Space Mission Engineering: The New SMAD

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Chapter 1.2
The History of Spaceflight

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Space
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the exploration of space itself, have just begun. These are truly exciting activities for a new generation of space mission engineers who can see further and do more. It's an exciting adventure.

1.2 The History of Spaceflight

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1.2.1 Humble Beginnings

The heavens had been attracting the imagination of humans for millennia. Some even argue that ancient texts, including the Old Testament, described spaceships in the sky. Reaching the cosmos requires powerful rockets. So, the first steps of the humans toward spaceflight were in rocketry. For centuries an essentially international endeavor of the pursuit of spaceflight attracted people from various lands who advanced the enabling science and technology.

Ancient Greeks observed the principle of jet propulsion more than 2,000 years ago. One thousand years later the first primitive rockets appeared in China and perhaps in India, later rediscovered in many other lands. A combination of charcoal, sulfur, and saltpeter—black powder—propelled the missiles. Natural abundance of saltpeter in China and India facilitated the emergence of the first war rockets in these countries.

Rockets had established a foothold in Europe some time in the 13th century. The word 'rocket' likely originated from the 'rocchetta,' a diminutive of the Italian word 'rocca' for distaff, a staff for holding the bunch of flux or wool from which the thread is drawn by spinning.

The early 19th century witnessed a major step in perfecting the rocket. A British inventor, William Congreve, turned ineffective and erratic missiles into a modern weapon system with standardized and interchangeable parts. These British war rockets, known as the Congreves (See Fig. 1-3), debuted during the Napoleonic wars. Then brought across the Atlantic Ocean, the Congreves bombarded Fort McHenry near Baltimore in 1813. Francis Scott Keys immortalized the deadly missiles in his famous line "…And the rockets' red glare…" in the American National Anthem.

War rocketry rapidly proliferated throughout Europe and reached North and South Americas and Asia. The young Chilean republic was among the first to employ the domestically-made rockets—in 1819—in the fight against its former colonial ruler, Spain. Many European countries—particularly Austria, France, and Russia—established large-scale manufacturing of war rockets. The Russian army even built in 1834 an iron-clad submarine with a crew of 10 men which fired missiles from a submerged position.

The Mexican War, 1846–1848, advanced rocketry beyond an occasional experimentation in the United States. In a short period of a few months, the Army and the Navy completed the purchase, evaluation, prototyping, and testing of a new type of spin-stabilized war rockets. (These rockets became known as the Hales, after their inventor William Hale.) The US Army formed the first missile unit, the Rocket and Mountain Howitzer battery. The mass-produced new missiles quickly reached the rocket battery deployed in Mexico with the American expeditionary force. Thus the two military services succeeded in 1840s in a joint procurement and fielding of a new technologically advanced weapon system in less than one year.

Fig. 1-3. Nineteenth Century Rockets: *Hale* (front), *Congreve* (with the centrally mounted guiding stick), and *skyrocket* (back). [Scoffern, 1859; Gruntman, 2004]

By the end of the 19th century, war rocketry had lost the competition to artillery with the introduction of rifled barrels, breech loading, and the Bessemer steel process. At this time the writers stepped in and replaced the men of sword as keepers of the interest in rocketry and spaceflight.

Nobody captured public imagination in space adventures more than the French writer Jules Verne (See Fig. 1-4). His novels "put on fire" and motivated many young men who would decades later transform a dream of spaceflight into a reality. Jules Verne's classic novel *From the Earth to the Moon* (first published in 1865) became a seminal work on spaceflight.

Early science fiction writers sent main characters on space voyages to satisfy their curiosity, as a bet, or to escape debts. Then, an American author, Edward Everett Hale, published a novel *The Brick Moon* in 1870. The story described a launch of an artificial satellite into orbit along a meridian to help sailors at sea in determining their longitude, in the same way as the Moon aids in determining latitude. It was the first description of an application satellite.

1.2.2 Great Pioneers

The late 19th century brought the realization that until the rocket was perfected there would be no trips through outer space, no landing on the Moon, and no visits to

Fig. 1-4. Jules Verne, *From the Earth to the Moon*—The future express. "Yes, gentleman," continued the orator," in spite of the opinion of certain narrow-minded people, who would shut up the human race upon this globe…we shall one day travel to the Moon, the planets, and the stars…" [Horne, 1911; Gruntman, 2004]

other planets to meet possible inhabitants. A long period followed when isolated visionaries and thinkers, including amateurs, began practical work and sketched out the sinews of the spaceflight concept. Many "intellectuals" of the day and assorted "competent authorities" dismissed the idea of space travel as ridiculous.

A number of outstanding individuals at the end of the 19th century and the beginning of the 20th century laid the foundations of practical rocketry and spaceflight. Four visionaries in 4 countries working under very different conditions became the great pioneers of the space age: the Russian Konstantin E. Tsiolkovsky; the French Robert Esnault-Pelterie; the American Robert H. Goddard; and the German Hermann Oberth. They contributed in unique ways to advancing the concept of spaceflight.

The writings of Konstantin E. Tsiolkovsky (1857–1935) combined development of scientific and technological ideas with the vision of space applications. While he never built rockets, Tsiolkovsky inspired a generation of Soviet rocket enthusiasts, including Sergei P. Korolev and Valentin P. Glushko, who achieved the first satellite.

An engineering graduate of the Sorbonne University, Robert Esnault-Pelterie, 1881–1957, first gained fame as an aviation pioneer who had introduced among other things an enclosed fuselage, aileron, joystick for plane control, four-bladed propeller, and safety belt. His prestige brought the much-needed credibility to the emerging space effort. It was Esnault-Pelterie who first published a spaceflight-related article in a mainstream archival physics journal in 1913; he also introduced the word "astronautics" in the language of science.

With a Ph.D. degree in what we would call today solid-state physics, Robert H. Goddard, 1882–1945, actually demonstrated the first liquid-propellant rocket engine in 1926. Goddard achieved numerous other firsts in rocketry. One of his rockets reached a 9,000 ft (2,700 m) altitude in 1937. Many results of Goddard's work remained largely unknown to contemporary scientists and engineers because of self-imposed secrecy, caused in part by ridicule by the ignorant and arrogant mainstream media.

Hermann Oberth, 1894–1989, published a detailed design of a sophisticated rocket in his book *The Rocket into Interplanetary Space* [Oberth, 1923]. He introduced numerous ideas including staging, film cooling of engine walls, and pressurization of propellant tanks. Oberth played an important role in early practical development of rocketry in Germany and provided inspiration for a generation of European space enthusiasts.

1.2.3 Building the Foundation

Powerful rockets belonged to a category of inherently complex advanced technologies where a lonely creative and gifted inventor could not succeed. Only concerted efforts of numerous well-organized professional scientists and engineers supported by significant resources could lead to practical systems. The totalitarian states were first to marshal the necessary resources and organize a large-scale development of ballistic missiles. In the Soviet Union, the military-sponsored *Jet Propulsion Scientific Research Institute* (RNII) employed 400 engineers and technicians in a sprawling complex in Moscow in the early 1930s. Later in the decade the Soviet program suffered from political purges and resumed its growth after 1944.

The German Army stepped up its rocket effort in 1932 by establishing a dedicated group that included Wernher von Braun. The German program grew immensely and by 1942 produced the first truly modern ballistic missile the A-4, better known as the V-2. The fueled A-4 weighed more than 12.5 metric tons and delivered a 1,000 kg warhead to distances up to 300 km. The German accomplishments also included mass production of the missiles. In a short period, under tremendous difficulties of wartime, the industry built 5,800 A-4's, with 2,000 fired operationally against England and liberated parts of Europe. The rocket manufacturing widely used slave labor from concentration camps, accompanied by atrocities especially during the construction of the underground facilities.

In the United States during WWII, rocketry concentrated on jet assisted take off (JATO) of the airplanes and on barrage solid-propellant missiles. The first American private rocket enterprises Reaction Motors and Aerojet Engineering Corp. were formed in December 1941 and in March 1942, respectively. After the war, several centers of rocketry emerged in the industry and government under sponsorship of the Army, Navy, and Air Force.

The US Army brought a number of captured German V-2 missiles to the United States. Military personnel and industrial contractors launched more than 60 V-2's from the White Sands Missile Range in New Mexico by 1951. Many missiles carried science payloads studying the upper atmosphere, ionosphere, solar radiation, and cosmic rays. These first rocket experiments gave birth to a vibrant experimental space science. Subsequently, many government and university scientists became energetic advocates of space exploration.

The US Army followed its century-long tradition of the arsenal system with significant in-house engineering capabilities. By the early 1950s, it had concentrated the development of ballistic missiles and emerging space activities at the Redstone Arsenal in Huntsville, AL. The California Institute of Technology (Caltech) managed another important Army rocket center, the Jet Propulsion Laboratory (JPL), in Pasadena, CA. The JPL grew out of pioneering research and development programs from the group of Theodore von Kármán at Caltech.

The Redstone Arsenal became the home to more than 100 "imported" German rocketeers, headed by Wernher von Braun. The Germans had come to work in the United States under contracts through *Operation Paperclip*. While von Braun's rocketeers got the most publicity, the Paperclip program brought to the United States in total more than 600 German specialists in various areas of science and technology. In contrast to the compact von Braun's group, the other scientists and engineers were dispersed among various American industrial and research organizations.

The Army, the Air Force, and the Navy were carrying out essentially independent development programs in guided missiles, with some overlap, occasional cooperation, and determined rivalry. In 1956, Secretary of Defense Charles E. Wilson attempted to resolve the problem of duplication by defining the "roles and missions" of the services. Consequently, the Air Force asserted control over intercontinental warfare, with the Army's role reduced to shorter range missiles.

The fateful roles-and-missions decision did not stop a most active leader of the Army's missile program, General John B. Medaris, and von Braun from finding ways to advance their visionary space agenda. In addition to such Army achievements as the development of the operationally-deployed ballistic missiles Redstone and Jupiter in 1950s, they would succeed in launching the first American artificial satellite, Explorer I, to space. Only by the end of 1950s, the Army had finally lost its programs in long-range ballistic missiles and space when the newly formed civilian space agency, the National Aeronautics and Space Administration (NASA), took over and absorbed the JPL and von Braun's team at Redstone.

In contrast to the Army, the Navy and especially the new service Air Force (formed in 1947) relied primarily on the contractors from the aircraft industry in their ballistic missile programs. In late 1940s and early 1950s, the Naval Research Laboratory (NRL) with Glenn L. Martin Co. developed the Viking sounding rocket as a replacement of the dwindling supply of the captured V-2's. This program laid the foundation for Martin's future contributions to ballistic missiles that would include the Titan family of Intercontinental Ballistic Missiles, (ICBM) and space launchers.

In 1946, the Air Force initiated development of a new test missile, the MX-774. The Convair (Consolidated Vultee Aircraft Corp.) team led by Karel J. (Charlie) Bossart introduced many innovations in the MX-774 missiles that reached an altitude of 30 miles. Based on this early experience, Convair later developed the first American ICBM, the Atlas. The Atlas program, including missile deployment became a truly national effort that dwarfed the Manhattan Project of World War II.

Other major ballistic missile programs initiated in 1950s included ICBMs Titan and Minuteman and Intermediate Range Ballistic Missile (IRBM) Thor. The Glenn L. Martin Company, Boeing Company, and Douglas Aircraft Company led the development, as prime contractors, of these missiles, respectively. Aerojet and the Rocketdyne Division of North American Aviation emerged as leading developers of liquid-propellant rocket engines. The Navy selected the Lockheed Aircraft Corporation as the prime contractor for its submarine-launched solid-propellant IRBM Polaris.

The Soviet government made rocket development a top national priority in 1946. The rocketeers first reproduced the German V-2 and then proceeded with building larger and more capable ballistic missiles. Soviet rocket pioneers from the early 1930s Korolev and Glushko emerged as the chief designer of ballistic missile systems and the main developer of the enabling liquid-propellant engines.

Both the Soviet Union and United States pursued development of the ICBMs, R-7, and Atlas. These large ballistic missiles called for new testing sites —the existing American White Sands and the Soviet Kapustin Yar did not meet the requirements of safety and security. Consequently, the United States established a new missile test range at Cape Canaveral in Florida in 1949 and later another site at the Vandenberg Air Force Base in California in 1958. Cape Canaveral would subsequently support space launches into low-inclination orbit while Vandenberg would send satellites into polar orbit, especially important for reconnaissance payloads. The Soviet Union initiated the construction of a new missile test site at Tyuratam (now commonly known as Baikonur) in Kazakhstan in 1955 and another site later in Plesetsk.

1.2.4 The Breakthrough to Space

In the 1950s, spaceflight advocates scattered among various parts of the US government, industry, and academia pressed for the American satellite. The national security policies would shape the path to space.

Rapidly progressing development of long-range ballistic missiles and nuclear weapons threatened devastating consequences should the Cold War turn into a full-scale military conflict. New technologies allowed no time for preparation for hostilities and mobilization and made an intelligence failure such as Pearl Harbor absolutely unacceptable. Therefore, monitoring military developments of the adversary, with accurate knowledge of its offensive potential and deployment of forces, became a key to national survival and (avoiding a fatal miscalculation,) reduced the risk of war.

Obtaining accurate information about closed societies of the communist world presented a major challenge. The perceived “bomber gap” and later the “missile gap” clearly demonstrated the importance of such information for the national policies. Consequently, President Dwight D. Eisenhower authorized development of overhead reconnaissance programs to be conducted in peacetime. The U-2 aircraft first overflew the Soviet Union in 1956, resolving the uncertainties of the bomber gap. Reconnaissance from space became a top priority for President Eisenhower who considered rare and sporadic U-2 overflights only a temporary measure because of improving Soviet air defenses. In 1956, the Air Force selected Lockheed’s Missile Systems Division to build reconnaissance satellites.

The international legality and acceptability of overflights of other countries by Earth-circling satellites—*freedom of space*—was uncertain in the 1950s. The Eisenhower administration considered testing the principle of freedom of space by launching a purely scientific satellite critically important for establishing a precedent enabling future space reconnaissance.

This was the time when scientists in many countries were preparing for the International Geophysical Year (IGY) to be conducted from July 1957–December 1958. They planned comprehensive world-wide measurements of the upper atmosphere, ionosphere, geomagnetic field, cosmic rays, and auroras. Space advocates emphasized that artificial satellites could greatly advance such studies. Consequently, both the United States and the Soviet Union announced their plans of placing into orbit artificial satellites for scientific purposes during the IGY. Both countries succeeded.

President Eisenhower insisted on clear decoupling of American scientific satellites from military applications in order to first assert freedom of space. This national security imperative determined the publicly visible path to the satellite. In 1955, the US government selected the NRL proposal to develop a new space launch vehicle and a scientific satellite, both known as the Vanguard. The choice of the new system was made over a more mature technology of the Project Orbiter advocated by Army’s Medaris and von Braun. The Army proposed to use the Jupiter C, an augmented Redstone ballistic missile. In fact, a test launch of the Jupiter C on September 20, 1956, could have put a simple satellite into orbit had the Army been permitted to use a solid-propellant missile — as it would later do launching the Explorer I—instead of an inactive fourth stage.

John P. Hagen led the Vanguard program with Glenn L. Martin Co. as the prime contractor of the launch vehicle and with NRL providing technical direction. The Vanguard program also built scientific satellites and established a process of calling for proposals and selecting space science experiments. In addition, it deployed a network of the Minitrack ground stations to detect and communicate with the satellites which laid the foundation for the future NASA’s Spaceflight Tracking and Data Network (STDN). Many optical stations around the world would also observe the satellites by the specially designed Baker-Nunn telescope tracking cameras.

The Soviet Union focused its resources on demonstrating the first ICBM. After the R-7 had successfully flown for the full range, Korolev launched the world’s first artificial satellite, Sputnik, into orbit on October 4, 1957. Ironically, this Soviet success had finally resolved the lingering issue of the space overflight rights that so concerned President Eisenhower: no country protested the overflight by the Soviet satellite, thus establishing the principle of freedom of space (see Fig. 1-5).

The second, much larger Soviet satellite with the dog Laika aboard successfully reached orbit on November 3, 1957. The Vanguard program had been steadily progressing but was not ready for launch yet. On November 8, the Secretary of Defense gave the permission to the eager Army team led by Medaris and von Braun to also attempt launching satellites. On January 31, 1958, the Army’s modified Jupiter C missile successfully placed the first American satellite Explorer I into orbit.

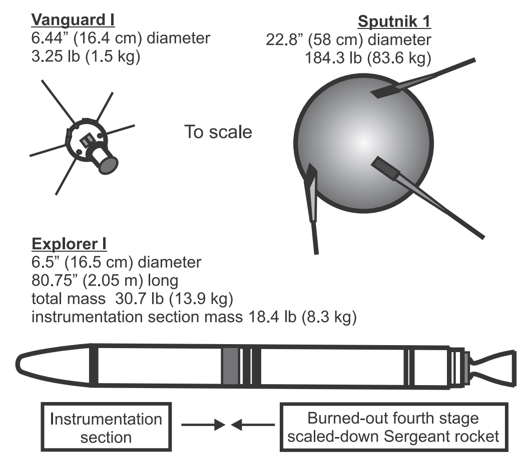

Fig. 1-5. Comparative Sizes and Masses of the Earth Satellites Sputnik 1, Explorer I, and Vanguard I [Gruntman, 2004].

Subsequently the Vanguard launch vehicle deployed the Vanguard I satellite into orbit on March 17, 1958. Popular sentiments in the United States have sometimes blamed the Vanguard program for losing the competition to the Soviet Union. It is grossly unfair. The Vanguard program demonstrated a record fast development of a new space launcher, with only 30 months from the vehicle authorization in August 1955 to the first successful launch in March 1958. The Vanguard spacecraft remains today the oldest man-made object in orbit, and it will reenter the atmosphere in a couple hundred years. We have time to find funding to bring the satellite back to the planet Earth for a place of honor in a museum.

There was no technological gap between the Soviet Union and the United States in the beginning of the space age. Being the first in launching the satellite was a matter of focus and national commitment. Fourteen months after the launch of Sputnik, the United States had placed spacecraft into orbit by 3 entirely different launchers developed by 3 different teams of government agencies and industrial contractors. (The Air Force's Atlas deployed the first communications satellite SCORE in December 1958.)

The last years of the Eisenhower administration shaped the structure of the American space program. The president established a new Advanced Research Projects Agency (ARPA, the predecessor of DARPA), to fund and direct the growing national space effort. The security-conscious president resisted expansion of the government programs but always supported advancement of spaceflight in the interests of national security.

Bending to powerful political forces Eisenhower reluctantly agreed to establish a new government agency responsible for a civilian effort in space. The president signed the National Aeronautics and Space Act into law which formed NASA on October 1, 1958. Within a short period of time, NASA subsumed the National Advisory Committee for Aeronautics (NACA), Army's Jet Propulsion Laboratory and major elements of the ballistic missile program in Huntsville, and NRL's Vanguard group.

NASA vigorously embarked on scientific exploration of space, launching increasingly capable spacecraft to study the space environment and the Sun and creating space astronomy. The missions to flyby the Moon and, later, nearby planets followed. These first space missions began a new era of discovery that laid the foundation for the flourishing American space science and planetary exploration of today. At the same time, NASA embarked on preparation for human spaceflight.

Rocketry Industry "Namescape"

Merges and acquisition have significantly changed the "namescape" of rocket industry. Titan's prime contractor, the Martin Company, merged with Marietta in 1961, forming Martin Marietta. Convair became Space System Division of General Dynamics in 1954, known as General Dynamics—Astronautics. Martin Marietta acquired General Dynamics' Space System Division in 1995 and then merged in the same year with Lockheed, forming The Lockheed Martin Corporation. Thus both, the Atlas and the Titan families of space launchers ended up under the same corporate roof. Another important component of Lockheed Martin's rocket assets is the submarine-launched solid-propellant Tridents. Boeing added to its Minuteman missiles the Delta family of space launchers after acquiring McDonnell-Douglas in 1997.

Gruntman [2004], p. 253

At the same time the military space program focused on communications, early warning, command and control, and support of military operations. The Air Force led this effort with the Navy engaged in selected important programs, such as space based navigation. The Army preserved the responsibility for major elements of missile defense.

Another national security program dealt with space reconnaissance and was directed jointly by the intelligence community and the military. In 1960, President Eisenhower established a special office in the Department of Defense (DoD), staffed by military officers and government civilians, to direct space reconnaissance, separated from military procurement and hidden by an extra protective layer of secrecy. This organization would become the National Reconnaissance Office (NRO) overseen by the Air Force and the CIA. The image intelligence satellite Corona achieved the first successful overflight of the Soviet Union in August 1960, returning images that effectively resolved the uncertainties of the perceived missile gap.

President Eisenhower handed over to his successor in the White House a structure of the national space program that has essentially survived in its main features until the present day. NASA leads the civilian space effort. National security space consists of two main components. The services are responsible for military space while the intelligence community and military directs gathering and processing of the intelligence information from space. While these 3 programs are sometimes viewed as separate, they all had originated from the early military space effort and they all have been interacting to varying degrees during the years.

1.2.5 Spacefaring Civilization

The heating up competition in space with the Soviet Union erupted into the public focus when the first man, Soviet cosmonaut Yuri Gagarin, orbited the Earth on April 12, 1961. President Kennedy responded by challenging the nation to land "a man on the Moon and returning him safely [back] to the Earth." The resulting Apollo program culminated with astronauts Neil Armstrong and Edwin (Buzz) Aldrin making man's first steps on the Moon in July 1969.

The late 1950s and early 1960s witnessed emerging commercial applications in space. The first transatlantic telephone cable had connected Europe and North America in 1956 to meet the increasing demand in communications. Space offered a cost-competitive alternative, and industrial companies showed much interest and enthusiasm for it, especially AT&T, RCA, General Electric, and Hughes Aircraft. The DoD supported the development of space communications on the government side. It was not clear at the time whether satellites in low, medium, or geostationary orbits would offer the best solution. While geostationary satellites provided excellent coverage, the technical challenges of building and deploying such satellites and their control had not yet been met.

Initially, the industry invested significant resources in the development of space communications. The situation drastically changed when President Kennedy signed the Communications Satellite Act in 1962. Now government, including NASA, became a major player in

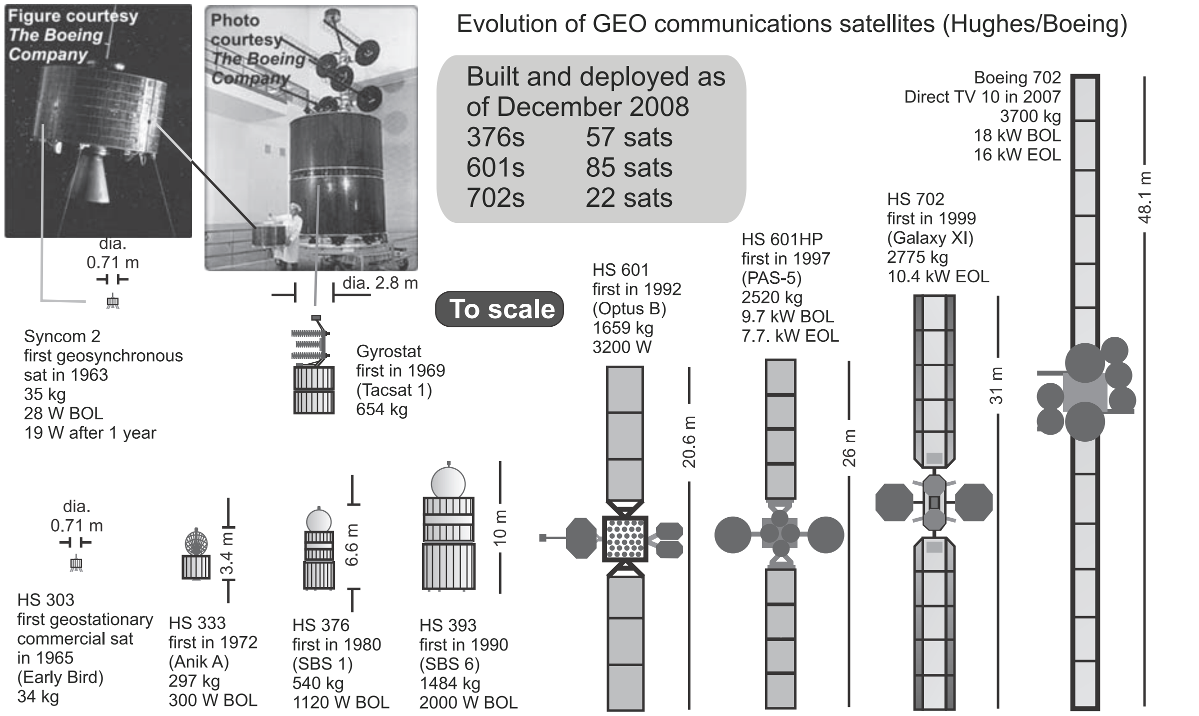

Fig. 1-6. Spectacular Growth of Communication Satellite Capabilities. Example of satellites developed by Hughes/Boeing [Gruntman, 2008].

commercial space communications, with the authority to regulate and to a significant extent dictate the development. Consequently, the Communications Satellite (Comsat) Corporation was formed in 1963 to manage procurement of satellites for the international communications consortium Intelsat.

The Hughes Aircraft Company demonstrated a practical geostationary communication satellite with launches of 3 test spin-stabilized Syncom satellites in 1963–1964. As the technology progressed, several companies introduced 3-axis stabilized geostationary satellites. Since the beginning of the space age, satellite communications have been dominating commercial space, with most of activities today concentrated in the direct-to-home TV broadcasting and fixed satellite services. Figure 1-6 demonstrates the astounding increase in capabilities of geostationary communication satellites with the example of one family of satellites built by Hughes, now part of the Boeing Company.

Military and reconnaissance satellites provided critically important capabilities essential for national survival. NASA missions, especially manned missions, were highly visible and reflected on the nation's international prestige, so important in the Cold War battles. As a result, National Security Space (NSS) and NASA missions had one feature in common: failure was not an option which inevitably led to a culture of building highly-reliable systems. Space missions were thus performance driven, with cost being of secondary importance. The consequent high-cost of the space undertaking led, in turn, to increased government oversight which drove the schedules and costs further up. The government-regulated commercial space, dominated by the same industrial contractors, could not develop a different culture.

After landing twelve astronauts on the Moon, NASA brought to us spectacular achievements in space science and in exploration of the Solar system. Numerous space missions advanced our understanding of the Sun's activity and the near-Earth environment. NASA spacecraft visited all planets of the Solar system with the exception of Pluto*—the New Horizons mission is presently enroute to the latter.

The Soviet Union established a permanent space station, Mir, in low-Earth orbit. The American human space flight concentrated on the development of the Space Shuttle and the International Space Station (ISS). The Space Shuttle carried astronauts to low-Earth orbit from 1981 to 2011. The ISS, with a mass of about 400 metric tons, has the opportunity to demonstrate what humans can do in space.

Today, space affects government, business, and culture. Many countries project military power, commercial interests, and national image though space missions. It is a truly high-technology frontier, expensive and government-controlled or government-regulated. Space has become an integral part of everyday lives of people. We are accustomed to weather forecasts based on space-based sensors. Satellites deliver TV broadcasts to individual homes. The Global Positioning System (GPS)

* Pluto is now officially a dwarf planet. See App. B.

reaches hundreds of millions of users worldwide, guiding drivers on the road, aircraft in the air, and hikers in the mountains.

After the end of the Cold War, the transformation of space from a primarily strategic asset into increasingly integrated tactical applications, supporting the warfighter, accelerated. NSS provides critically important capabilities in command and control, communications, reconnaissance, monitoring of international treaties, and guiding precision munitions to targets. Missile defense heavily relies on space sensors and communications for early warning and intercept guidance. NSS spends annually twice as much as NASA.

The space enterprise has become a true international endeavor. Seven countries joined the Soviet Union and United States in the elite club of nations that launched their own satellites on their own space launchers: France (1965), Japan (1970), People's Republic of China (1970), United Kingdom (1971), India (1980), Israel (1988), and Iran (2009). The European countries have combined their efforts and launch their satellites today through the European Space Agency (ESA). Canada also conducts an active space program. Brazil has an active space program and it is only a question of time until it successfully launches its satellite. South Korea also pursues development of space launch capabilities, with Russia initially providing important parts of launch technology. The secretive North Korea tries to launch a satellite. In addition, numerous other countries bought and operate various satellite systems.

Very few countries presently match the American commitment to space exploration and space applications. "Only France (and the old Soviet Union in the past) approaches the US space expenditures in terms of the fraction of the gross domestic product (GDP). Most other industrialized countries (Europe and Japan) spend in space, as fraction of GDP, 4 to 6 times less than the United States." [Gruntman, 2004, p. 462] People's Republic of China and India are expanding their space programs. The highly space-capable Russia is also increasing its space activities after the decline of the 1990s.

For many years, the United States has led the world in space. The health and the future of the American space enterprise depend on the national commitment—there is no limit to what we can do. President Kennedy observed that "for while we cannot guarantee that we shall one day be first [in space], we can guarantee that any failure to make this effort [in space] will make us last…" Gruntman [2004, p.383].

1.3 Spaceflight Technology

Space is exceptionally expensive and nearly all spaceflight hardware is uniquely built for use in space or launch systems. This section addresses the question of why this is the case and how space technology differs from non-space technology. There are several key ideas that are involved:

1. Getting to space is really hard
2. Rockets are a lousy way to get anywhere, but better than any alternative we have available
3. Space parts are nearly all unique

This section addresses each of these and introduces the idea of *Technology Readiness Levels* (TRLs) that are often used to help manage the space development and acquisition process, but may, in some respects, contribute to the problem as well as the solution.

1.3.1 Getting to Space is Really Hard

The easiest place to get to in space, and the closest, is low Earth orbit (LEO), which is the space between the top of the atmosphere at roughly 100 km and the beginning of the Van Allen radiation belts at about 1,000 km. To get there, and stay there rather than fall back to Earth, we need to go up about 200 km, turn left, and accelerate to 7.8 km/s. Taking into account the losses along the way caused primarily by gravity and atmospheric drag, we realistically need to provide a change in velocity, called *delta V*,* of over 9 km/s. This is an extremely high velocity relative to any moving objects we have experience with. Commercial jet aircraft travel at about Mach 0.8 (= 610 mph = 0.34 km/s). The muzzle velocity of a modern rifle with a high speed cartridge is quite a bit higher at around 4,000 fps (= 1.22 km/s), but still far short of the velocity we need of 9 km/s.

Modern launch vehicles have multiple stages, such that the first stage is dropped off after its fuel is used to reduce the mass that is being accelerated, then the second stage is dropped off when it's done, and so on. Consider this in the context of our high-speed rifle bullet at 4,000 fps. To increase the final speed, we'll make our first bullet large enough to hold another gun inside the first bullet, such that after you fire the first bullet, a gun pops out of that bullet and fires again, so that the second bullet is now going at 8,000 fps. This is basically what staging does for us. However, our rifle is so inefficient relative to launch vehicles that we would have to add 6 larger rifles, for a total of 8 consecutive rifles each contained in a bullet fired from a larger rifle in order to get to the velocity we need. That very first rifle is going to have to be pretty big. (See Fig. 1-7.)

Another way to get a feel for the high velocities involved is to consider someone in a vacuum falling freely toward the Earth at 1 g (9.8 m/s^2). It would take 13 min of continuous falling to reach orbital velocity, without any drag, gravity losses, or whatever.

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*ΔV, using the Greek Δ (delta) is the standard math symbol for a change in V, the velocity. Given the propensity of modern word processors and E-mail programs to mess up Greek letters, many people have found it easier to simply write out the Greek, so a change in velocity in astronautics is often written delta V. In this book we will usually write "delta V" in the text and ΔV in equations.