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Trends in Chemical Rocket Systems and New Approaches to Launching Satellites

Introduction

The world of satellite applications has been turned upside down for several reasons in the past decade. The advent of small satellites and large-scale constellations, high throughput satellites, new types of Earth stations employing metamaterial and electronic beam forming, and new launcher design and operation – including reusable vehicles – have all served to reinvent the world of space. The common factors these innovations share are innovative thought and entrepreneurial initiative. The significant changes that have come to the launch industry, on which the broader space industry depends, is truly a key part of the reinvention of the space industry. This chapter examines the most important of these changes and also sets the stage for an exploration of the further changes yet to come, which will be explored in chapter eleven.

In the world of spacecraft design, the shrinking size of high-speed digital processors and miniaturized sensors have allowed the satellites of today to shrink in size while increasing performance. Spacecraft have become smarter, more capable and more cost effective. This shrinkage in size with increased performance has been a good deal of what the reinvention of the satellite industry has been about. When computers get smaller they get faster and more capable. Satellite designers have found more economical ways to perform the same trick.

The reinvention of launcher systems has been the other half of the equation. We are now seeing better launchers that are better adapted to the needs of Space 2.0 spacecraft systems. We are especially seeing the development of new capabilities such as reusable rocket systems, more efficient manufacturing techniques and clever new ways to launch rocket systems that do not require the operation of expensive rocket launch sites such as were an essential part of the rocket industries' infrastructure. Paul Allen and Vulcan, Inc., have now developed the massive Stratolaunch aircraft that can fly out of an airport and carry a massive rocket up to high altitude for quite cost-effective launches. The world is not like it used to be.

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The Evolutionary Design of Launch Vehicles and How They Work

The idea of rocket propulsion is actually not at all new. Just recall the story of Archytas of Tarentum, 400 to 350 B. C. He was particularly noted for his steam-powered pigeon that flew around in a tethered circle on a rope inside of his home. The idea of heating some sort of fuel that could be expelled through a jet to create a propulsive force was thus documented to have taken place 2400 years ago [1].

The Chinese creation of gunpowder led to the pyro-techno rockets of the 14th century. There is perhaps the apocryphal story of the Chinese nobleman who aspired to be the world's first astronaut. Supposedly he sat astride a giant array of 144 rockets for a journey into space, but his reward for his efforts, unfortunately, was to be instantly immolated. If true it indicates that the aspiration to fly into space on a rocket-powered vehicle is a concept that has long been with us.

The first rockets thus were solid-fueled. These were built by the Chinese some 900 years ago and were reportedly first used in warfare in 1232 in the Chinese war with the Mongols. They were then, as they are today, essentially rocket-shaped bombs [2].

These rockets were first fueled by gunpowder and then by other explosive compounds. The compounds have become more sophisticated, but the principles remain the same. The designs have involved placing various explosive solid-rocket fuels within a chamber that allowed continuous ignition and expulsion from a rocket cone. There was no opportunity for stopping the ignition once started, since this was, in effect, a continuously firing bomb. Solid-fueled rockets as they exist today are well-suited for missile weapon systems. This is because they can be instantly fired at any time without the loading of the rocket with fuel.

The liquid-fueled rocket came later. The idea of liquid fuel being pumped into a combustion chamber in a controlled manner was perhaps first realistically envisioned by the Russian Konstantin Tsiolkovsky in the late 19th and early 20th centuries [3].

The first actual liquid-fueled rocket system was developed on a rudimentary level by the American rocket scientist Robert Goddard in the 1920s and 1930s. For his efforts, *The New York Times* ridiculed him and called him "The Moon Man." [4] When Neil Armstrong and Buzz Aldrin walked on the Moon nearly a half century later, *The New York Times* offered Goddard a formal apology for making fun of his prediction that liquid-fueled rockets would allow people to walk on the Moon someday.

There are several efficiencies that can be derived from liquid-fueled rockets. These advantages include the fact that they can be throttled, turned on and off and produce less pollution, especially regarding particulates. The most explosive liquid fuel combinations, such as liquid hydrogen that is oxidized by liquid oxygen, generates greater thrust as well. The basic aspects of the operation of a liquid-fueled rocket plus key formulas of physics concerning their propulsion systems are shown in Fig. 10.1.

These types of liquid-fueled rocket systems do require complicated fueling, pumping and valve systems. Those that use liquid oxygen and liquid hydrogen, for instance, also require special and

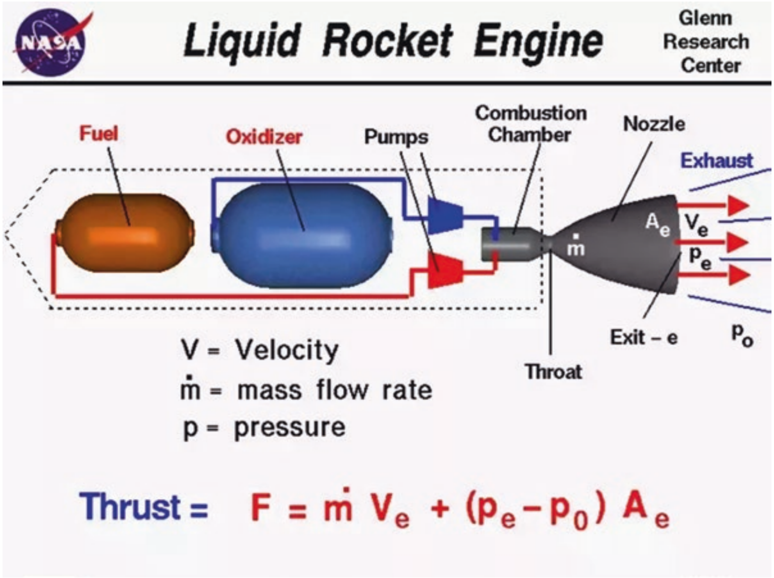

Fig. 10.1 The basic concept of a liquid-fueled rocket. (Graphic courtesy of NASA.)

expensive refrigerant systems. These types of rockets are thus best suited to scientific or commercial missions, where there is no need for an instant response, such as to fire off a weapon.

Today there are also so-called hybrid systems. These types of rocket systems might have a solid fuel but are oxidized by a gas or liquid that can be throttled. This control feature makes this type of propulsion system suited for such applications as spaceplanes, which have human crew aboard. The first such workable system was developed by the Benson Space Development Company and included the seemingly unconventional fuel of neoprene rubber that was oxidized in a controlled fashion with laughing gas (i.e., nitrous oxide). The supply of nitrous oxide, which could be cut off, served as the throttle oxidizer.

Other hybrid rocket propulsion systems are now being used in the SpaceShipTwo spaceplane to achieve a higher efficiency level of propulsion. The ability to throttle off the oxidizer is a key safety feature, but it is still true that all solid-fuel rocket systems produce high levels of pollution and spew particulates into the stratosphere.

It is especially important to note the particular effects of pollutants in the stratosphere. In these high altitudes, where the atmosphere is perhaps 100 times less dense than at sea level, means that the adverse environmental effects are much, much greater when particulates are released into the stratosphere.

Ion Propulsion and Electrical Space Vehicles

The most recent area of development for rocket propulsion involves electric propulsion. This approach uses electronic guns to accelerate ions.

Electric propulsion is now used to achieve more cost efficient and longer-lived station-keeping for spacecraft, particularly for those operating in GEO orbit. It typically uses ionized xenon fuel. This type of approach has become widely used for spacecraft system control, but the motors do not create enough thrust for launching satellites into orbit. In short, this type of system creates thrust and accelerative forces for much longer periods of time than a chemically fueled rocket. They can last hundreds or thousands of times longer, but there is not enough thrust – or concentrated surge – to overcome the pull of gravity at sea level.

There is some thought that ion propulsion might be able to lift a small satellite – like a cubesat – to orbit from a dark sky station positioned many kilometers high in the stratosphere. Ion propulsion can be more efficient and less polluting**.** The first type of electrical propulsion system was developed for lower thrust station-keeping and Vernier-jet orientation systems for spacecraft (See Fig. 10.2, which is a functional diagram of a gridded ion thruster that uses xenon fuel).

The thrusting power of ion propulsion, as just explained, is much too low to support launching operations. However, these systems are very fuel efficient and could allow a spacecraft to be maintained in a geosynchronous orbit with over a particular location for many years and do so with a reasonably small amount of xenon gas as the fuel. An electronic gun is used to electrically ionize the xenon gas to create low thrust levels for needed station-keeping operations. Despite the thrust levels being low, the overall net performance

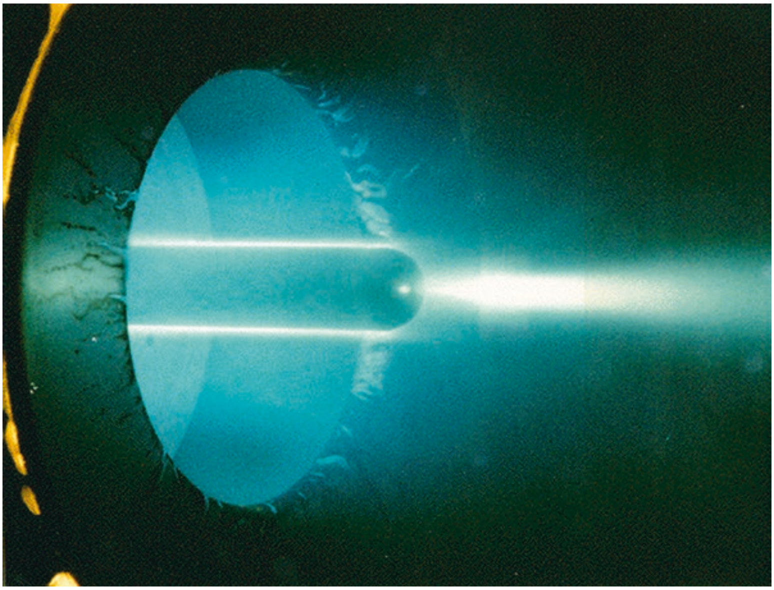

Fig. 10.2 Artist conception of the xenon-fueled gridded electronic ion thruster. (Graphic courtesy of NASA.)

over time is much higher. In testing of the NASA NEXT electric ion propulsion system, which ionizes xenon gas inside of its chamber and then emits them at very high speed, the thrust is impressive.

The net total measured effective propulsion is 12 times higher than a chemical rocket propulsion system when it is measured over time and a comparison is made of fuel consumed. It is thought that in time such systems, with perhaps a nuclear power supply for the electronic gun, could be used to support interplanetary missions. The thrust levels are low but constant. Thus great speeds could be built up over the span of months for such missions traveling to outer reaches of the Solar System [5].

New Approaches to Design and Manufacture of Launch Systems

The basic approaches for designing rockets and missile systems are now well known, but there is still room for improvement in how these systems are designed and manufactured. These improvements do not have to involve a new type of propulsion. The key is finding better ways to design, manufacture, undertake quality testing and even ways to build reusable rocket systems. In the manufacturing there is the potential to use 3D printing or additive manufacturing. There are some that envision using additive manufacturing to create rocket engines and other key components for rocket launchers. This approach might not only reduce the cost of producing the motors and the components but also could help streamlining and simplifying the quality assurance assets of the manufacturing process.

There is an even more fundamental shift now in process, and that is the changeover from expendable launch vehicles (ELVs), which can be used only one time, to launchers that might be reused from twenty to even thirty times. These design concepts require that first stage vehicles return to predetermined locations. This technology has been demonstrated at least in early stages by both Elon Musk's SpaceX and Jeff Bezos's Blue Origin. If these two reusable launch programs are successful, then other programs will undoubtedly follow.

Yet another aspect of the SpaceX launch program's effort to achieve greater cost efficiency is the drive to vertical integration. Thus SpaceX is seeking to build its launchers motors, fuel tanks, pumping and refrigerating systems and other components so that it can control supply chains and optimize its production to both ensure quality and to control costs.

In design concept anyway, rocket systems that might be used over and over again could serve to reduce the cost of launches by a very meaningful degree. This could be the most significant change in reducing costs sufficiently to make large-scale solar power satellites viable and make the assemblage in space of other large-scale structures for research or to create a 'Sun shield' against large-scale coronal mass ejections during the period when Earth's magnetic poles are shifting from north to south and south to north. Such new launch economies could also facilitate the creation of permanent colonies on the Moon or Mars.

Reusable launch vehicles might also allow for the creation of larger scale structures and habitats in space that might be used for everything from space tourism to various forms of planetary defense and even create structures in space to cope with climate change. In short, it could be a whole new ballgame.

However, we must temper our sense of enthusiasm to consider the environmental effects of a major increase in chemically fueled launches to orbit and the potential for pollution of the stratosphere. In short, reusable launch vehicles might be best seen as a transitional step from chemically fueled launch vehicles to new systems that might use tethers or even space elevators to lift mass to orbit perhaps four or five decades from now. It is important not to view the future through a rear view mirror. It is probably good to think that there are better ways to put people and satellites into space than putting them on top of a controlled bomb.

Launch Systems for Cubesats and Small Satellites

There are systems such as the largest Arianne vehicle that will be able to launch as many as 35 of the OneWeb small satellites (250 kg each) all at once, where economies of scale are clearly at work. Yet for emergency restoration purposes, the option of an efficient small scale launch becomes apparent. The Virgin Galactic Corporation is not only developing SpaceShipTwo for suborbital flights but another carrier vehicle that would lift Launcher One to 50,000 ft (about 14 km) for launch. The current design for Launcher One would allow it to launch two OneWeb small sats at a time. This would give OneWeb the opportunity to be able to respond quickly to satellite outages (See Fig. 10.3). The use of carrier vehicles as

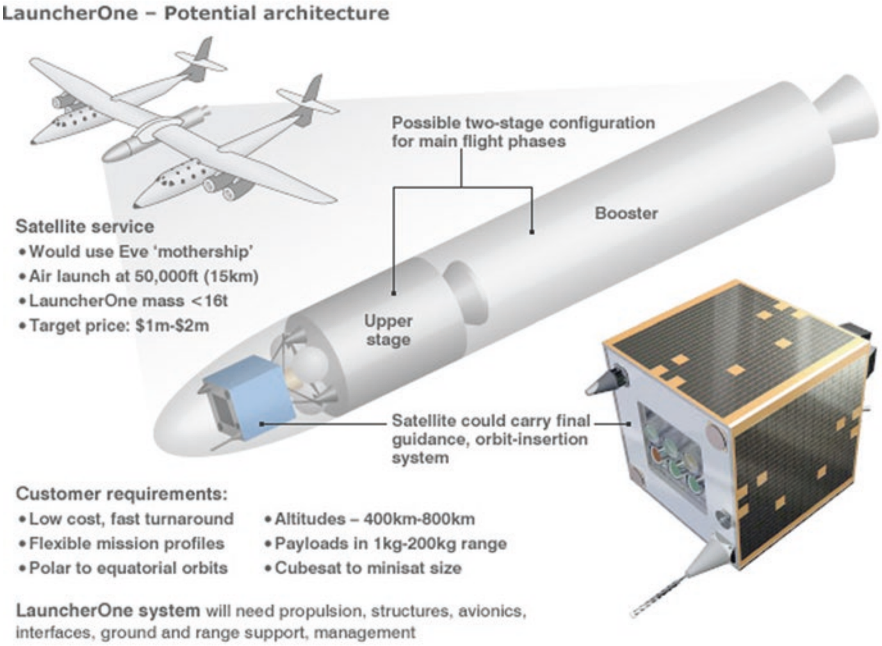

Fig. 10.3 Launcher One provides new small sat capabilities. (Graphic courtesy of Virgin Galactic.)

Fig. 10.4 The range in the size of launch vehicles keeps expanding. (Graphic courtesy of Vector Space.)

a part of the first stage of a reusable launch system will be discussed in more detail below.

There are now a number of small-scale launchers under development that will be able to launch cubesats and larger small satellites with good efficiency. Some of these options include the Vector R and Vector H Launchers. Figure 10.4 provides perspective on the huge range in size and lift capability that is now available to accommodate spacecraft that today might range in size from 100 g–10,000 kg. It should be noted that new configurations that allow launchers to accommodate many small satellites on a single launch adds great flexibility. The Indian Polar Satellite Launch Vehicle managed to launch two medium-sized spacecraft and 104 cube satellites in a single launch. This represented a new record for the number of satellites launched on a single launcher.

Carrier Vehicles and Spaceplanes as First-Stage Ascent Systems

The effort to develop spaceplanes as a way to provide for reliable suborbital flights for so-called space tourists could be said to have given rise to the idea of reusable launch vehicles. As companies developed plans to build spaceplanes such as SpaceShip2 by Virgin Galactic or the now defunct S-3 spaceplane, their business objectives grew to include the launch of small satellites to low Earth orbit. In some scenarios, it was also planned to have reusable spaceplanes at the first stage of the launch.

Thus, as noted above, Virgin Galactic is now offering Launcher One services to launch small satellites. The Launcher One will fly on a carrier vehicle called Eve. The S-3 spaceplane, however, had been envisioned to fly on a modified jumbo jet that would have served as the first stage of a small satellite launch system. The lift system to get quite small payloads to orbit would then be the final stage that would launch from the S-3 spaceplane. This ambitious venture has now gone bankrupt.

At the other end of the scale from the Launcher One and the S-3 small payload to orbit system is the plan of Vulcan Industries. Vulcan is now the sole developer of the Stratolaunch system, which is designed to serve as a reusable carrier vehicle for much larger rockets. The Stratolaunch carrier vehicle is powered by six 747 engines and is being designed to take much larger rocket launchers to high altitude for launch. Again, the thought process is that if one can reuse the first part of a launch system over and over again it becomes much more cost effective.

The traditional approach to launching rockets into orbit has logically involved the creation of launch sites. The creation of such launch sites have resulted in the construction of launch gantry towers, systems to load fuel into rockets and control rooms where key components on the launcher can be monitored by launch operation engineers and scientists. These launch sites take up a fair amount of room in order to accommodate all these functions and to isolate them from populated areas for safety and security reasons. The Kennedy Space Center in Florida in the United States, the Space Center in French Guiana, or the Baikonur Cosmodrome launch facility first built by the Soviet Union, are indicative of how expensive these launch sites were to design and build up into the giant complexes they are today.

As innovations have been made over time to create more reliable launch systems and innovators have sought to find more cost-effective ways to operate them, part of the focus has been on how to launch at points of maximum efficiency (such as along the equator for geosynchronous orbit launches) and how to avoid the high cost of launch facilities. One approach that has been taken is that of a sea launch. This approach was to have a mobile and seaworthy launch platform in the ocean (operating out of southern California) that could take a rocket and launch it from the high seas near the equator. A wide range of other options have been explored. One idea is to lift the rocket up with balloon systems that would launch from the upper atmosphere. Another concept is to have a towing system to haul rockets or spaceplanes to a high altitude for launch. One idea that has been in practice for some time is to have a carrier vehicle that would transport a rocket to a certain altitude and release it for mid-air ignition. This approach was used by Orbital Space Systems for the Pegasus and Taurus vehicles. As already noted, this is also fairly similar to the approach that is being used by Virgin Galactic with Launcher One and with Stratolaunch for a larger launcher, and was used for the now defunct S-3 spaceplane system.

The other advantage that comes with such an approach is that it is simply a more efficient way to overcome the gravitational pull of Earth's gravity well. This decreases as one achieves higher altitude. A rocket launch that occurs at perhaps 14 or 15 km high requires somewhat less fuel to reach orbit. Also a launch to GEO orbit from the Kennedy Space Center has a 14% disadvantage as compared to a launch from the Kourou Space Center in French Guiana because of the relative

Fig. 10.5 The rollout of the Stratolaunch by Vulcan Industries – the world's largest plane. (Graphic courtesy of Vulcan Industries.)

rotational speed of Earth at these respective latitudes.

It was the intention of Microsoft founder Paul Allen, who is the owner of Vulcan Industries, that his largest plane, the Stratolaunch, be a boon to rocket launcher companies (See Fig. 10.5). His company hopes to offer rocket companies the ability to launch large rockets at low cost and high efficiency because: (i) they would not have to pay the high cost of creating, maintaining and licensing a ground-based facility and scheduling a launch at such a facility; (ii) there would be fuel and safety advantages of launching from high altitudes in the stratosphere; and (iii) the launch could take place at exactly the longitude and latitude location desired, such as along the equator for GEO orbit launches. These same cumulative advantages also accrue to similar carrier launch systems, such as the Launcher One.

Launch Sites Around the World

There will remain a significant number of launch sites that are from ground locations. Most spacefaring nations maintain one or more launch complexes in their own country. There are several launch sites, such as those of the European Space Agency in French Guiana and the ISRO launch site in India, that have been established at locations that are attractive because of proximity to the equator. Others have been chosen due to their suitability for polar-orbit launches or because of their isolated or shore locations. This is because it provides a useful safety measure in case of a rocket malfunction or accident involving rocket fuel combustion. The following list represents significant launch sites currently operating around the world.

Australia
Site Name: Spaceport Australia
Location: Woomera, Australia (Latitude 31.1°S Longitude 136.6°E)
Launch Vehicles Supported: None currently active

Site Name: Asia Pacific Space Center (proposed)
Location: Christmas Island, Australia (Latitude 10.4°S Longitude 105.7°E)
Launch Vehicles Supported: Aurora (proposed)

Brazil
Site Name: Alcantara Launch Center
Location: Alcantara, Brazil (Latitude 2.3°S Longitude 44.4°W)
Launch Vehicles Supported: VLS-1 (proposed)

China
Site Name: Jiuquan Satellite Launch Center (JSLC)
Location: Gobi desert, Inner Mongolia (Latitude 40.6°N Longitude 99.9°E)
Launch Vehicles Supported: Long March 2C/2D/2F & Long March 4B/4C

Site Name: Xichang Satellite Launch Center (XSLC)
Location: Xichang City, China (Latitude 28.3°N Longitude 102.0°E)
Launch Vehicles Supported: Long March 2C & Long March 3A/3B/3BE/3C

Site Name: Taiyuan Satellite Launch Center (TSLC)
Location: Shanxi Province, China (Latitude 37.5°N Longitude 112.6°E)
Launch Vehicles Supported: Long March 2C/2D and Long March 4B/4C

Site Name: Wenchang Satellite Launch Center (WSLC)
Location: Hainan Island, China (Latitude 19.7°N Longitude 111.0°E)
Launch Vehicles Supported: Long March 5 (proposed)

Europe
Site Name: Guiana Space Center (Centre Spatial Guyanais)
Location: Kourou, French Guiana (Latitude 5.2°N Longitude 52.8°W)
Launch Vehicles Supported: Ariane 5, Soyuz, Vega, and Ariane 6 (Proposed)

India
Site Name: Satish Dhawan Space Center (SHAR)
Location: Sriharikota Island, India (Latitude 13.9°N Longitude 80.4°E)
Launch Vehicles Supported: Polar Satellite Launch Vehicle (PSLV) and Geosynchronous Satellite Launch Vehicle (GSLV)

Iran
Site Name: Iranian Space Agency Emamshahr Space Center, where suborbital LV have been launched. Qom, below, is the other launch site
Location: Emamshahr Space Center located at 36°25′0″N 55°01′0″E
Launch Vehicles Supported: Shahab 3

Site Name: Qom Space Center
Location: Qom, Iran, located at 34°39′0″N 50°54′0″E
Launch Vehicles Supported: Shahab 3

Israel
Site Name: Palmachim Air Force Base
Location: Negev Desert, Israel (Latitude 31.5°N Longitude 34.5°E)
Launch Vehicles Supported: Shavit

Japan
Site Name: Tanegashima Space Center (TNSC)
Location: Tanegashima, Japan (Latitude 30.4°N Longitude 131.0°E)

Launch Vehicles Supported: H-IIA and H-IIB

South Korea
Site Name: Naro Space Center
Location: Goheung County, South Jeolla (Latitude 34.4°N Longitude 127.5°E)
Launch Vehicles Supported: Naro-1

Russia
Site Name: Baikonur Cosmodrome
Location: Tyuratam, Kazakhstan (Latitude 45.6°N Longitude 63.4°E)
Launch Vehicles Supported: Proton, Strela, Dnepr, Zenit, Rockot, and Cyclone 2 (In addition the Soyuz and Vega are launched from the Guiana Space Center as noted above.)

Site Name: Plesetsk Cosmodrome
Location: Arkhangelsk Oblast, Russia (Latitude 62.8°N Longitude 40.1°E)
Launch Vehicles Supported: Kosmos 3M, Rockot, Soyuz, Start-1, Angara

Site Name: Svobodny Cosmodrome
Location: Amur Oblast, Russia (Latitude 51.4°N Longitude 128.3°E)
Launch Vehicles Supported: Start-1 and Rockot

United States
Site Name: Cape Canaveral Air Force Station (CCAFS)
Location: Cape Canaveral, Florida (Latitude 28.3°N Longitude 80.3°W)
Launch Vehicles Supported: Falcon 9, Atlas V, Delta IV
Site Name: Kennedy Space Center (KSC)
Location: Merrit Island, Florida (Latitude 28.5°N Longitude 81.5°W)
Launch Vehicles Supported: Space Shuttle (retired), Space Launch System Constellation

Site Name: The Mojave Spaceport
Location: California, USA (Latitude 35.0°N Longitude 118.2°W)
Launch Vehicles Supported: Various horizontal takeoff spaceplanes

Site Name: Spaceport America (formerly known as the Southwest Regional Spaceport)
Location: Las Cruces, New Mexico (Latitude 32°N Longitude 107°W)
Launch Vehicles Supported: White Knight Two Carrier Plane and SpaceShip Two

Site Name: Vandenberg Air Force Base (VAFB)
Location: Lompoc, California (Latitude 34.4° N Longitude 120.35° W)
Launch Vehicles Supported: Delta II, Delta IV, Atlas V, Minotaur I, Minotaur IV, Taurus, Pegasus, Falcon 1

Site Name: Wallops Flight Facility (WFF) and adjacent Mid Atlantic Spaceport of the State of Virginia and the State of Maryland
Location: Wallops Island, Virginia (Latitude 37.8°N Longitude 75.5°W)
Launch Vehicles Supported: Pegasus, Minotaur, and Antares launch vehicles of Orbital ATK

Site Name: West Texas Test Facility for Blue Origin
Location: West Texas near the New Mexico State Line
Launch Vehicles Supported: Latest is the New Shepard. New Glenn Operations to be moved to Florida along with a new Blue Origin plant (See Fig. 10.6).

Note: Several dozen other U. S.-based spaceports (essentially all for horizontal takeoff and landing operations) have been licensed or have licensing pending, but none is currently operational, with

Fig. 10.6 New Shepard reusable vehicle preparing for launch at west Texas site. (Photo courtesy of Blue Origin.)

actual spaceplane operations. Several other spaceports in locations such as the United Kingdom, Singapore, Malaysia, Sweden and Italy, among others, are now anticipated. Recently a framework agreement was signed by Virgin Galactic and Italian companies Altec and Sitael. Under this agreement the two companies will continue planning for potential flights of Virgin Galactic's SpaceShipTwo from the Taranto-Grottaglie airport in the southern part of Italy [6].

Many of the above-mentioned launch sites are equipped with launch gantries and also contain special refrigerant facilities for liquid oxygen and liquid hydrogen and other specialized facilities, test firing systems for engines and system integration equipment. Many of the launch facilities located around the world are also designed to allow missiles or rockets to be launched from these locations as well. There are a growing number of spaceports that have been or are being built or licensed, but few are operational in that the spaceplanes that would use them are still at the research, development or early testing stage. Virgin Galactic and Blue Origin are among the first of these spaceplane and small satellite launching enterprises, but others will undoubtedly follow in the near future.

There are many missile silos for weapons systems. Further there are also missile systems on ships and submarines as well as missiles that can be launched off of mobile platforms such as specially equipped trucks and trains. These types of missile systems, however, are virtually all solid rocket systems that do not involve loading of liquid fuels.

There are also many spaceports that are quite diverse in their size, sophistication and safety specifications.

The capabilities vary from airports that have suitable runways that can basically only accommodate horizontal take-off and landing and yet get authorized by their governments to be called "a spaceport." At one time there was the thought that spaceports had to be limited to locations with takeoff and landing over an ocean, for safety purposes, but this restriction no longer applies in most countries. The location is, however, frequently limited to either an ocean adjacent location or isolated areas.

Essential Ground Support Systems for Launch Operations

It might be easy to assume that launch operations are all about the launchers and their design and operation. It is important to note that these systems do not operate without systems on the ground for tracking, telemetry and command of the launch vehicles as they are launched into space, achieve specific orbits and deploy spacecraft.

There are a number of command and control centers for satellite networks that are also used to support launch operations. Specific commands are needed to launch operations, and these can come at different locations and altitudes all around the world. Just as many satellites are moving toward autonomous operations, launch vehicle systems can be preprogrammed to carry out specific functions such as the cutoff of engines or re-ignition of engines to achieve specific orbital conditions and altitudes.

It is important to maintain the ability to send critical commands to cope with such happenstances as a misfiring of a rocket motor. This might even include the need to execute a command to destroy a launcher if the rocket flies off course and threatens a community. Manned missions, in particular, require the ability to stay constantly in radio contact with a rocket at all points in its operation.

Stratospheric High Altitude Platforms: The Launch of Pseudo-Sats

The advantage of satellite systems is their very high altitude, which provides them with a very broad field of view. The higher the altitude, the greater area that can be surveyed by remote-sensing satellites or the greater the number of communications stations that can be connected. It is more difficult to launch a satellite into geosynchronous orbit because it requires greater thrust, but then it requires only three satellites at the high altitude to essentially cover the entire Earth. In low Earth orbit, of say 800 km, it takes perhaps 60 satellites to cover the entire Earth because of the lesser coverage, but each of these launches require less fuel and thrust to achieve orbit. Until recently the options for remote sensing or communications were towers, aircraft, aerostats or the deployment of additional satellites to achieve much broader coverage.

More recently there has been attention given to the concept of high-altitude platform systems (HAPS) and unattended aeronautical vehicles (UAVs) as means of achieving broad coverage that is greater than towers but less than that of satellites. Frequencies have been allocated for such service, and an increasing number of studies are being made as to how such systems would be managed in terms of safety and flight traffic management. HAPS are being designed to operate in the stratosphere for longer term operation. Thales Alenia, for instance, has recently signed an agreement with the Southwest Research Institute to develop the Stratobus HAPS system [7].

These platforms are sufficiently elevated in altitude that they can provide coverage for island countries such as Jamaica, Fiji, or even Iceland. Because of their lower altitude, the path loss is minimal. Thus such HAPS systems can have high digital throughput capabilities.

These systems are varied in their design in terms of their maneuverability and stability. Some that involve lighter than air dirigibles can stay aloft for sustained periods of time. Some are conceived as automated jet aircraft that have to be periodically refueled, while others are designed as solar-powered craft with electric motors that can stay up for sustained periods of time. Yet others are simply stratospheric balloon systems that depend on global wind current conditions.

There are today concerns about not only space traffic management and how to control spacecraft and debris against collisions, but also about safe operation of HAPS and other things that might be designed to operate high in the upper stratosphere in future years. There could also be environmental concerns about systems that are designed to fly in the stratosphere that would require the use of expendable fuel systems such as those that would use jet engines for propulsion.

Conclusions

There have been significant improvements in the design and operation of various types of launch systems in the past decade. Innovations that have allowed launch vehicles to become more reliable and progress to create reusable launch systems have shown a pathway to much more reliable and cost-effective launchers. New techniques such as 3D printing and additive manufacturing have also contributed to lower costs of the production of launch systems.

For environmental reasons, rocket launches for commercial operations are heavily geared toward the use of liquid-fueled vehicles. For reasons of safety, launch operations are designed to clear all aircraft flights in proximity to rocket launches. There is the thought that with the advent of space traffic management it might be possible to integrate air traffic management and control systems and space traffic management systems in the future.

Key aspects to be focused on for the future are new manufacturing and design innovations to reduce the cost of launch operations while also making launches safer. The advent of more launches of large-scale constellations into orbit raises new concerns with regard to orbital space debris and also with regard to pollution of the stratosphere.

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