GSO forecast. Half of the GSO satellites

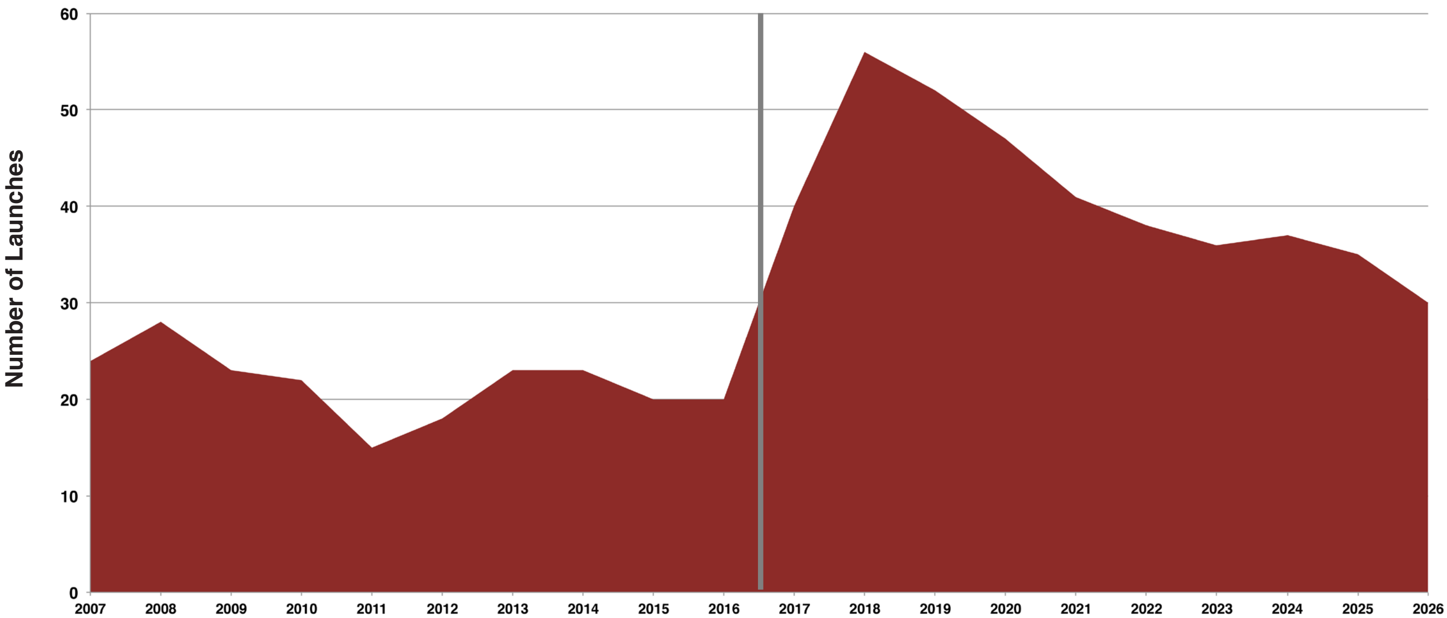


Figure 9. Historical and Projected Commercial Orbital Launches

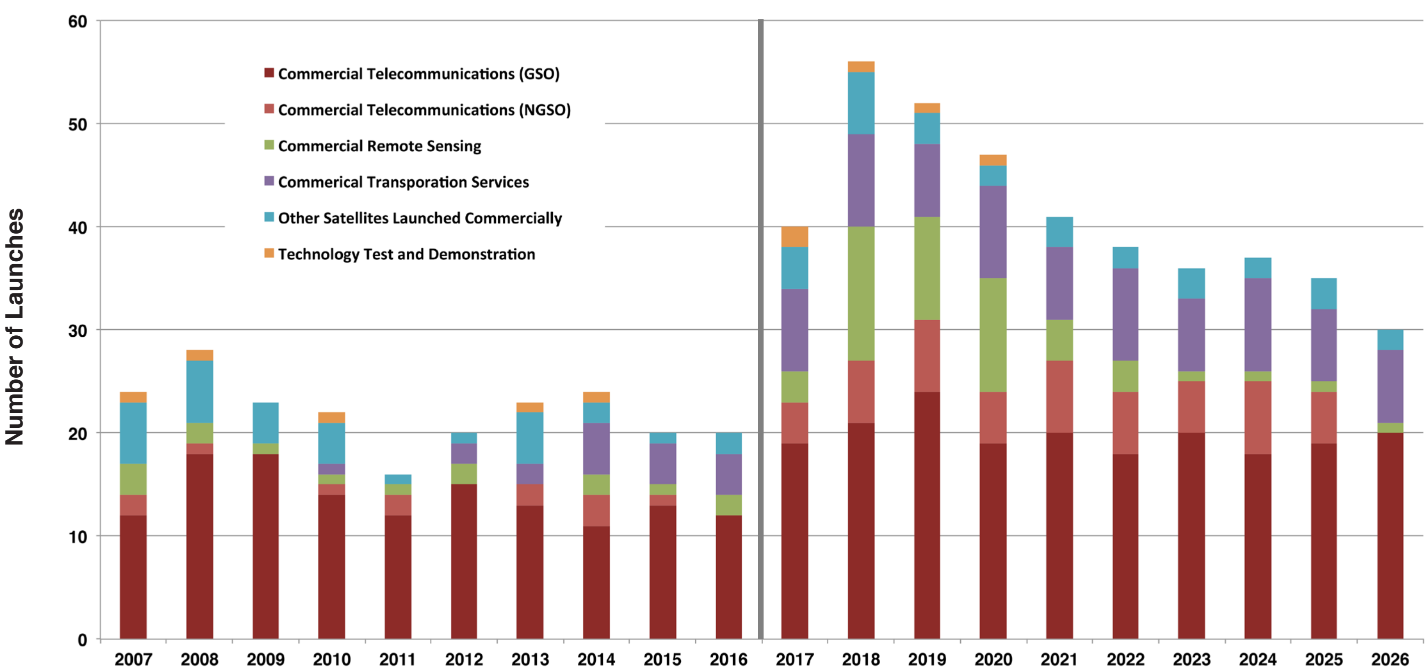


Figure 10. Historical and Projected Commercial Orbital Launches by industry Segment

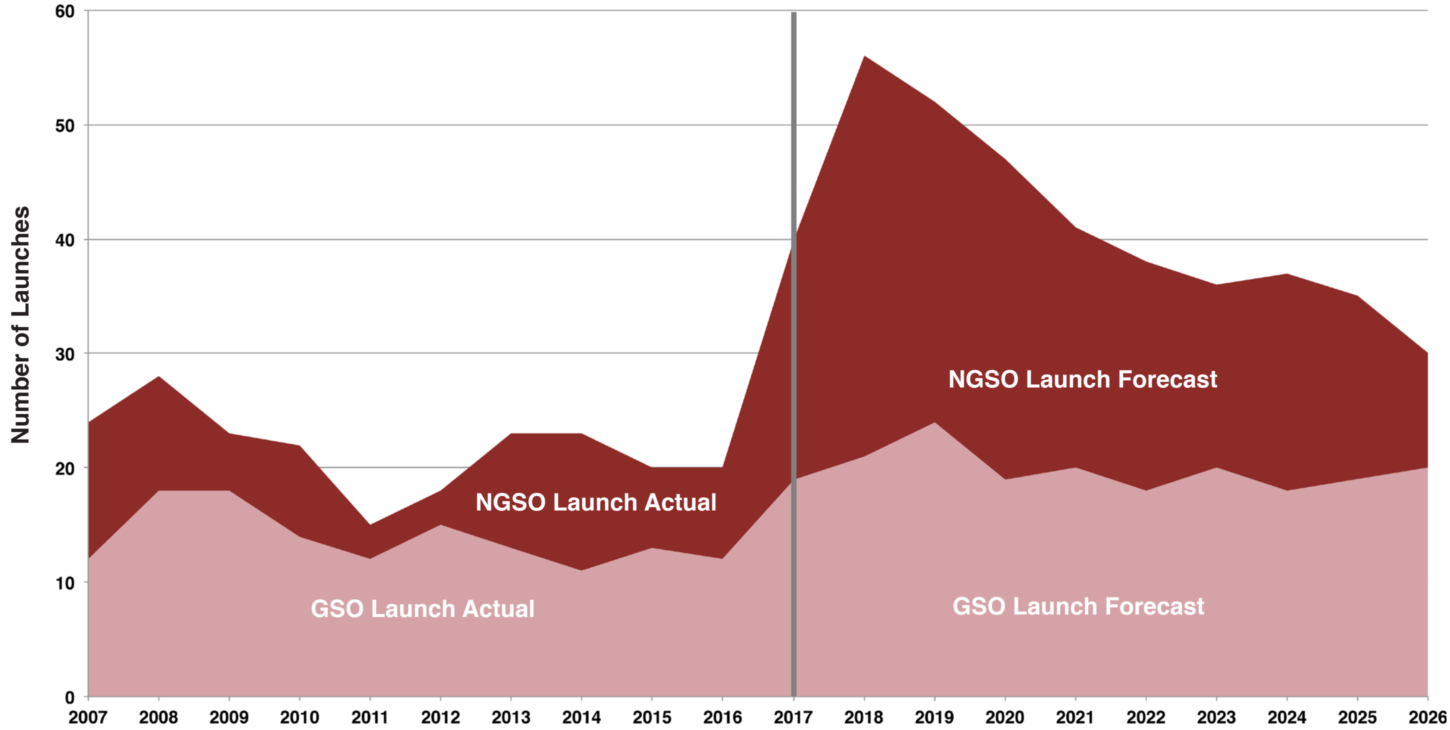


Figure 11. Historical and Projected Commercial Orbital Launches by Orbital Destination

projected to launch from 2017 to 2026 are in the heaviest mass class (above 5,400 kg, or 11,905 lb). At the same time, ten percent of the satellites in the same period are in the lowest mass class (below 2,500 kg, or 5,512 lb). In 2016, unaddressable launches, launch contracts that are not open to international (including U.S.) competition, dropped to a relatively low level of three launches (compared to eight in 2015). However, unaddressable launches are projected

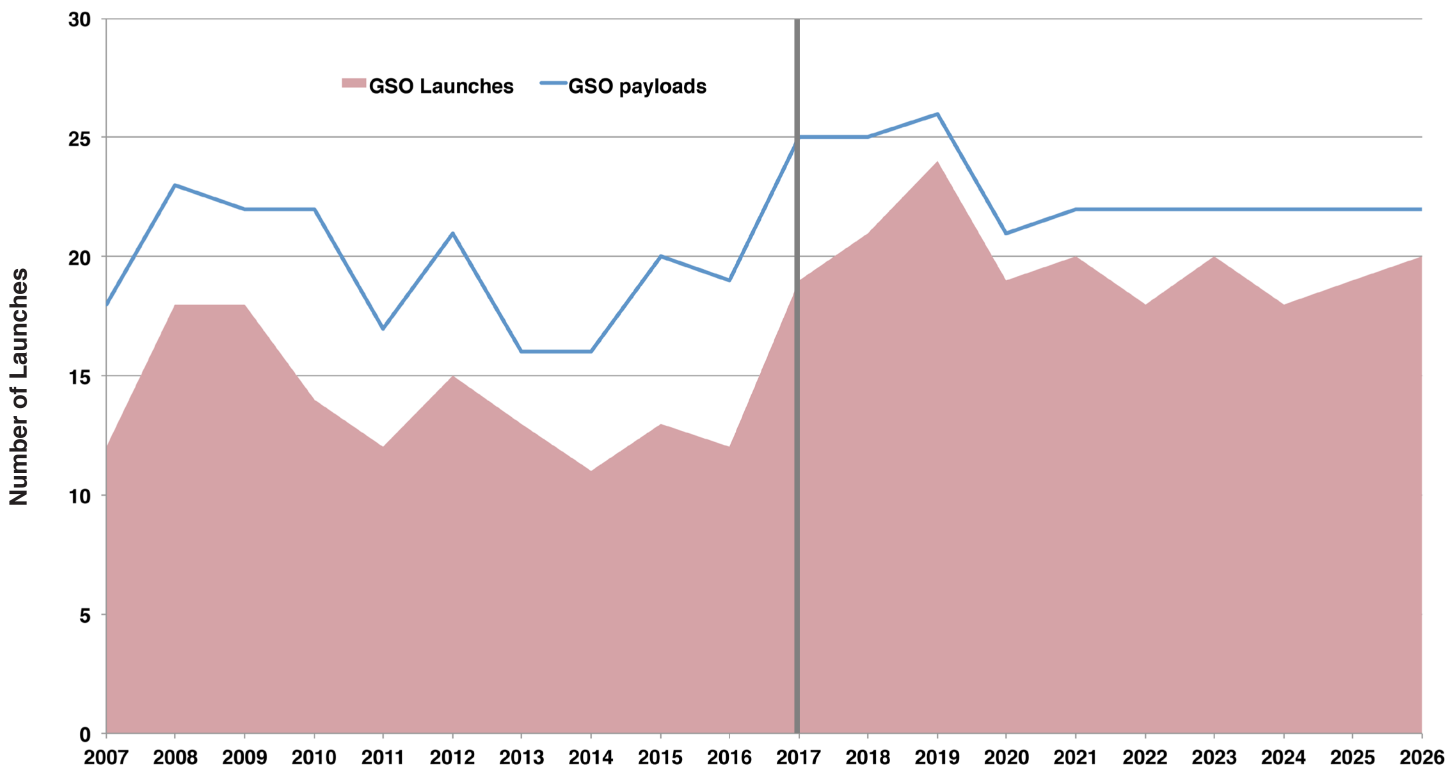


Figure 12. GSO Historical Launches and Launch Forecast

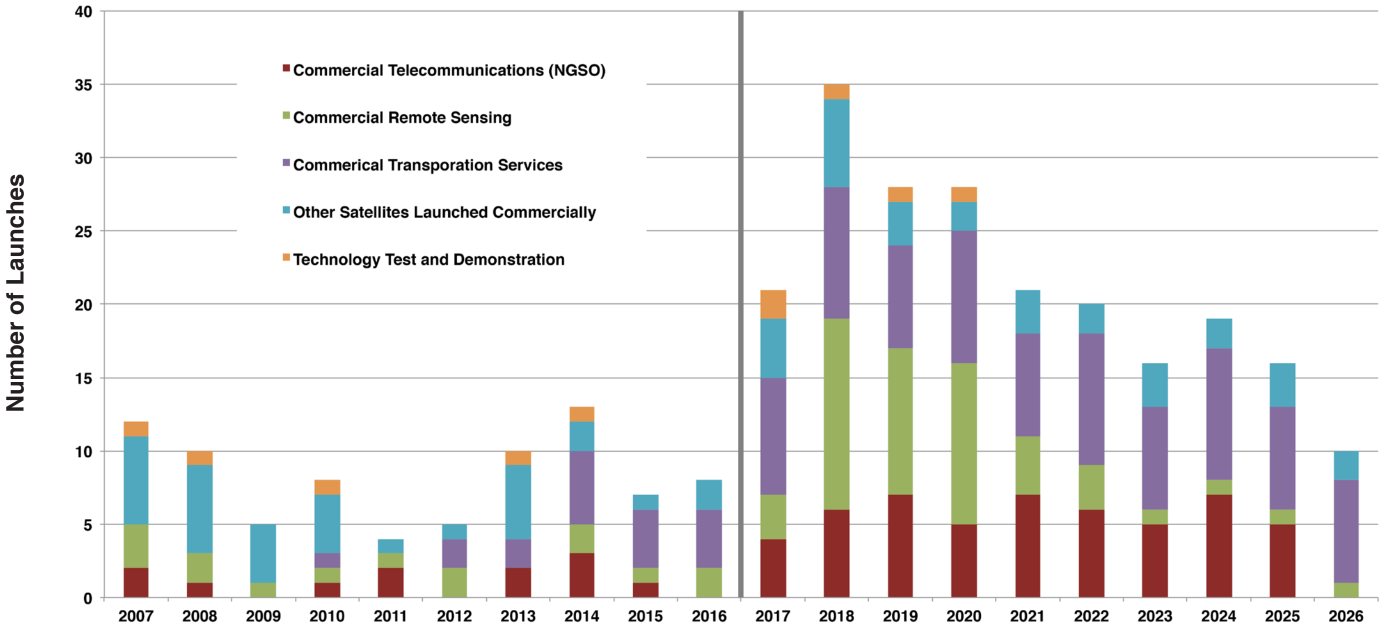


Figure 13. NGSO Historical Launches and Launch Forecast

to increase to 5.3 launches per year through 2026 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 conducting of NASA ISS commercial crew and cargo resupply missions also keep NGSO launch levels high. The annual average of NGSO commercial launches is expected to grow from 7.8 launches a year over the last ten years to about 21.4 launches annually. From 2017 to 2026, 2,390 payloads are projected to launch commercially, driving 214 launches with 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. The launches in the 10 year period are predominantly commercial launches to the ISS and for commercial remote sensing and telecommunications, which require medium-to-heavy vehicles. Seventy-one percent of all commercial NGSO launches during the forecast period are missions launched by medium-to-heavy vehicles. The relatively higher number of small launches is due to new remote sensing constellations' plans to use the newly developed commercial small launch vehicles following the test flights of such vehicles in 2017–2019.

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, and
- 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 GSO 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

COMSTAC helped compile the 2017 commercial GSO forecast. This 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:

- COMSTAC projects 25 addressable commercial GSO satellites on 19 launches in 2017 and an annual average of 22.9 satellites on 19.8 launches for the period from 2017 through 2026.
- The number of addressable satellites launched in 2015 and 2016 (20 and 19 satellites respectively) increased from 16 in 2013 and 2014, although the pattern of satellite delays and launch failures continued.

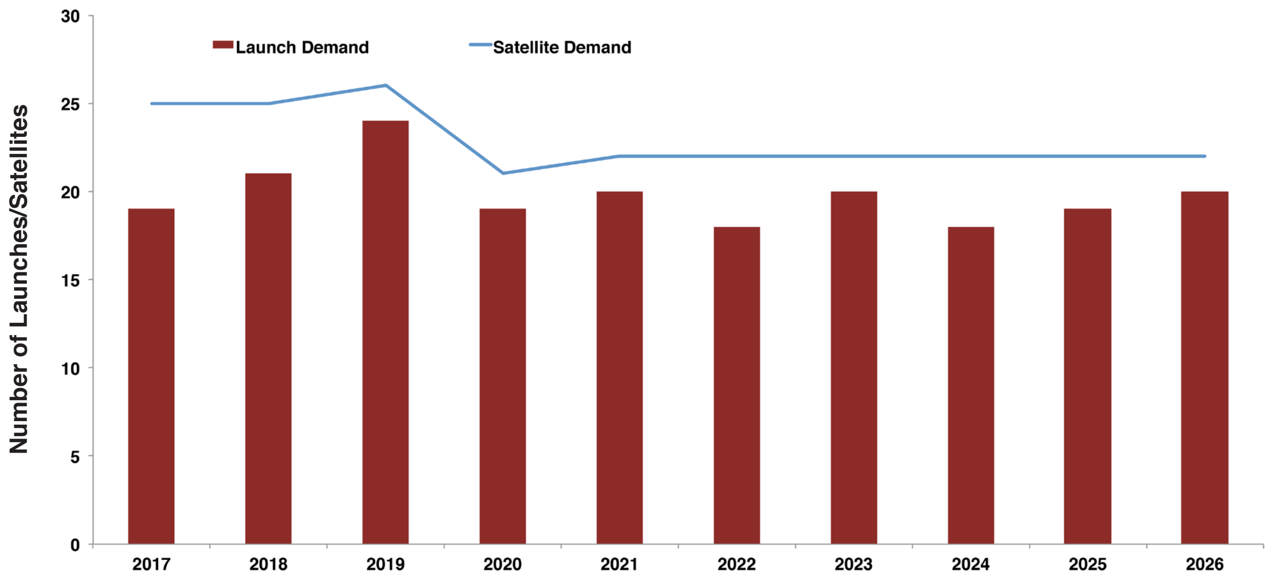


Figure 14. Forecast Commercial GSO Satellite and Launch Demand

	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	Total	Average
Satellite Demand	25	25	26	21	22	22	22	22	22	22	229	22.9
Launch Demand	19	21	24	19	20	18	20	18	19	20	198	19.8
Dual Launch Demand	6	4	2	2	2	4	2	4	3	2	31	3.1

Table 12. Forecast Commercial GSO Satellite and Launch Demand

- The average number of satellites to be launched in the next three years has not changed from last year's report, with 25 in 2015 and in 2017. The number of launches has increased, however, from 17.0 in 2015 to 21 in 2017, representing a further reduction in the overall percentage of dual-manifest launches.
- The satellite services market is generally robust, 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 25 satellites are projected to be launched in 2017, applying the realization factor adjusts this to a range of 21 to 25 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 2007.

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.

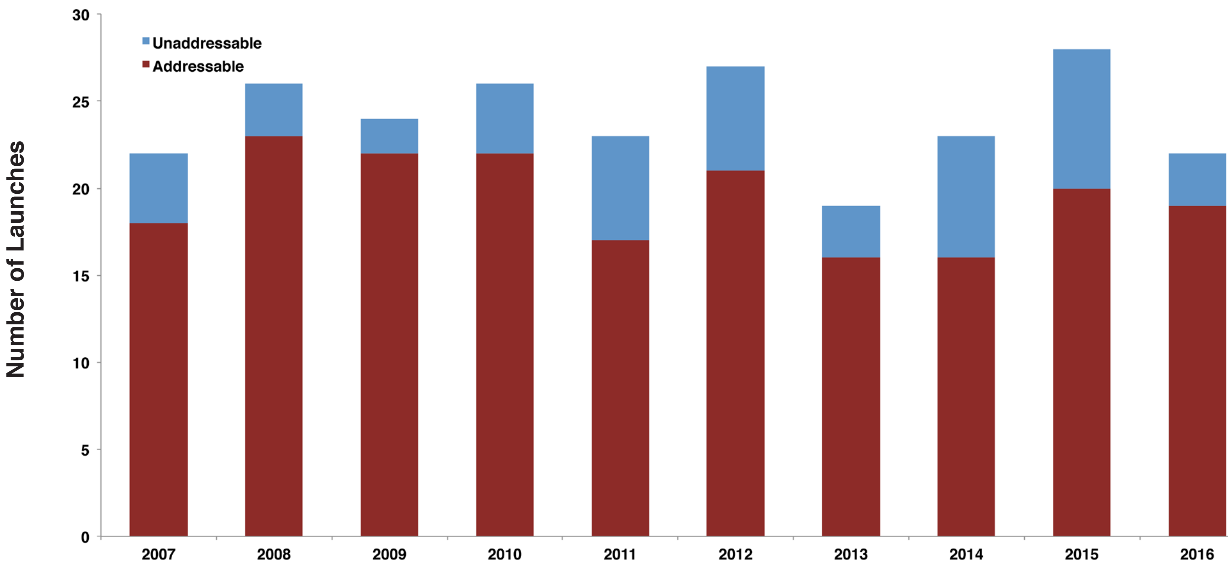


Figure 15. Addressable and Unaddressable Satellites since 2007

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Average
Addressable	18	23	22	22	17	21	16	16	20	19	194	19.4
Unaddressable	4	3	2	4	6	6	3	7	8	3	46	4.6
Total	***22***	***26***	***24***	***26***	***23***	***27***	***19***	***23***	***28***	***22***	***240***	***24.0***

Table 13. Addressable and Unaddressable Satellites Since 2007

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.

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

One technical development that has affected the trend towards increasing satellite mass is the development of satellites using electric propulsion rather 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 42 percent of satellites launched in 2016 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 4,466 kg (9,846 lb), reaching a new high of over 5,000 kg (11,023 lb) in 2013. The

	Actual									Forecast		
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total Mass Launched per Year (kg)	68,241	94,692	85,724	72,068	103,499	80,921	74,752	87,363	91,929	115,350	108,650	113,984
Average Mass per Satellite (kg)	4,334	4,315	4,286	4,239	4,929	5,058	4,672	4,368	4,838	4,614	4,346	4,384

Table 15. Total Satellite Mass Launched per Year and Average Mass per Satellite

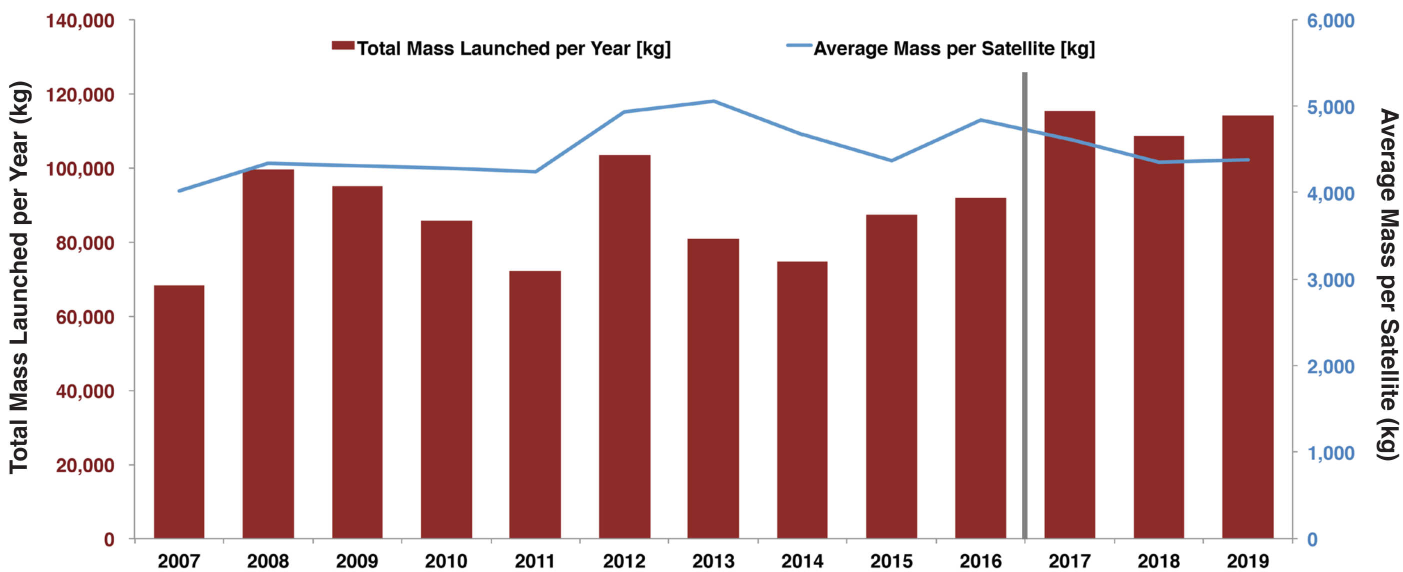


Figure16. Total Satellite Mass Launched per Year and Average Mass per Satellite

average mass in 2017–2019 is expected to remain in the 4,500–4,600 kg (9,921–10,141 lb) range. Figure 17 and Table 16 show the trends in satellite mass class distribution.

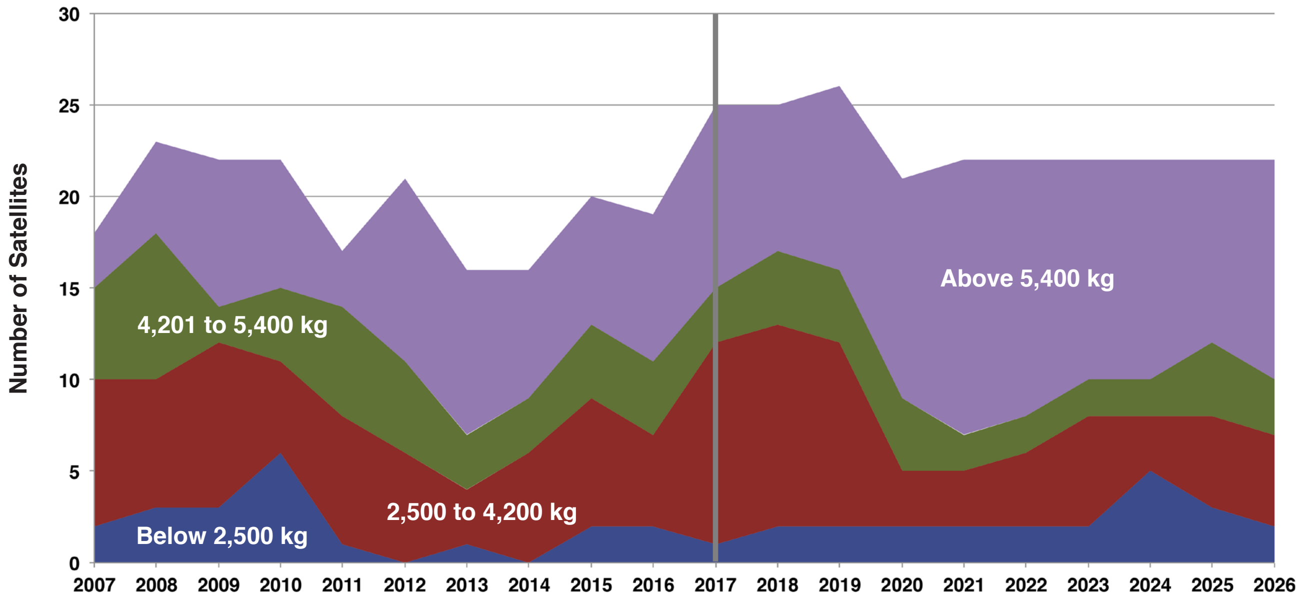


Figure 17. Trends in Satellite Mass Class Distribution

	Actual										Forecast										Total 2017 to 2026	Avg. 2017 to 2026	% of Total 2017 to 2026
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026			
Above 5,400 kg	3	5	8	7	3	10	9	7	7	8	10	8	10	12	15	14	12	12	10	12	115	12	50%
4,201 - 5,400 kg	5	8	2	4	6	5	3	3	4	4	3	4	4	4	2	2	2	2	4	3	30	3	13%
2,500 - 4,200 kg	8	7	9	5	7	6	3	6	7	5	11	11	10	3	3	4	6	3	5	5	61	6	27%
Below 2,500 kg	2	3	3	6	1	0	1	0	2	2	1	2	2	2	2	2	2	5	3	2	23	2	10%
Total	***18***	***23***	***22***	***22***	***17***	***21***	***16***	***16***	***20***	***19***	***25***	***25***	***26***	***21***	***22***	***22***	***22***	***22***	***22***	***22***	***229***	***23***	***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 10,000 kg (22,046 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 4 solid rocket boosters will be able to carry up to 11,000 kg (24,251 lb) to GTO. ILS plans to phase out Proton and replace it with Angara 5 in 2020. Angara 5 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 2017–2018, with 21,000 kg (46,297 lb) capability to GTO, may also permit dual manifesting of large communications 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 2017 single- and dual-manifest satellite and launch demand forecast from 2017 through 2026 and the actual launch statistics from 2007 through 2016. After the next three years, the number of addressable dual manifest launches may stabilize at a lower level of about 3 per year, 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 5 and Falcon Heavy proves a reliable and more economical option, this number may increase.

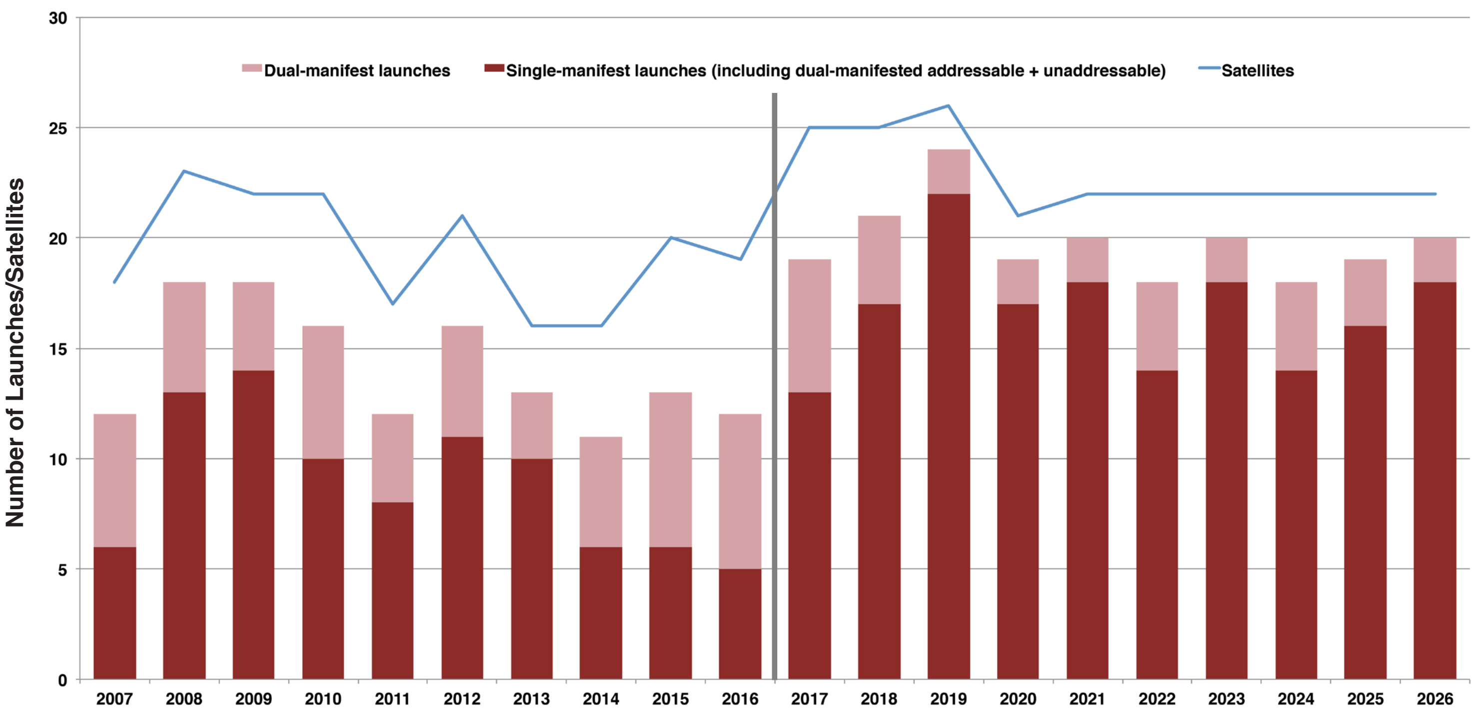


Figure 18. Dual Manifesting and Launch Demand

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 2017 to 2019 show an increase in the number of satellites to be launched over the previous three years (2014–2016). 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 2017 may be launched in the following year(s) while the launch industry is making up for the down time after several launch incidents.

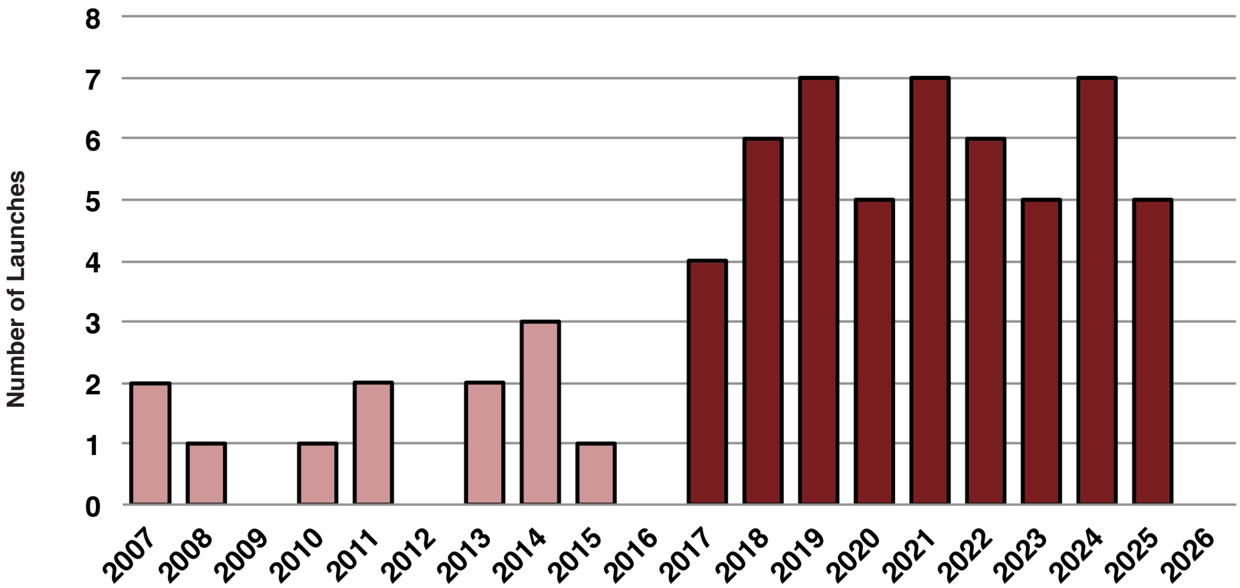
	2017			2018			2019		
Total Launches	**19**			**21**			**24**		
Total Satellites	**25**			**25**			**26**		
Below 2,500 kg	**1**			**2**			**2**		
		SES 15	Soyuz 2		ABS 8	TBD		MEV 2	TBD
				DM	MEV 1	Proton M		MEV 3	TBD
2,500 - 4,200 kg	**11**			**11**			**10**		
	DM	Al Yah 3	Ariane 5	DM	Azerspace 2 (Intelsat 38)	Ariane 5		ABS 9	TBD
		Bangabandhu 1	Falcon 9	DM	BSat 4a	Ariane 5		BSat 4b	TBD
	DM	Eutelsat 127B	Ariane 5		BulgariaSat 1	Falcon 9		Eutelsat 48E	TBD
	DM	GSAT 17	Ariane 5		Eshail 2	Falcon 9	DM	Eutelsat BB4A (Africa BB)	Ariane 5
		Hispasat 36W1 (AG1)	Soyuz 2	DM	Eutelsat 5WB	Proton M		Eutelsat Quantum	TBD
	DM	HYLAS 4	Ariane 5		Eutelsat 7C	TBD	DM	GEO-Kompsat 2B	Ariane 5
		Koreasat 5A	Falcon 9	DM	GEO-Kompsat 2A	Ariane 5		MEASAT 2A	TBD
	DM	Koreasat 7	Ariane 5	DM	GSAT 21	Ariane 5		Thor 8	TBD
		SES 14 (47.4W)	Falcon 9	DM	GSAT G20	Ariane 5		Turksat 5A	TBD
		SES 16 (GovSat)	Falcon 9		Sky Mexico 2	TBD		Turksat 6A	TBD
	DM	Telkom 3S	Ariane 5		Telkom 4	TBD			
4,201 - 5,400 kg	**3**			**4**			**4**		
		PSN 6	Falcon 9		Amazonas 5	Proton M		Amos 6B	TBD
		SES 10	Falcon 9	DM	DSN 1 (JCSAT SB 8)	Ariane 5		Eutelsat 69WA	TBD
	DM	SES 12	Ariane 5	DM	GSAT 11	Ariane 5		KMILCOMSAT	TBD
					Hispasat 1F (Hispasat 30W-6)	Falcon 9		SES 17	TBD
Above 5,400 kg	**10**			**8**			**10**		
		Asiasat 9	Proton M		Arabsat 6A	Falcon Heavy		Arabsat 6C	TBD
		EchoStar XXI (Dish T2)	Proton M		EchoStar XX	Falcon Heavy		DirecTV 16	TBD
		EchoStar XXIII (CMBSTAR)	Falcon 9		Horizons 3E (EPIC)	Falcon 9		GISAT	TBD
	DM	Hellas Sat 3 (Inmarsat S)	Ariane 5		Inmarsat 5F4	Falcon 9		Inmarsat 6F1	TBD
	DM	Hellas Sat 4 (SGS 1)	Ariane 5		Intelsat 35E	Falcon 9		Intelsat 906RE (EPIC 5)	TBD
	DM	Intelsat 37E	Ariane 5	DM	Intelsat 39	Ariane 5		Silkwave 1	TBD
		SES 11 (EchoStar 105)	Falcon 9		Telstar 18V	Falcon 9		Sirius SXM 7	TBD
	DM	SGDC 1	Ariane 5		Telstar 19V	Falcon 9		Telstar 20V	TBD
	DM	Sky Brasil 1 (Intelsat 32E)	Ariane 5				DM	ViaSat 3 Americas	Ariane 5
		ViaSat 2	Ariane 5					Thuraya FO	TBD

DM = Potential Dual-Manifested Satellites
* = Satellite proposed, not yet identified publicly

Table 17. Commercial GSO Satellite Near-Term Manifest

NGSO Commercial Telecommunications Satellite Launch Demand Projection

From 2017 through 2020, an average of 5.5 launches of NGSO telecommunications satellites will occur each year, dominated by launches of Iridium NEXT and OneWeb satellite constellations. Iridium NEXT intends to finish the replacement of its existing constellation within 2 to 3 years, 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 larger part of the 10-year forecast period. Figure 11 provides a representation of telecommunications launch history and projected launch plans.



2017	2018	2019	2020
Iridium (10) - Falcon 9	Iridium (10) - Falcon 9	Iridium (10) - Falcon 9	OneWeb (2) - LauncherOne
Iridium (10) - Falcon 9	Iridium (10) - Falcon 9	Iridium (2) - TBD	OneWeb (2) - LauncherOne
Iridium (10) - Falcon 9	Iridium (10) - Falcon 9	OneWeb (32) - Soyuz 2	OneWeb (2) - LauncherOne
Iridium (10) - Falcon 9	OneWeb (32) - Soyuz 2	OneWeb (32) - Soyuz 2	OneWeb (32) - Soyuz 2
	OneWeb (32) - Soyuz 2	OneWeb (32) - Soyuz 2	OneWeb (32) - Soyuz 2
	O3b (4) - Soyuz 2	OneWeb (2) - LauncherOne	
		OneWeb (2) - LauncherOne	

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 1GHz and primarily provide M2M (Mashine-to-Machine) and AIS (Automatic Identification System) 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.

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

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.

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

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 53º – 81º

Table 20. Broadband Systems

were from Baikonur, Kazakhstan on Soyuz rockets carrying six satellites per launch. Globalstar reported significant improvement in service availability, quality, and revenue (see Figure 13) after the new generation satellites came online.

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 2015 revenue was \$90.5M, slightly higher than in 2014 (\$90.1M). Revenue data for 2016 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), beginning in 2017. Iridium revenues in 2015 were $411.4M, slightly up from $408.6 in 2014. Revenue data for 2016 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 dramatically from $96.2M in 2014 to $178.3M in 2015. Revenue data for 2016 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. Additional four satellites are to be deployed tentatively 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 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 as early as 2017 and achieve deployment of a functional initial constellation by 2019. OneWeb has contracts for 21 Soyuz 2 launches with Arianespace and multiple LauncherOne small launches with Virgin Galactic.

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 2026

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 2015–2024 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, and
- 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.

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, DMC International Imaging, MDA Geospatial Services, Planet, and Terra Bella. New companies like Spire Global, GeoOptics, and many others are expected to deploy satellites during the forecast period. For all of these companies, GIS products and services are 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 satellite systems designed for weather forecasting. This capability does not depend on imagery but rather radio signals generated by global position system 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.

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.

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

System	Operator	Manufacturer	Satellites	Mass kg (lb)	Highest Resolution (m)	Revisit Time (hrs)	Launch Year
CERES	Planetary Resources	Planetary Resources	10	TBD	10	12	2018
Capella	Capella	Capella	30	TBD	1	TBD	2020
CICERO	GeoOptics	GeoOptics/LASP	CICERO 1-24	TBD	N/A	24	TBD
Deimos	UrtheCast	Dauria Aerospace	Deimos 1 Deimos 2	120 (265) 300 (661)	20 0.75	24 24	2009 2014
DMC3	DMCii/21ST	SSTL	DMC3 1-3	350 (771)	1	24	2015
Dove	Planet	Planet	100+	<10 (22)	3-5	24	2013
EROS	ImageSat International	IAI	EROS A	280 (617)	1.5	24-288	2000
Gaojing	CAST Corp.	CAST Corp.	24+	TBD	0.5	TBD	2017
GeoEye	DigitalGlobe	Lockheed Martin	GeoEye 1	907 (2,000)	0.41	50-199	2008
GRUS	AxelSpace	AxelSpace	50	95 (209)	2.5	24	2017
HawkEye 360	HawkEye 360	HawkEye360/DSI	3	TBD	N/A	TBD	2017
HOPSat	Hera Systems	Hera Systems	48	12	1	<24	2017
HSAT	Harris	Harris	HSAT 1	<10	698	TBD	TBD
HyperSat	HyperSat	TBD	HyperSat 1-3	TBD	TBD	TBD	TBD
HySpec	HySpecIQ	TBD	HySpec 1-2	600 (1,324)	TBD	TBD	2018
Iceye	Iceye	York Space Systems	10-20	150 (331)	TBD	TBD	2017
IKONOS	DigitalGlobe	Lockheed Martin	1	816 (1,800)	1	<72	1999
Jilin	CST Co. Ltd.	CST Co. Ltd.	60+	420 (926)	0.7-2.8	<24	2016
LandMapper	Astro Digital	Astro Digital	30	10-20	2.5-22	24-96	2017
Lemur	Spire Global	Spire Global/ Clyde Space	50+	4 (9)	N/A	<24	2016
NorthStar	NorStar Space Data	NovaWurks	40	750 (1,653)	TBD	TBD	TBD
ÑuSat	Satellogic	Satellogic	25	37 (82)	TBD	<24	2017
OptiSAR	UrtheCast	SSTL	16	SAR: 1,400 (3,086) Optical: 670 (1,477)	TBD	<24	2021
Overview	Space VR	SpaceVR	Overview 1a Overview 1b	4 (9)	215	TBD	TBD
PlanetiQ	PlanetiQ	Blue Canyon Technologies	18	20 (44)	N/A	24	TBD
RADARSAT	MDA	MDA	RADARSAT 2 RCM 1-3	2,195 (4,840) 1,200 (2,645)	3 TBD	48-72 TBD	2007 2018
RapidEye	Planet	MDA	RapidEye 1-5	150 (330)	6.5	24	2008
SeeMe	Raytheon	Raytheon	24	25 (55)	TBD	TBD	2016
SIMPL	NovaWurks	NovaWurks	SIMPL 1	TBD	TBD	TBD	TBD
SkySat	Planet	Skybox Imaging/ SSL	24	91 (200)	<1	<24	2013
TerraSAR/ TanDEM X	BMBF/DLR/Airbus	Airbus	TerraSAR-X TanDEM X TerraSAR NG	1,023 (2,255) 1,023 (2,255) TBD	3 0.5 0.25	264 264 264	2007 2010 2018
UrtheDaily	UrtheCast/ OmniEarth	SSTL	8	TBD	5	24	TBD
WorldView	DigitalGlobe	Ball Aerospace/ Lockheed Martin/ TAQNIA	WorldView 1 WorldView 2 WorldView 3 WorldView 4 TAQNIA (6)	2,500 (5,510) 2,800 (6,175) 2,800 (6,175) 2,087 (4,601) 150 (331)	0.5 0.5 0.3 0.25 TBD	41-130 26-89 <24 <72 TBD	2007 2009 2014 2016 TBD
XpressSAR	XpressSAR, Inc.	TBD	4	TBD	1	TBD	TBD

Table 21. Current and Near-Term Commercial Remote Sensing Satellites and Launches

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 FY 1996 to FY 2010, the number of licenses issued was 26. From FY 2010 to FY 2016, the number was 63. Still, only five licenses were issued in 2016 (see Table 21).

Licensee	Date License Granted or Updated	Remarks
HyperSat	6/2/16	License for three satellites
Planet	10/5/16	License for Flock 2k and Flock 3p
Space Virtual Reality Corp.	11/5/16	License for two 3U CubeSats
The Planetary Society	11/28/16	License for LightSail 2
Harris	12/16/16	License for HSAT 1, a 6U CubeSat

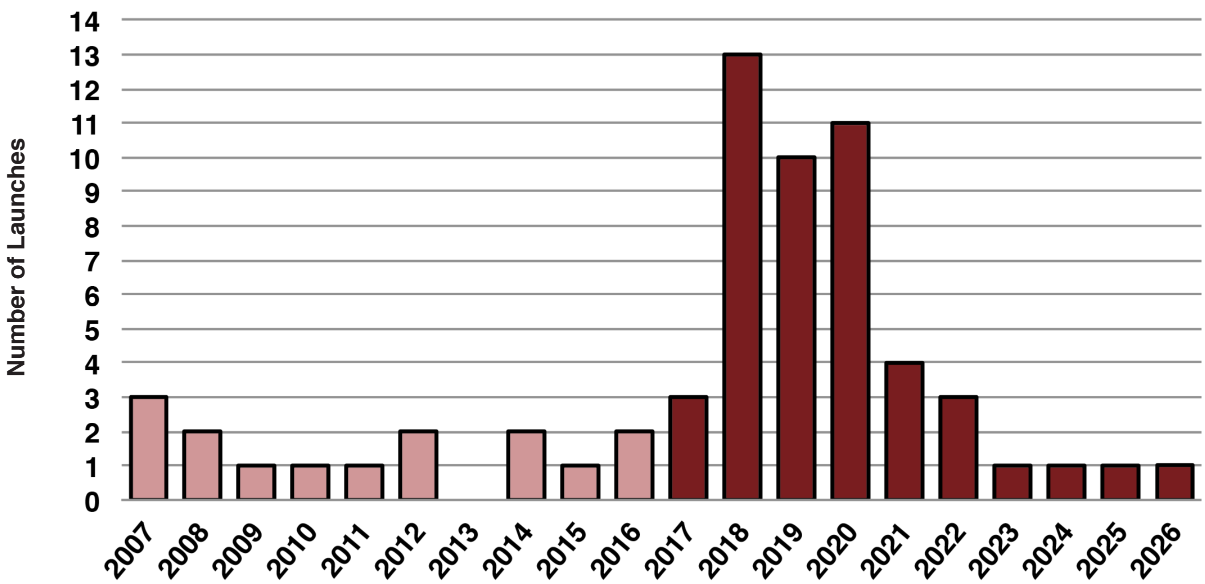
Table 21. NOAA Remote Sensing Licenses Issued in 2016.

Remote Sensing Launch Demand Summary

Since 1999, the commercial satellite remote sensing industry has been characterized by relatively stable satellite replacement schedules, generating about one to two launches per year. Peaks in the number of launches can be seen during 2016 through 2019, reflecting projected deployment of satellites operated by Iceye and Planet, both of which have contracted with launch providers. Virtually all other systems listed in Table 21 have either not signed launch contracts or will not generate a dedicated launch. Figure 20 on the next page provides a launch history and projected launch plans for commercial remote sensing satellites.

Nearly 1,445 commercial remote sensing satellites are projected to be launched through 2026, an unprecedented number. The vast majority of these will be microsatellites, including CubeSats, and the key driver is the data analytics industry. 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. Thus far, no launch contracts using these new vehicles have been publicly announced.

Commercial remote sensing satellites in the near-term forecast (2017–2020) 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 (2021–2026) 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.



2017	2018	2019	2020
TSX-NG - TBD	Iceye - Vector H	Iceye - Vector H	Airbus Follow-on (2) - TBD
Planet (30) - Electron	Iceye - Vector H	Iceye - Vector H	Iceye - Vector H
Terra Bella (6) - Minotaur-C	Iceye - Vector H	Iceye - Vector H	Iceye - Vector H
	Iceye - Vector H	Iceye - Vector H	Iceye - Vector H
	Iceye - Vector H	Iceye - Vector H	Iceye - Vector H
	Iceye - Vector H	Iceye - Vector H	Iceye - Vector H
	Iceye - Vector H	Iceye - Vector H	Iceye - Vector H
	EROS C - TBD	Planet (30) - Electron	Iceye - Vector H
	RCM (3) - Falcon 9		Planet (30) - Electron
	Planet (30) - Electron		

Figure 20. Commercial Telecommunications Launch History and Projected Launch Plans

Airbus Defense and Space

Airbus Defense and Space (Airbus) operates the French remote sensing constellation, Satellite Pour l'Observation de la Terre (SPOT) and the German synthetic aperture radar (SAR) remote sensing missions TerraSAR-X and TanDEM-X. Airbus also handles sales of imagery obtained by two Pléiades satellites operated by CNES, the Deimos-1 satellite operated by DMC International Imaging on behalf of the Spanish government, and Formosat-2 operated by the government of Taiwan.

The TerraSAR-X and TanDEM-X missions are public private partnerships between the 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 and TanDEM-X.

The TerraSAR-X Mission is performed by two satellites, TerraSAR-X and TanDEM-X, each contributing a part of the imaging resources. The TanDEM-X

Mission uses the same two satellites to perform close formation flight with distances of 200 m (656 ft). The two satellites will fly in this formation through 2016 and both satellites are expected to remain in service until 2018 (TerraSAR-X) and 2020 (TanDEM-X). The goal of the TanDEM-X Mission is to generate a homogeneous, high-quality global digital elevation model. Work is currently underway for a second generation of SAR satellites called TerraSAR-X Next Generation. The launch is planned for launch in 2018. No launch vehicle has been selected.

The Centre National d'Etudes Spatiales (CNES), France's space agency, was majority shareholder of SPOT Image until 2009, when responsibility for the system transferred to EADS Astrium. In 2011 the company formed the Geo Information Division to specifically manage the SPOT satellites and data sales. EADS Astrium has since acquired and built SPOT-6 and SPOT-7, which launched in 2013 and 2014 respectively. In 2014, through mergers, EADS Astrium became part of Airbus Group, and SPOT-7 (renamed Azersky) was sold to Azercosmos, based in Azerbaijan. The SPOT constellation consists of four operational satellites, SPOT-4, launched in 1998, SPOT-5, launched in 2002, SPOT-6 launched in 2012, and SPOT-7 launched in 2014. The launch of SPOT-7 is not included in the forecast because it was not internationally competed; like SPOT-6, SPOT-7 was launched aboard a PSLV as a result of a partnership between CNES and the Indian Space Research Organization (ISRO).

BlackBridge

Berlin-based BlackBridge operated the RapidEye constellation of five satellites. The satellites and data library were purchased by Planet in 2015. The BlackBridge satellites provide wide-area, repetitive coverage and 5-meter-pixel-size multi-spectral imagery. MacDonald, Dettwiler and Associates (MDA) was the prime contractor for the development of the satellites, responsible for design and implementation. MDA subcontracted Surrey Satellite Ltd (SSTL) in the UK to supply the bus and integrate the satellites, and Jena-Optronik from Germany provided the camera payloads. All five satellites were launched aboard a Dnepr launch vehicle from Baikonur, Kazakhstan on August 29, 2008. The constellation is expected to remain in service until at least 2019, four years beyond the designed service life.

BlackSky Global, LLC

In 2014, U.S.-based BlackSky Global was issued a NOAA license authorizing deployment of an "Earth observation satellite system." The system, which is planned for deployment in 2017, will feature one or more satellites in a polar orbit with an altitude of between 450 and 600 km (280 and 373 mi). Because no technical details have been made public, the BlackSky system is not included in the forecast.

Dauria Aerospace-Elecnor Deimos

In mid-2014, Dauria Aerospace and Elecnor Deimos announced a joint partnership to develop Perseus, an 8-microsatellite remote sensing constellation. These satellites, manufactured by Canopus Systems LLC, appear to have been cancelled. Elecnor Deimos operated Deimos-1, a commercial remote sensing satellite deployed in 2009, and Deimos-2, launched in 2014. DX-1, a Dauria-operated satellite also launched in 2014, is a technology development platform being used to inform the design of the Perseus constellation. Dauria received a $20M investment from I2BF Global Ventures in October 2013 to support the Perseus constellation.

Canada-based Urthecast purchased both Deimos satellites and the associated data archive in 2015.

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: IKONOS, GeoEye-1, WorldView-1, WorldView-2, and WorldView-3. WorldView-3 successfully launched in 2014 aboard an Atlas V 401 vehicle. Another satellite, WorldView-4 (formerly GeoEye-2), was launched in 2016.

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).

DMC International Imaging

DMC International Imaging, Ltd. (DMCii), based in the United Kingdom, operates the Disaster Monitoring Constellation (DMC) on behalf of governments that provide the satellites. DMCii is a wholly owned subsidiary of SSTL. The constellation's primary purpose is to distribute imagery for commercial and humanitarian purposes.

The original DMC constellation (Alsat-1, Beijing-1, BilSat, Nigeriasat-1, and UK-DMC1) became fully operational in 2006, with satellites evenly distributed in a single sun-synchronous orbit (SSO). 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. The satellites orbit at an altitude of 700 km (435 mi). Nigeria's satellites Nigeriasat-2 and NX were launched in 2011 and represent the latest members of the DMC constellation.

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 will provide one-meter panchromatic and four-meter multispectral imaging.

GeoOptics Inc.

GeoOptics is a relatively new company 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.

GeoOptics aims to have an operational constellation of 24 satellites by the end of 2018. GeoOptics plans to have all the satellites launched by smallsat launch providers such as Virgin Galactic's LauncherOne system. However, because the company has not yet announced sufficient financing for the space-based segment, these launches are not included in the forecast.

Iceye

Finland-based Iceye is planning to deploy up to 20 satellites equipped with synthetic aperture radar (SAR). These satellites, built by York Space Systems (bus) and Iceye itself (payload), will begin deploying in 2018 aboard Vector H vehicles provided by Vector Space Systems. A prototype satellite designed to test the system's uniquely small SAR technology may launch in late 2017. The company had raised at least $2.8M in funding by the end of 2016.

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, it is expected that EROS-C will be launched in 2017 aboard a small vehicle. EROS-C is designed to have a service life of about ten years.

MacDonald, Dettwiler and Associates (MDA)

MDA built and operates RADARSAT-2. The company is a commercial provider of advanced geospatial information products derived from the high-resolution RADARSAT-1 (no longer in service) and RADARSAT-2 satellites. 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 1-m (3.3-ft) 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.

Urthecast/OmniEarth

Canada-based Urthecast and U.S-based OmniEarth aim to deploy three satellites and possibly more as part of a constellation called OptiSAR. OptiSAR will consist of satellites featuring both optical and radar sensors. In addition to GIS, the company plans to provide change detection services for commercial and government clients.

OmniEarth originally planned to deploy 18 optical satellites, but it has partnered with UrtheCast to develop and deploy UrtheDaily, an optical constellation of 8 satellites.

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 Global Positioning System) in a proven process called radio occultation. The current plan is to launch 12 satellites by 2017 with 18 total by 2020, all likely to be secondary payloads. PlanetiQ is currently raising funds to support construction of the constellation.

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 Black Bridge. In February 2017, Planet purchased Google's Terra Bella system for an undisclosed amount.

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 2017. Other Planet satellites will continue to be launched on cargo missions to the ISS following an operational pattern begun in 2014.

Terra Bella

Terra Bella, formerly Skybox Imaging, Inc. and based in Mountain View, California, is a new entrant to the commercial satellite remote sensing industry. The company obtained a NOAA license for SkySat-1 on April 20, 2010, and has applied to amend the license to include a second satellite, SkySat-2. SkySat-1 launched in 2013 aboard a Dnepr vehicle along with several other satellites. SkySat-2 launched as secondary satellite aboard a Soyuz 2 in 2014. The long-term goal is to field a 24-satellite constellation. Space Systems Loral is building the first 13 of these satellites under a contract signed in February 2014. Terra Bella was acquired by Planet in February 2017.

Four SkySat satellites were launched in 2016 aboard a PSLV, and six SkySat satellites are to follow in 2017 aboard an Orbital ATK Minotaur-C vehicle. Terra Bella has also been in discussions with Virgin Galactic for the launch of satellites aboard LauncherOne, a new small-class launch vehicle. Since this vehicle can only carry one SkySat at a time, the forecast projects that three SkySat satellites will be launched individually in 2017.

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) 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/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 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 2016, Spire had raised about $71 million.

Spire satellites will likely be launched as secondary payloads. However, they may also be launched as primary payloads on small satellite launch vehicles. Because these vehicles have not yet flown, and no launch contracts have been publicly announced, dedicated launches of Spire satellites are not included in this forecast.

COMMERCIAL CARGO AND CREW TRANSPORTATION SERVICES

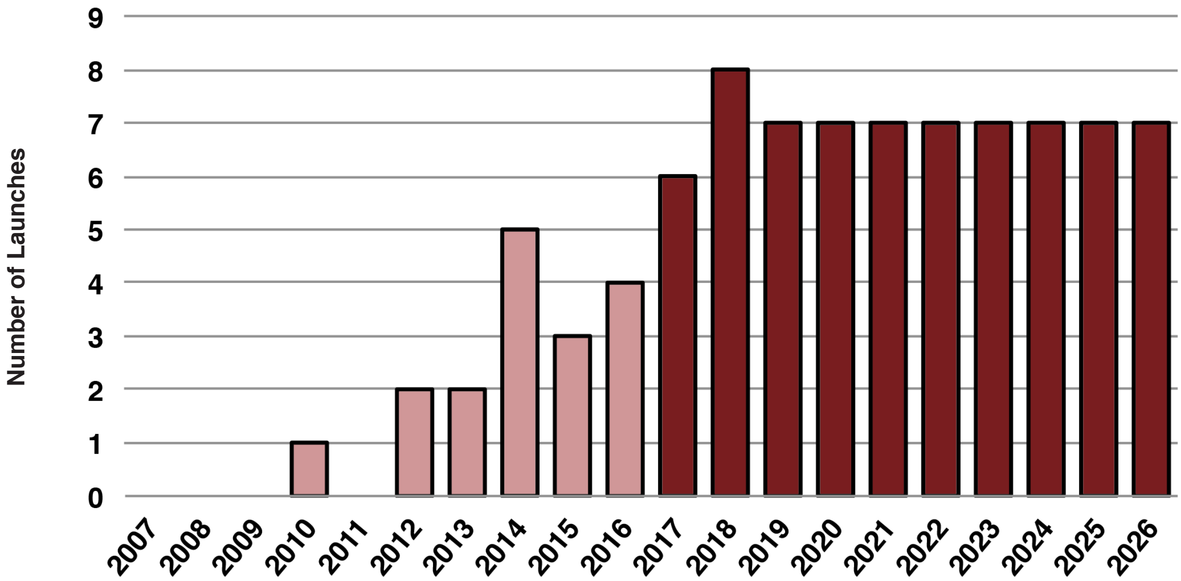
Commercial cargo and crew transportation capabilities include commercial launches of cargo and humans to LEO, the Moon, or other solar system destinations. Specifically, commercial cargo and crew transportation captures commercial crew and cargo services in support of NASA's mission and other private 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 cargo and crew missions conducted from the U.S. are licensed by FAA AST.

Commercial Cargo and Crew Transportation Services Launch Demand Summary

Seventy-nine commercial cargo and crew launches are projected from 2017 to 2026. All the launches forecasted in the next ten years are in support of commercial crew and cargo resupply to the ISS. 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 2017 to 2024 (it is not yet clear how ISS support operations will be conducted 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

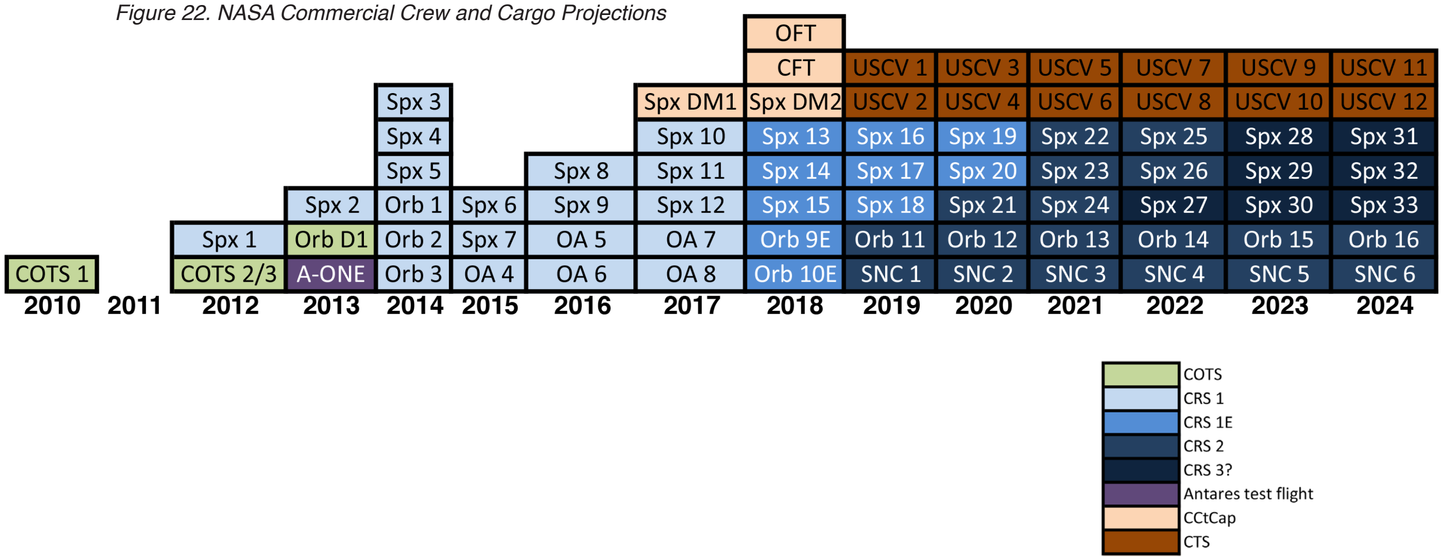
In 2006, NASA announced Commercial Orbital Transportation Services (COTS), a program focused on the development and demonstration of commercial cargo transportation systems. Total Space Act Agreement (SAA) funding under this program was $889M. Under COTS, SpaceX developed the intermediate Falcon 9 launch 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.



2017	2018	2019	2020
Spx 10 - Falcon 9	Spx 13 - Falcon 9	Spx 16 - Falcon 9	Spx 19 - Falcon 9
Spx 11 - Falcon 9	Spx 14 - Falcon 9	Spx 17 - Falcon 9	Spx 20 - Falcon 9
Spx 12 - Falcon 9	Spx 15 - Falcon 9	Spx 18 - Falcon 9	Spx 21 - Falcon 9
OA 7 - Antares	Orb 9E - Antares	Orb 11 - Antares	Orb 12 - Antares
OA 8 - Antares	Orb 10E - Antares	SNC 1 - Atlas V	SNC 2 - Atlas V
Spx DM1 - Falcon 9	Spx DM2 - Falcon 9	USCV 1 - Falcon 9	USCV 3 - Falcon 9
	OFT - Altas V	USCV 2 - Atlas V	USCV 4 - Atlas V
	CFT - Atlas V		

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. NASA awarded a second commercial resupply services contract (CRS 2) in January 2016 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.

Table 22 on the following page 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

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 sq m (341,550 sq ft), 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.

Planetary Resources

In April 2012, Planetary Resources, Inc., a company formed by Space Adventures founder Eric Anderson and X PRIZE Chairman Peter Diamandis, introduced its plans to mine near-Earth asteroids for raw materials. In its initial efforts, Planetary Resources is focusing on telescopes designed to identify resource-rich targets. It has entered into an agreement with Virgin Galactic to launch several constellations of Arkyd-100 Series LEO space telescopes on Virgin Galactic's LauncherOne. The company has decided to use its Arkyd platform, combined with hyperspectral sensors, for an Earth observing constellation called CERES. Revenue generated and experience gained from this constellation will inform future plans for asteroid detection and characterization. No date has been set for deployment of the CERES constellation.

Google Lunar X PRIZE

The 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 land 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, 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.

Space Adventures

Space Adventures, a broker for space tourism and expeditions, indicated in 2011 that it was in the late planning stages for a three-person expedition to circumnavigate the Moon. Two of the individuals will pay for their seats, while a third will be a Roscosmos cosmonaut. This effort will include two separate launches, one of a Proton-M carrying a Block-DM lunar transfer stage and one of a Soyuz with two crew members. The ticket price for each of the seats is rumored to be about $150M. The company has indicated that at least one ticket has been sold and that the other is in final negotiations. However, conflicting information from Russian industry sources and a lack of announced launch contracts means that this lunar mission is not included in the forecast.

Stratolaunch Systems-Sierra Nevada Corporation

Following NASA's September 2014 CCtCap awards, SNC vowed to continue development of its Dream Chaser vehicle. A joint effort between Stratolaunch Systems and SNC emerged late in 2014, in which a scaled down version of Dream Chaser capable of carrying two crew members may be launched around 2019. The spaceplane would be carried into orbit using Stratolaunch's Eagle system, featuring a large aircraft called Roc as the first stage and an Orbital ATK solid motor second stage with a LEO capacity of at least 5,000 kg (11,023 lb) called Thunderbolt. This particular test launch is not included in the forecast as few technical details have been released publicly.

OTHER COMMERCIALLY LAUNCHED SATELLITES

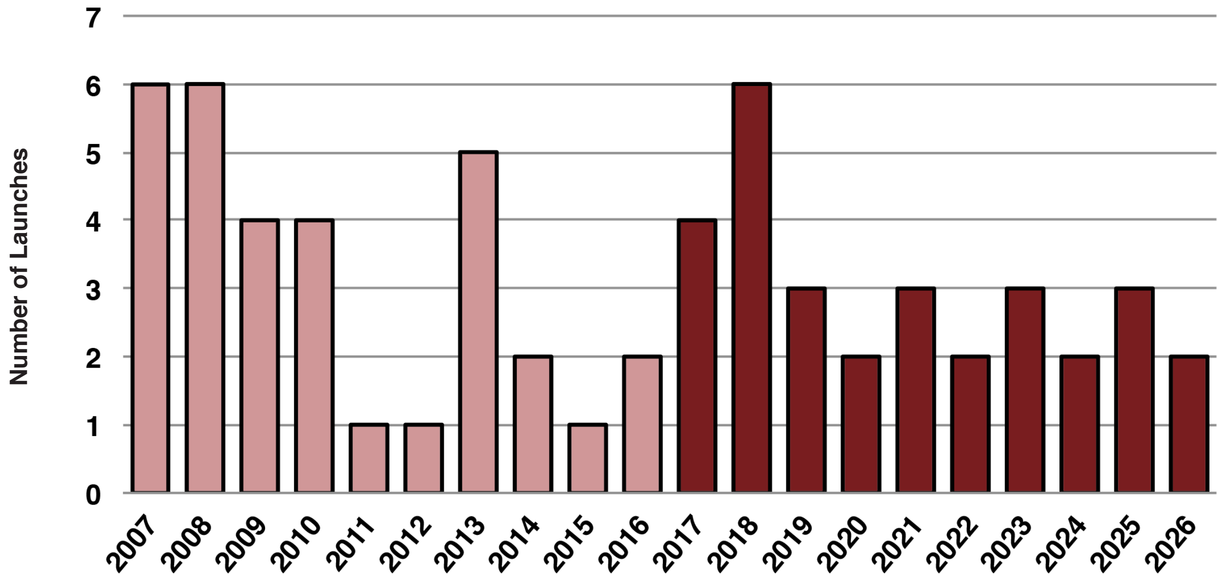
This section contains predominantly government satellites launched commercially. It also includes university payloads that are scientific, education, or outreach. Though many government missions do not commercially procure or obtain commercial licenses for their launches, there are select missions that 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 (2017–2020) includes 15 manifested launches. For the period 2021–2026, forecasting projects 15 launches for an average of 2.5 in each of the 6 out years. Figure 23 provides a launch history and projected launch plan demands for Other Commercially Launched Satellites.

TECHNOLOGY TEST AND DEMONSTRATION LAUNCHES

Technology test and demonstration launches are conducted to test primarily



2017	2018	2019	2020
SAOCOM 1A - Falcon 9	DragonLab - Falcon 9	TBD (govt) - TBD	DragonLab - Falcon 9
Formosat 5 - Falcon 9	DubaiSat 3 - HII-A	TBD (govt) - TBD	Kompsat 6 - Angara 1.2
PAZ - Dnepr	SAOCOM 1B - Falcon 9	Spaceflight Ind. - Falcon 9	
Spaceflight Ind. - Falcon 9	EnMAP - PSLV		
	Formosat 7 (6) - Falcon H		
	INGENIO - Vega		

Figure 23. Other Commercially Launched Satellites Launch History and Projected Launch Plans

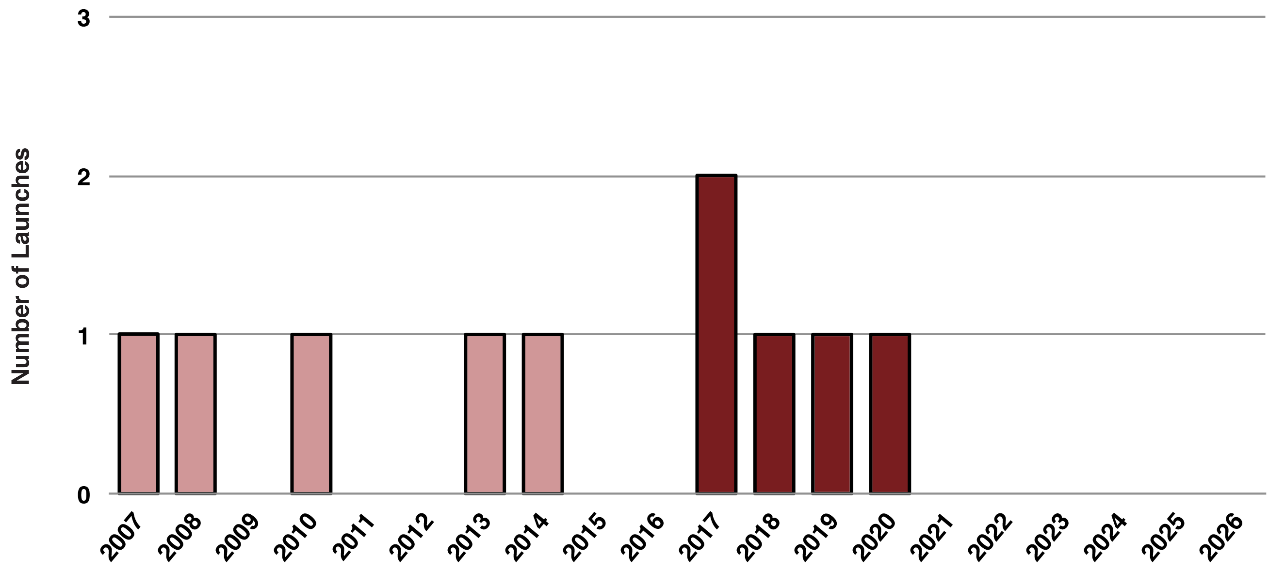
new launch and space vehicles. By their nature, these are not events taking place on a regular basis. Figure 24 provides a launch history and projected launch plans for technology test and demonstration launches.

Technology Test and Demonstration Demand Summary

The inaugural launch of SpaceX's Falcon Heavy launch vehicle is now planned for launch in 2017. The report also includes the technology test and demonstration launches of new small class commercial launch vehicles like Electron, GOLauncher-2, LauncherOne, and Stratolaunch. Test flights of other new orbital launch vehicles currently in development are anticipated in the same time frame and are either not reflected in this forecast as intended primarily for launching government missions or shown in other sections if their inaugural launches carry payloads from commercial customers.

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:



2017	2018	2019	2020
Electron test flight	LauncherOne test flight	GOLauncher-2 test flight	Stratolaunch test flight
Falcon Heavy test flight			

Figure 24. Technology Test and Demonstration Launch History and Projected Launch Plans

- 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.

Blue Origin conducts a successful launch of its New Shepard on a suborbital test mission, October 5, 2016. 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. AST also receives public input in support of regulatory development via the Commercial Space Transportation Advisory Committee (COMSTAC), so this section includes a description of that body and its activities during the calendar year.

CURRENT LAW AND POLICY

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 by the Senate on November 10, the House of Representatives on November 16, 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.

COMMERCIAL SPACE TRANSPORTATION ADVISORY COMMITTEE

Commercial Space Transportation Advisory Committee (COMSTAC) was established in 1984 to provide information, advice, and recommendations to the FAA Administrator on critical matters concerning the U.S. commercial space transportation industry.

The economic, technical, and institutional expertise provided by COMSTAC members has been invaluable to AST in developing effective regulations that ensure safety during commercial launch operations and policies that support international competitiveness for the industry.

Purpose, Scope, and 2016 Membership

COMSTAC provides information, advice, and recommendations to the FAA Administrator on all matters relating to U.S. commercial space transportation industry activities. It does not exercise program management responsibilities and makes no decisions directly affecting the programs on which it provides advice; it only provides a forum for the development, consideration, and communication of information from a knowledgeable, independent perspective.

COMSTAC’s charter allows it to:

- Undertake such information-gathering activities as necessary to address issues identified by the FAA for consideration by the committee, develop recommendations on those issues, and present the committee’s recommendations to the Administrator.
- Evaluate economic, technological, and institutional developments relating to commercial space transportation and submit to the Administrator recommendations on promising new ideas and approaches for federal policies and programs.
- Provide the FAA with direct, first-hand information and insight from the substantially affected interests by exchanging ideas about FAA regulations

and rulemakings that may require changes or elimination. The committee's activities must satisfy the normal rulemaking and public comment process. The FAA will disclose in the public docket any committee communication on any particular issue in a rulemaking. The FAA will include an assessment of how the communication affects the development of proposed rules in the docket or preamble of any proposed rule. The committee will undertake only those tasks assigned by the FAA. Neither the committee nor any of its working groups may assign a task without prior approval by the FAA.

- Serve as a forum for the discussion of problems involving the relationship between industry activities and federal government requirements.

The following individuals served as members of COMSTAC during 2016:

- **Michael Gold (Chair), Bigelow Aerospace *(from May 2016, SSL)***
- **Michael Lopez-Alegria (Vice-Chair), MLA Space**
- Bretton Alexander, Blue Origin
- Chuck Beams, Vulcan
- Bill Beckman, The Boeing Company
- Daniel Collins, United Launch Alliance
- Richard DalBello, Virgin Galactic
- Debra Facktor Lepore, Ball Aerospace
- Oscar Garcia, InterFlight Global Corporation
- Jeff Greason, XCOR Aerospace
- Michael Griffin, Schafer Corporation
- Wayne Hale, Special Aerospace Services
- Dan Hendrickson, Astrobotic Technology
- Timothy Hughes, SpaceX
- Livingston Holder, Holder Aerospace
- Janet Karika, Interagency Launch Programs
- Bill Khourie, Oklahoma Space Industry Development Authority
- Christopher Kunstadter, XL Insurance
- Kris Lehnhardt, George Washington University
- Steven Lindsey, Sierra Nevada Corporation
- Samantha Marquart, George Washington University
- Dale Nash, Virginia Commercial Space Flight Authority
- Carl Rising, Stellar Solutions
- Frank Slazer, Aerospace Industries Association
- Mark Sundhahl, Cleveland State University
- Jennifer Warren, Lockheed Martin
- Charity Weeden, Satellite Industry Association

DEFINITIONS

Commercial Suborbital or Orbital Launch

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

- The launch is licensed by 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).

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 (such as those used for Russian Molniya satellites), 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.

Payload Mass Class

Table 11 provides the payload mass classes used by AST.

Class Name	Kilograms (kg)	Pounds (lb)
Femto	0.01 - 0.1	0.02 - 0.2
Pico	0.09 - 1	0.19 - 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. Payload 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
COMSTAC	Commercial Space Transportation Advisory Committee
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

2016 Worldwide Orbital Launch Events

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
15-Jan-16			Long March 3B	Xichang		Belintersat 1	GEO	Belintersat	China Academy of Space Technology (CAST)	Communications		S	S
17-Jan-16			Falcon 9 v1.1	Vandenburg AFB (VAFB)		Jason 3	GEO	NOAA/Eumetsat	Thales Alenia Space	Scientific		S	S
20-Jan-16			PSLV XL	Satish Dhawan		IRNSS 1E	GEO	Indian Space Research Organization (ISRO)	ISRO	Navigation		S	S
27-Jan-16	√		Ariane 5 ECA	Guiana Space Center	*	Intelsat 29e	GEO	Intelsat	The Boeing Company	Communications	$178M	S	S
29-Jan-16	√		Proton M	Baikonur	*	Eutelsat 9B	GEO	Eutelsat	Airbus	Communications	$65M	S	S
01-Feb-16			Long March 3C	Xichang		BeiDou M3-S	MEO	China National Space Agency (CNSA)	China Academy of Sciences (CAS)	Navigation		S	S
05-Feb-16			Atlas V 401	Cape Canaveral AFS (CCAFS)		GPS IIF-12 (USA 266)	MEO	USAF	The Boeing Company	Navigation		S	S
07-Feb-16			Soyuz 2.1b	Plesetsk		Glonass M 751 (Cosmos 2514)	MEO	Russian Aerospace Forces	ISS Reshetnev	Navigation		S	S
07-Feb-16			Unha 3	Sohae		Kwangmyŏngsŏng 4	LEO	Korean Committee of Space Technology	Korean Committee of Space Technology	Development		S	S
10-Feb-16			Delta IV Medium+ (5,2)	VAFB		NRO L-45 (USA 267)	LEO	National Reconnaissance Office (NRO)	Classified	IMINT		S	S
16-Feb-16			Rockot	Plesetsk		Sentinel 3A	SSO	European Space Agency (ESA)	Thales Alenia Space	Remote Sensing		S	S
17-Feb-16			H-IIA 202	Tanegashima		Hitomi (ASTRO H)	LEO	Japan Aerospace Exploration Agency (JAXA)/NASA	JAXA	Scientific		S	F
						Chubusat 2	LEO	Nagoya University	Nagoya University	Communications			S
						Chubusat 3	LEO	Mitsubishi Heavy Industries (MHI)	MHI	Remote Sensing			S
						Horyu 4	LEO	Kyushu Institute of Technology	Kyushu Institute of Technology	Development			S
04-Mar-16	√	+	Falcon 9 FT	CCAFS	*	SES 9	GEO	SES SA	The Boeing Company	Communications	$62M	S	S
09-Mar-16	√		Ariane 5 ECA	Guiana Space Center	*	Eutelsat 65 West A	GEO	Eutelsat	Space Systems Loral (SSL)	Communications	$178M	S	S
10-Mar-16			PSLV XL	Satish Dhawan		IRNSS 1F	GEO	Indian Space Research Organization (ISRO)	ISRO	Navigation		S	S
13-Mar-16			Soyuz 2.1b	Baikonur		Resurs P No. 3	SSO	Roscosmos	TsSKB Progress	Remote Sensing		S	S
14-Mar-16			Proton M	Baikonur		ExoMars Trace Gas Orbiter	EXT	ESA	Khrunichev State Research and Production Space Center	Scientific		S	S
18-Mar-16			Soyuz FG	Baikonur		Soyuz TMA-20M	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
23-Mar-16	√	+	Atlas V 401	CCAFS	*	OA 6	LEO	Orbital ATK	Orbital ATK	Cargo Transport	$109M	S	S
					*	ISS deployment: Flock 2e (20)	LEO	Planet	Planet	Remote Sensing			S
					*	ISS deployment: Lemur 2 (9)	LEO	Spire Global	Spire Global/Clyde Space	Remote Sensing			S
						ISS deployment: Diwata 1	LEO	Department of Science and Technology (DOST)	DOST/Tohoku University	Remote Sensing			S
24-Mar-16			Soyuz 2.1a	Plesetsk		Bars M (Cosmos 2515)	SSO	Russian Aerospace Forces	TsSKB Progress	IMINT		S	S
29-Mar-16			Long March 3A	Xichang		BeiDou IGSO-6	ELI	CNSA	CAST	Navigation		S	S
31-Mar-16			Soyuz 2.1a	Baikonur		Progress MS-2	LEO	Roscosmos	RKK Energia	Cargo Transport		S	S
05-Apr-16			Long March 2D	Jiuquan		Shijian 10	LEO	CNSA	CAS	Scientific		S	S
08-Apr-16	√	+	Falcon 9 FT	CCAFS	*	Spx 8	LEO	Space Exploration Technologies (SpaceX)	SpaceX	Cargo Transport	$62M	S	S
					*	BEAM	LEO	Bigelow Aerospace	Bigelow Aerospace	Development			S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
25-Apr-16			Soyuz 2.1a	Guiana Space Center		Sentinel 1B	SSO	ESA	Thales Alenia Space	Remote Sensing		S	S
						MICROSCOPE	SSO	Centre National d'Etudes Spatiales (CNES)	CNES/Airbus	Scientific			S
						AAUSAT 4	SSO	Aalborg University Cubesat	Aalborg University Cubesat	Development			S
						e-st@r II	SSO	Politecnico di Torino	Politecnico di Torino	Development			S
						OUFTI 1	SSO	Université de Liège	Université de Liège	Development			S
28-Apr-16			Soyuz 2.1a	Vostochny		Mikhailo Lomonosov	SSO	Moscow State University	Moscow State University	Scientific		S	S
						Aist 2D	SSO	Samara State Aerospace University	Samara State Aerospace University	Development			S
						SamSat 218/D	SSO	Samara State Aerospace University	Samara State Aerospace University	Development			S
28-Apr-16			PSLV XL	Satish Dhawan		IRNSS 1G	GEO	ISRO	ISRO	Navigation		S	S
06-May-16	√	+	Falcon 9 FT	CCAFS	*	JCSAT 14	GEO	SKY Perfect JSAT Group (JSAT)	SSL	Communications	$62M	S	S
15-May-16			Long March 2D	Jiuquan		Yaogan 30	SSO	CNSA	CAST	IMINT		S	S
24-May-16			Soyuz 2.1b	Guiana Space Center		Galileo FOC FM10 (Danielė)	MEO	ESA/ European GNSS Agency	OHB System GmbH	Navigation		S	S
						Galileo FOC FM11 (Alizée)	MEO	ESA/ European GNSS Agency	OHB System GmbH	Navigation			S
27-May-16	√	+	Falcon 9 FT	CCAFS	*	Thaicom 8	GEO	Thaicom	Orbital ATK	Communications	$62M	S	S
29-May-16			Soyuz 2.1b	Plesetsk		Glonass M 753 (Cosmos 2516)	MEO	Russian Aerospace Forces	ISS Reshetnev	Navigation		S	S
30-May-16			Long March 4B	Taiyuan		Ziyuan III No. 2	SSO	CNSA	CAST	Remote Sensing		S	S
					*	ÑuSat 1	SSO	Satellogic SA	Satellogic SA	Remote Sensing			S
					*	ÑuSat 2	SSO	Satellogic SA	Satellogic SA	Remote Sensing			S
04-Jun-16			Rockot	Plesetsk		Geo IK-2 No. 12 (Cosmos 2517)	LEO	Russian Aerospace Forces	ISS Reshetnev	Remote Sensing		S	S
09-Jun-16	√		Proton M	Baikonur	*	Intelsat 31 (DLA 2)	GEO	Intelsat/DirecTV	SSL	Communications	$65M	S	S
11-Jun-16			Delta IV Heavy	CCAFS		NRO L-37 (USA 268)	GEO	NRO	Classified	SIGINT		S	S
12-Jun-16			Long March 3C	Xichang		BeiDou G7	GEO	CNSA	CAST	Navigation		S	S
15-Jun-16	√	+	Falcon 9 FT	CCAFS	*	Eutelsat 117 West B (Satmex 9)	GEO	Eutelsat	The Boeing Company	Communications	$62M	S	S
					*	ABS 2A	GEO	Asia Broadcast Satellite (ABS)	The Boeing Company	Communications			S
18-Jun-16	√		Ariane 5 ECA	Guiana Space Center	*	EchoStar XVIII	GEO	EchoStar	SSL	Communications	$178M	S	S
					*	BRIsat	GEO	Bank Rakyat Indonesia	SSL	Communications			S
22-Jun-16			PSLV XL	Satish Dhawan		Cartosat 2C	SSO	ISRO	ISRO	Remote Sensing		S	S
						SathyabamaSat	SSO	Sathyabama University	Sathyabama University	Remote Sensing			S
						Swayam	SSO	Pune College of Engineering	Pune College of Engineering	Development			S
					*	Flock 2P (12)	SSO	Planet	Planet	Remote Sensing			S
					*	GHGSat D	SSO	GHGSat, Inc.	UTIAS Space Flight Laboratory (SFL)	Remote Sensing			S
						M3MSat	SSO	Canadian Space Agency (CSA)	CSA	Communications			S
					*	SkySat 3	SSO	Terra Bella	SSL	Remote Sensing			S
						BIROS	SSO	Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)	DLR	Remote Sensing			S
						LAPAN A3	SSO	Lembaga Penerbangan dan Antariksa Nasional (LAPAN)	LAPAN	Remote Sensing			S
24-Jun-16			Atlas V 551	CCAFS		MUOS 5	GEO	U.S. Navy	Lockheed Martin	Communications		S	S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
25-Jun-16			Long March 7	Wenchang		Duoyongtu Feichuan Fanhui Cang	LEO	CNSA	CAST	Development		S	S
						Aoxiang Zhixing	LEO	Northwestern Polytechnical University	Northwestern Polytechnical University	Development			S
						Aolong 1	LEO	China Academy of Launch Vehicle Technology (CALT)	China Academy of Launch Vehicle Technology (CALT)	Development			S
						Tiange Feixingqi 1	LEO	Unknown	Unknown	Development			S
						Tiange Feixingqi 2	LEO	Unknown	Unknown	Development			S
29-Jun-16			Long March 4B	Jiuquan		Shijian 16-02	LEO	People's Liberation Army (PLA)	CAS	ELINT		S	S
07-Jul-16			Soyuz FG	Baikonur		Soyuz MS-1	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
16-Jul-16			Soyuz U	Baikonur		Progress MS-3	LEO	Roscosmos	RKK Energia	Cargo Transport		S	S
18-Jul-16	√	+	Falcon 9 FT	CCAFS	*	Spx 9	LEO	SpaceX	SpaceX	Cargo Transport	$62M	S	S
28-Jul-16			Atlas V 421	CCAFS		NRO L-61 (USA 269)	GEO	NRO	Classified	Communications		S	S
05-Aug-16			Long March 3B	Xichang		Tiantong 1 No. 1	GEO	CAST	CAST	Communications		S	S
09-Aug-16			Long March 4C	Taiyuan		Gaofen 3	SSO	CNSA	CAST	Remote Sensing		S	S
14-Aug-16	√	+	Falcon 9 FT	CCAFS	*	JCSAT 16	GEO	JSAT	SSL	Communications	$62M	S	S
15-Aug-16			Long March 2D	Jiuquan		QUESS	SSO	CAS	CAS	Development		S	S
						Lixing 1	SSO	CAS	CAS	Development			S
						3Cat 2	SSO	Polytechnic University of Catalonia	Polytechnic University of Catalonia	Development			S
19-Aug-16			Delta IV Medium+ (4,2)	CCAFS		GSSAP 3 (USA 270)	GEO	U.S. Air Force (USAF)	Orbital ATK	Space Surveillance		S	S
						GSSAP 4 (USA 271)	GEO	USAF	Orbital ATK	Space Surveillance			S
24-Aug-16	√		Ariane 5 ECA	Guiana Space Center	*	Intelsat 33e	GEO	Intelsat	The Boeing Company	Communications	$178M	S	S
					*	Intelsat 36	GEO	Intelsat	SSL	Communications			S
31-Aug-16			Long March 4C	Taiyuan		Gaofen 10	SSO	CNSA	CAST	Remote Sensing		F	F
08-Sep-16			GSLV Mk II	Satish Dhawan		Insat 3DR	GEO	ISRO	ISRO	Meteorology		S	S
08-Sep-16			Atlas V 411	CCAFS		OSIRIS-REx	EXT	NASA	Lockheed Martin	Scientific		S	S
13-Sep-16			Shavit	Palmachim AFB		Ofeq 11	LEO	Israel Defense Forces (IDF)	Israel Aerospace Industries (IAI)	IMINT		S	S
15-Sep-16			Long March 2F	Jiuquan		Tiangong 2	LEO	CNSA	CAST	Space Station		S	S
						BanXing 2	LEO	SAST	SAST	Development			S
16-Sep-16	√		Vega	Guiana Space Center		PerúSat 1	SSO	Fuerzas Armadas del Perú	Airbus	IMINT	$37M	S	S
					*	SkySat (4)	SSO	Terra Bella	SSL	Remote Sensing			S
26-Sep-16			PSLV G	Satish Dhawan		ScatSat 1	SSO	ISRO	ISRO	Meteorology		S	S
						Pratham	SSO	IIT Bombay	IIT Bombay	Development			S
						PISAT	SSO	PES University	PES University	Remote Sensing			S
					*	Pathfinder 1	SSO	BlackSky Global	BlackSky Global	Remote Sensing			S
						Alsat 1N	SSO	Algerian Space Agency	Algerian Space Agency	Remote Sensing			S
						Alsat 1B	SSO	Algerian Space Agency	Algerian Space Agency	Remote Sensing			S
						Alsat 2B	SSO	Algerian Space Agency	Algerian Space Agency	Remote Sensing			S
						CanX 7	SSO	UTIAS Space Flight Laboratory	UTIAS Space Flight Laboratory	Development			S
05-Oct-16	√		Ariane 5 ECA	Guiana Space Center	*	NBN Co 1B	GEO	NBN Co Limited	SSL	Communications	$178M	S	S
						GSAT 18	GEO	ISRO	ISRO	Communications			S
16-Sep-16			Long March 2F	Jiuquan		Shenzhou 11	LEO	CNSA	CAST	Crew Transport		S	S
17-Oct-16	√	+	Antares 230	Mid-Atlantic Regional Spaceport (MARS)	*	OA 5	LEO	Orbital ATK	Orbital ATK	Cargo Transport	$80M	S	S
					*	ISS deployment: Lemur (4)	LEO	Spire Global	Spire Global/Clyde Space	Remote Sensing			S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
19-Oct-16			Soyuz FG	Baikonur		Soyuz MS-2	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
02-Nov-16			H-IIA 202	Tanegashima		Himawari 9	GEO	Japan Meteorological Agency	Mitsubishi Electric (MELCO)	Meteorology		S	S
03-Nov-16			Long March 5	Wenchang		Shijian 17	GEO	CAST	CAST	Development		S	S
09-Nov-16			Long March 11	Jiuquan		XPNAV 1	SSO	CAS	CAS	Scientific	S		S
						Xiaoxiang 1	SSO	Changsha Gaoxinqu Tianyi Research Institute	Changsha Gaoxinqu Tianyi Research Institute	Development			S
11-Nov-16	√	+	Atlas V 401		*	WorldView 4	SSO	DigitalGlobe	Ball Aerospace	Remote Sensing	$109M	S	S
						CELTEE 1	SSO	M42 Technologies	M42 Technologies	Development			S
						Prometheus 2 (2)	SSO	Los Alamos National Laboratory (LANL)	LANL	Development			S
						AeroCube 8 (2)	SSO	The Aerospace Corporation	The Aerospace Corporation	Development			S
						OptiCube 4	SSO	NASA	NASA	Development			S
						RAVAN	SSO	Johns Hopkins University Applied Physics Laboratory (APL)	APL	Development			S
11-Nov-16			Long March 2D	Jiuquan		Yunhai 1	LEO	SAST	SAST	Remote Sensing		S	S
17-Nov-16			Ariane 5 ES	Guiana Space Center		Galileo FOC FM7 (Antonianna)	MEO	ESA/ European GNSS Agency	OHB System GmbH	Navigation		S	S
						Galileo FOC FM12 (Lisa)	MEO	ESA/ European GNSS Agency	OHB System GmbH	Navigation			S
						Galileo FOC FM13 (Kimberly)	MEO	ESA/ European GNSS Agency	OHB System GmbH	Navigation			S
						Galileo FOC FM14 (Tijmen)	MEO	ESA/ European GNSS Agency	OHB System GmbH	Navigation			S
17-Nov-16			Soyuz FG	Baikonur		Soyuz MS-3	LEO	Roscosmos	RKK Energia	Crew Transport		S	S
19-Nov-16			Atlas V 541	CCAFS		GOES R	GEO	NASA/NOAA	Lockheed Martin	Meteorology		S	S
22-Nov-16			Long March 3C	Xichang		Tianlian I-04	GEO	CNSA	CAST	Communications		S	S
01-Dec-16			Soyuz U	Baikonur		Progress MS-4	LEO	Roscosmos	RKK Energia	Cargo Transport		F	F
05-Dec-16	√		Vega	Guiana Space Center		Göktürk-1	SSO	Türk Silahlı Kuvvetleri (TSK)	Thales Alenia Space/ Turkish Aerospace Industries (TUSAŞ)	IMINT		S	S
07-Dec-16			PSLV XL	Satish Dhawan		Resourcesat 2A	SSO	ISRO	ISRO	Remote Sensing		S	S
07-Dec-16			Delta IV Medium+ (5,4)	CCAFS		WGS 8 (USA 272)	GEO	USAF	The Boeing Company	Communications		S	S
09-Dec-16			H-IIB	Tanegashima		HTV 6	LEO	JAXA	MHI	Cargo Transport		S	S
						ISS deployment: EGG	LEO	University of Tokyo	University of Tokyo	Development			S
						ISS deployment: STARS C	LEO	Kagawa University	Kagawa University	Development			S
						ISS deployment: FREEDOM	LEO	Nakashimada Engineering Works/ Tohoku University	Nakashimada Engineering Works/ Tohoku University	Development			S
						ISS deployment: ITF 2	LEO	University of Tsukuba	University of Tsukuba	Development			S
						ISS deployment: Waseda-SAT 3	LEO	Waseda University	Waseda University	Development			S
						ISS deployment: AOBA-VELOX 3	LEO	Kyushu Institute of Technology/ Nanyang Technological University	Kyushu Institute of Technology/ Nanyang Technological University	Development			S
						ISS deployment: OSNSAT	LEO	Open Space Network	Open Space Network	Development			S
						ISS deployment: TechEDSat	LEO	San Jose State University/University of Idaho	San Jose State University/University of Idaho	Development			S
						ISS deployment: Tancredo 1	LEO	Escola Municipal Presidente Tancredo de Almeida Neves	Escola Municipal Presidente Tancredo de Almeida Neves	Development			S
					*	ISS deployment: Lemur 2 (4)	LEO	Spire Global	Spire Global/Clyde Space	Remote Sensing			S

Date			Vehicle	Site		Payload(s)	Orbit	Operator	Manufacturer	Use	Comm'l Price	L	M
10-Dec-16			Long March 3B	Xichang		Fengyun 4A	GEO	China Meteorological Administration (CMA)	SAST	Meteorology		S	S
15-Dec-16			Pegasus XL	CCAFS		CYGNSS (8)	LEO	NASA	University of Michigan and Southwest Research Institute (SwRI)	Scientific		S	S
18-Dec-16	√	+	Atlas V 431	CCAFS	*	EchoStar XIX	GEO	EchoStar	SSL	Communications	$152M	S	S
20-Dec-16			Epsilon	Uchinoura		Arase (ERG)	ELI	JAXA	JAXA	Scientific		S	S
21-Dec-16			Long March 2D	Jiuquan		TanSat	SSO	CAS	CAS	Remote Sensing		S	S
						Spark (2)	SSO	CAS	CAS	Remote Sensing			S
21-Dec-16	√		Ariane 5 ECA	Guiana Space Center	*	Star One D1	GEO	Star One	SSL	Communications	$178M	S	S
					*	JCSAT 15	GEO	JSAT	SSL	Communications			
28-Dec-16			Long March 2D	Taiyuan	*	SuperView 1 (Gaojing 1-01)	SSO	Beijing Space View Technology	CAST	Remote Sensing		S	S
					*	SuperView 2 (Gaojing 1-02)	SSO	Beijing Space View Technology	CAST	Remote Sensing			S
						Bayi Kepu 1	SSO	CAST/Beijing Bayi High School	CAST/Beijing Bayi High School	Develoopment			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 Firefly Space Systems was founded in 2014 to provide launch services catering to operators of microsatellites.

The company plans to offer the Alpha launch vehicle, the first vehicle since Lockheed Martin's X-33 and *VentureStar* to feature an aerospike engine. If successful, it will be the first operational vehicle to employ an aerospike engine. A conventional rocket engine uses a nozzle to direct exhaust in one direction, maximing the output pressure needed to impart thrust. An aerospike differs by directing the exhaust along two paths that exit at the base of a linear spike and merge at the tip. The spike serves as one edge of a "virtual nozzle" while the ambient air pressure serves as the other edge. This means an aerospike engine is lighter, more aerodynamic, and more efficient through all altitudes, particularly at lower altitudes where the air is denser. An aerospike is 30% more efficient than a nozzle at sea level.

Fifty hot fire tests of the engine combustor were completed by September 2016, with full aerospike tests anticipated by "the end of 2016." However, these tests did not take place; in October 2016, the company laid off its entire staff following withdrawal of an undisclosed investor. Further developments have not been disclosed, though nine customers sent letters of intent to Firefly indicating interest in 42 Alpha launches through 2025 at an estimated value of $300M.

Firefly was selected in 2015 by NASA to conduct a demonstration CubeSat launch by March 2018. The Venture Class Launch Services (VCLS) contract to Firefly is valued at $5.5M.

Launch service provider
Firefly Space Systems

Organization Headquarters
USA

Manufacturer
Firefly Space Systems

Mass, kg (lb)
Undisclosed

Length, m (ft)
23.6 (77.3)

Diameter, m (ft)
1.5 (4.8)

Year of Planned First Launch
TBD

Launch site
KSC (LC-39C)

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
400 (882)

SSO capacity, kg (lb)
200 (441)

Estimated Price per Launch
$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/).

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

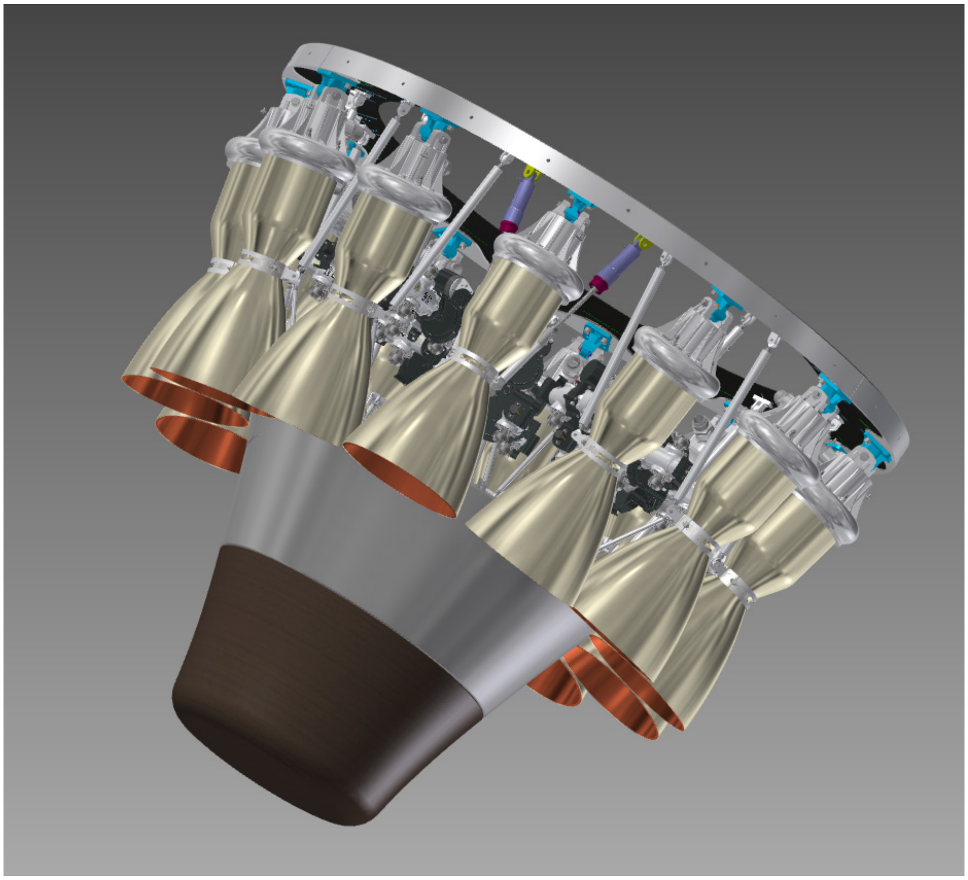
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Alpha 1.0

FAA AST



A 3D diagram of the FRE-2 aerospike engine that will be used to power the Alpha's first stage. (Source: Firefly Space Systems)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	1.8 (5.8)	1.5 (4.8)

	1st Stage	2nd Stage
Stage designation	1st Stage	2nd Stage
Length, m (ft)	16.7 (54.8)	4.6 (15)
Diameter, m (ft)	2 (6.6)	1.5 (4.8)
Manufacturer	Firefly Space Systems	Firefly Space Systems
Propellant	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	443 (99,600)	27.6 (6,200)
Engine(s)	1 x FRE-2	1 x FRE-1
Engine manufacturer	Firefly Space Systems	Firefly Space Systems
Engine thrust, kN (lbf)	556 (125,000)	31.1 (7,000)

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

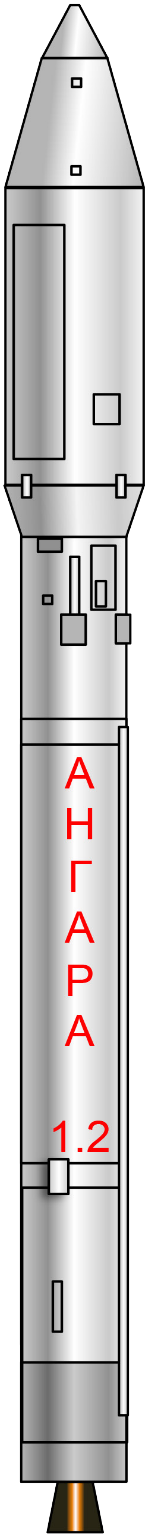
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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). 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
2016

Launch sites
Plesetsk

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
2,960 (6,526)

SSO capacity, kg (lb)
2,270 (5,004)

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.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

Launch Vehicle Fact Sheet

Angara 1.2

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)
Short Fairing	7.8 (25.6)	2.5 (8.2)
Long Fairing	9.9 (32.5)	3 (9.8)

	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/).

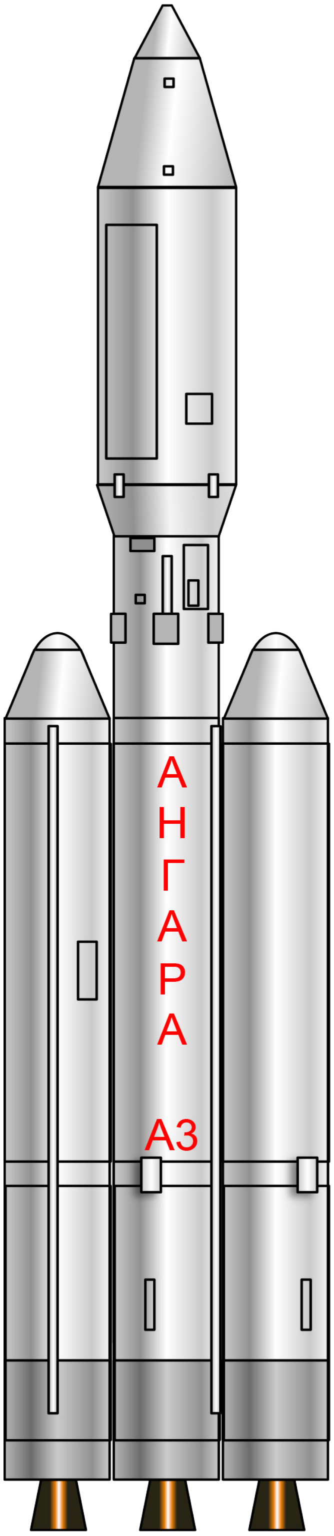
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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
Vostochny

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/).

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

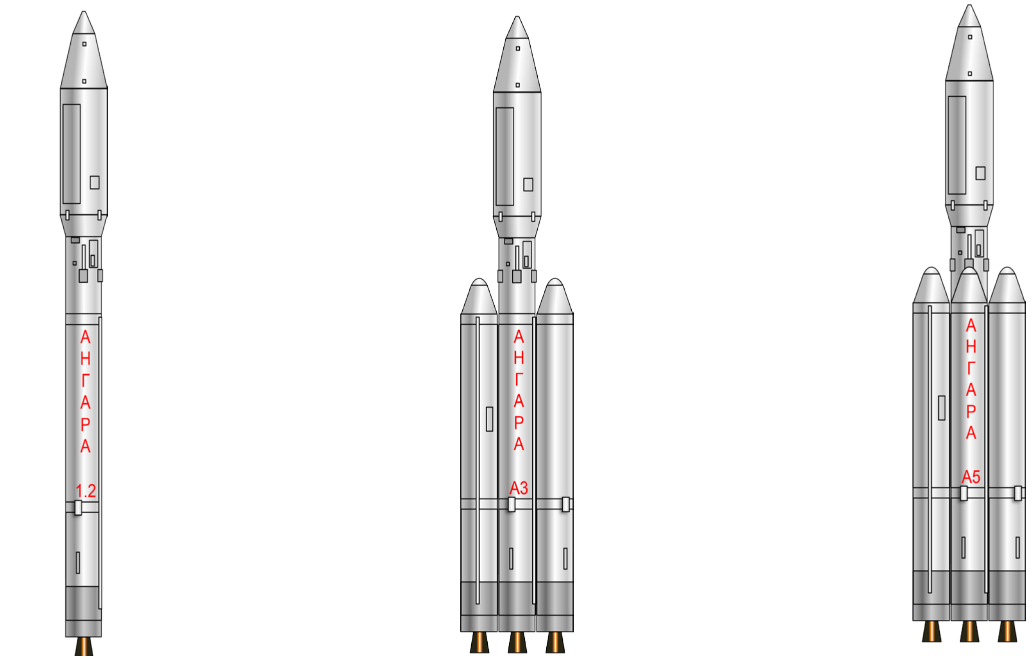
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Angara A3

FAA AST



Angara 1.2 **Angara A3** **Angara A5**

The Angara launch vehicle family. Note the modular approach based on the URM-1 booster for the first stage (one for Angara 1.2, three for Angara A3, and five for Angara A5) and the URM-2 for the seond stage.

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. 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/).

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

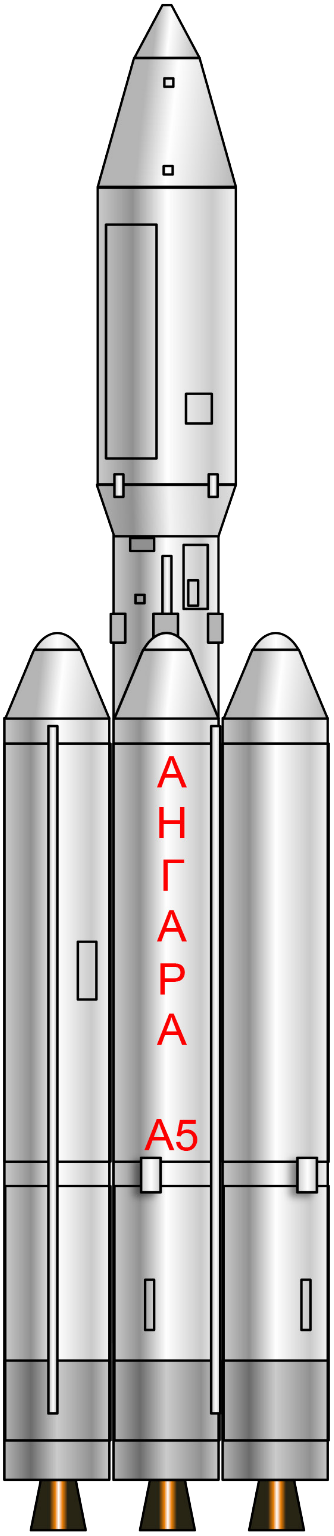
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Angara A5

FAA AST



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 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. The second flight is planned for 2017 and will carry Agnola-1 for the government of Angola.

A launch complex is being developed at Russia's new Vostochny Cosmodrome to accomodate 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 Launches
1

Reliability
100%

Launch sites
Plesetsk
Vostochny

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

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

SSO capacity, kg (lb)
N/A

Estimated Price per Launch
$100M

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

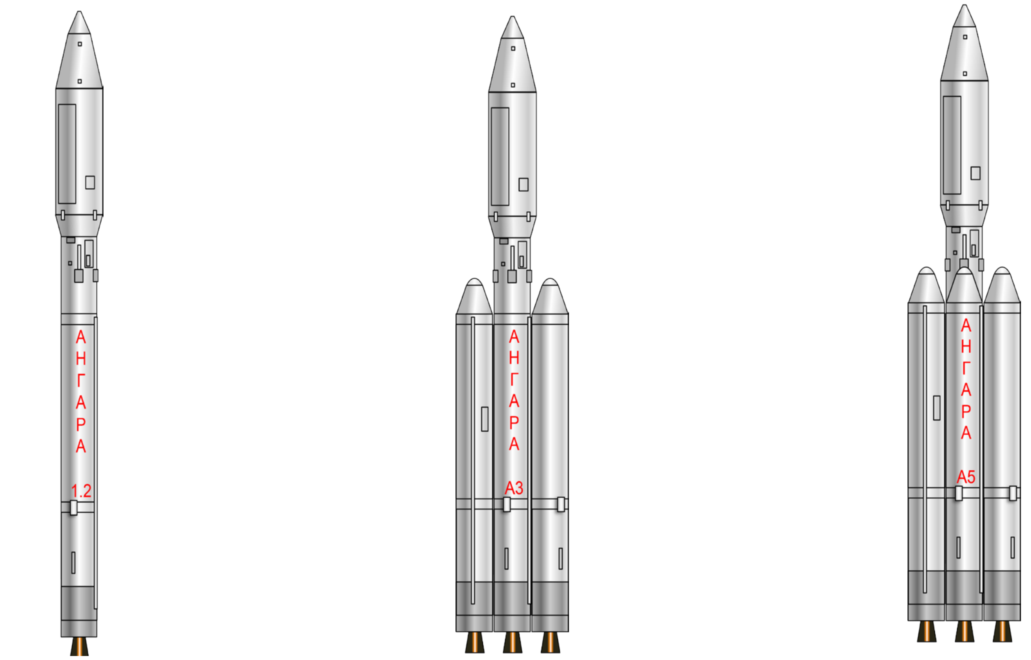
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Angara A5



Angara 1.2 **Angara A3** **Angara A5**

The Angara launch vehicle family. Note the modular approach based on the URM-1 booster for the first stage (one for Angara 1.2, three for Angara A3, and five for Angara A5) and the URM-2 for the seond stage.

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)	19.2 (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. 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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 customer can select from two different second stages, the Castor-30B or the Castor-30XL. 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 (originally named Taurus II) 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 Launches
6

Reliability
83%

Launch site
MARS (Pad 0-A)

GTO capacity, kg (lb)
N/A

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/).

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

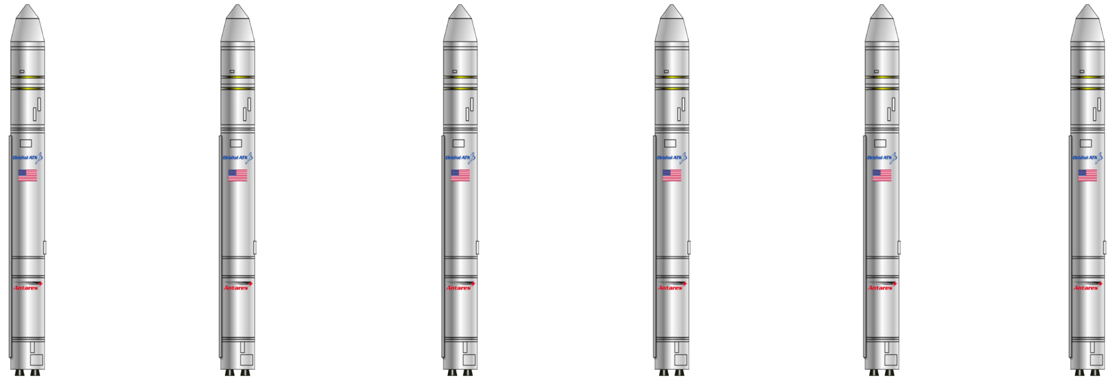
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Antares

The Antares family consists of six variants. The first stage, which is common to all six variants, can be outfitted with either a Castor 30B or 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.



Antares 220 | Antares 221 | Antares 222 | Antares 230 | Antares 231 | Antares 232

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-30B/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)	30B: 12,887 (28,411) 30XL: 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)	--

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Ariane 5 ECA

Launch service provider
Arianespace

Organization Headquarters
France

Manufacturer
Airbus Safran Launchers

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 Launches
65 (ECA and ES versions)

Reliability
98%

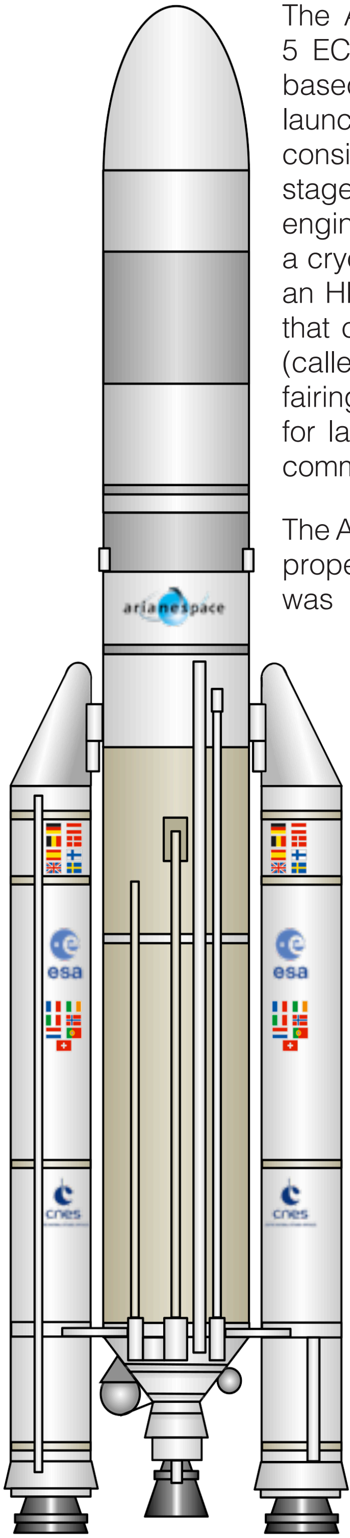
Launch site
Guiana Space Center (ELA-3)

GTO capacity, kg (lb)
9,500 (20,944)

LEO capacity, kg (lb)
21,000 (46,297)

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

Estimated Price per Launch
$178M



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 Airbus Safran Launchers and established in late 2014, 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.

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Ariane 5 ECA

FAA AST

An Ariane 5 ECA launches from the Guiana Space Center on August 20, 2015 carrying Eutelsat 8 West B and Intelsat 34. (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	Airbus Safran Launchers	Airbus Safran Launchers	Airbus Safran Launchers
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. 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/).

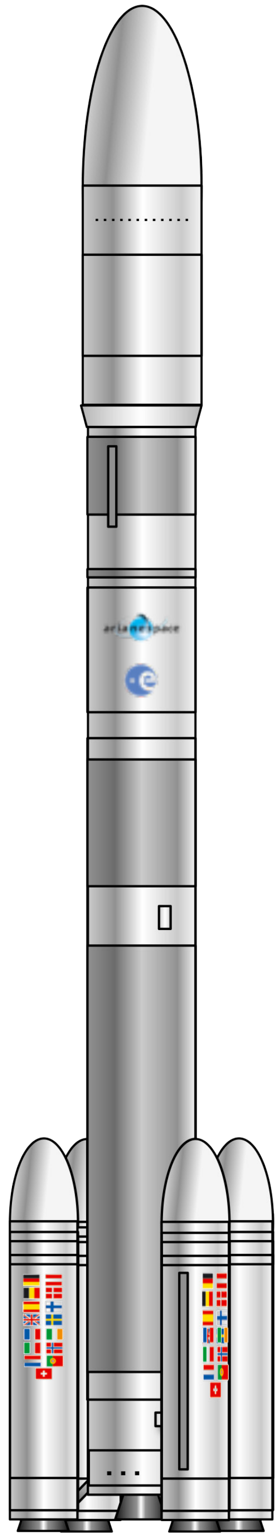
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Airbus Safran Launchers (ASL). ASL 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
Airbus Safran Launchers

Mass, kg (lb)
800,000 (1,763,698)

Length, m (ft)
70 (230)

Diameter, m (ft)
4.6 (15.1)

Year of Planned First Launch
2020

Launch site
Guiana Space Center (ELA-3)

GTO capacity, kg (lb)
5,000-11,000 (11,023-24,251)

LEO capacity, kg (lb)
10,000-21,000 (22,046-46,297)

SSO capacity, kg (lb)
Undisclosed

Estimated Price per Launch
$94M-$117M

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

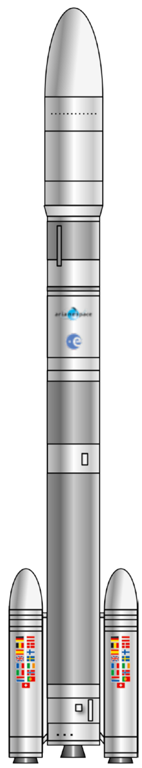
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

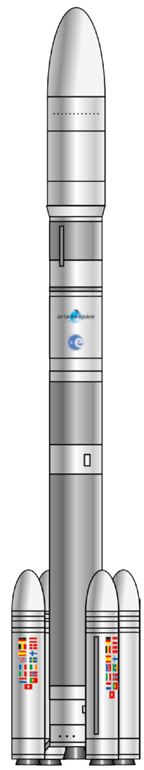
FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 (16.4) *est*

	SRB*	1st Stage	2nd Stage
Stage designation	P120C	2nd Stage	3rd Stage
Length, m (ft)	11.5 (37.7)	40 (131) *est*	15 (49) *est*
Diameter, m (ft)	3.3 (10.8)	4.6 (15.1)	4.6 (15.1)
Manufacturer	Airbus Safran Launchers	Airbus Safran Launchers	Airbus Safran Launchers
Propellant	Solid	LOX/H_2	LOX/H_2
Propellant mass, kg (lb)	120,000 (264,555)	149,000 (328,489)	30,000 (66,139)
Total thrust, kN (lbf)	3,500 (786,831)	350 (78,683)	180 (40,466)
Engine(s)	--	1 x Vulcain 2.1	1 x Vinci
Engine manufacturer	--	Airbus Safran Launchers	Airbus Safran Launchers
Engine thrust, kN (lbf)	--	350 (78,683)	180 (40,466)

** Figures are for each booster. 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/).

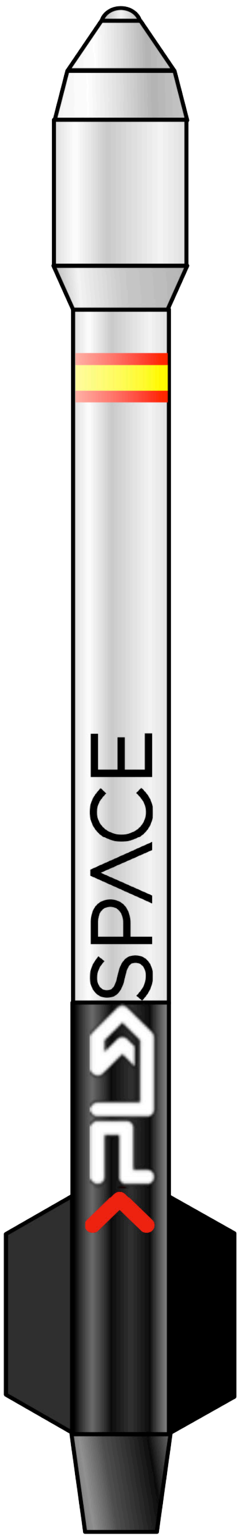
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 site
El Arenosillo
Canary Islands

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
150 (331)

SSO capacity, kg (lb)
N/A

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/).

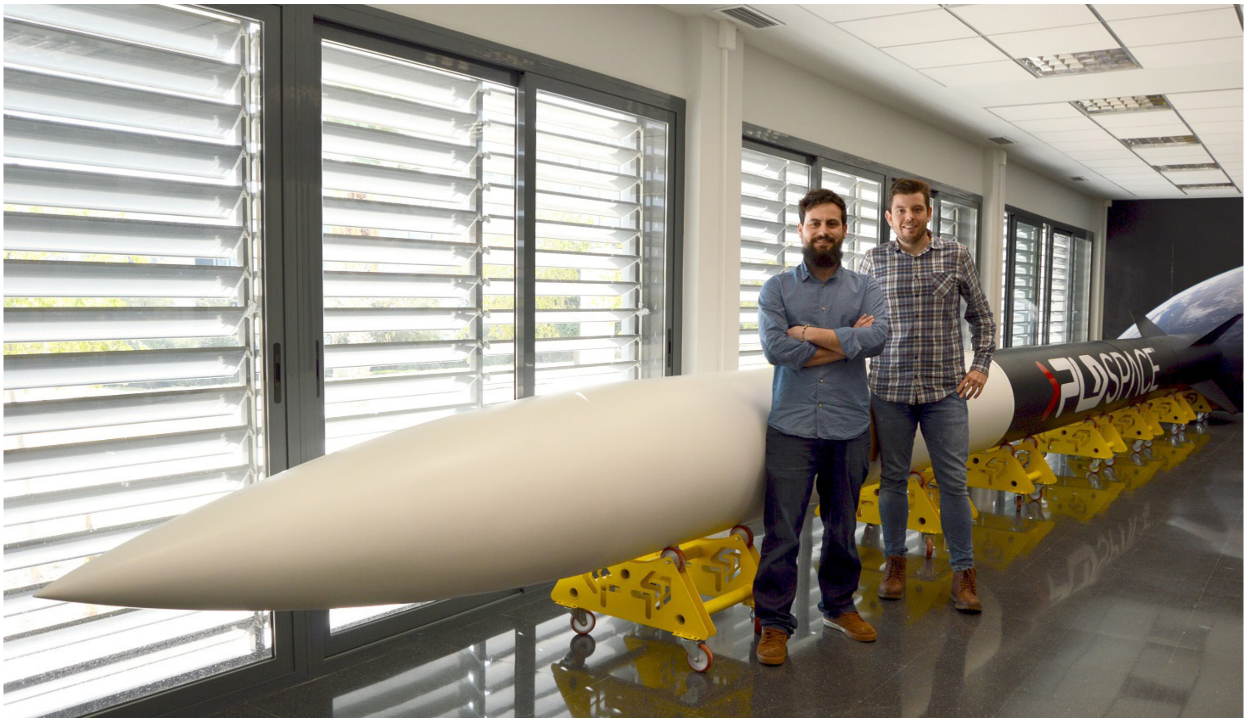
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Arion 2

FAA AST



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)

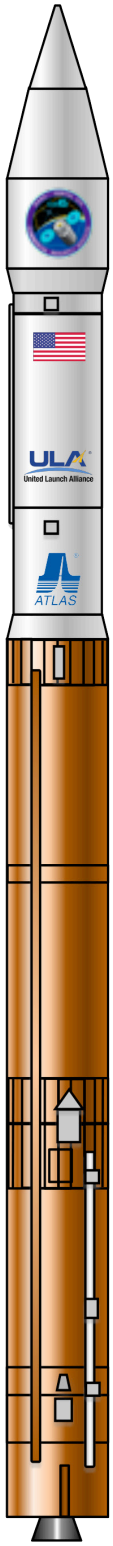
	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	10.8 (35.4)	4.8 (15.7)	1.2 (3.9)
Diameter, m (ft)	1.2 (3.9)	1.2 (3.9)	1.2 (3.9)
Manufacturer	PLD Space	PLD Space	PLD Space
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	Undisclosed	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

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
68

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
$137M-$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/).

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

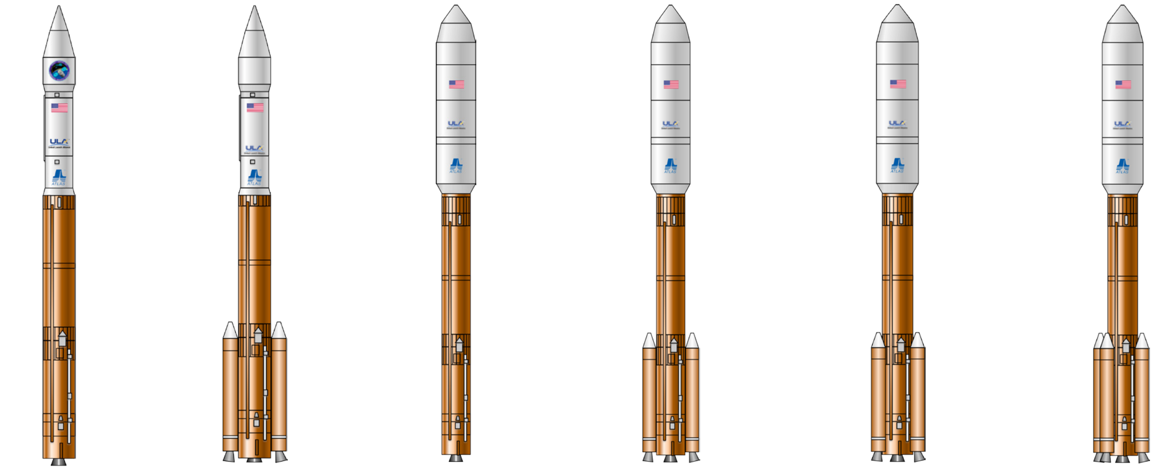
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. 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/).

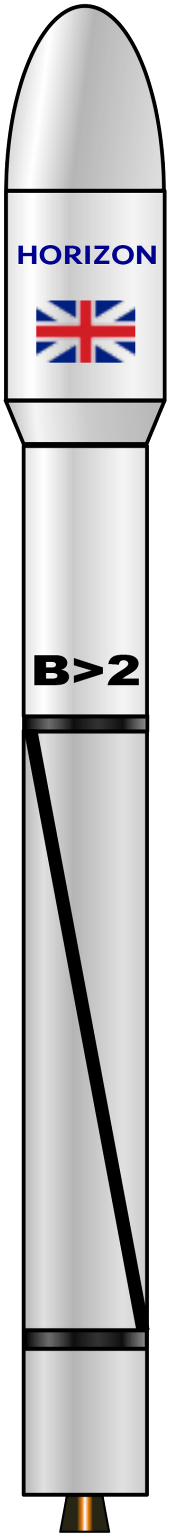
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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
2018

Launch site
Northern Scotland
Possible ocean platform

GTO capacity, kg (lb)
N/A

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

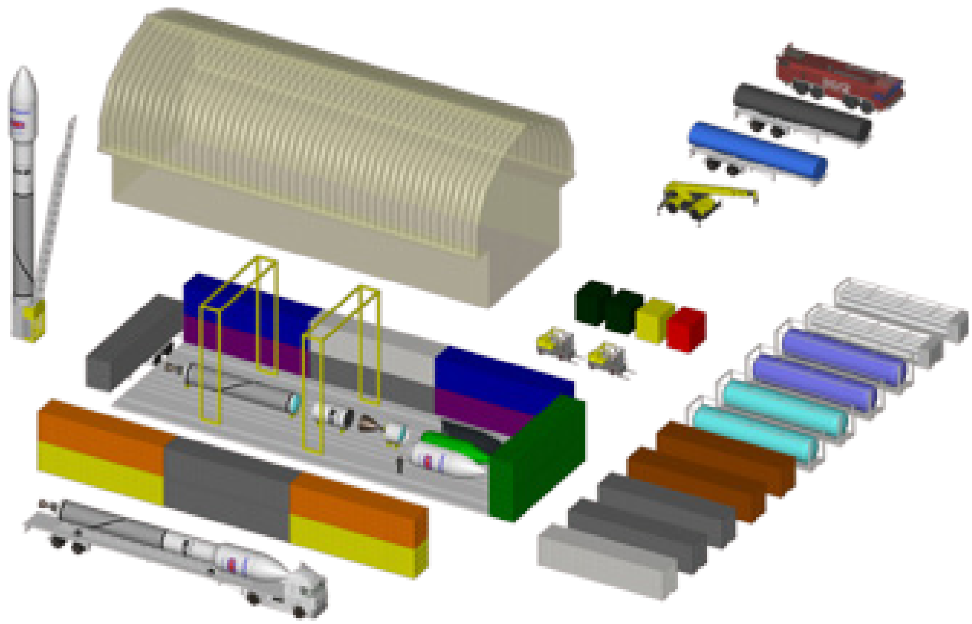
SSO capacity, kg (lb)
200 (441)

Estimated Price per Launch
$6.12M

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Black Arrow 2

FAA AST



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	7 (23)	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)	360 (80,931)	45 (10,116)
Engine(s)	Undisclosed	Undisclosed
Engine manufacturer	Horizon Space Technologies	Horizon Space Technologies
Engine thrust, kN (lbf)	360 (80,931)	45 (10,116)

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

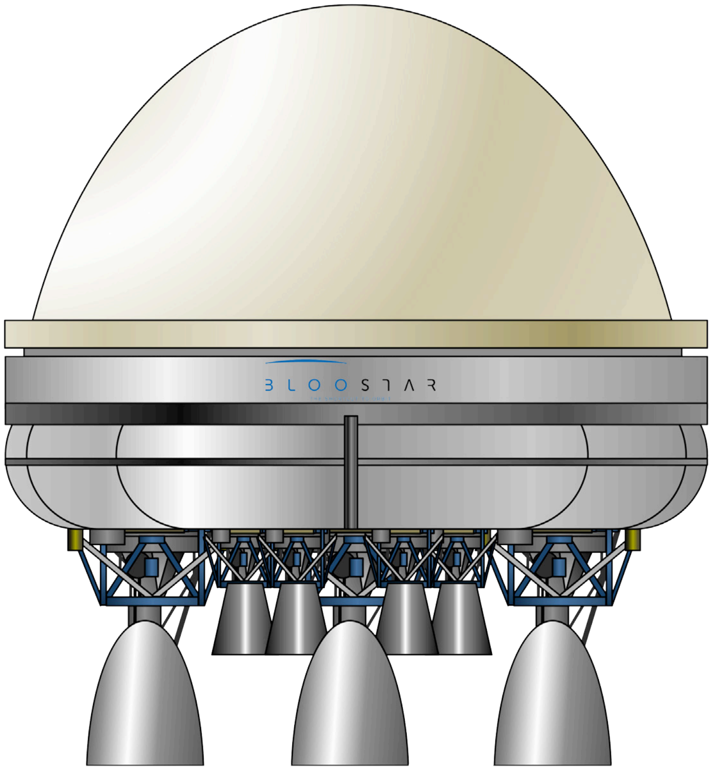
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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
2020

Launch site
Undisclosed

GTO capacity, kg (lb)
N/A

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 October 2016, Zero2infinity has $200 million in pre-sales from nanosatellite operators.

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Bloostar

FAA AST

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)

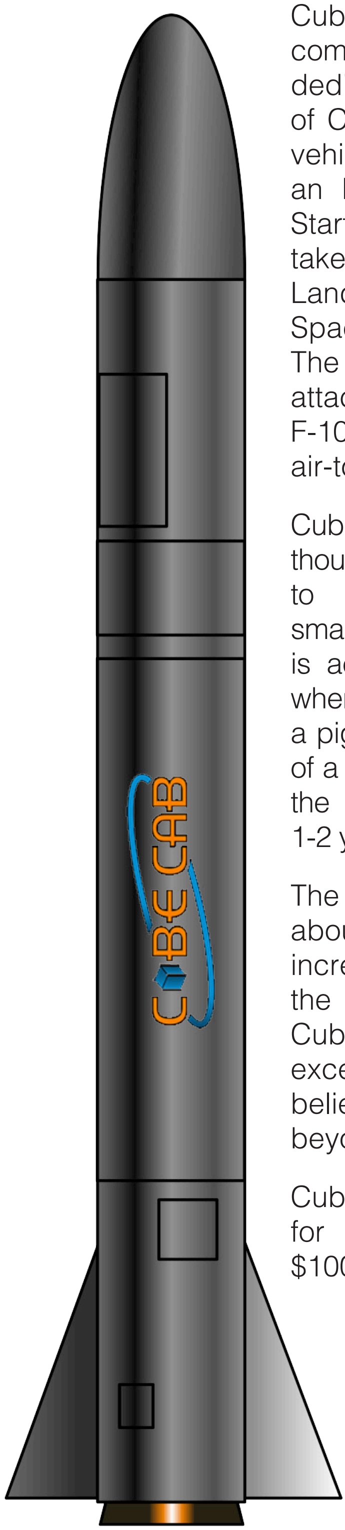
	1st Stage	2nd Stage	3rd Stage	4th Stage
Stage designation	Balloon	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Diameter, m (ft)	Undisclosed	Undisclosed	Undisclosed	Undisclosed
Manufacturer	Zero2Infinity	Zero2Infinity	Zero2Infinity	Zero2Infinity
Propellant	--	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

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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)

GTO capacity, kg (lb)
N/A

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/).

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

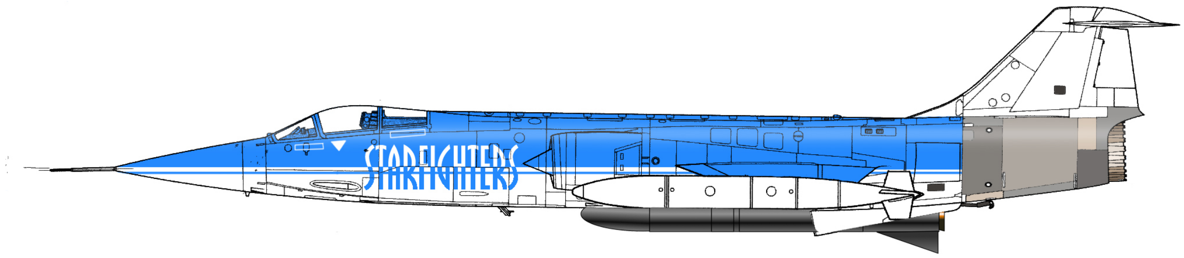
Publication produced for FAA AST by The Tauri Group under contract.

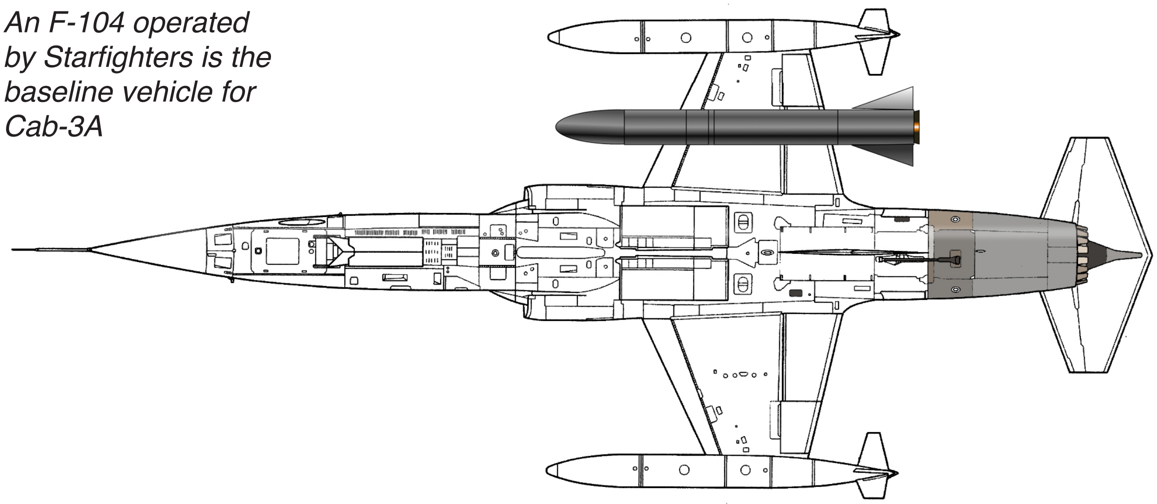
FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Cab-3A

FAA AST





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

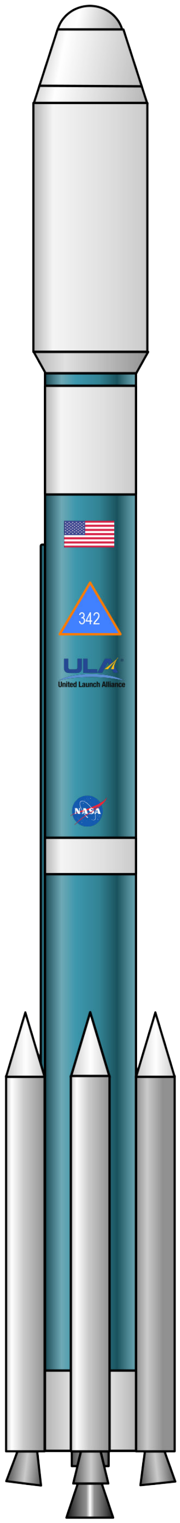
Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	0.5 (1.7) *est*	0.5 (1.7) est

	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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 missions. One failure did occur in 1997 during a Navstar GPS mission. United Launch Alliance 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 Delta II will retire in 2017 with the launch of the first satellite in the Joint Polar Satellite System (JPSS) program.

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 Launches
153

Reliability
99%

Launch sites
CCAFS (SLC-17)
VAFB (SLC-2W)

GTO capacity, kg (lb)
1,578-2,171 (3,479-4,786)

LEO capacity, kg (lb)
3,599-6,097 (7,934-13,442)

SSO capacity, kg (lb)
2,984-6,886 (6,579-15,181)

Estimated Price per Launch
$137.3M

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Delta II

The first stage of the final Delta II vehicle is trucked to the launch site in preparation for the JPSS-1 mission. (Source: 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	3rd Stage Option	3rd Stage Option
Stage designation	9 x GEM-40	1st Stage	2nd Stage	Star-37FM	Star-48B
Length, m (ft)	11.1 (36.4)	26.1 (85.6)	6 (19.7)	1.7 (5.5)	2 (6.7)
Diameter, m (ft)	1 (3.3)	2.4 (7.9)	2.4 (7.9)	0.9 (3.1)	1.2 (41.)
Manufacturer	Orbital ATK	ULA	ULA	Orbital ATK	Orbital ATK
Propellant	Solid	LOX/Kerosene	N_2O_4/ Aerozine-50	Solid	Solid
Propellant mass, kg (lb)	11,766 (25,940)	96,120 (211,908)	6,000 (13,228)	1,025-1,066 (2,260-2,350)	1,739-2,010 (3,833-4,430)
Total thrust, kN (lbf)	5,794 (1,302,543)	890 (200,080)	43.4 (9,757)	47.9 (10,768)	66 (14,837)
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)		--	--

** Figures are for each booster. 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/).

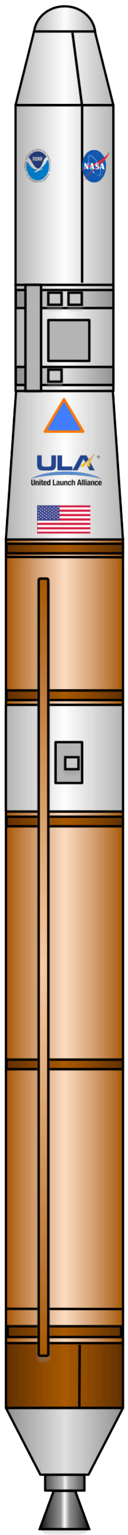
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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, though Boeing can make the Delta IV available to commercial customers worldwide.

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 between two and 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 Launches
34

Reliability*
100%

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

GTO capacity, kg (lb)
3,060-14,220 (6,746-31,350)

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/).

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

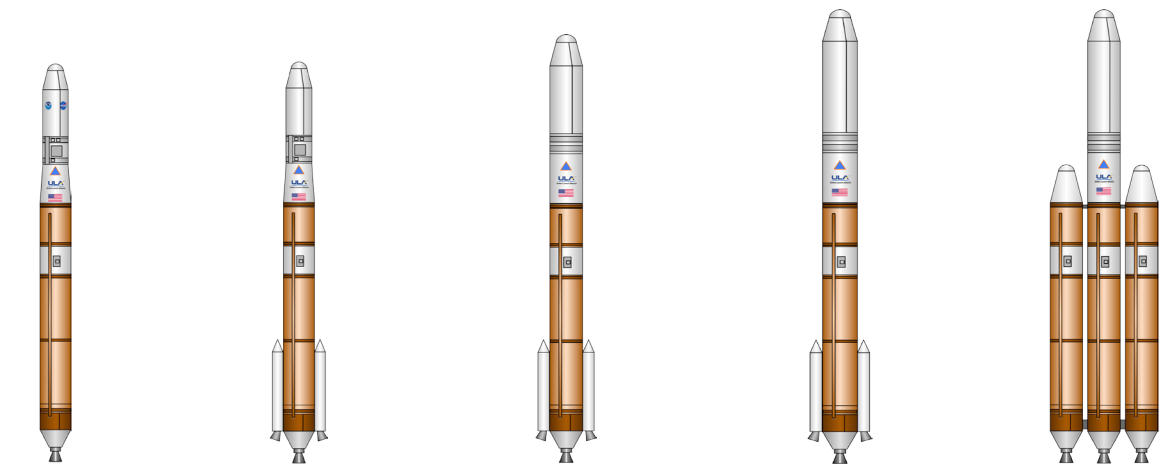
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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	GEM-60	4-Meter Cryogenic Upper Stage	5-Meter Cryogenic Upper Stage
Length, m (ft)	46.7 (153.2)	15. 8 (52)	10.4 (34)	12.2 (40)
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)	59,520 (130,944)	20,410 (45,000)	27,200 (60,000)
Total thrust, kN (lbf)	2,891 (650,000)	1,245.5 (280,000)	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)	2,891 (650,000)	1,245.5 (280,000)	110 (24,750)	110 (24,750)

** Delta IV Heavy uses 3 CBC units*

*** Figures are for each booster. 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/).

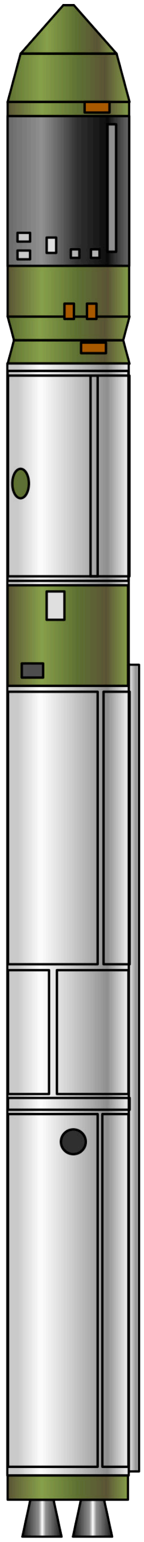
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 is marketed by the Russian-based company ISC 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, ISC Kosmotras has reassured existing and potential customers that the Dnepr will be available.

Launch service provider
ISC Kosmotras

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 Launches
22

Reliability
95%

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

GTO capacity, kg (lb)
N/A

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

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

Estimated Price per Launch
$29M

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Dnepr

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)

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Planned First Launch
2017

Launch sites
PSCA
Kaitorete (New Zealand)

GTO capacity, kg (lb)
N/A

SSO capacity, kg (lb)
150 (331)

Estimated Price per Launch
$4.9M

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Electron

FAA AST

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)

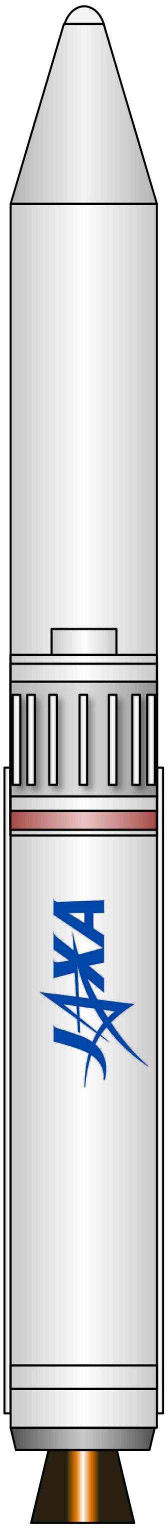
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
2

Reliability
100%

Launch site
Uchinoura Space Center

GTO capacity, kg (lb)
N/A

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

SSO capacity, kg (lb)
450 (992)

Estimated Price per Launch
$39M

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Epsilon

FAA AST

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)

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Falcon 9

Space Exploration Technologies (SpaceX), founded in 2002, first launched its Falcon 9 in 2010 from Cape Canaveral Air Force Station (CCAFS). The Falcon 9 is designed to facilitate horizontal vehicle and payload integration, a somewhat unique characteristic in the U.S. space industry. The launch facilities are relatively simple, resulting in what is described as a "clean pad." It is also used to transport the Dragon cargo module to the International Space Station (ISS), and in 2017 will begin transporting crewed versions of the Dragon. SpaceX will also provide Falcon 9 launches under the Air Force's Orbital/Suborbital Program-3 (OSP-3).

The vehicle consists of a first stage powered by nine SpaceX Merlin-1D engines, a second stage powered by a single Merlin-1D Vacuum engine, a payload adapter, and a large payload fairing. Launches of the company's Dragon capsule do not require a fairing.

The first version of the Falcon 9 (v1.0) launched successfully five times since its introduction in 2010. The current upgraded version of the Falcon 9 (v1.1) was introduced in September 2013. Falcon 9 v1.1 features a longer first stage, new higher thrust engines (the Merlin-1D instead of the Merlin-1C), and an octagonal arrangement of engines on the first stage (instead of a "tic-tac-toe" pattern) to relieve loads on the vehicle during launch. SpaceX introduced the Falcon 9 (Full Thrust) in 2015, featuring 20 percent greater capacity than the Falcon 9 v1.1. Falcon 9 FT. The company is working on the final version of the Falcon 9, called "Block 5," due for introduction in late 2017.

The Falcon 9 v1.1 flew six times in 2015. The Falcon 9 FT was introduced in December 2015 and has flown an additional eight times since. During the December 2015 mission, the vehicle's first stage landed vertically 10 minutes following launch as planned, marking the first time in history such an event took place for a vehicle capable of orbital flight.

Launch service provider
SpaceX

Organization Headquarters
USA

Manufacturer
SpaceX

Mass, kg (lb)
541,300 (1,194,000)

Length, m (ft)
70 (239)

Diameter, m (ft)
3.7 (12)

Year of First Launch
2010 (Falcon 9 family)

Number of Launches
29 (Falcon 9 family)

Reliability
97%

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
$61.2M

Unless otherwise noted, this fact sheet reflects data for the expendable version of the Falcon 9 FT, which debuted in December 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/).

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.

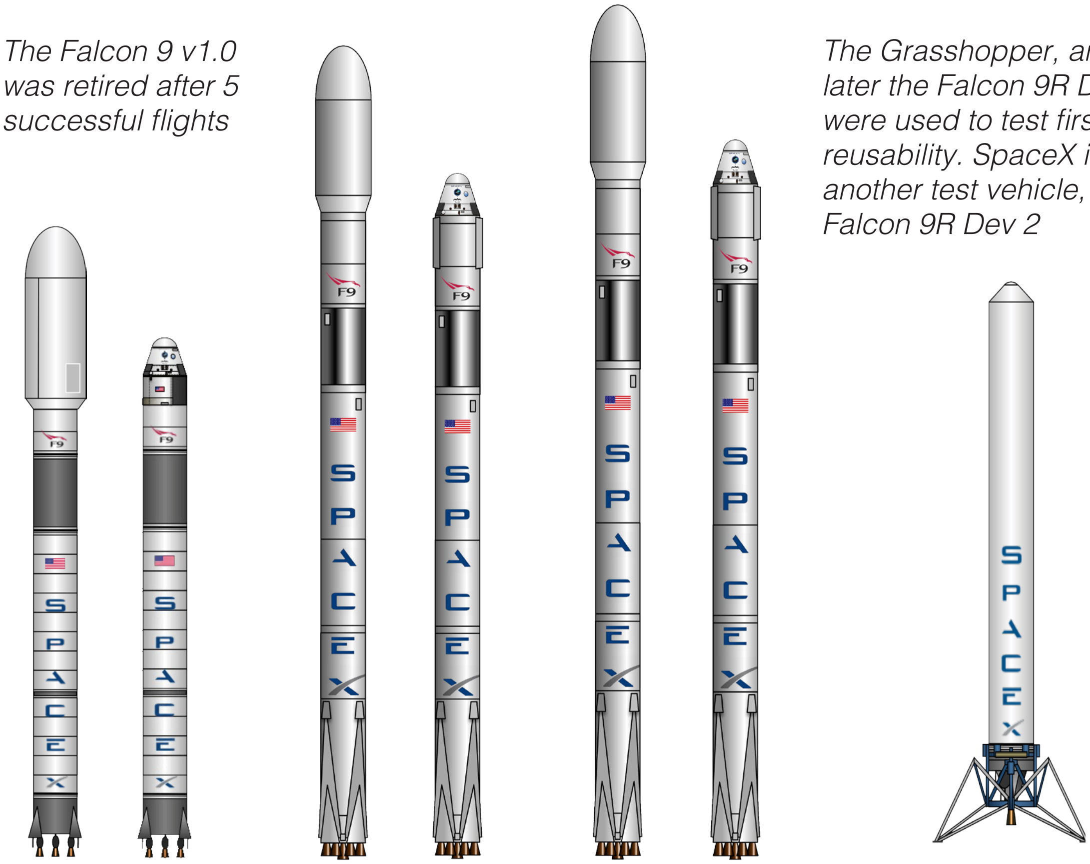
FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Falcon 9

The Falcon 9 v1.0 was retired after 5 successful flights

The Grasshopper, and later the Falcon 9R Dev 1, were used to test first stage reusability. SpaceX is building another test vehicle, the Falcon 9R Dev 2



Falcon 9 v1.0
Retired (2010-2013)

Falcon 9 v1.1
Retired (2013-2016)

Falcon 9 FT
Active (2015-)

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)	411,000 (906,010)	73,400 (161,819)
Total thrust, kN (lbf)	5,885 (1,323,000)	801 (180,000)
Engine(s)	9 x Merlin-1D	1 x Merlin-1D
Engine manufacturer	SpaceX	SpaceX
Engine thrust, kN (lbf)	653.8 (147,000)	801 (180,000)

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

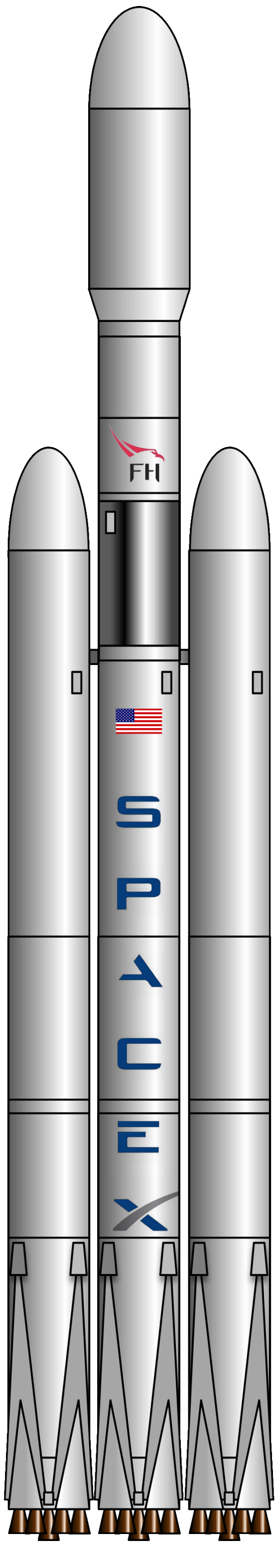
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 the Falcon Heavy essentially consists of three Falcon 9 first stages linked together with propellant crossfeed lines that allow the center center core to tap propellant from the side boosters. The core and boosters are each powered by nine Merlin-1D engines. Each booster is designed to be reused, and requires three separate landing pads. The second stage is similar to the one used for the Falcon 9.

The lift capacity of the Falcon Heavy is 54,400 kg (119,931 lb) to low Earth orbit (LEO), making it the most powerful U.S.-built launch vehicle since the Saturn V.

The first launch of the Falcon Heavy is scheduled to take place in 2017 from Kennedy Space Center's (KSC) LC-39A. 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 22,200 kg, 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)
1,394,000 (3,075,000)

Length, m (ft)
70 (229.6)

Width, m (ft)
12.2 (39.9)

Year of Planned First Launch
2017

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

GTO capacity, kg (lb)
22,200 (48,943)

LEO capacity, kg (lb)
54,400 (119,931)

Estimated Price per Launch
$270M *est.*

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Falcon Heavy

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)

	Liquid Boosters*	1st Stage	2nd Stage
Stage designation	Boosters	1st Stage	2nd Stage
Length, m (ft)	42.6 (139.8)	42.6 (139.8)	12.6 (41.3)
Diameter, m (ft)	3.7 (12)	3.7 (12)	3.7 (12)
Manufacturer	SpaceX	SpaceX	SpaceX
Propellant	LOX/Kerosene	LOX/Kerosene	LOX/Kerosene
Propellant mass, kg (lb)	411,000 (906,010)	411,000 (906,010)	73,400 (161,819)
Total thrust, kN (lbf)	5,885 (1,323,000)	5,885 (1,323,000)	801 (180,000)
Engine(s)	9 x Merlin-1D	9 x Merlin-1D	1 x Merlin-1D
Engine manufacturer	SpaceX	SpaceX	SpaceX
Engine thrust, kN (lbf)	653.8 (147,000)	653.8 (147,000)	801 (180,000)

** Figures are for each booster. 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/).

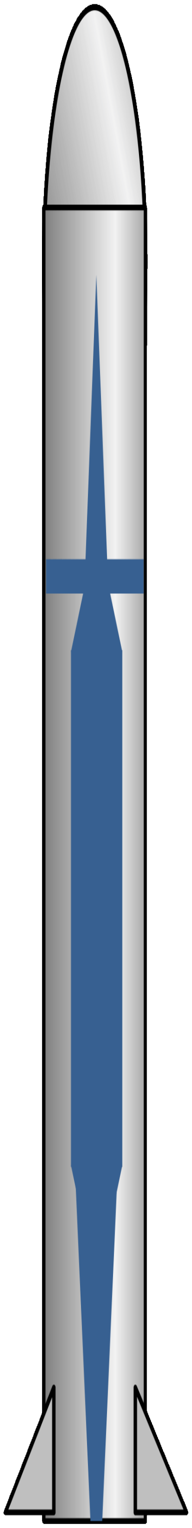
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

GOLauncher-2



U.S.-based Generation Orbit Launch Services was founded in 2011 to provide dedicated orbital launch services to microsatellite operators. The company, which is a subsidiary of Atlanta-based SpaceWorks Engineering, forecasts significant grwoth in microsatellites per year. Generation Orbit aims to tap this rapidly growing market by offering low-cost, rapid launch cycles.

The GOLauncher system features an air-launched approach. The first stage consists of a Gulfstream III aircraft capable of launching the suborbital GOLauncher-1 or a Gulfstream IV for the orbital GOLauncher-2.

The two-stage GOLauncher-2 is designed to send 45 kg (100 lb) to low Earth orbit (LEO). The vehicle can accommodate three payload configurations: A single microsatellite of up to 45 kg, a cluster of nanosatellites, or a dedicated CubeSat mission. Because the vehicle is air-launched, a wide range of orbital options exist, with inclinations of 0° to 90°.

In 2015, Generation Orbit was awarded a Phase II Small Business Innovative Research (SBIR) contract from the Air Force Research Laboratory (AFRL) for continued development of GOLauncher-1. Though this work focuses on the suborbital launch vehicle, it is expected lessons learned will be applied to the company's orbital capability.

As of the end of 2016, few details regarding the technical specifications of the GOLauncher-2 are publicly available.

Launch service provider
Generation orbit

Organization Headquarters
USA

Manufacturer
Generation orbit

Mass, kg (lb)
Undisclosed

Length, m (ft)
25.3 (83)

Wingspan, m (ft)
23.7 (77.8)

Year of Planned First Launch
2019

Launch site
Cecil Field Spaceport

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
45.4 (100)

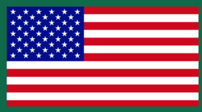
Estimated Price per Launch
$2.5M

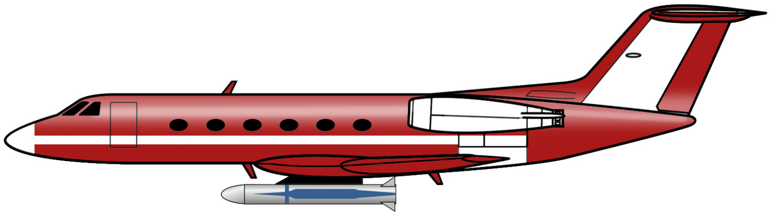
FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

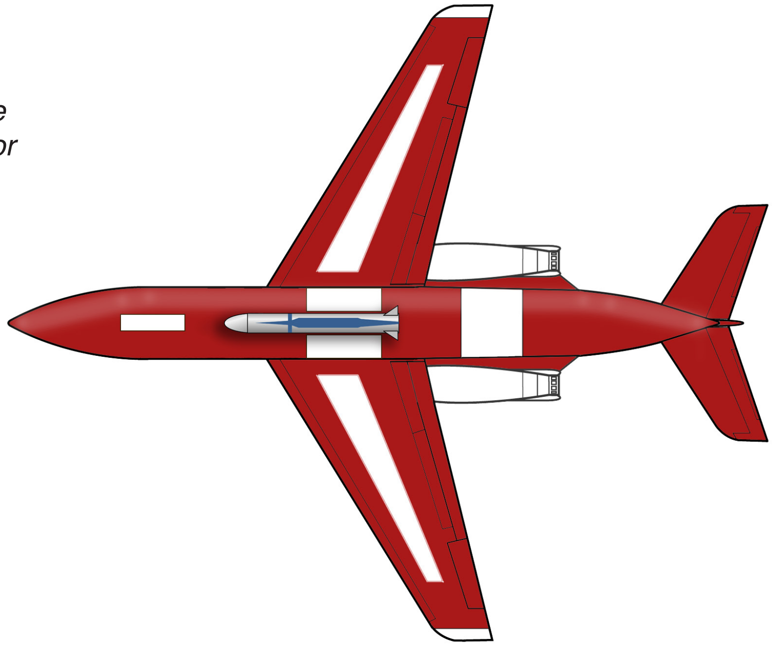
Launch Vehicle Fact Sheet

GOLauncher-2





A Gulfstream IV business jet is the baseline carrier for GOLauncher-2



Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	1.1 (3.7) *est*	0.8 (2.7) *est*

	1st Stage	2nd Stage	3rd Stage
Stage designation	Gulfstream III	1st Stage	2nd Stage
Length, m (ft)	25.3 (83)	5.9 (19.5) *est*	1 (3.3) *est*
Diameter/Wingspan, m (ft)	23.7 (77.8)	0.8 (2.7) *est*	0.8 (2.7) *est*
Manufacturer	Gulfstream Aerospace	Generation Orbit	Generation Orbit
Propellant	Kerosene (Jet-A1)	Solid	LOX/kerosene
Propellant mass, kg (lb)	14,379 (31,700)	Undisclosed	Undisclosed
Total thrust, kN (lbf)	101.4 (22,800)	Undisclosed	Undisclosed
Engine(s)	2 x Spey RB.163 Mk 511-8	Undisclosed	Undisclosed
Engine manufacturer	Rolls-Royce	Generation Orbit	Ventions
Engine thrust, kN (lbf)	50.7 (11,400)	Undisclosed	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.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
10

Reliability
70%

Launch sites
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

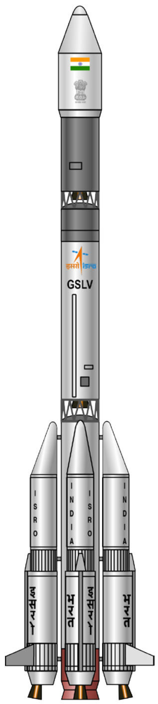
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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

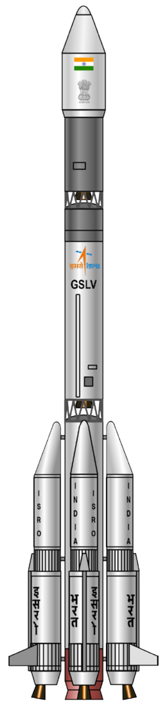
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. 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/).

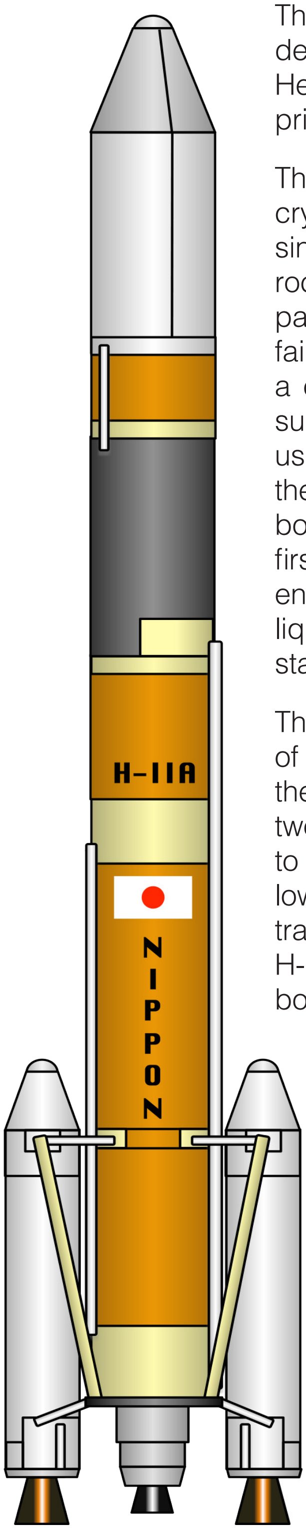
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

H-IIA/B



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 Launches
H-IIA: 31, H-IIB: 6

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

Launch sites
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/).

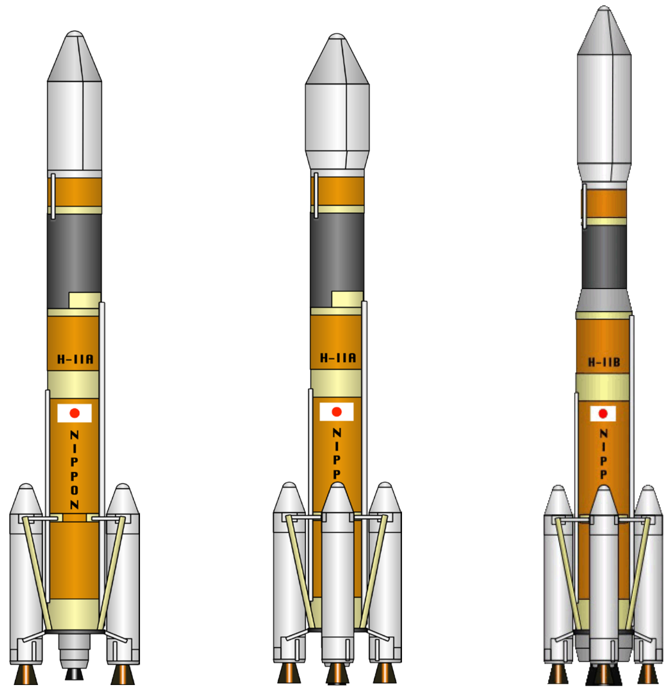
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

H-IIA/B



H-IIA 202

H-IIA 204

H-IIB

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)*	Solid Boosters (H-IIB)*	1st Stage	2nd Stage
Stage designation	SRB-A	SRB-A3	1st Stage	2nd Stage
Length, m (ft)	15 (49.2)	15.1 (49.5)	37 (121.4)	11 (36.1)
Diameter, m (ft)	2.5 (8.2)	2.5 (8.2)	4 (13.1)	4 (13.1)
Manufacturer	Nissan	Nissan	Mitsubishi	Mitsubishi
Propellant	Solid	Solid	LOX/LH_2	LOX/LH_2
Propellant mass, kg (lb)	60,500 (133,380)	66,000 (145,505)	101,000 (222,667)	17,000 (37,479)
Total thrust, kN (lbf)	2,260 (508,068)	1,580 (355,198)	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)	1,580 (355,198)	1,098 (246,840)	137 (30,799)

** Figures are for each booster. 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/).

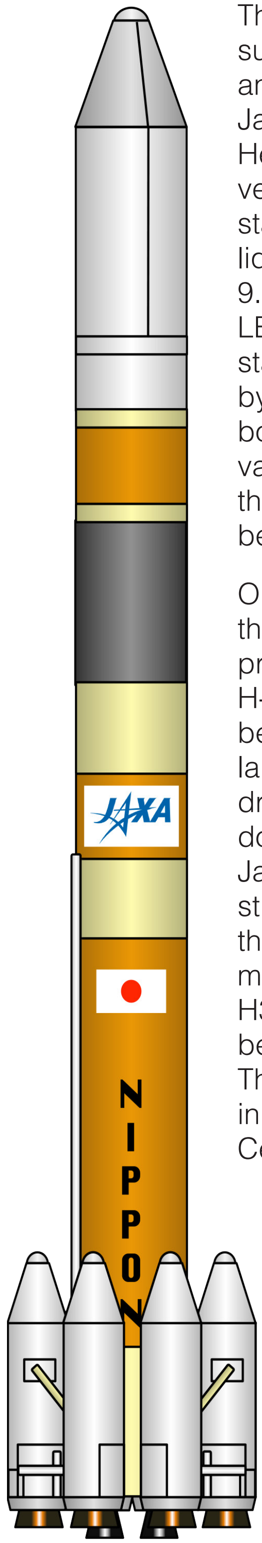
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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/).

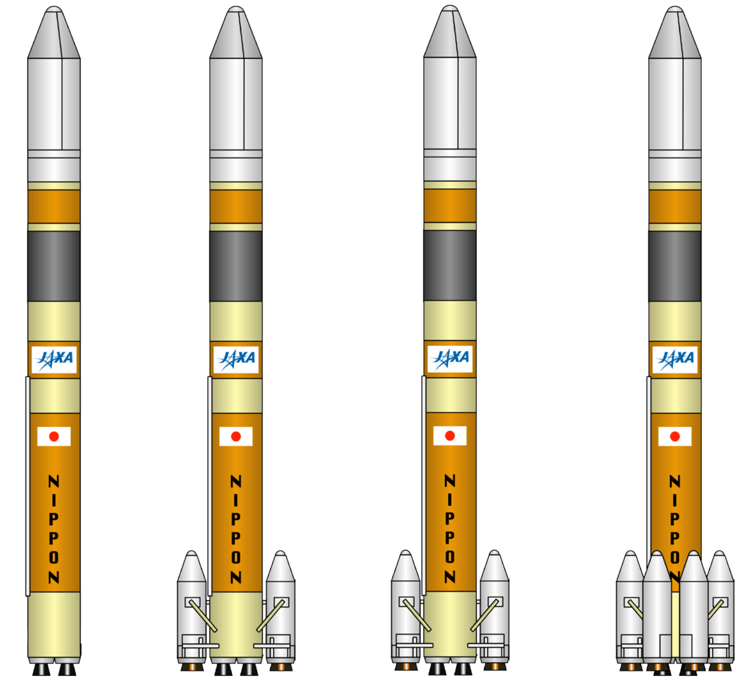
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. Total thrust is sum of all boosters.*

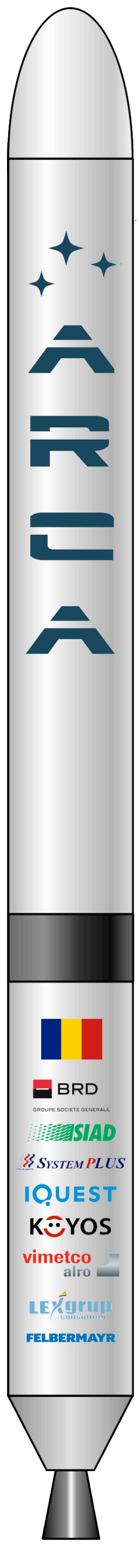
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Haas 2C

FAA AST

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)

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

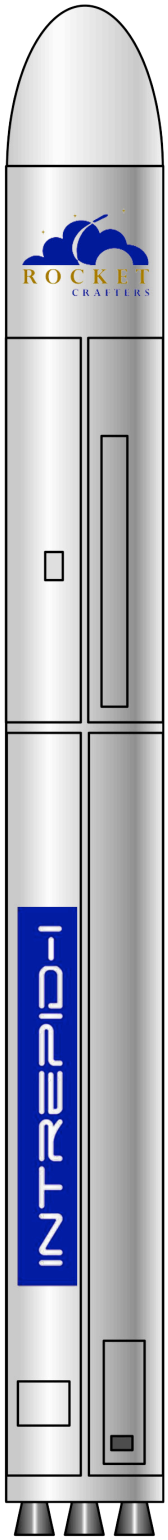
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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

GTO capacity, kg (lb)
N/A

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/).

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

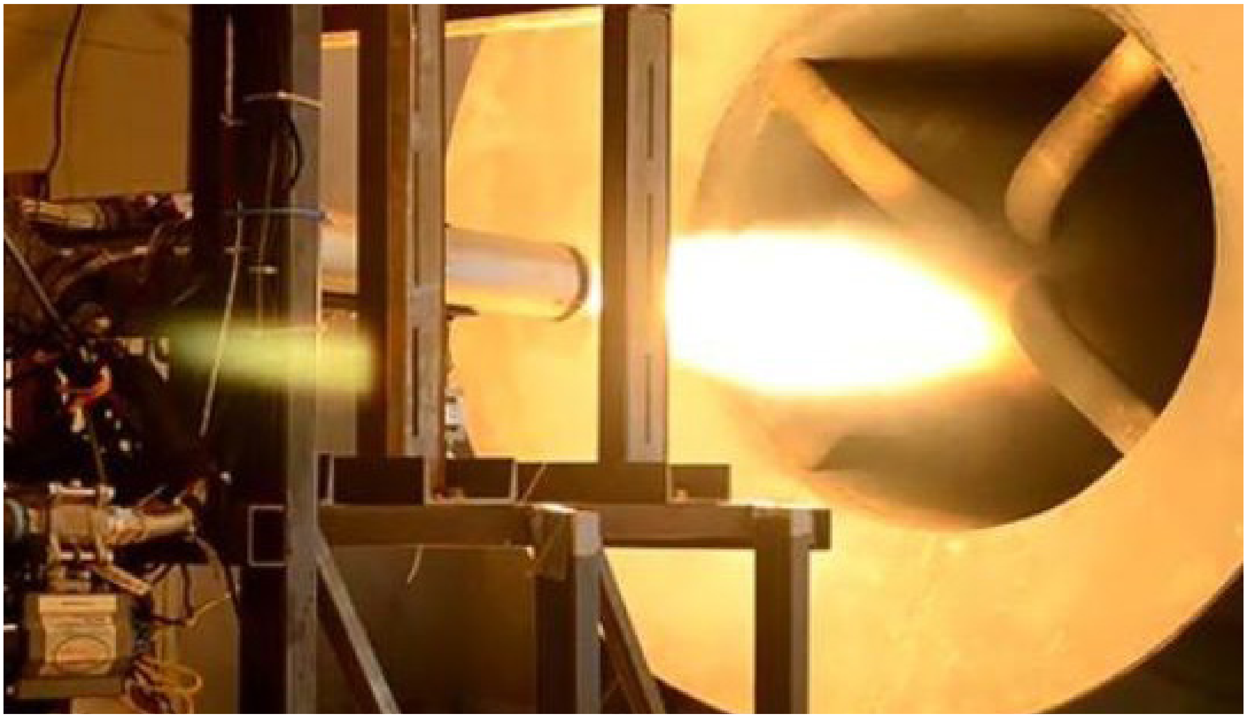
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Intrepid 1

FAA AST



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)

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

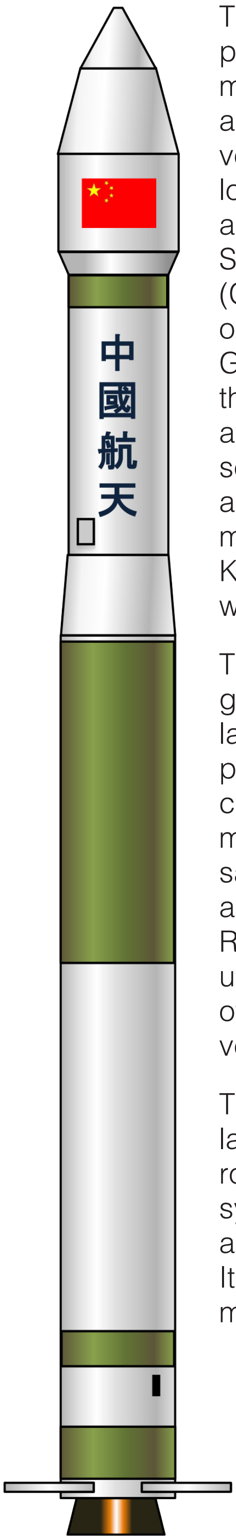
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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). A third version called Kuaizhou 21 may be 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)
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 Launches
3

Reliability
100%

Launch sites
Jiuquan (mobile)

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Kuaizhou 1/1A

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

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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). A third version called Kuaizhou 21 may be 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
2017

Launch sites
Jiuquan (mobile)

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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

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

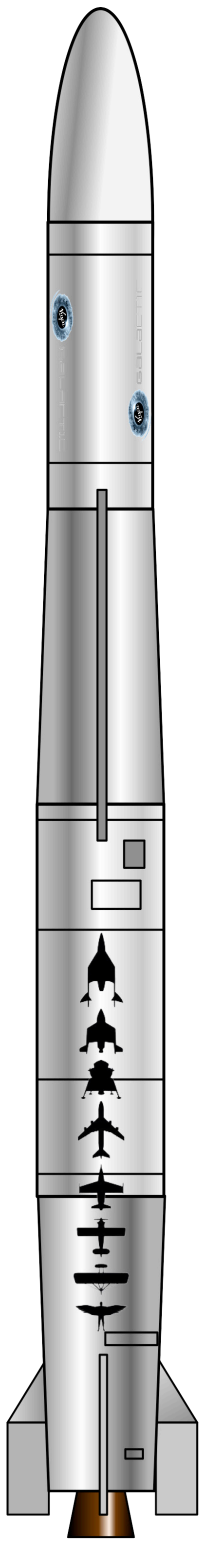
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

LauncherOne



Virgin Galactic and The Spaceship Company are co-developing the air-launched, two-stage LauncherOne vehicle. The Spaceship Company is a joint venture between Virgin Galactic and Northrop Grumman-owned Scaled Composites.

LauncherOne is designed to address the growing demand for microsatellites by providing dedicated microsatellite services, including rapid scheduling and fast constellation replenishment. The Virgin Galactic is more widely known as the company poised to provide space tourism flights with its SpaceShipTwo vehicles, it will also be the launch service provider for LauncherOne.

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 Galactic has secured a Boeing 747-400 aircraft, repurposed from its former role as a Virgin Atlantic airliner.

Virgin Galactic has been selected by Skybox Imaging, Spaceflight Industries, GeoOptics, Planetary Resources, and OneWeb as a launch provider. The 2015 OneWeb contract covers 39 LauncherOne missions with an option for 100 more.

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 Galactic

Organization Headquarters
USA

Manufacturer
Virgin Galactic
The Spaceship Company

Mass, kg (lb)
Undisclosed

Length, m (ft)
Undisclosed

Diameter, m (ft)
Undisclosed

Year of Planned First Launch
2017

Launch sites
Mojave Air and Space Port
KSC (SLF)
WFF

GTO capacity, kg (lb)
N/A

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

SSO capacity, kg (lb)
300 (661)

Estimated Price per Launch
$10M

FAA AST

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

LauncherOne

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

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	The Spaceship Company	The Spaceship Company
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	The Spaceship Company	The Spaceship Company
Engine thrust, kN (lbf)	274.2 (61,500)	327 (73,500)	22.2 (5,000)

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

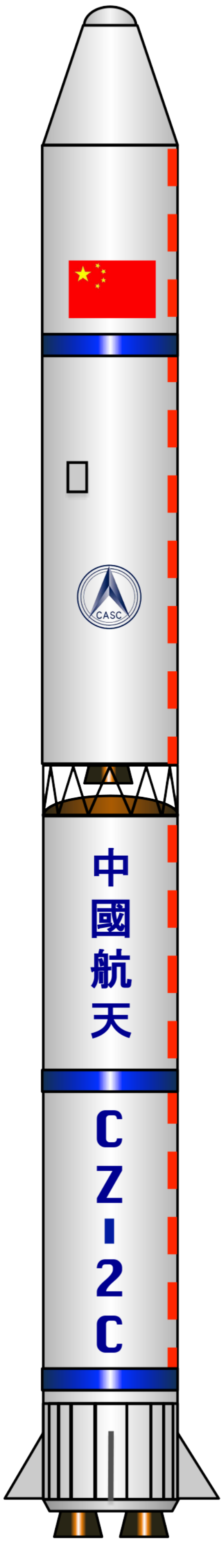
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

Launch service provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
SAST

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 Launches
41

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

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	SAST	SAST	SAST
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/).

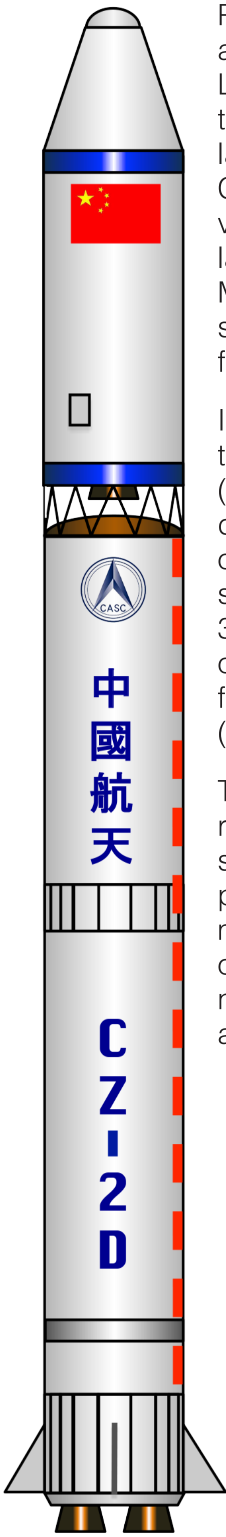
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 employe 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.

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 Launches
31

Reliability
100%

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

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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	SAST
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)

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

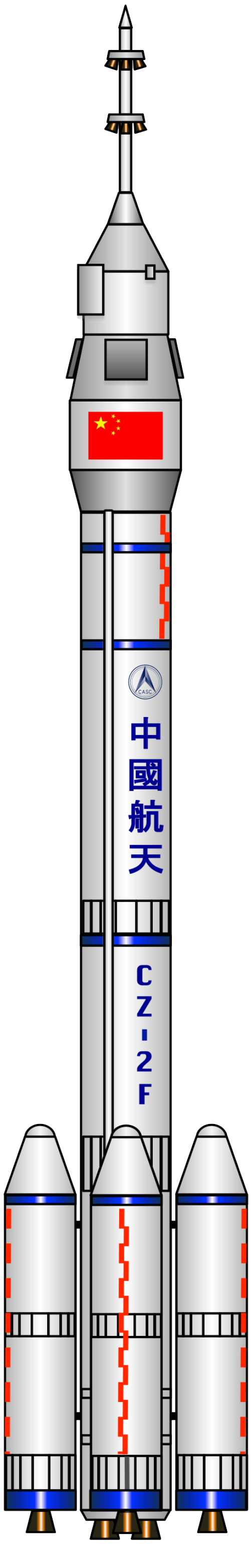
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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, which may be 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 Launches
13

Reliability
100%

Launch sites
Jiuquan (LC-43/921)

GTO capacity, kg (lb)
N/A

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

SSO capacity, kg (lb)
N/A

Estimated Price per Launch
N/A

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.

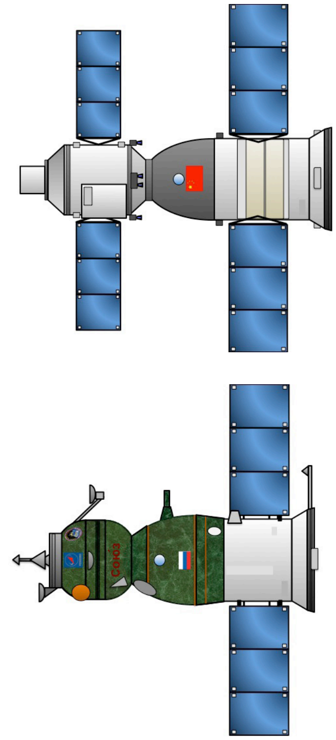
FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Long March 2F

FAA AST

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)	13,024 (2,927,912)	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)	3,256 (731,978)	3,256 (731,978)	831 (186,816)

** Figures are for each booster. 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/).

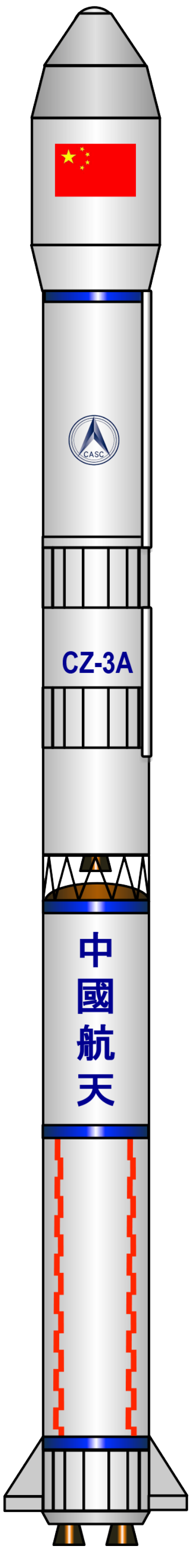
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

Launch service provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
CALT/SAST

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 Launches
25

Reliability
100%

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

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

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

SSO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

Launch Vehicle Fact Sheet
Long March 3A

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)

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

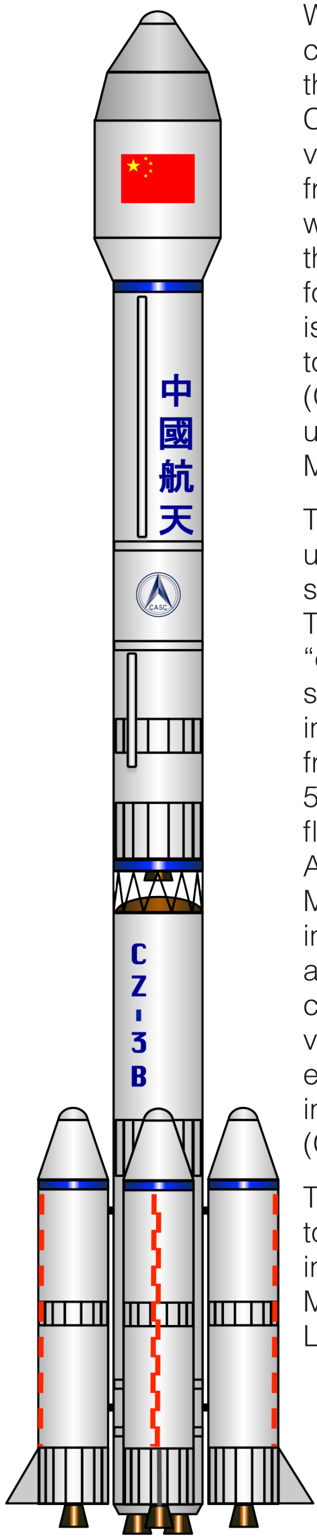
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

Launch service provider
PLA/CGWIC

Organization Headquarters
China

Manufacturer
CALT/SAST

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 Launches
37

Reliability
97%

Launch sites
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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. 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/).

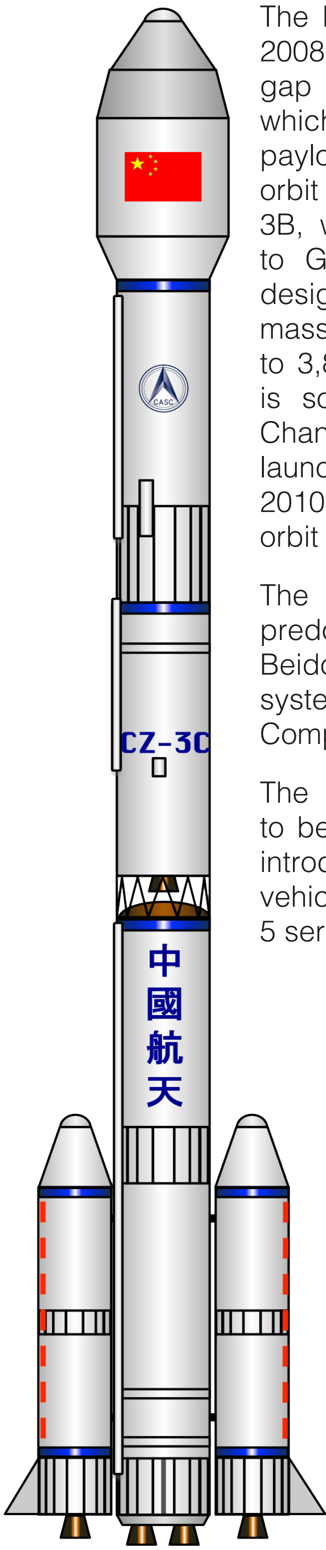
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

Launch service provider
PLA/CNSA

Organization Headquarters
China

Manufacturer
CALT/SAST

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 Launches
15

Reliability
100%

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

GTO capacity, kg (lb)
3,800 (8,378)

LEO capacity, kg (lb)
N/A

SSO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

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)

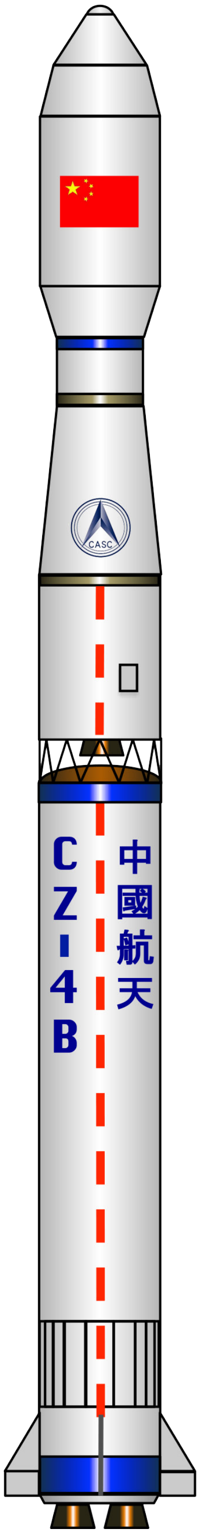
	Liquid Boosters*	1st Stage	2nd Stage	3rd Stage
Stage designation	Liquid Boosters (2)	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	16.1 (52.8)	24.8 (81.4)	12.9 (42.3)	12.4 (40.7)
Diameter, m (ft)	2.3 (7.5)	3.4 (11)	3.4 (11)	3 (9.8)
Manufacturer	CALT	SAST	SAST	CALT
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	41,100 (90,610)	186,200 (410,501)	49,400 (108,908)	18,200 (40,124)
Total thrust, kN (lbf)	740.4 (166,449)	3,265 (734,001)	742 (166,808)	167 (37,543)
Engine(s)	1 x YF-25	4 x YF-21C	1 x YF-24E	1 x YF-75
Engine manufacturer	CALT	SAST	SAST	CALT
Engine thrust, kN (lbf)	740.4 (166,449)	816.3 (183,512)	742 (166,808)	167 (37,543)

** Figures are for each booster. Total thrust is sum of all boosters.*

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 occassion, 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 imporvment 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 Launches
28

Reliability
96%

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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)

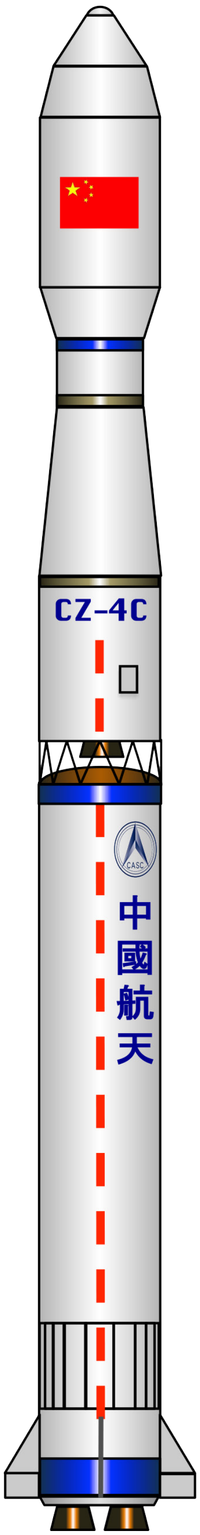
	1st Stage	2nd Stage	3rd Stage
Stage designation	1st Stage	2nd Stage	3rd Stage
Length, m (ft)	27.9 (91.5)	10.9 (35.8)	14.8 (48.6)
Diameter, m (ft)	3.4 (11.2)	3.4 (11)	2.9 (9.5)
Manufacturer	SAST	SAST	SAST
Propellant	N_2O_4/UDMH	N_2O_4/UDMH	N_2O_4/UDMH
Propellant mass, kg (lb)	182,000 (401,241)	52,700 (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)

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

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 primarilly 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 Launches
20

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

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

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)
Larger 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)

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

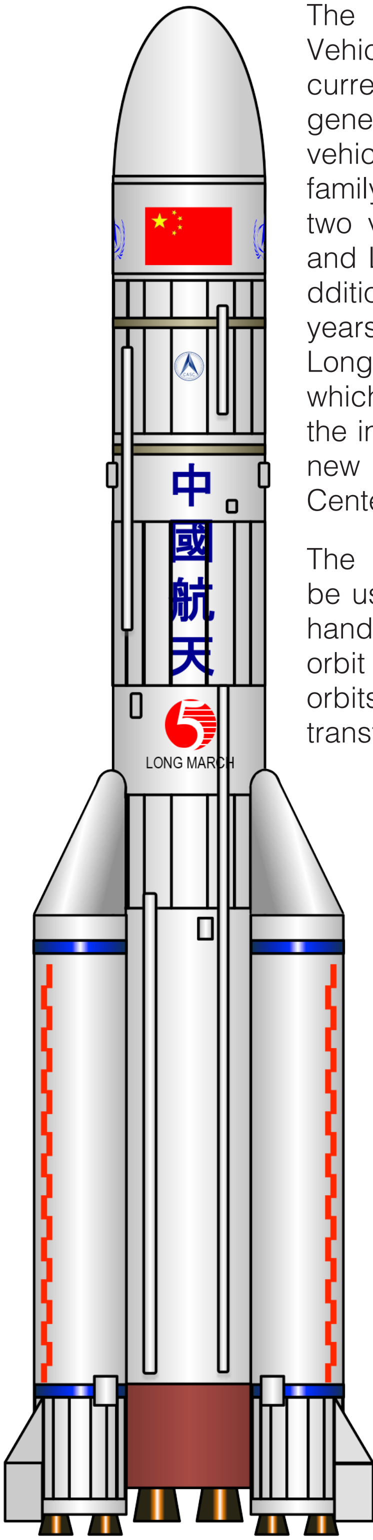
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

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 Launches
1

Reliability
100%

Launch sites
Wenchang (LC-1)

GTO capacity, kg (lb)
14,000 (30,865)

LEO capacity, kg (lb)
25,000 (55,116)

SSO capacity, kg (lb)
N/A

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.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. 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/).

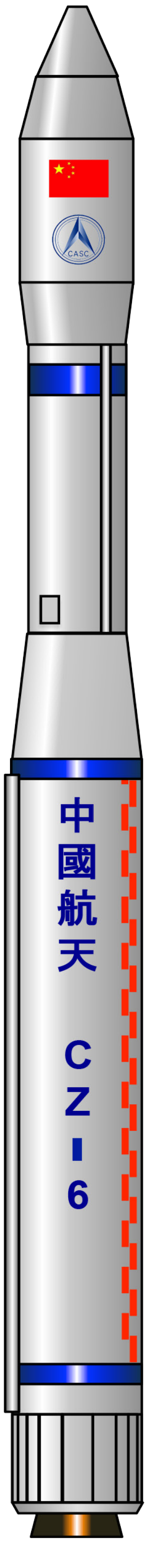
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
1

Reliability
100%

Launch sites
Taiyuan (LA-16)

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Long March 6

The Long March 6 being tested at SAST prior to deliver to the launch site. (Source: SAST)

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)

FAA AST

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

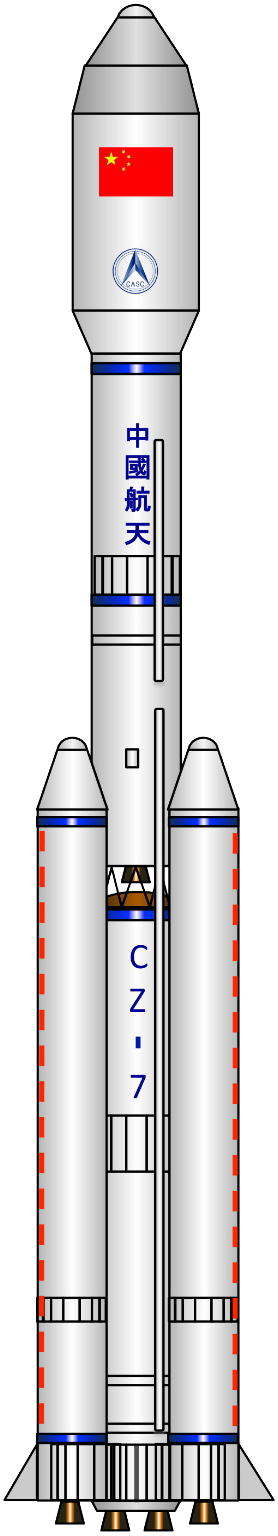
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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

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 Launches
1

Reliability
100%

Launch sites
Wenchang (LC-2)

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
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. Total thrust is sum of all boosters.*

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 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

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 Launches
2

Reliability
100%

Launch sites
Jiuquan

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
530 (1,168)

SSO capacity, kg (lb)
400 (882)

Estimated Price per Launch
$5.3M

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Long March 11

FAA AST

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

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

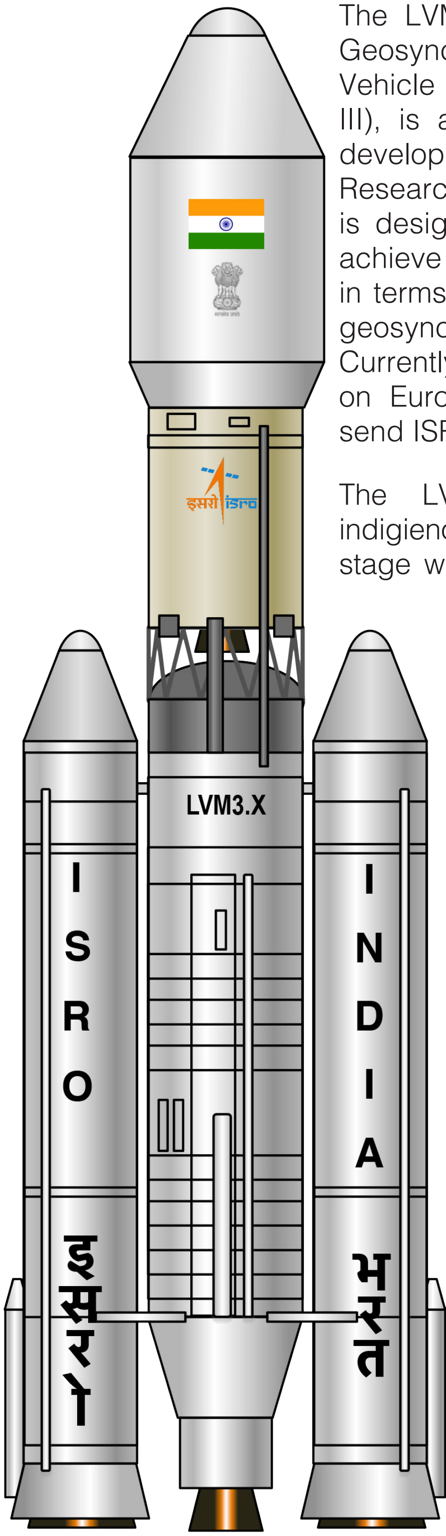
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 indigienously 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 Launches
1

Reliability
100%

Launch sites
Satish Dhawan (SLP)

GTO capacity, kg (lb)
4,000 (8,818)

LEO capacity, kg (lb)
8,000 (17,637)

SSO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. 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/).

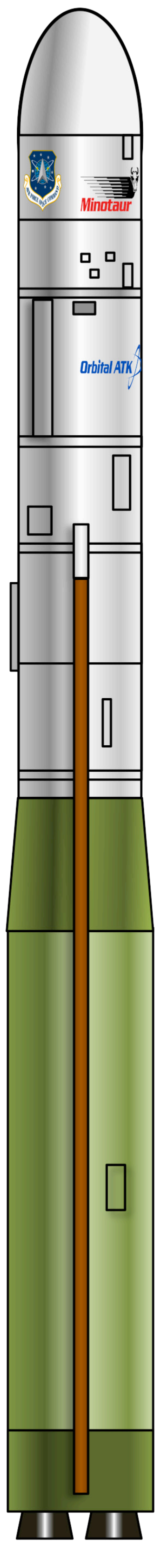
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 gimballed 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 Launches
11

Reliability
100%

Launch sites
VAFB (SLC-8)
MARS (LP-0B)

GTO capacity, kg (lb)
N/A

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/).

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

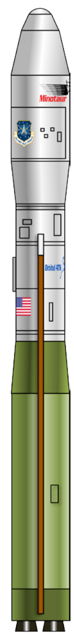
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Minotaur I

Minotaur I
Standard Fairing



Minotaur I
Extended 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)
Stretched 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)

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

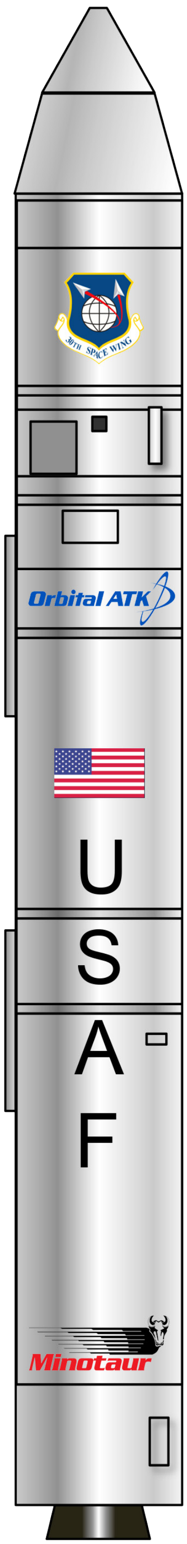
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
3

Reliability
100%

Launch sites
CCAFS (SLC-46)
VAFB (SLC-8)
MARS (LP-0B)
PSCA (LP-1)

GTO capacity, kg (lb)
N/A

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/).

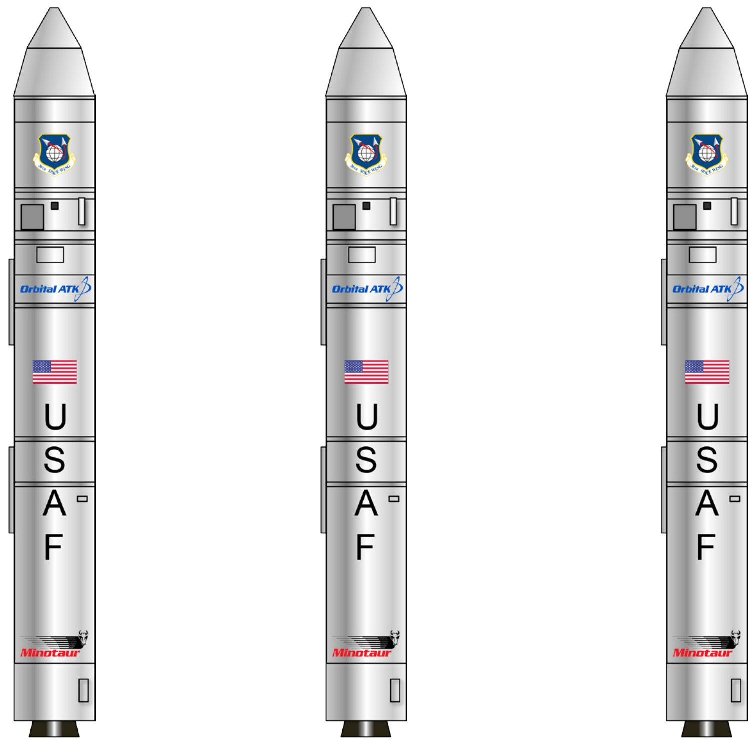
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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	5th Stage
Stage designation	SR-118	SR-119	SR-120	Orion-38	STAR-48V
Length, m (ft)	8.5 (27.9)	7.9 (25.9)	2.4 (7.9)	1.8 (5.8)	2 (6.6)
Diameter, m (ft)	2.3 (7.5)	2.3 (7.5)	2.3 (7.5)	1.2 (4.1)	1.2 (3.9)
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)	770 (1,698)	2,010 (4,431)
Total thrust, kN (lbf)	1,607 (361,000)	1,365 (307,000)	329 (74,000)	34.8 (7,800)	64 (14,000)

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

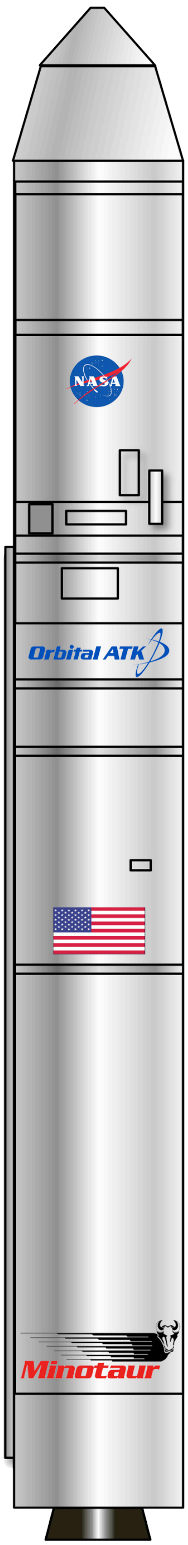
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
1

Reliability
100%

Launch sites
VAFB (SLC-8)
MARS (LP-0B)
PSCA (LP-1)

GTO capacity, kg (lb)
532 (1,173)

LEO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/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-48V	STAR-37FM/V
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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Minotaur VI

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**
Stage designation	SR-118	SR-118	SR-119	SR-120	STAR-48V
Length, m (ft)	8.5 (27.9)	8.5 (27.9)	7.9 (25.9)	2.4 (7.9)	2 (6.6)
Diameter, m (ft)	2.3 (7.5)	2.3 (7.5)	2.3 (7.5)	2.3 (7.5)	1.2 (3.9)
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)	45,400 (100,090)	24,500 (54,013)	7,080 (15,609)	2,010 (4,431)
Total thrust, kN (lbf)	1,607 (361,000)	1,607 (361,000)	1,365 (307,000)	329 (74,000)	64 (14,000)

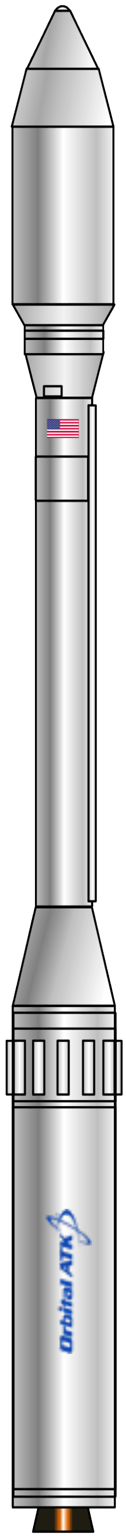
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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). 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) signed a contract with Orbital ATK in 2014 for the launch of six SkySat satellites on a single Minotaur-C. The launch is planned for 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 Planned First Launch
2017

Launch sites
CCAFS (SLC-46)
VAFB (LC-576E)
MARS (LP-0B)
PSCA (LP-1)

GTO capacity, kg (lb)
N/A

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/).

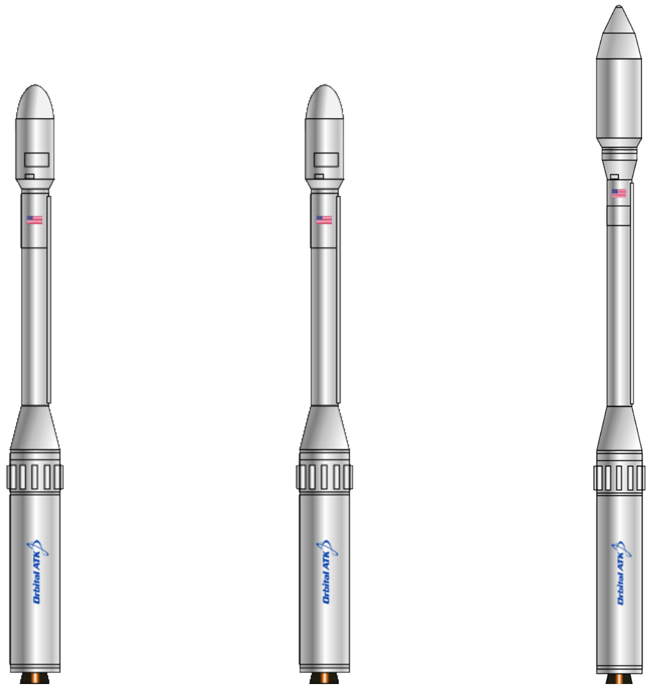
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Option	3rd Stage Option	4th Stage Option
Stage designation	Castor-120	Orion-50SXLG	Orion-38	STAR-37	STAR-37
Length, m (ft)	9.1 (29.9)	8.9 (29.2)	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)	0.7 (2.3)	0.7 (2.3)
Manufacturer	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK	Orbital ATK
Propellant	Solid	Solid	Solid	Solid	Solid
Propellant mass, kg (lb)	48,960 (107,939)	15,023 (33,120)	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)	47.3 (10,625)	47.3 (10,625)

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

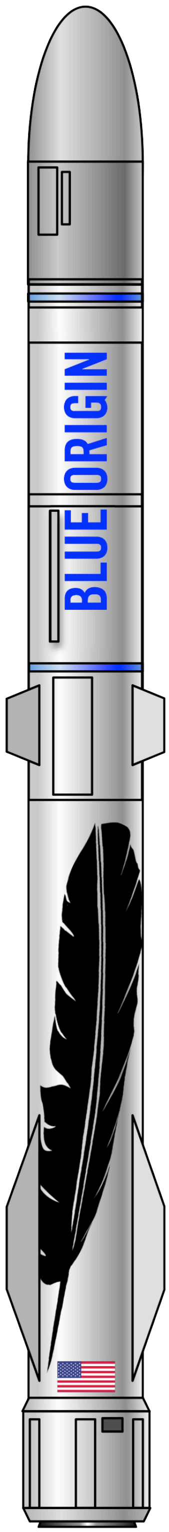
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

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)
7 (23)

Year of Planned First Launch
2020

Launch site
CCAFS (SLC-36)

GTO capacity, kg (lb)
Undisclosed

LEO capacity, kg (lb)
35,000-70,000 (77,162-154,324)

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.

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

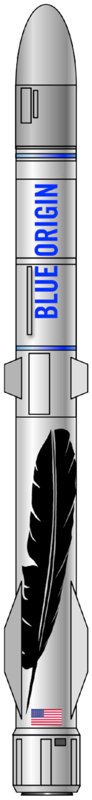
FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

New Glenn

FAA AST

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)	7 (23)	7 (23)	7 (23)
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)	16,800 (3,776,790)	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)	2,400 (539,542)	2,400 (539,542)	670 (150,622)

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

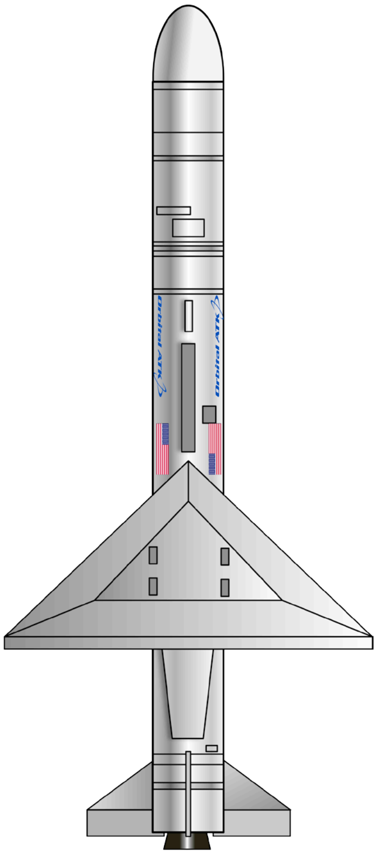
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 ATK, but it may also include an Orbital-built 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 manufactured by 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 26 consecutive successful missions since 1997, but did not fly in 2014 or 2015.

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 Launches
33

Reliability
97%

Launch sites
CCAFS, Kwajalein, VAFB, WFF

GTO capacity, kg (lb)
N/A

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/).

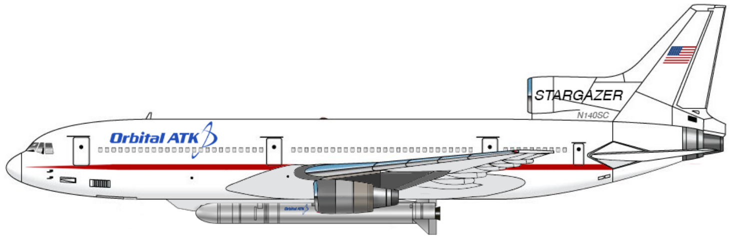
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

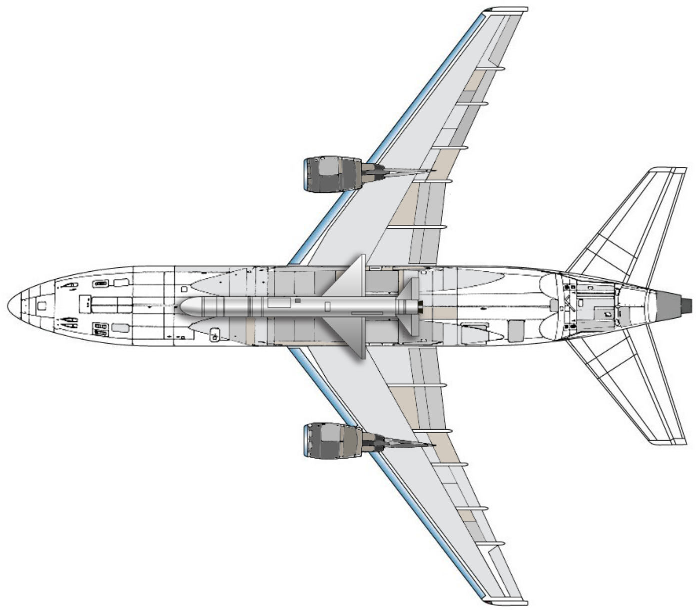
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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)	726 (163,247)	196 (44,171)	36 (8,062)	0.2 (45)

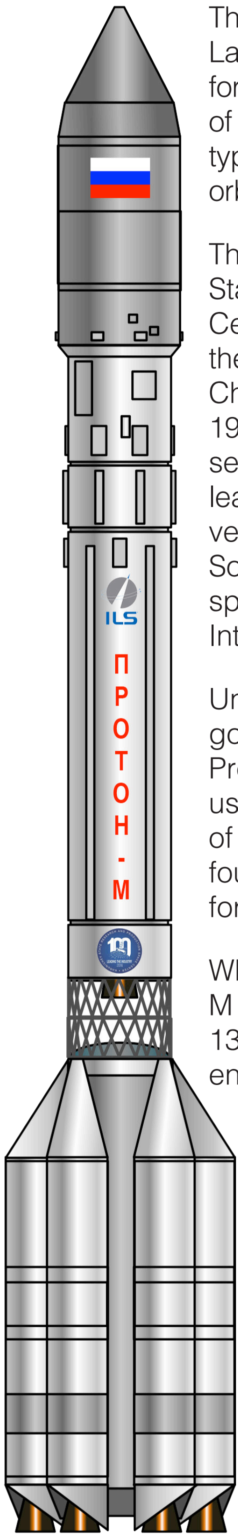
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. The 2014 failure in May resulted in the loss of the Express AM4R satellite.

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)
712,800 (1,571,400)

Length, m (ft)
53 (173)

Diameter, m (ft)
7.4 (24)

Year of First Launch
2001

Number of Launches
98

Reliability
91%

Launch sites
Baikonur (LC-81, LC-200)

GTO capacity, kg (lb)
6,920 (15,256)

LEO capacity, kg (lb)
23,000 (50,706)

SSO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Proton M

A Proton M is poised from launch from Baikonur Cosmodrome in 2014. (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)

	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/).

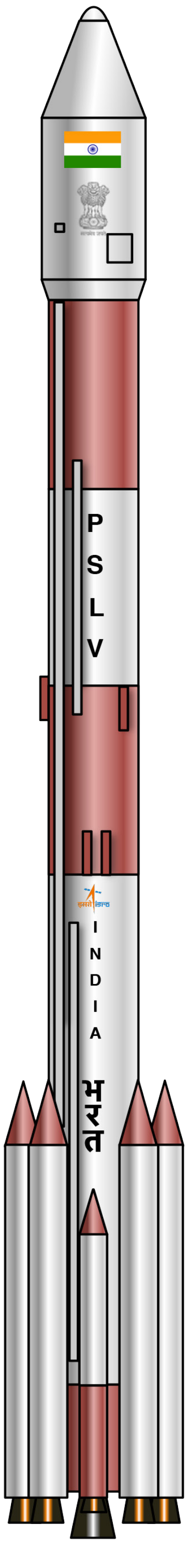
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

Launch service provider
ISRO/Antrix

Organization Headquarters
India

Manufacturer
ISRO

Mass, kg (lb)
320,000 (705,479)

Length, m (ft)
44 (144)

Diameter, m (ft)
2.8 (9.2)

Year of First Launch
1993

Number of Launches
38

Reliability
97%

Launch sites
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)

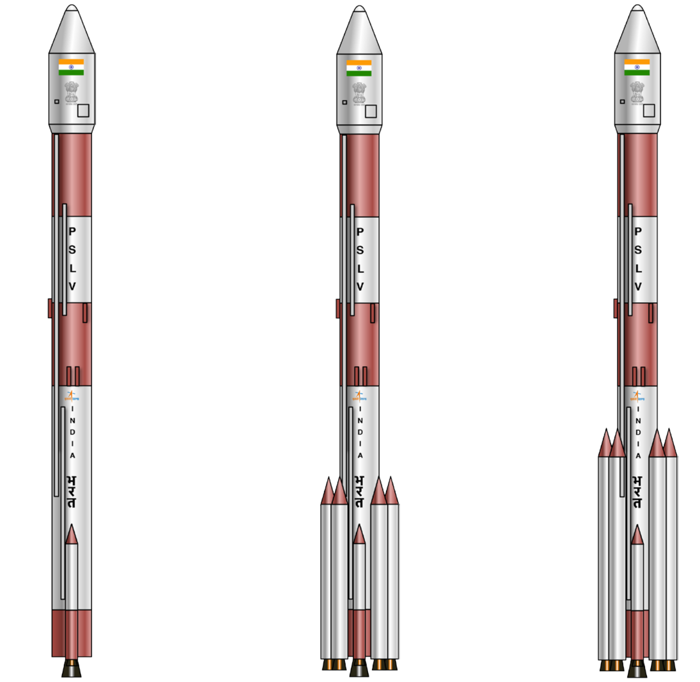
Estimated Price per Launch
$21M-$31M

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

PSLV

FAA AST



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)	719 (161,638)	4,800 (1,079,082)	799 (179,622)	240 (53,954)	7.3 (1,641)

* *Figures are for each booster. Total thrust is sum of all boosters.*

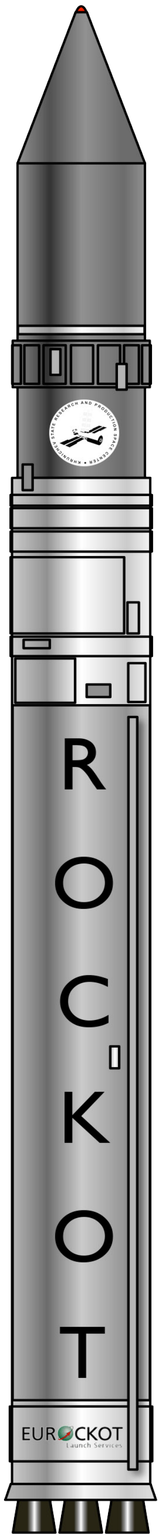
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
27

Reliability
93%

Launch sites
Plesetsk (LC-133)

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Rockot

FAA AST

A Rockot vehicle is launched from Plestesk Cosmodrome. (Source: Eurockot)

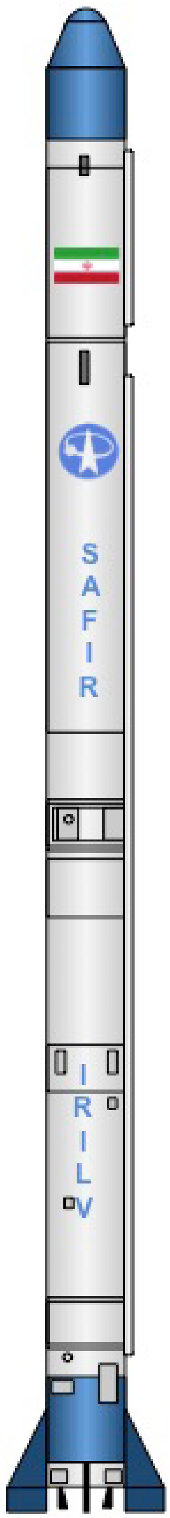
Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	2.6 (8.5)	2.5 (8.2)

	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)

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
6

Reliability
67%

Launch sites
Semnan

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
50 (110)

SSO capacity, kg (lb)
< 50 (< 110)

Estimated Price per Launch
N/A

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Safir

FAA AST

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)	--

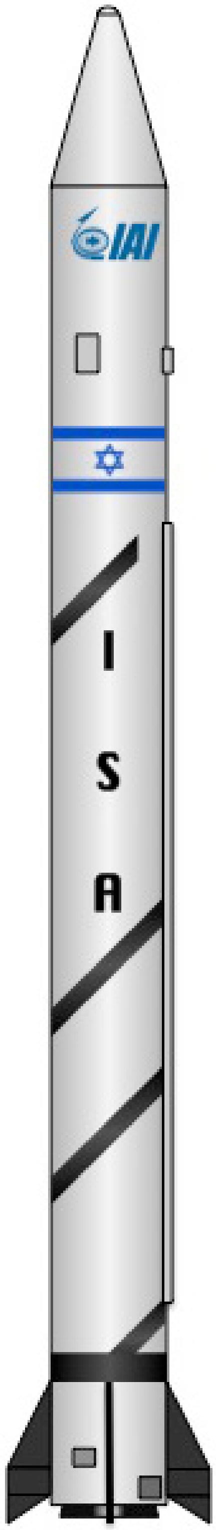
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
10

Reliability
90%

Launch sites
Palmachim AFB

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
N/A

SSO capacity, kg (lb)
500 (1,102)

Estimated Price per Launch
N/A

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Shavit 2

FAA AST

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)

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

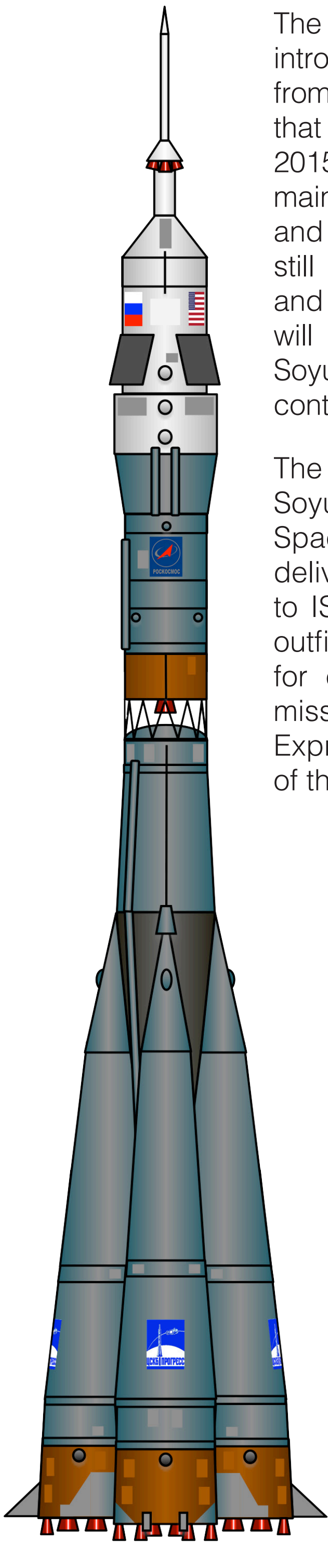
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Progess 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/Roscosmos

Organization Headquarters
Russia

Manufacturer
TsSKB 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 Launches
58

Reliability
100%

Launch sites
Baikonur (LC-1, LC-31)

GTO capacity, kg (lb)
N/A

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/).

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

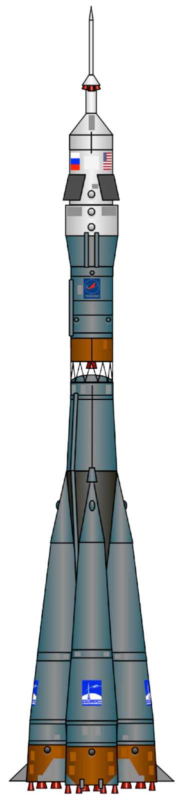
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

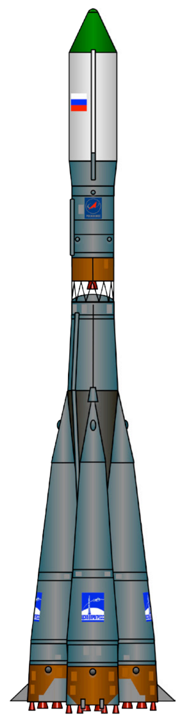
Launch Vehicle Fact Sheet

Soyuz FG

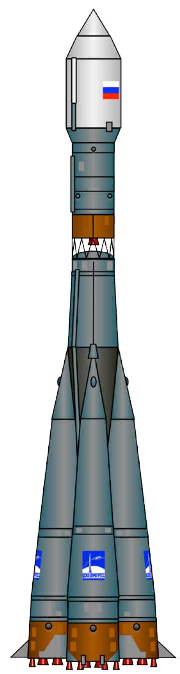
FAA AST



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	TsSKB-Progress	TsSKB-Progress	TsSKB-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	Voronyezh	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/).

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

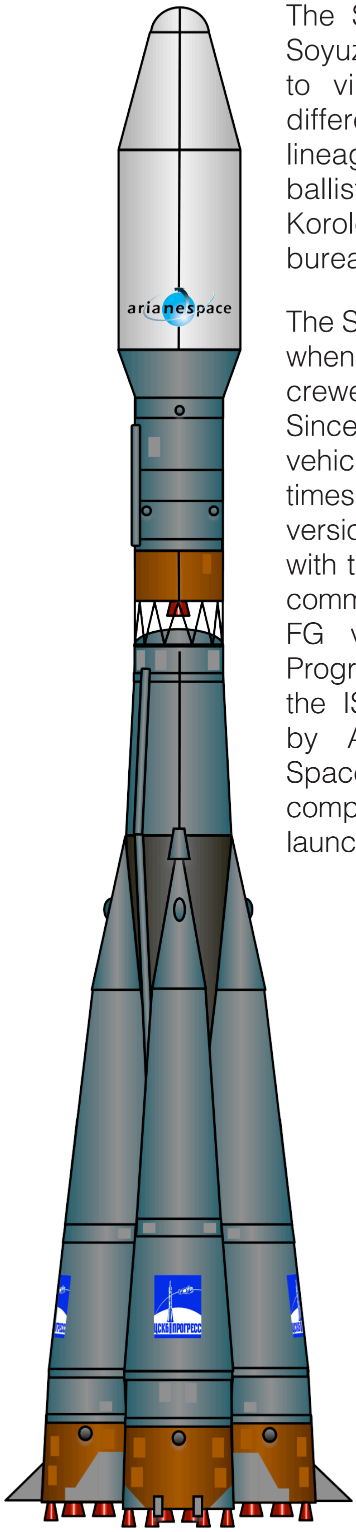
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Soyuz 2.1a/b

FAA AST



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 TsSKB-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/Starsem

Organization Headquarters
Russia/France

Manufacturer
TsSKB Progress

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
2.1a (2004), 2.1b (2006)

Number of Launches
2.1a (28), 2.1b (32)

Reliability
93%

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Soyuz 2.1a/b

FAA AST

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	TsSKB-Progress	TsSKB-Progress	TsSKB-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	Voronyezh	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)

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

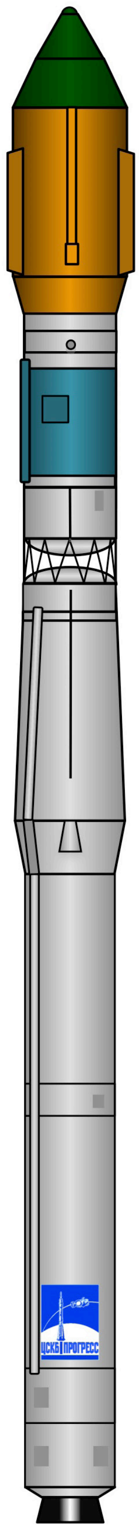
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 diamter is 2.7 m, compared to 2 m 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 Enrgomash. 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 km (932 mi) 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 vehilce's upper stage.

Launch service provider
VKS/Roscosmos

Organization Headquarters
Russia

Manufacturer
TsSKB 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 Launches
2

Reliability
100%

Launch sites
Baikonur (LC-31 or LC-6)
Plesetsk (LC-43)

GTO capacity, kg (lb)
N/A

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

SSO capacity, kg (lb)
1,400 (3,086)

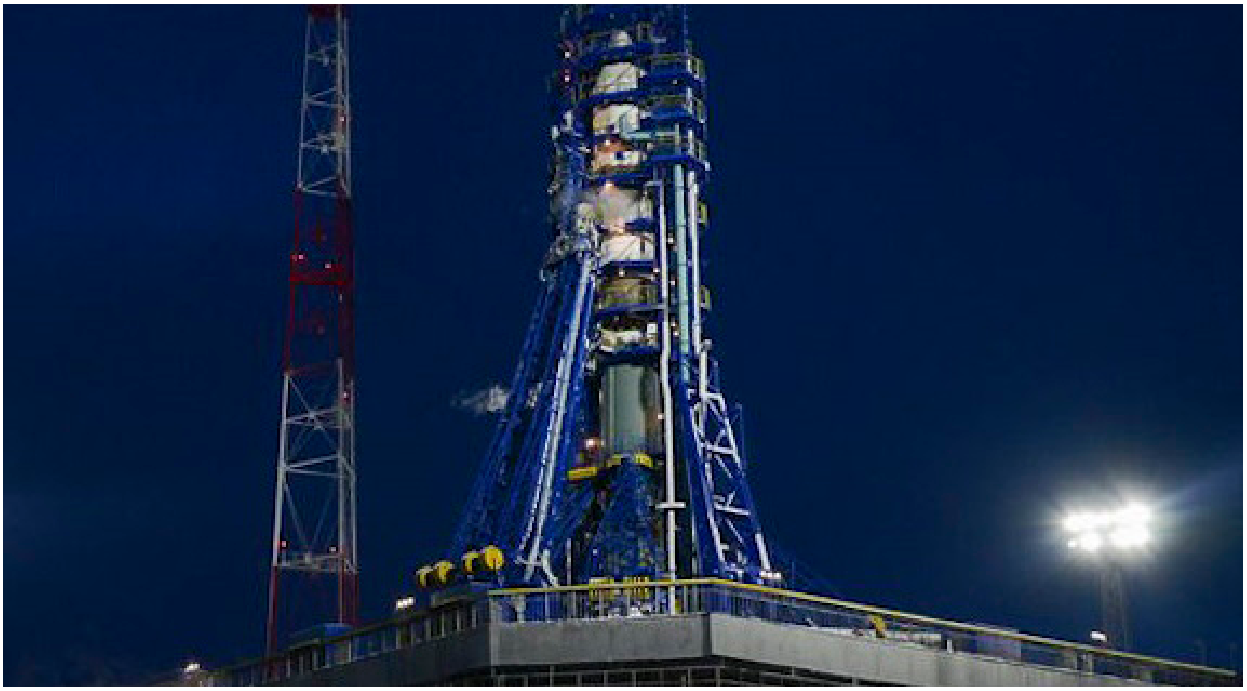
Estimated Price per Launch
$40M

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Soyuz 2.1v



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	TsSKB Progress	TsSKB Progress	TsSKB 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	Voronyezh	TsSKB Progress
Engine thrust, kN (lbf)	1,510 (339,462)	297.9 (66,971)	2.94 (661)

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

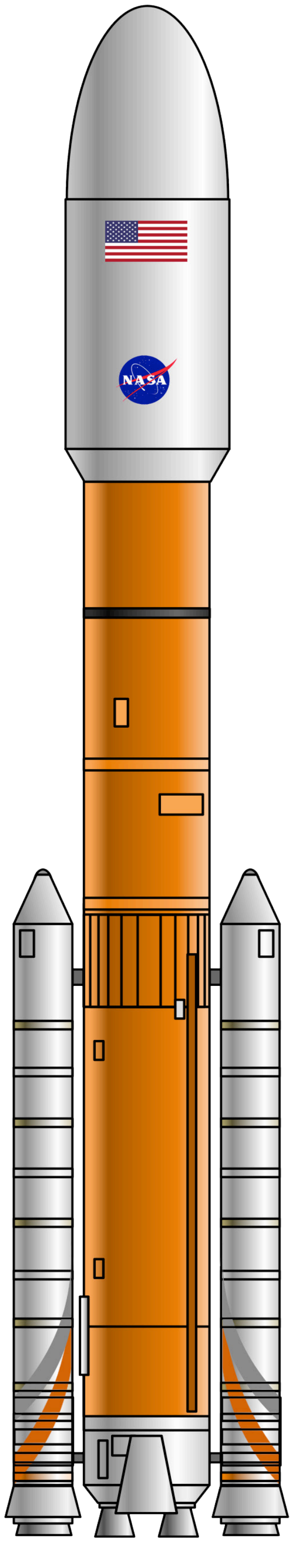
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Space Launch System



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 an uncrewed test of Orion in 2018 (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.

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
2018

Launch sites
KSC (LC-39B)

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
70,000-130,000
(154,324-286,601)

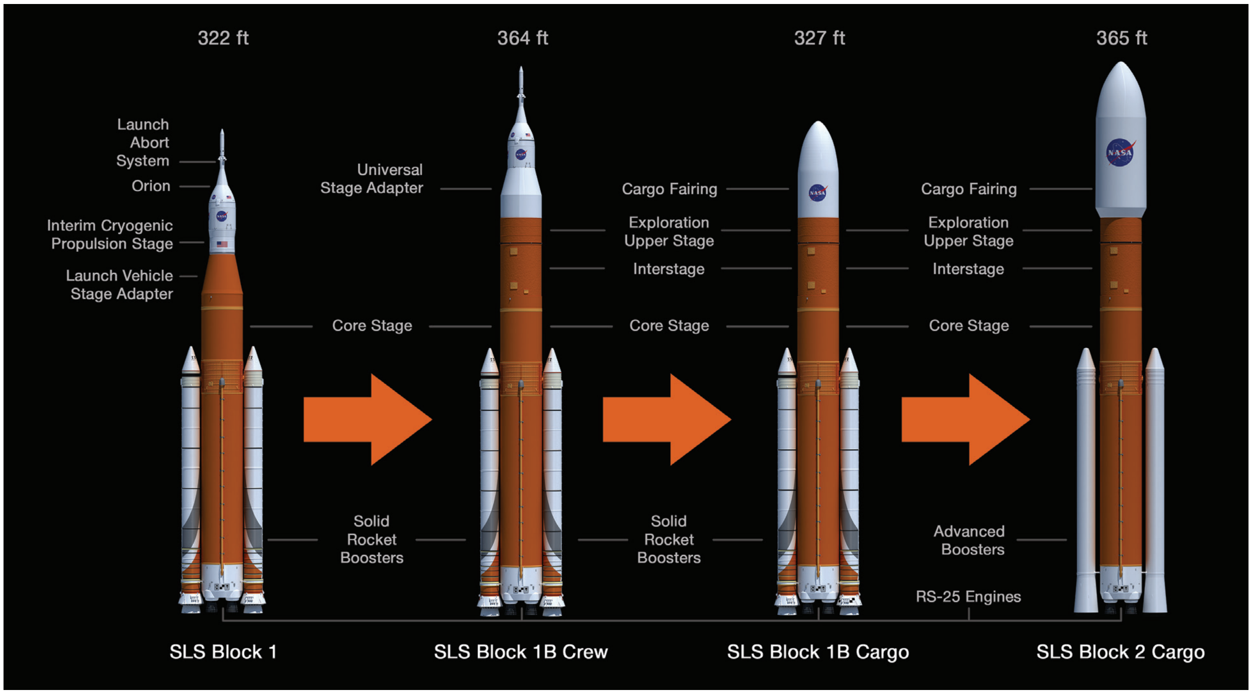
SSO capacity, kg (lb)
N/A

Estimated Price per Launch
N/A

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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. Total thrust is sum of all boosters.*

FAA AST

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

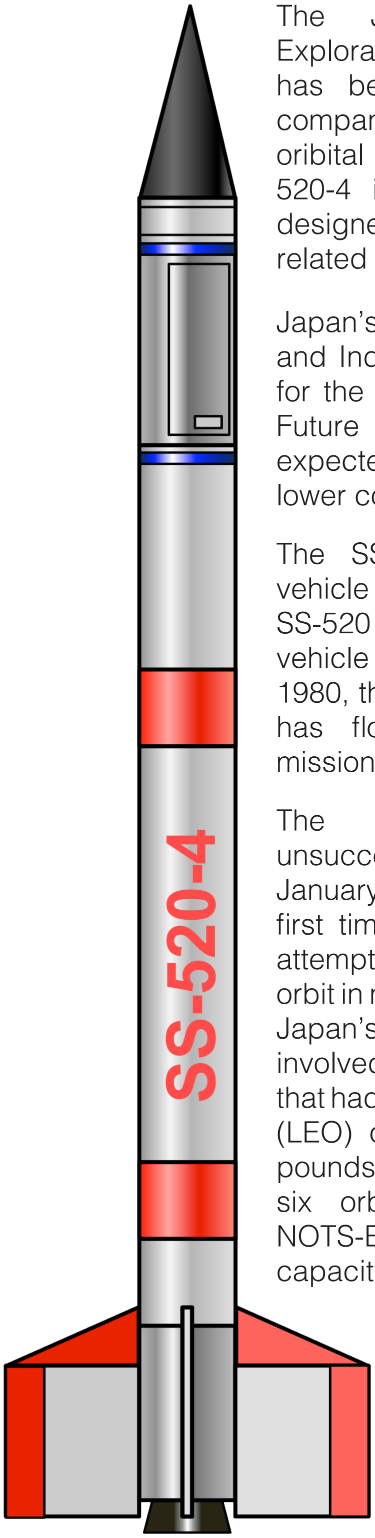
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

SS-520-4



The Japan Aerospace and Exploration Agency (JAXA) has been working with several companies to develop a very small oribital launch vehicle. The SS-520-4 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-520-4 vehicle program. Future operational launches are expected to be conducted at much lower costs.

The SS-520-4 is a three-stage vehicle derived from the two-stage SS-520 sounding rocket. This vehicle has flown 30 times since 1980, though a three stage version has flown twice on suborbital missions.

The 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.

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 Launches
1

Reliability
0%

Launch sites
Uchinoura

GTO capacity, kg (lb)
N/A

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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

SS-520-4

The SS-520-4 is launched in January 2017 ccarrying a student-built CubeSat called TRICOM-1 The launch ended in failure. (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

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

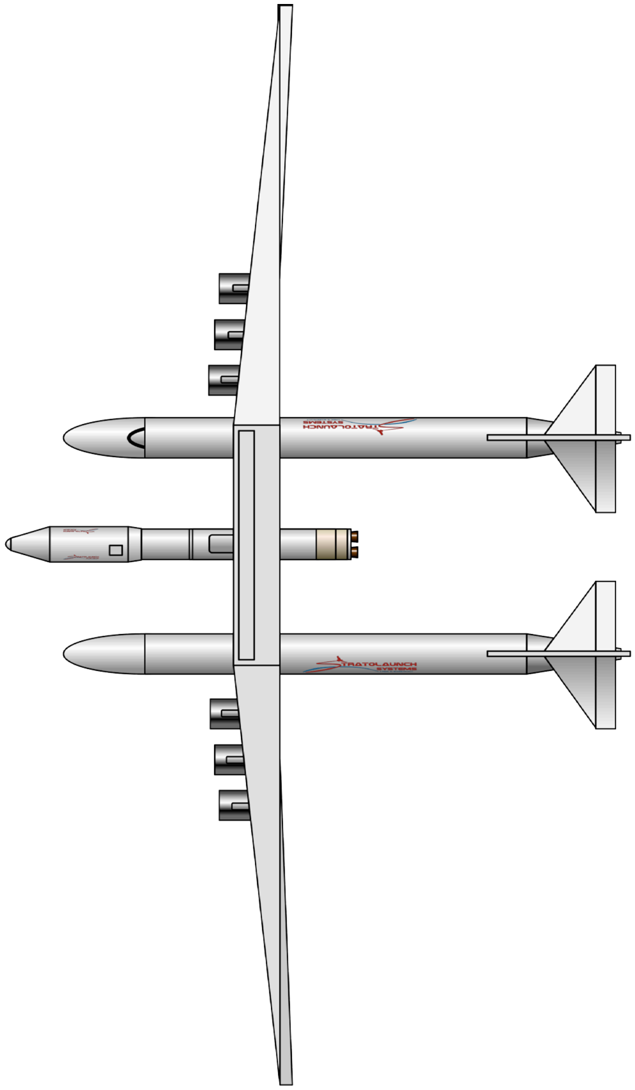
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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)

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
450 (992)

SSO capacity, kg (lb)
325 (717)

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.

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Stratolaunch

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)	726 (163,247)	196 (44,171)	36 (8,062)	0.2 (45)

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.

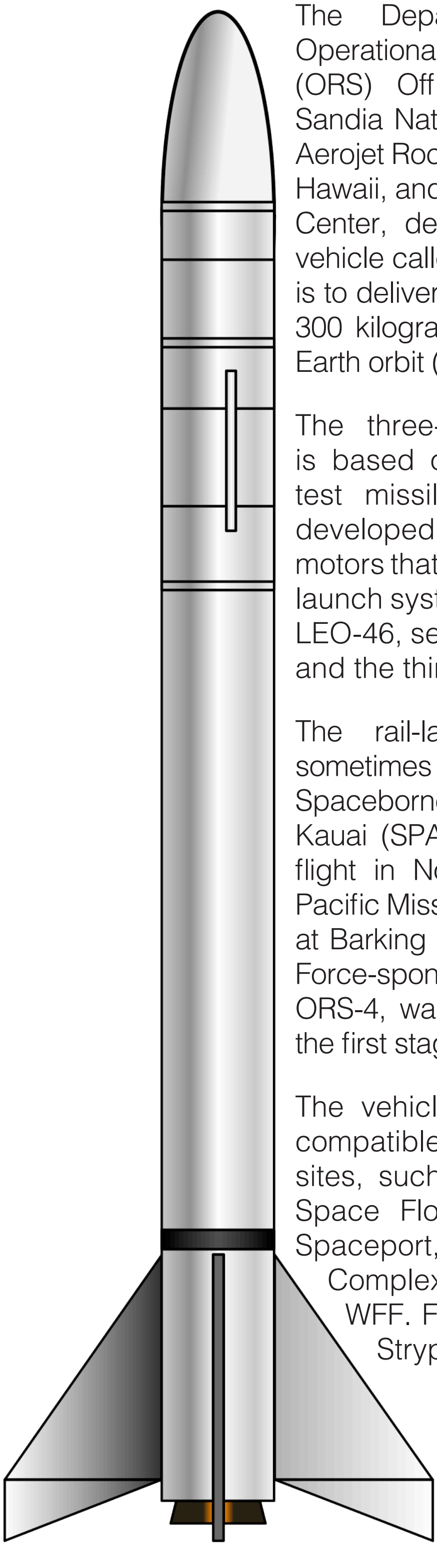
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Super Strypi

FAA AST



The Department of Defence's Operationally Responsive Space (ORS) Office, with support from Sandia National Laboratories (SNL), Aerojet Rocketdyne, the University of Hawaii, and NASA's Ames Research Center, developed a small launch vehicle called Super Strypi. The goal is to deliver payloads in the range of 300 kilograms (661 pounds) to low Earth orbit (LEO).

The three-stage all-solid vehicle is based on the 1960s-era Strypi test missile. Aerojet Rocketdyne developed three new solid rocket motors that support the Super Strypi launch system. The first stage is the LEO-46, second stage is the LEO-7 and the third stage is the LEO-1.

The rail-launched Super Strypi, sometimes also refered to as the Spaceborne Payload Assist Rocket Kauai (SPARK), made its inaugural flight in November 2015 from the Pacific Missile Range Facility (PMRF) at Barking Sands in Hawaii. The Air Force-sponsored mission, called ORS-4, was lost following failure of the first stage.

The vehicle was designed to be compatible with other launch sites, such as, but not limited to, Space Florida's Cape Canaveral Spaceport, Kodiak Launch Complex in Alaska, and NASA's WFF. Future launches of Super Strypi appear unlikely.

Launch service provider
ORS Office
Sandia National Laboratory

Organization Headquarters
USA

Manufacturer
ORS Office
Sandia National Laboratory
Aerojet Rocketdyne

Mass, kg (lb)
505,846 (1,155,200)

Length, m (ft)
68.4 (224.4)

Diameter, m (ft)
3.7 (12)

Year of First Launch
2015

Number of Launches
1

Reliability
0%

Launch sites
PMRF (Pad 41)

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
320 (705)

SSO capacity, kg (lb)
275 (606)

Estimated Price per Launch
TBD

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

FAA AST

Launch Vehicle Fact Sheet
Super Strypi

The Super Strypi vehicle installed on its launcher rail system at PMRF in Hawaii. The inaugural launch on November 3, 2015 ended with a first stage booster failure. (Source: U.S. Air Force)

Fairing	Length, m (ft)	Diameter, m (ft)
Standard Fairing	1.5 (5)	1.5 (5)

	1st Stage	2nd Stage	3rd Stage
Stage designation	LEO-46	LEO-7	LEO-1
Length, m (ft)	11.3 (37)	2.7 (9)	1.5 (5)
Diameter, m (ft)	1.5 (5)	1.5 (5)	1.5 (5)
Manufacturer	Aerojet Rocketdyne	Aerojet Rocketdyne	Aerojet Rocketdyne
Propellant	Solid	Solid	Solid
Propellant mass, kg (lb)	20,413 (45,004)	3,233 (7,128)	643 (1,417)
Total thrust, kN (lbf)	1,265 (284,470)	195 (43,865)	50 (11,234)

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

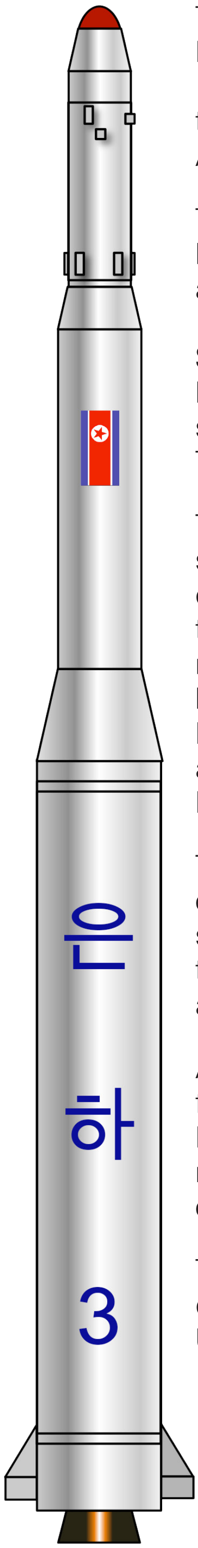
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
4

Reliability
50%

Launch sites
Tonghae (Musudan-ri)
Sohae (Pongdong-ri)

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
100 (220)

SSO capacity, kg (lb)
< 100 (< 220)

Estimated Price per Launch
N/A

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Unha

FAA AST

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)

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

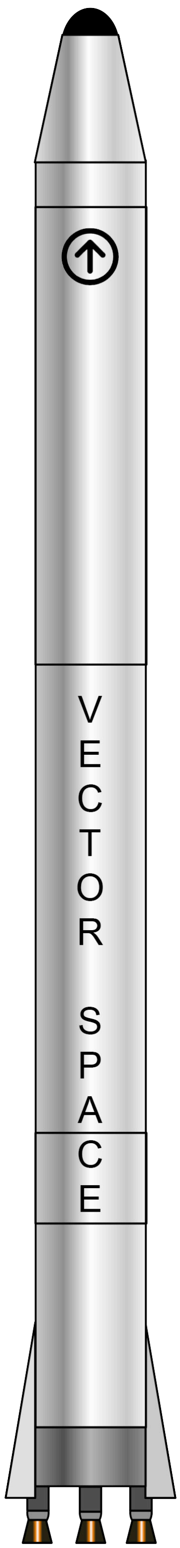
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Vector H



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 Space Systems

Organization Headquarters
USA

Manufacturer
Vector Space Systems

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

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
160 (353)

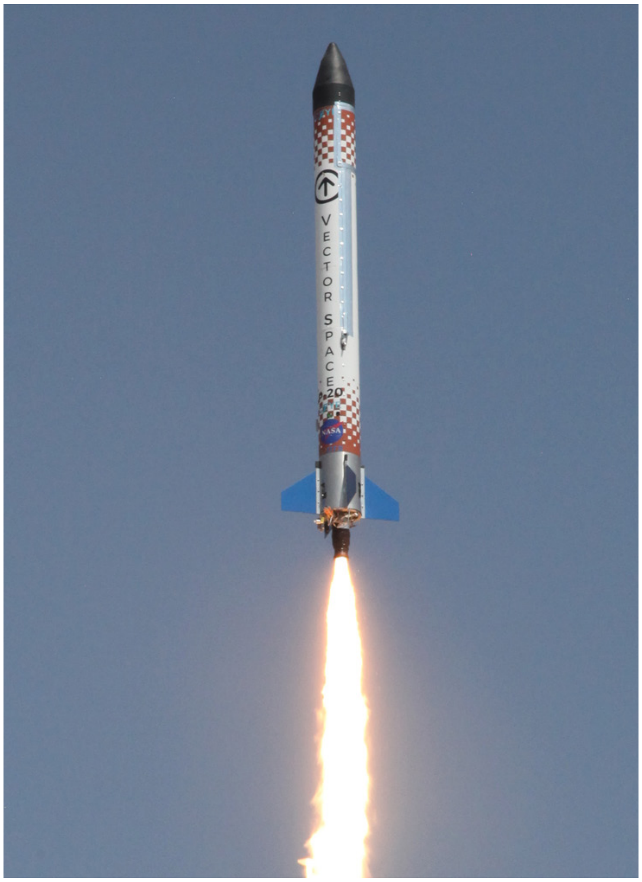
SSO capacity, kg (lb)
75 (165)

Estimated Price per Launch
$3.5M

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Vector H

FAA AST



Vector Space Systems tests a 3.7-meter (12-foot) prototype vehicle. Source: Vector Space Systems.

Fairing	Length, m (ft)	Diameter, m (ft)
Fairing	1.7 (5.6)	1.1 (3.6)

	1st Stage	2nd Stage	3rd Stage
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 Space Systems	Vector Space Systems	Vector Space Systems
Propellant	LOX/Propylene	LOX/Propylene	
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	66 (14,837)	2.2 (500)	Undisclosed
Engine(s)	6 x TBD	1 x TBD	1 x TBD
Engine manufacturer	Vector Space Systems	Vector Space Systems	Vector Space Systems
Engine thrust, kN (lbf)	22 (5,000)	2.2 (500)	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/).

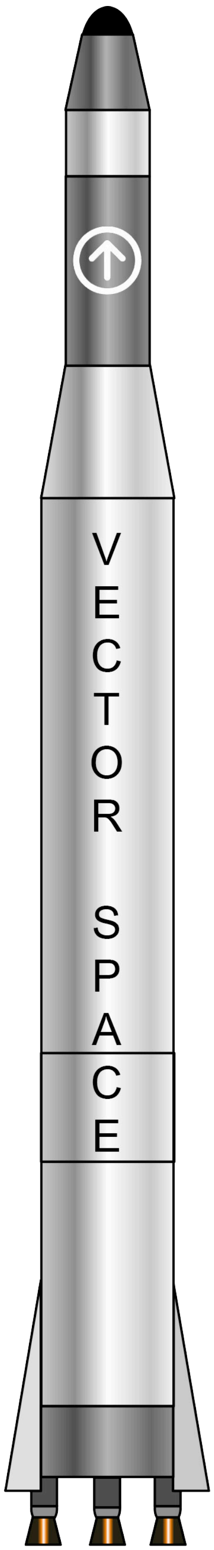
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Vector R (Rapide)



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 Space Systems

Organization Headquarters
USA

Manufacturer
Vector Space Systems

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

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
66 (146)

SSO capacity, kg (lb)
40 (88)

Estimated Price per Launch
$1.5M

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

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

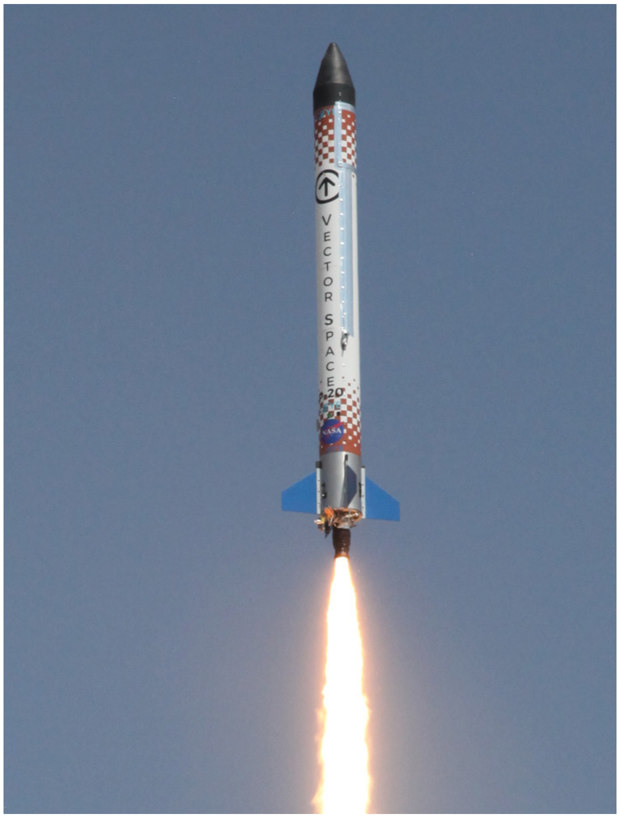
Publication produced for FAA AST by The Tauri Group under contract.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

Vector R (Rapide)

FAA AST



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
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 Space Systems	Vector Space Systems	Vector Space Systems
Propellant	LOX/Propylene	LOX/Propylene	
Propellant mass, kg (lb)	Undisclosed	Undisclosed	Undisclosed
Total thrust, kN (lbf)	66 (14,837)	2.2 (500)	Undisclosed
Engine(s)	3 x TBD	1 x TBD	1 x TBD
Engine manufacturer	Vector Space Systems	Vector Space Systems	Vector Space Systems
Engine thrust, kN (lbf)	22 (5,000)	2.2 (500)	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.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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.

Development of the Vega began in 2003 led by the European Space Agency with contributions from the Italian space agency, the French space agency, and Italy-based Avio.

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. 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 Launches
8

Reliability
100%

Launch sites
Guiana Space Center (ZLA)

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
1,963 (4,328)

SSO capacity, kg (lb)
1,430 (3,153)

Estimated Price per Launch
$37M

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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)

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

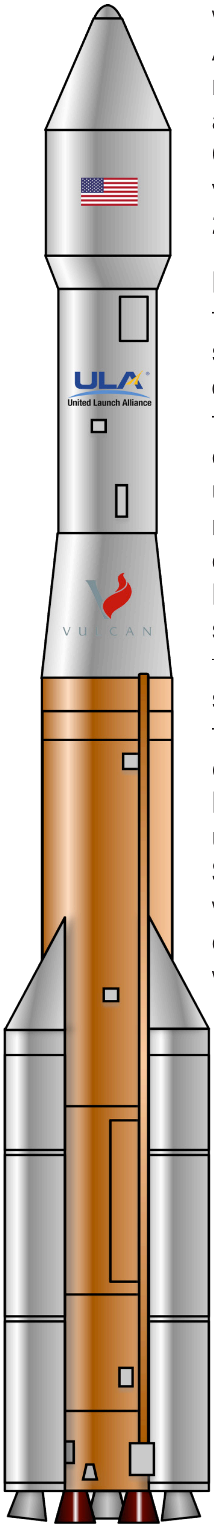
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 2019.

Leveraging technologies and processes from the Atlas V and Delta IV programs since 2002, and even earlier in terms of research and development time, the Vulcan will nevertheless feature a couple of unique capabilities. First is the use of a liquid oxygen (LOX)-liquified natural gas (LNG, or methane) engine called the BE-4. The BE-4, provided by Blue Origin, will power the vehicle's first stage. ULA is developing the capability to reuse the BE-4. Once the first stage is spent, the BE-4 subsystem will separate from the stage, deploy a reentry shield, deploy a parachute, and be recovered by an aircraft. The second is planned use of the Advanced Cryogenic Evolved Stage (ACES) as an upper stage, which will dramatically increase the vehicle's capacity to orbit. In addition, ACES, which will burn a LOX-liquid hydrogen mix, will be capable of remaining on-orbit for future use, allowing for a "distributed launch" capability. Until it is introduced in 2023, the Vulcan will use the proven Centaur upper stage.

The deployment strategy will take place in phases. First, the Delta IV Medium vehicles will be retired in 2018, except for the Delta IV Heavy. The first launch of Vulcan is expected in 2019. It will fly concurrently with the Atlas V for an undisclosed period of time. The Delta IV Heavy and the Atlas V will be retired following successful deployment of the Vulcan-ACES combination in 2023.

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)
58.3-63 (191-207) *est*

Diameter, m (ft)
3.8 (12.5)

Year of Planned First Launch
2019

Launch sites
CCAFS (SLC-41)
VAFB (SLC-3E)

GTO capacity, kg (lb)
4,750-8,900 (10,472-19,621)

LEO capacity, kg (lb)
9,370-18,510 (20,657-40,510)

SSO capacity, kg (lb)
7,724-15,179 (17,029-33,464)

Estimated Price per Launch
$85M-$260M

The ACES upper stage is currently under development. The final design and selection of an engine provider has not yet been decided.

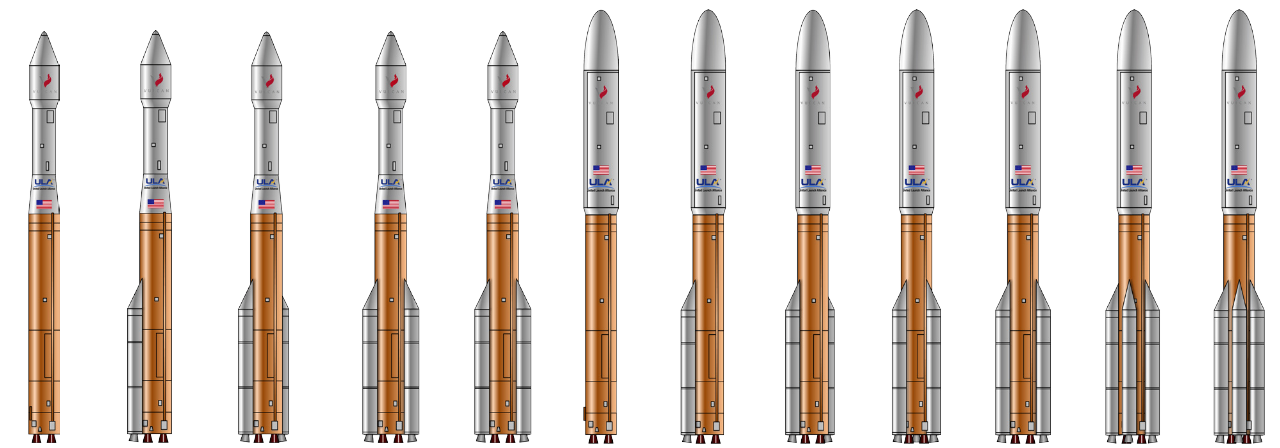
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet
Vulcan



Vulcan 400 | Vulcan 401 | Vulcan 402 | Vulcan 403 | Vulcan 404 | Vulcan 500 | Vulcan 501 | Vulcan 502 | Vulcan 503 | Vulcan 504 | Vulcan 505 | Vulcan 506

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 five versions of the 400 series and seven 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 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)

	SRB*	1st Stage	2nd Stage Option	2nd Stage Option	2nd Stage Option
Stage designation	GEM-63XL	1st Stage	Single Engine Centaur	Dual Engine Centaur	ACES
Length, m (ft)	19.2 (63) *est*	32.5 (106.6) *est*	12.7 (41.7)	12.7 (41.7)	TBD
Diameter, m (ft)	1.6 (5.3)	5.1 (16.7) *est*	3.1 (10.2)	3.1 (10.2)	5.1 (16.7) *est*
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)	46,300 (102,074) *est*	368,000 (811,301) *est*	20,830 (45,922)	20,830 (45,922)	63,500 (139,994) *est*
Total thrust, kN (lbf)	1,833 (412,075) *est*	4,800 (1,079,083)	99.2 (22,300)	198.4 (44,600)	431 (96,893) *est*
Engine(s)	--	2 x BE-4	1 x RL10A-4-2	2 x RL10A-4-2	TBD
Engine manufacturer	--	Blue Origin	Aerojet Rocketdyne	Aerojet Rocketdyne	TBD
Engine thrust, kN (lbf)	--	2,400 (550,000)	99.2 (22,300)	99.2 (22,300)	TBD

** Figures are for each booster. 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/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

XS-1

FAA AST

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), 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

GTO capacity, kg (lb)
N/A

LEO capacity, kg (lb)
1,361 (3,000)

SSO capacity, kg (lb)
TBD

Estimated Price per Launch
$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/).

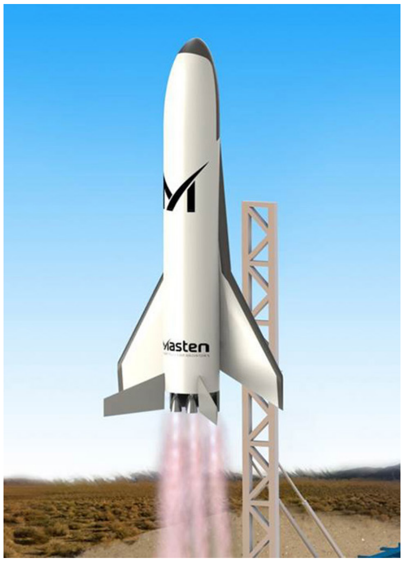
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 is 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)

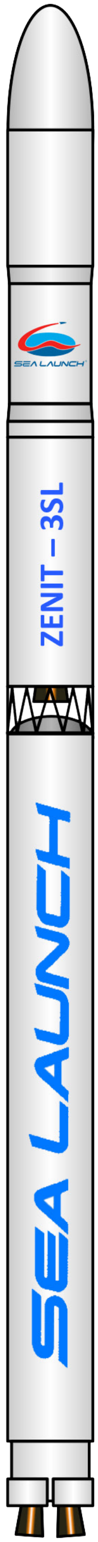
Detailed information can be found in the Annual Compendium of Commercial Space Transportation(www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/).

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

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 Launches
83

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)

LEO capacity, kg (lb)
N/A

SSO capacity, kg (lb)
N/A

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/).

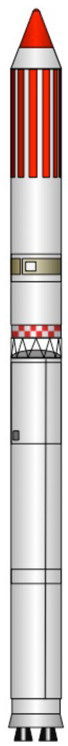
Data is maintained in FAA AST's Space Transportation Analysis and Research (STAR) database.

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

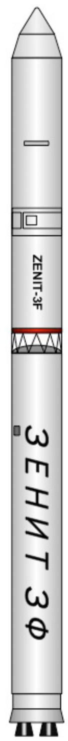
FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast

Launch Vehicle Fact Sheet

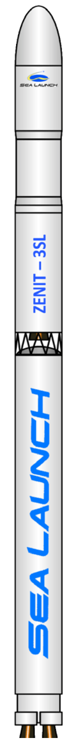
Zenit



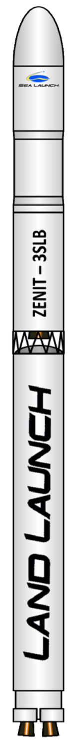
Zenit 2



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	11.39 (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)

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.

FAA Office of Commercial Space Transportation
800 Independence Avenue SW (AST)
Washington, DC 20591
202.267.5450 (fax)
http://www.faa.gov/go/ast