26 Launch Vehicles

26.5 Available Launch Vehicles

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This last section will only attempt to provide qualitative observations, avenues for gaining additional information, and a rough overview of the fleets, such as the Soyuz in Fig. 26-24, that are in actual service worldwide today. The book website is updated from time to time with more current vehicle information. In addition, vehicle providers have embraced the internet as a means of communicating performance, contact, and availability information to a wider audience than was possible before, so that kind of contact information will be included here, as available. There are two caveats to this section, however. The first being that a detailed treatment of world fleet performance, features, and history would fill a book in its own right, e.g., Isakowitz, Hopkins, and Hopkins Jr. [2004] , which provides an authoritative and widely-used survey of world vehicles. An extension of this caveat is yet another reminder to take published vehicle performance data as only a starting point in your investigations, even if it comes from the vehicle providers themselves. Again, what's published in any forum or media is a best faith estimate of the vehicle performance offered at that time, but vehicles, even those with venerable histories, usually see a series of changes and upgrades as parts become obsolete, or manufacturing techniques change, or even as they build in measures for greater reliability. All of this affects the performance available for your use. Refer to Table 26-7 for a summary of vehicles providing launch services today, along with their advertised LEO and GTO performance capabilities.

The other caveat is that I personally tend to apply a ruthlessly-pragmatic filter on vehicle availability and capability, and that is "Is it flying to orbit today?" There are a number of vehicles in various stages of development at any one moment in time, and most carry a high degree of credibility in their development plans. Governments and other investors tend not to throw their money into such ventures unless the credibility is there. Even so, many never fly. This is as true in 2010 as it was in any year of the previous three decades and prior, and this observation respects neither nationality nor vehicle performance class. Obviously, new fleets are developed and successfully placed into service; however, the number of fleets under development with this intent consistently exceeds the number that actually reaches their goal. If it hasn't yet flown, then there's considerable risk that it will never enter service at all. I'm a great fan of "daring mighty things", but you should be pragmatic about finding a ride to orbit that will be there when you need it.

26.5.1 United States

Atlas V

The Atlas V was developed by Lockheed Martin as part of the US Air Force Evolved Expendable Launch Vehicle (EELV) Program [ULA, 2010b] and is today manufactured and operated by ULA (a joint venture between Boeing and Lockheed Martin). The Atlas V launches from CCAFS, Florida and VAFB, California. ULA advertises a LEO performance range of 9.8–18.8 metric tons, using a mix of configurations varying the number of strap-on thrust augmentation solid rocket motors (similar to the Delta II). This vehicle also services GTO orbits from CCAFS, advertising a payload range of 4.7–8.9 metric tons. An Atlas V "Heavy" is advertised, but has not yet flown at the time of this writing. The other Atlas V variants are in active production.

Delta II

The Delta II has seen lengthy service to the US and international customer base, including a series of missions to populate the US DoD's Global Position System (GPS), as well as interplanetary scientific missions and a range of telecommunications customers. Launches are conducted from Cape Canaveral Air Force Station (CCAFS) in Florida, and Vandenberg Air Force Base (VAFB) in California. The provider, United Launch Alliance, LLC [ULA, 2010b] advertises a range of 2.5–5.4 metric tons to LEO with a mix of configurations that vary the number of thrust augmentation solid rocket motors that are "strapped on" to the booster. This vehicle is capable of servicing GTO orbits, with an advertised range of 0.9–2.1 metric tons. The subject of Delta II retirement from service received considerable investigation after the booster engine production was halted earlier this decade, but ULA continues to advertise the availability of the remaining flight assets at the time of this writing.

Delta IV

ULA manufactures and markets the Delta IV vehicle, which, like the Atlas V, was originally developed in partnership (by Boeing prior to the formation of ULA) with the USAF EELV Program [ULA, 2010b]. Also like the Atlas V, the Delta IV launches from both US coasts (CCAFS, Florida and VAFB, California) and is capable of servicing GTO missions. ULA advertises a LEO performance range of 9–22.5 metric tons, using a mix of configurations varying the number of strap-on solid rocket motors, as well as a choice of two different second stages, reaching the maximum performance using the "Heavy" configuration that employs three LO2/LH2 liquid booster cores strapped together. This vehicle also services GTO orbits from CCAFS, advertising a payload range of 4.3–13 metric tons. The Delta IV is in active production.

Table 26-7. Summary of Available Launch Vehicles. The book website contains a more extensive table with a more complete description of each vehicle, web references for each vehicle, and is also updated as vehicles change.

Nation	Vehicle	Orbits Serviced	Performance (mT)		Active Launch Sites*	Comments
			LEO	GTO		
USA	Atlas V	LEO, GTO, GSO, Escape	9.4–18.5	4.8–8.9	CCAFS, VAFB	Two payload fairing sizes, one to five strap-on solid motors
	Delta II	LEO, GTO, Escape	2.5–5.5	0.8–2.0	CCAFS, VAFB	Three, four or nine strap-on solid motors
	Delta IV	LEO, GTO, Escape	9.2–22.6	4.3–13	CCAFS, VAFB	Two upper stage sizes, two or four strap-on solid motors, or three-core “Heavy”
	Falcon 1	LEO	1	n/a	RTS	
	Falcon 9	LEO, GTO	10.4	4.5	CCAFS	
	Minotaur I	LEO	0.6	n/a	WFF, VAFB	Uses decommissioned ICBM motors for the first two stages
	Minotaur IV	LEO	1.7	n/a	WFF, VAFB	Uses decommissioned ICBM motors for the first three stages
	Pegasus XL	LEO	0.45	n/a	Air-mobile	Prior launches from CCAFS, RTS, VAFB, WFF, and the Canary Islands
	Taurus	LEO	1.4	n/a	VAFB	Vehicle and launch equipment designed to be road-, rail-, and sea-portable to austere launch sites.
China	Long March 2C/D	LEO, GTO	3.8	1.2	JSLC, TSLC, XSLC	
	Long March 3A/B/C	GTO	n/a	2.–5.5	XSLC	Primarily marketed for GTO missions
	Long March 4	LEO	4.2	n/a	JSLC, TSLC	Mostly sun-synchronous use
European Union	Ariane 5	LEO, GTO	20	10	CSG	Two upper stage choices, ECA (cryogenic) and ES (storable) for LEO and GTO missions, respectively
India	PSLV	LEO, GTO	1.6	1	SDSC	The LEO performance figure quoted by ISRO is for sun-synchronous
	GSLV	GTO	n/a	2.5	SDSC	No LEO performance quoted by ISRO
Israel	Shavit	LEO	0.3*	n/a	Palamchim AFB	Launches to date have been westward, however a polar capability is being offered and the launch system design is intended to operate from austere sites.
Japan	H-IIA	LEO, GTO	n/a	4–6	TSC	Two to four strap-on solid rocket motors. This vehicle is primarily marketed for GTO missions
	H-IIB	LEO	16.5	8	TSC	Used for International Space Station servicing missions to date
Russia	Dnepr	LEO	3.7	n/a	Baikonur, Yasny	Converted RS-20 (NATO SS-18) ICBM, with commercial services marketed by ISC Kosmotras
	Proton	LEO, GTO, Escape	23	6.9	Baikonur	Commercial services marketed by International Launch Services (ILS)
	Rockot	LEO	2	n/a	Plesetsk	Converted UR100N (NATO SS-19) ICBM, with commercial services marketed by Eurockot, GmBH
	Soyuz	LEO, GTO, Escape	5.0–8.2	1.5–3.0	Baikonur, Plesetsk, CSG	Commercial services marketed by Starsem (Baikonur) and Arianespace (CSG)
Ukraine	Zenit	LEO, GTO	n/a	n/a	Baikonur, Sea-mobile	Commercial services marketed by Sea Launch, LLC

*** Site Names/Acronyms**

Baikonur – Baikonur Cosmodrome, Kazakhstan
CCAFS – Cape Canaveral Air Force Station, Florida
CSG – Guiana Space Center, Guiana, France
JSLC – Jiuquan Satellite Launch Center, China
RTS – Reagan Test Site, Kwajalein Atoll, Marshall Islands
SDSC – Satish Dhawan Space Center, Sriharikota, India
TSC – Tanegashima Space Center, Japan
TSLC – Taiyuan Satellite Launc Center, China
VAFB – Vandenberg Air Force Base, California, United States
XSLC – Xichang Satellite Launch Center, China
WFF – NASA Wallops Flight Facility, Virgina, United States
Yasny – Yasny Launch Base, Orenburg Region, Russia

Falcon 1

Space Exploration Technologies Corporation (SpaceX) developed, manufactures, and markets the Falcon 1 launch vehicle [2010], which has flown successfully from the US Army's Reagan Test Site in the Republic of the Marshall Islands. SpaceX advertises a LEO performance capability just over 1 metric ton for launches from KMR, based on a series of performance improvements that are in development. The Falcon 1 is not currently advertised for service to GTO missions.

Falcon 9

SpaceX also developed, manufactures, and markets the Falcon 9 launch vehicle [2010]. To date, this vehicle has flown twice from CCAFS, Florida, with an advertised LEO payload performance capability of 10.5 metric tons and a GTO performance range of 4.5 metric tons (CCAFS launch) to 4.7 metric tons (Reagan Test Site, Republic of the Marshall Islands).

Minotaur I

Orbital Sciences Corporation (Orbital) developed and manufactures the Minotaur family of vehicles, of which the Minotaur I [2010b] is the smallest. The Minotaur I has previously launched from NASA's Wallops Flight Facility (WFF) located on Wallops Island, Virginia and VAFB. Like several other vehicles that are primarily solid-fueled, this vehicle fleet advertises the capability to launch from other sites with minimal infrastructure. The advertised LEO payload performance capability is just short of 0.6 metric tons for a CCAFS launch. One essential caveat to the Minotaur I is that its use is restricted by US law and policy [White House, 2004] to US Government missions, by dint of the use of decommissioned ICBM motors for the first two stages of this vehicle.

Minotaur IV

Orbital also manufactures the Minotaur IV [OSC, 2010c], which at the time of this writing has completed two successful launches to orbit from WFF, Virginia and Alaska Aerospace Corporation's Kodiak Launch Complex (KLC) located on Kodiak Island, Alaska. This vehicle is also solid-fueled, with the accompanying intent to be capable of launching from multiple sites with minimal infrastructure. Maximum advertised LEO payload performance capability is just over 1.7 metric tons for a launch from CCAFS. The same limitation to US Government missions that applies to Minotaur I also applies to Minotaur IV, given that the first three stages of the Minotaur IV use decommissioned ICBM motors as well.

Pegasus XL

The Pegasus XL is unique among launch vehicles in service today in that it launches to orbit from an aircraft, rather than a fixed launch site [OSC, 2010c]. This vehicle has launched to orbit from CCAFS, VAFB, WFF, KMR, and the Canary Islands, Spain. Orbital manufactures and markets this vehicle which, unlike the Minotaur family, uses no ICBM assets and remains available for commercial and international service. Maximum advertised LEO payload performance capability is approximately 0.45 metric tons for a launch from CCAFS airspace.

Taurus

The Taurus vehicle is manufactured by Orbital Sciences Corporation [2010c], with the Taurus XL being the most-recent variant of a vehicle family that has been in service with launches to orbit from VAFB since 1994. This vehicle was a forerunner to the Minotaur family in terms of developing a solid-fueled system capable of launching with minimal launch site infrastructure, but to date the launches have been limited to VAFB. Performance to LEO from CCAFS is advertised as 1–1.4 metric tons, using varying combinations of extended-length solid rocket motors in a single-core vehicle. Three of the eight missions have been launched using a decommissioned ICBM solid rocket motor for the first stage (last flown in 2000). The other missions used the Alliant Techsystems (ATK) Castor 120 solid rocket motor for the first stage, which is not subject to the restrictions that accompany decommissioned ICBM motors.

26.5.2 China

Long March

The Long March family of vehicles encompasses multiple variants that are marketed by China Great Wall Industries [2010]. Performance ranges from just over 1 metric ton to LEO up to 3.8 metric tons payload performance capability to GTO for the Long March 3C.

26.5.3 European Union

Ariane 5

EADS-Astrium manufactures the Ariane 5 vehicle, which is marketed and operated by Arianespace and launched from Guiana Space Center (CSG), France. Payload performance capability to LEO is advertised as roughly 20 metric tons, with 10 metric ton performance to GTO.

26.5.4 Japan

H-II

Mitsubishi Heavy Industries manufactures the H-IIA and H-IIB vehicles for Japanese Government and commercial use [JAXA, 2007]. Both are launched from Tanegashima Space Center, Japan. H-IIA payload performance capability is approximately 4 metric tons to GTO and 10 metric tons to LEO. The higher-capability H-IIB vehicle is advertised to deliver 8 metric tons to GTO and over 16 metric tons to LEO.

26.5.5 India

PSLV

The Indian Polar Space Launch Vehicle (PSLV) is operated by the Indian Space Research Organisation (ISRO), an agency of the Indian Government [2010].

The vehicle is launched from Satish Dhawan Space Center (SDSC), Sriharikota, India and nominally intended for polar scientific missions. However, the vehicle is also capable of flying to GTO from the same site. Payload performance capability to polar LEO is advertised to be approximately 1.6 metric tons, and just over 1 metric ton to GTO.

GSLV

The ISRO developed and operates the Geosynchronous Space Launch Vehicle (GSLV) to service Indian Government and commercial telecommunications missions to geosynchronous orbit. Like the PSLV, the GSLV also launches from SDSC in Sriharikota, India. Advertised payload performance capability to GTO is 2–2.5 metric tons, but an increased capability "Mark III" version is under development.

26.5.6 Israel

Shavit

The three-stage Shavit booster is manufactured and marketed by Israel Aerospace Industries, Ltd [2010]. To date, the Shavit has lofted several Ofeq (Hebrew for "Comet") [US Dept. of Transportation, 1997] spacecraft for the Israeli government, including Ofeq 9 [Opall-Rome, 2010], but no commercial customers. Launches are conducted from Palamchim Air Base near Tel Aviv, launching westward over the Mediterranean Sea to avoid overflight concerns for neighboring countries. Capability achieved thus far to LEO at this unique inclination (~142 deg) is on the order of 0.3 metric tons. Like the US Taurus vehicle, the launch system is described as being designed for transportability and operation from austere environments. IAI [2011] advertises an intended system growth to serve polar LEO customers in the same or higher weight class.

26.5.7 Russia

Dnepr

The Dnepr Project was initiated when the International Space Company Kosmotras was formed in 1997 by Russia and the Ukraine [ISC, 2001] to market converted SS-18 (RS-20) ICBM for international commercial launch services while disposing of decommissioned stages. In direct contrast to US space transportation policy [US Congress, 2011], the Russian Government does not use the Dnepr for either military or Russian civil space missions. Launches are conducted from Baikonur Cosmodrome in Kazakhstan, with a maximum advertised performance of just over 3.6 metric tons to LEO. This vehicle does not service GTO missions. The launch system is unique in that the integrated vehicle/spacecraft is lowered into a silo, essentially identical to that used for the ICBM counterpart, from which it is later ejected by a gas generator charge prior to engine start during the launch sequence.

Proton

The first Proton (aka UR-500K) test launches were conducted in 1967, with the vehicle entering operational service in 1968 [Isakowitz, 2004]. The vehicle never actually entered service as a ballistic missile. The vehicle is manufactured and operated by Khrunichev State Research and Production Space Center [KhSC, 2010], and marketed in the US by International Launch Services, Inc. [ILS, 2010]. Launches are conducted from Plesetsk, Russia (high inclination) and Baikonur, Kazakhstan. LEO performance is roughly estimated to be 23 metric tons, but this vehicle is mostly used for GTO applications with an advertised 5.5 metric ton payload performance capability to GTO [ILS, 2010].

Rockot

The Rockot is based on SS-19 (RS-18) ICBM, and is marketed commercially and internationally by the joint venture Eurockot Launch Services GmbH. Launches are conducted from Plesetsk, Russia, with maximum advertised performance just over 1.9 metric tons to LEO [Eurockot, 2004]. This vehicle does not service GTO missions.

Soyuz

Multiple variants of the Soyuz remain in service, supporting International Space Station crew changes and logistics, Russian Government missions, and upcoming commercial telecommunications missions from a new launch site at the Guiana Space Center (CSG), France. Existing launch sites include Plesetsk, Russia, and Baikonur, Kazakhstan. The word "venerable" is insufficient to describe this long-lived fleet, descended from the original R-7 booster used to orbit the Sputnik satellite. The Soyuz family of vehicles is manufactured by the Samara Space Center "TsSKB-Progress" after original development by the OKB-1 Design Bureau (now Rocket Space Company Energia (RSC Energia)). Advertised payload performance to GTO from CSG [Ariane, 2010] is 3.2 metric tons, reduced to roughly 3 metric tons advertised for launch from Baikonur [Starsem, 2010].

26.5.8 Ukraine

Zenit

The Zenit family is manufactured by Yuzhnoye/YuzhmashDesign Office in the Ukraine, and marketed by the international partnership SeaLaunch, LLC [2010]. The vehicles can be launched from Baikonur or from a seaborne platform in the Pacific Ocean. The three-stage version services the GTO market, while the two-stage vehicle services the LEO market. Performance estimates from the US FAA are 15.2 metric tons to LEO and 6.1 metric tons to GTO when launched from the Odyssey Pacific Ocean Platform [US Dept. of Transportation, 2009].

Useful References

NASA-STD-5002 [NASA, 1996a], "Loads Analyses of Spacecraft and Payloads" is twenty well spent pages that provide useful high-level guidance which any spacecraft manager or engineer should find useful, if nothing more than to furnish a common framework for future discussions. Likewise, NASA Preferred Reliability PD-AP-1317 [NASA, 1996b] "Flight Loads Analysis as a Spacecraft Design Tool" also offers good high-level guidance, particularly with respect to checking a spacecraft mathematical model prior to submittal for coupled loads analysis. More on this subject in a subsequent paragraph.

Useful References

Both MIL-STD-1540C [DoD, 1994] "Test Requirements for Launch, Upper-Stage, and Space Vehicles" and NASA-STD-7003 [2011] "Pyroshock Test Criteria" offer useful and widely applied descriptions of shock as it relates to launch vehicles. Though both date from the mid-to-late 1990s, they are still used to establish a common context for discussions of sharp, intense pyrotechnic or mechanical transients of 20 ms (or less) duration, with broad frequency content that may extend to 10,000 Hz or several hundred thousand Hz.

Useful References

MIL-STD-1540C "Test Requirements for Launch, Upper-Stage, and Space Vehicles" [DoD, 1994] is a good basic guide to vibration and acoustics test requirements, but NASA-HDBK-7005 "Dynamic Environmental Criteria" [NASA, 2001] offers greater depth of discussion regarding the physics, sources, analytical, and test techniques. Additional useful guidance is available in NASA-STD-7001 "Payload Vibroacoustic Test Criteria" [NASA, 2011] and NASA-HDBK-7004 "Force Limited Vibration Testing" [NASA, 2001].

Useful References

My senior colleagues in the field recommend MIL-STD-464C "Electromagnetic Environmental Effects Requirements for Systems" as useful system-level guidance, though insufficient by itself. MIL-STD-461F "Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment" provides good subsystem and box-level guidance. Significantly, MIL-STD-1541A "Electromagnetic Compatibility Requirements for Space Systems" remains a widely-favored, though dated, reference for spacecraft and launch vehicles, probably for the reason that it's among the more straightforward guidance to read and understand, providing useful background material for those documents intended to replace it. There's no implied criticism here, the subject matter is complex and challenging to express in simple terms. MIL-STD-1541A was released as a companion to MIL-STD-461C and specifically addresses the additional EMC requirements for spacecraft and launch vehicle power, composite materials, surface conductivity, multipaction, and on-orbit electrostatic discharge, among other hazards. USAF SC SMC-S-008 [AFSC, 2008] and AIAA-S-121-2009 [AIAA, 2009], both titled "Electromagnetic Compatibility Requirements for Space Equipment and Systems," have been released as replacements for MIL-STD-1541A, though not without some accompanying controversy given the differences between them and the older military standard. The European Cooperative for Space Standardization's ECSS-E-ST-20-07C [ECSS, 2008], "Space Engineering: Electromagnetic Compatibility" is another useful source of guidance released in July 2008.

Useful References

The NASA Technical Reports Server (ntrs.nasa.gov) contains useful guidance of the subject of compartment venting. NASA SP 8060 "Compartment Venting—Space Vehicle Design Criteria" [1970] was published in 1970, yet remains almost universally referenced. The basic science hasn't changed much since then. J. Scialdone at the NASA Goddard Space Flight Center published updated guidance, "Spacecraft Compartment Venting," in 1998, also available from NTRS [Scialdone 1998]. If interested in the design considerations on the launch vehicle side, there's also a four-page paper by Moraes and Pereira entitled "Verification of the Pressure Equalisation Inside the Satellite Compartment of the Brazilian Satellite Launch Vehicle" [Moraes, 2005] that I found to offer a concise description of the problem.