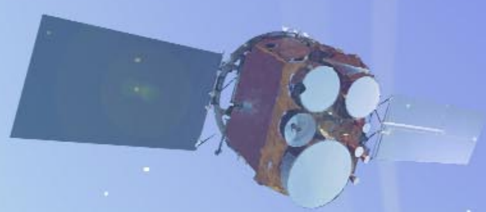

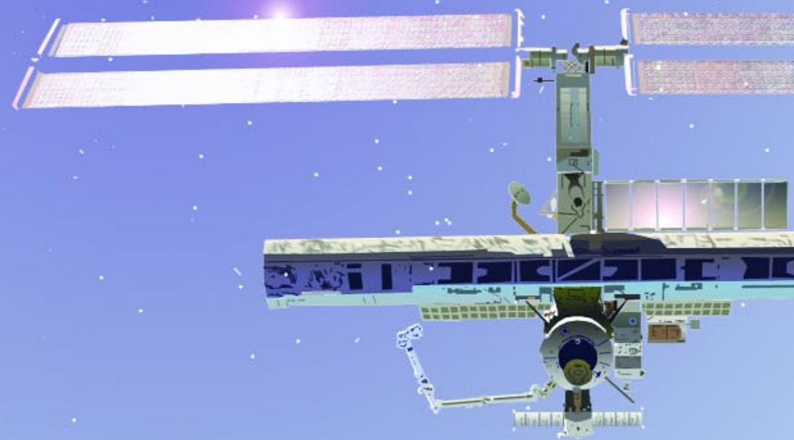

Space Primer

A student guide to the principles of space

T H E   A E R O S P A C E   C O R P O R A T I O N

A New Era in Space

Engineers and scientists are continually challenged to apply space technology to life on Earth. Today communication satellites provide access to virtually anywhere on our planet and link people together in a way never before possible. Satellites scan our planet for changing weather patterns, new natural resources and signs of the effects of human activities on the environment. The Global Positioning System enables anyone with an inexpensive receiver to pinpoint his or her location on Earth within meters. Space has become the new “high ground” for defending and maintaining peace among nations.

The men and women who conceived and developed today’s most advanced launch vehicles and space systems were once young people fascinated with chemistry, the physical laws of the universe, or the marvelous order of mathematics. Their successors will come from your generation.

The Aerospace Corporation publishes the Space Primer to provide students with fundamental information about the development of rocketry and spacecraft. The booklet is intended to stimulate your interest. If you find the material exciting, continue your study of the disciplines involved and consider a career in one of the many fields supporting space exploration and development. The sky is literally the limit when it comes to career opportunities in this new era of space.

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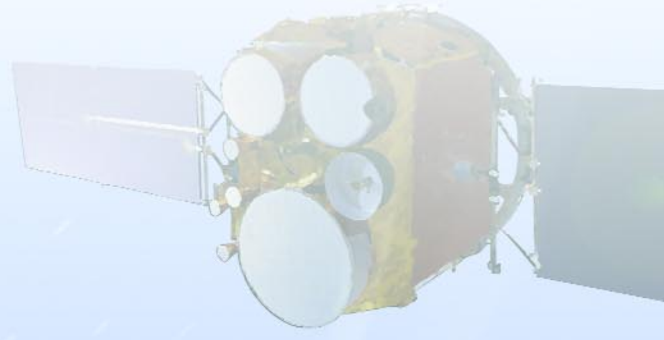


Milestones in Human Spaceflight

Oct. 4, 1957 The Soviet Union launches the first artificial satellite, Sputnik 1.

Nov. 3, 1957 Sputnik 2 carries a dog into orbit, proving that animals (and possibly humans) can survive in space.

Jan. 31, 1958 The United States launches its first satellite, Explorer 1.

April 12, 1961 Soviet cosmonaut Yuri Gagarin is the first person to orbit Earth.

May 5, 1961 Alan Shepard is the first American in space.

Feb. 20, 1962 John Glenn is the first American to orbit Earth.

June 16, 1963 Cosmonaut Valentina Tereshkova is the first woman in space.

March 18, 1965 Cosmonaut Aleksei Leonov takes a 10-minute space walk tethered to Voskhod 2.

June 3, 1965 Edward White II is the first American to walk in space, tethered to Gemini 4.

July 20, 1969 Neil Armstrong and Edwin "Buzz" Aldrin spend 21 hours on the moon.

April 19, 1971 The Soviet Union launches Salyut 1, an orbiting laboratory.

May 14, 1973 The United States launches Skylab 1, the first U.S. orbiting laboratory.

April 12, 1981 The United States launches space shuttle Columbia, the first reusable spacecraft to carry humans.

June 18, 1983 Sally Ride becomes the first American woman in space.

Jan. 28, 1986 The shuttle Challenger explodes 73 seconds after launch.

May 29, 1999 The shuttle Discovery docks with the International Space Station, a multinational, permanent, orbiting research laboratory.

Feb. 1, 2003 The shuttle Columbia breaks apart over Texas 16 minutes before it was to land in Florida.

A Brief History of Space Exploration

Humans have dreamed about spaceflight since antiquity. The Chinese used rockets for ceremonial and military purposes centuries ago, but only in the latter half of the 20th century were rockets developed that were powerful enough to overcome the force of gravity to reach orbital velocities that could open space to human exploration.

As often happens in science, the earliest practical work on rocket engines designed for spaceflight occurred simultaneously during the early 20th century in three countries by three key scientists: in Russia, by Konstantin Tsiolkovski; in the United States, by Robert Goddard; and in Germany, by Hermann Oberth.

In the 1930s and 1940s Nazi Germany saw the possibilities of using long-distance rockets as weapons. Late in World War II, London was attacked by 200-mile-range "V-2" missiles, which arched 60 miles high over the English Channel from Germany at more than 3,500 miles per hour.

After World War II, the United States and the Soviet Union created their own missile programs. On October 4, 1957, the Soviets launched the first artificial satellite, Sputnik 1, into space. Four years later on April 12, 1961, Russian Lt. Yuri Gagarin became the first human to orbit Earth in Vostok 1. His flight lasted 108 minutes, and Gagarin reached an altitude of 327 kilometers (about 202 miles).

The first U.S. satellite, Explorer 1, went into orbit on January 31, 1958. In 1961 Alan Shepard became the first American to fly into space. On February 20, 1962, John Glenn's historic flight made him the first American to orbit Earth.

"Landing a man on the moon and returning him safely to Earth within a decade" was a national goal set by President John F. Kennedy in 1961. On July 20, 1969, Astronaut Neil Armstrong took "a giant step for mankind" as he stepped onto the moon. Six Apollo missions were made to explore the moon between 1969 and 1972.

During the 1960s unmanned spacecraft photographed and probed the moon before astronauts ever landed. By the early 1970s orbiting communications and navigation satellites were in everyday use, and the Mariner spacecraft was orbiting and mapping the surface of Mars. By the end of the decade, the Voyager spacecraft had sent back detailed images of Jupiter and Saturn, their rings, and their moons.

Skylab, America's first space station, was a human-spaceflight highlight of the 1970s, as was the Apollo Soyuz Test Project, the world's first internationally crewed (American and Russian) space mission.

In the 1980s satellite communications expanded to carry television programs, and people were able to pick up the satellite signals on their home dish antennas. Satellites discovered an ozone hole over Antarctica, pinpointed forest fires, and gave us photographs of the nuclear power-plant disaster at Chernobyl in 1986. Astronomical satellites found new stars and gave us a new view of the center of our galaxy.

In April 1981 the launch of the space shuttle Columbia ushered in a period of reliance on the reusable shuttle for most civilian and military space missions. Twenty-four successful shuttle launches fulfilled many scientific and military requirements until January 1986, when the shuttle Challenger exploded after launch, killing its crew of seven.

Space Shuttle

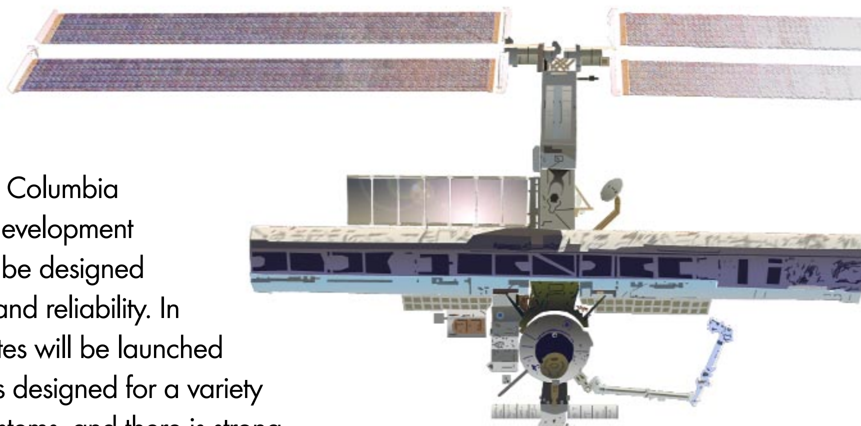
The Challenger tragedy led to a reevaluation of America's space program. The new goal was to make certain a suitable launch system was available when satellites were scheduled to fly. Today this is accomplished by having more than one launch method and launch facility available and by designing satellite systems to be compatible with more than one launch system.

The Gulf War proved the value of satellites in modern conflicts. During this war allied forces were able to use their control of the "high ground" of space to achieve a decisive advantage. Satellites were used to provide information on enemy troop formations and movements, early warning of enemy missile attacks, and precise navigation in the featureless desert terrain. The advantages of satellites allowed the coalition forces to quickly bring the war to a conclusion, saving many lives.

Space systems will continue to become more and more integral to homeland defense, weather surveillance, communication, navigation, imaging, and remote sensing for chemicals, fires and other disasters.

The International Space Station is now in orbit and permanently crewed. With many different partners contributing to its design and construction, this high-flying laboratory has become a symbol of cooperation in space exploration, with former competitors now working together.

International Space Station



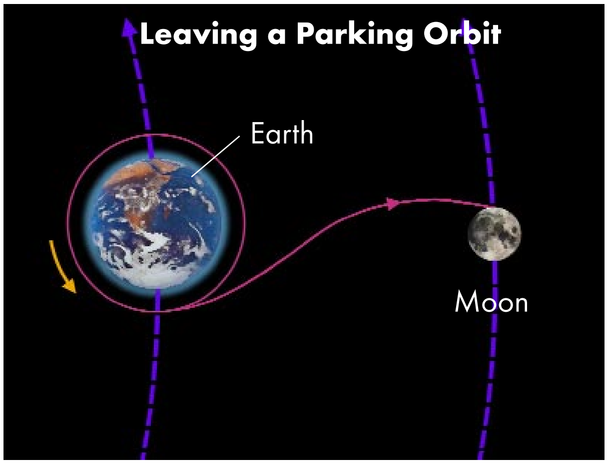
And while the space shuttle will likely continue to carry out important space missions, particularly supporting the International Space Station, the Columbia disaster in 2003 signaled the need to step up the development of its replacement. Future space launch systems will be designed to reduce costs and improve dependability, safety, and reliability. In the meantime most U.S. military and scientific satellites will be launched into orbit by a family of expendable launch vehicles designed for a variety of missions. Other nations have their own launch systems, and there is strong competition in the commercial launch market to develop the next generation of launch systems.

Paths to Space

Getting to the International Space Station, the moon, Mars, or Venus is not simply a matter of aiming directly at the object and pushing a firing button. Because these bodies, like our own planet, move in their own elliptical orbits around the sun, engineers must plan the orbits of spacecraft so that they arrive at the same point in space and time as their targets. Hitting a "target" in space is a complicated mathematical challenge, similar to shooting a high-flying duck from a racing speedboat.

During the Apollo program launches, the moon was the "duck," traveling around Earth at an average speed of 2,268 miles per hour. Earth, or "the speedboat," was revolving on its own axis as well as orbiting the sun. The launch point, Kennedy Space Center in Florida, was moving eastward at 910 miles per hour because of Earth's rotation. Earth itself was orbiting the sun at 66,000 miles per hour. Moreover, gravitational fields of the moon, sun, and Earth all were tugging at the "bullet," the Saturn rocket-launched Apollo spacecraft.

During the Apollo missions, Apollo spacecraft were boosted into Earth parking orbits, where the spacecraft coasted until they were in proper position to begin the second leg of their journeys. At the appointed time, the spacecraft were boosted out of a parking orbit and into a trajectory or path to their target, the moon.



Orbital paths rarely form a perfect circle. In many cases, the paths of objects around the sun are elliptical. The farthest point from Earth in an orbit is called the apogee; the nearest point is called the perigee.

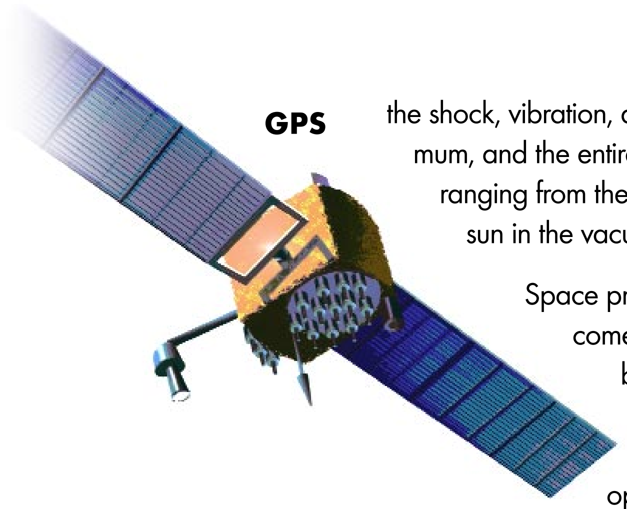
Unmanned spacecraft have landed on Mars and Venus and have flown past Mercury, Jupiter, Saturn, Uranus, and Neptune. The travel plans for long journeys into space are devised using mathematical calculations similar to those used to get a spacecraft to the moon. These calculations are far more involved, however, because the gravitational influences of the sun, the planets, and other objects that occupy our universe, such as asteroids and comets, exert their own gravitational and orbital influences on spacecraft during extended journeys from Earth out into space.

The Space System Challenge

Because remote systems operate thousands of miles away from Earth's surface and are rarely accessible once launched and in orbit, satellites must be reliable and self-sufficient. The high cost of putting a satellite into orbit means that it may have to operate for a decade or more, performing functions such as relaying communications, transmitting precision navigation signals, monitoring weather conditions, pinpointing activities on our planet, providing strategic warning, or exploring the solar system. The types of services spacecraft provide are so critical that there is little room for error or "downtime" in their operation.

Space systems rely on miniaturization techniques, innovative materials, and computer technology to enhance their performance. To get the most out of a limited payload, structures must be light and strong, electronics must be microminiaturized and densely packed, and optical and radio-frequency devices must be built with great precision. That typically means a compact package that may have more than 200,000 parts. These parts, which may include deployable devices with intricate mechanisms, must operate reliably after being subjected to

GPS



the shock, vibration, and acceleration of launch. Power consumption must be kept to a minimum, and the entire spacecraft must be able to pass unaffected through temperatures ranging from the intense cold of Earth's shadow to the radiation and intense heat of the sun in the vacuum of space.

Space projects are unforgiving of neglect or human error, particularly when it comes to engineering. Their real-time performance cannot be tested fully before they are sent into space because the space and launch environment cannot be fully simulated here on Earth. An aircraft like the B-2 is tested very carefully for a year or more before it becomes operational; but a space booster like the Titan IV rocket carrying a military satellite the size of a school bus becomes operational the first time it flies. All systems must work the first time—and every time—throughout a satellite's working life.

Today the majority of payloads are unmanned and carried into space by expendable boosters, each of which has a demanding task complicated by many issues and conditions. The booster is unable to return to Earth if something goes wrong, its structure is highly stressed by launch loads, and its rocket engines operate at very high temperatures. As the booster ascends through Earth's atmosphere it endures an enormous range of aerodynamic conditions. Its guidance system must operate from the crawl of liftoff to the hypersonic speed of orbit injection with pinpoint accuracy. All information to and from the booster rocket must be carried by communication links, and the rocket's payload must be released without human intervention.

Careful technical oversight is the only way to ensure that the system will operate the first time and throughout the mission, which might last a decade or more. Technical oversight requires the skills to get the highest performance levels out of each item as well as the modeling and simulation capabilities to determine how variations in individual components affect the performance of the entire system.

Atlas V

Success in space systems results from dedication to detail, repeated testing and careful checking—up to the final minutes before launch—to find and fix any potential problems. The technical skills needed to successfully master space systems require a high level of engineering talent, study and training.

How a Rocket Works

The "Star-Spangled Banner" speaks of "the rockets' red glare" at Fort McHenry in the War of 1812. Those were British rockets, fired in an unsuccessful attempt to destroy the American fort, located in Baltimore. Conceived and designed by Sir William Congreve 12 years earlier, the so-called "Congreves" were not the first war rockets. Some six centuries before the War of 1812, the Chinese connected a tube of primitive gunpowder to an arrow, creating an effective rocket weapon to defend against the invading Mongols.

According to Chinese legend, a Chinese official named Wan Hoo designed a chair equipped with two kites and 47 gunpowder rockets in 1500 A.D. The rockets were ignited, presumably with "punk," a dry, spongy material prepared from fungi and used to ignite firework fuses. When the ensuing explosion and smoke cleared, Wan Hoo and his innovative chair were gone.

Although Wan Hoo's flight was likely his last, actual attempts at human spaceflight didn't get off the ground until much later in history during the late 1950s and 1960s.

The early Chinese "fire arrows," the British Congreves, and even our familiar Fourth of July skyrockets have certain things in common: they are basically tubes of gunpowder lighted at the bottom, where explosive thrust moves them in the opposite direction. They are similar in principle to the space booster rockets used to launch payloads into space today.

In both cases some type of fuel is burned with an oxidizer, or propellant, in a combustion chamber, creating hot gases accompanied by high pressure. In the combustion chamber these gases expand, pushing equally in every direction. A relatively small hole, called the throat, exists at the bottom of the chamber and leads to an exhaust nozzle that flares out like a bell. The expanding gasses pushing in all directions inside the chamber push through the throat and out against the widening sides of the nozzle.

As a given volume of gas reaches the edge of the nozzle, it spreads out over a much greater area than at the throat, so that the pressure on the edge of the nozzle is less than that within the combustion chamber.

The sum of all the pressures inside the chamber acting on the chamber and nozzle skirt in a forward or upward direction is more than the sum of all the pressures acting in a rearward or downward direction. This net difference makes the rocket engine and the vehicle attached to it–its fuel and oxidizer (propellant) tanks, plus payload or spacecraft–lift from the launch pad.

Rocket Principle

You can demonstrate this principle by blowing up a balloon.

After you blow up the balloon, hold the opening tightly closed. The air inside the inflated balloon is made up of gases that are pushing equally in all directions. Let the balloon go and it will fly across the room or up to the ceiling. The opening you have released is the exhaust nozzle, where the gases escape and expand. Enabling the gases to pass through the opening at the rear of the balloon reduces the pressure inside the balloon. The pressure opposite the nozzle at the front of the balloon remains unchanged, however, and the higher pressures being released at the rear of the balloon push it forward.

The balloon's flight will be erratic because it has no guidance system, fixed shape, or exhaust control.

The balloon's flight demonstrates Sir Isaac Newton's Third Law of Motion: "To every action, there is an equal and opposite reaction."

In the inflated balloon, the pressure of the gases inside is the "action." The counter-pressure of the balloon walls holding the gases in is the "opposite reaction." When these two factors are in balance, the gas in the balloon remains at rest. The balloon also remains at rest because its weight is balanced by the force you exert to hold the balloon shut and because the force exerted by the internal gas on each part of the balloon is balanced by a force of the gas outside of the balloon.

Newton's First Law of Motion says in essence: "A body at rest will remain at rest…unless an unbalanced force is exerted upon it."

When an opening or nozzle is provided for the gases inside the balloon, an imbalance occurs because the internal gases can escape through this low-pressure area. There is no longer an equal pressure maintaining the balance. The internal pressure of the gases creates an unbalanced force that drives the gases through the opening.

The side of the balloon opposite the opening is now experiencing a force that is no longer balanced by an equal and opposite force on the side of the balloon where the opening is. This unbalanced force on the balloon in a direction opposite to the side of the balloon where the internal gases are escaping through the hole makes the balloon move forward.

Because Newton's laws were postulated in the 17th century, some people might say, "All the basic scientific problems of spaceflight were solved 300 years ago. Everything since has been engineering."

Many scientific developments in mathematics, chemistry, and other disciplines were needed, however, before man could apply Newton's basic principles to achieve controlled spaceflight.

Liquid and Solid Rockets

As he sought to develop operational rockets, U.S. scientist Dr. Robert Goddard found in the early years of the 20th century that many people rejected his ideas as fantastic. Some opponents insisted rockets would not operate in the vacuum of space. They said there would be no air to push against and no air to sustain the burning of the rocket fuel once a spacecraft reached the vacuum of space.

On the first point, Goddard believed Newton's theories of action, reaction and unbalanced forces were universal.

On the second point, his answer was to take along the needed oxygen in extremely cold liquid form plus a liquid fuel, such as kerosene, and pump the two together into a combustion chamber. He proved both points initially in his laboratory. The test device not only operated in a vacuum but actually operated more efficiently—with more thrust per pound of propellant—than in the normal air outside.

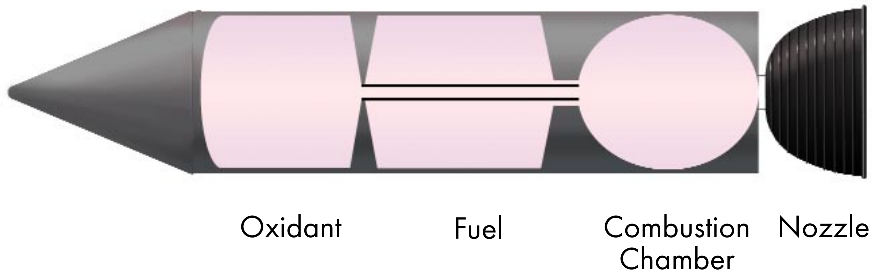
Goddard successfully launched the world's first liquid-fuel rocket in Massachusetts in 1926. Rudimentary by today's standards, the rocket was ignited by a blowtorch and flew about 184 feet in two-and-a-half seconds.

Today's mighty space launch vehicles are, in principle, refinements of Goddard's simplistic rocket.

Solid Propellants

Another kind of rocket has come into wide use as part of military weapon systems and spaceflight boosters. This is the solid-propellant rocket, such as the Air Force's intercontinental ballistic missile, or ICBM, and the Navy's submarine-launched fleet ballistic missile, or FBM. The space shuttle and other space boosters use both solid- and liquid-fueled rockets as a part of their "stack."

Liquid-Fuel Rocket



There is a big difference between these solid rockets and the early solids such as the Chinese fire arrows and the British-made Congreves.

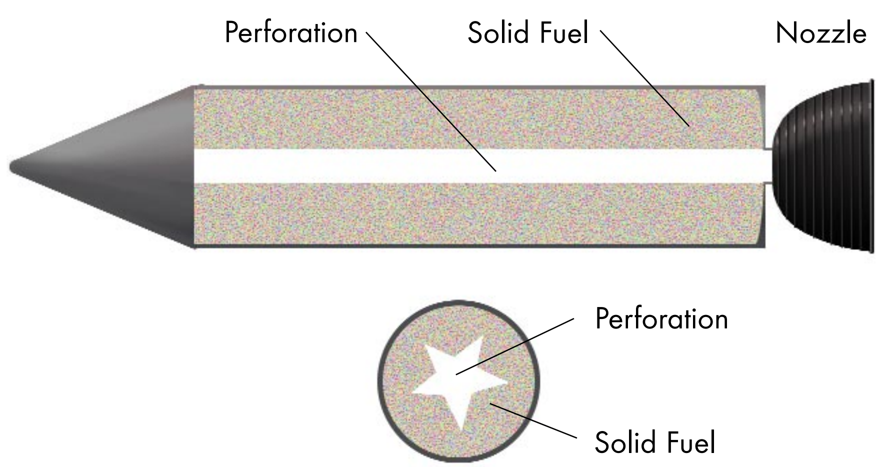
It is true those modified skyrockets had one characteristic necessary for spaceflight, even though it was not recognized then: their basic gunpowder propellant would ignite in a vacuum because the ingredients of gunpowder contain an oxidizer.

But the relatively small amount of thrust per pound produced by ignited gunpowder prevented its use as a propellant. Producing only a relatively small amount of thrust per pound—a range of two miles for rockets—was considered good through the 19th century.

As conventional guns gained greater range and accuracy, military rockets fell from favor until they were virtually forgotten by all, except for a few like Dr. Goddard, who realized that liquid fuels held much more promise than the solid propellants of his day.

New interest in solid propellants began during and after World War II from experimental work at the Jet Propulsion Laboratory using a liquid polymer developed for industrial use as a propellant. (A polymer is made by stringing identical molecules together, necklacelike, to create larger molecules without changing the basic chemical composition.) Polymers are the basis of synthetic rubber and plastics and include substances like nylon.

Solid-Fuel Rocket



It was discovered that mixing a chemical oxidizer and fuel, often aluminum powder, with the polymer to provide the needed oxygen with the polymer resulted in a substance with a consistency similar to peanut butter. This substance could be poured into forms and baked into a rubbery solid material that burned furiously when ignited and created large volumes of gases, producing much greater thrust per pound than gunpowder.

In solid rockets the propellant mixture is called the "grain," a word carried over from gunpowder days. The perforation, a carefully designed hole through the propellant, is formed when the fuel is cast to fit into the rocket's cavity. Varying the size and shape of the perforation determines the rate and duration of combustion, which controls the thrust.

Liquid- and solid-fuel rockets each have special capabilities, advantages, and applications. For military purposes the "rifle-readiness" of solid rocket motors gives them an advantage over liquid rockets. There is no need to lose the precious minutes required for fueling liquid propellants with a solid motor.

Liquid rockets are often preferred for space missions because of their more efficient use of propellants. Because of their high thrust and simplicity, however, solid-fuel rockets are also used with space launch vehicles. Some launch vehicles, such as the space shuttle, combine both liquid engines and solid motors.

Thrust

Whether powered by liquids or solids, rocket systems are propelled by gas pressure resulting from fuel combustion. The force driving them forward is called thrust.

If the rocket system—the liquid or solid booster plus payload—is to move upward against gravity, the thrust must be greater than gravity's counteracting downward pull.

If you hold a one-pound ball in the palm of your extended hand, you are exerting one pound of thrust. In doing so you are burning fuel and oxygen—the foods you eat and the air you breathe—to exert the energy to cancel the gravitational pull on the ball. The ball is not going up. If you let it go, the ball will be pulled to the ground by gravity.

Now bring your hand up quickly, so the ball leaves your palm and flies upward a bit farther before falling back to the ground.

You have done something more than merely cancel gravity for a moment. You have imparted thrust of more than one pound to the ball.

The Atlas was the first U.S. intercontinental ballistic missile. It was also used extensively as a space booster. Fully fueled, the Atlas rocket weighed about 260,000 pounds (1,160,000 newton). Its engines developed a thrust at liftoff of more than 360,000 pounds of force (1,600,000 newton), considerably more than its total initial weight.

The ratio between these two values is called the thrust-to-weight ratio of the booster. At liftoff, the Atlas IIA thrust-to-weight ratio is 1.2, enough to accelerate a payload to speeds of 8 kilometers per second (18,000 miles per hour), sending the Atlas IIA to targets or orbits many thousands of miles away. As propellants burn, the thrust-to-weight ratio increases, and the booster continues to accelerate at higher rates.

There is a direct analogy here to the experiment with the one-pound ball mentioned above. Your hand and arm are, in effect, the Atlas rocket with its engines and tanks of fuel and liquid oxygen. The ball is the payload.

The upward swing of your hand duplicates the powered-flight phase of an Atlas launch. The instant you stop your hand is similar to the instant of engine burnout or shutdown on the Atlas, when the rocket's fuel is exhausted or the engines are stopped by plan.

From this instant, both the ball and the payload begin decelerating, slowing down in their ascent. Gravity pulls each back toward Earth.

How have we put vehicles and people into orbit around Earth, landed scientific payloads and humans on the moon, sent spacecraft to land on Mars with an automated laboratory, and launched other space probes to help unravel the mysteries of our planetary neighbors?

By exerting more force, or thrust, to a given payload, it will achieve a much higher velocity before thrust termination. It will also go much farther from Earth before gravity succeeds in pulling it back. Velocity, therefore, is a critical factor.

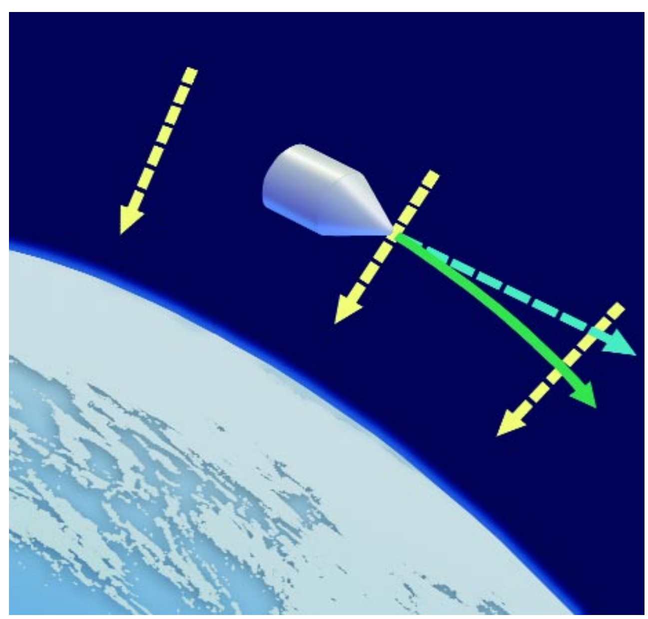
The velocities needed for specific space missions were calculated long before spaceflight was possible. To put an object into orbit around Earth, for instance, a velocity of at least 8 kilometers per second (18,000 miles per hour) must be achieved, depending on the precise orbit desired. This is called orbital velocity.

Orbital velocity is attained when the vehicle is moving in the right direction, fast enough to miss Earth as it falls back. The actual resulting course keeps it in space. In effect, it is falling continually around Earth.

To break away from Earth's gravity for distant space missions, a velocity greater than 11 kilometers per second (25,000 miles per hour) is required. This is called escape velocity.

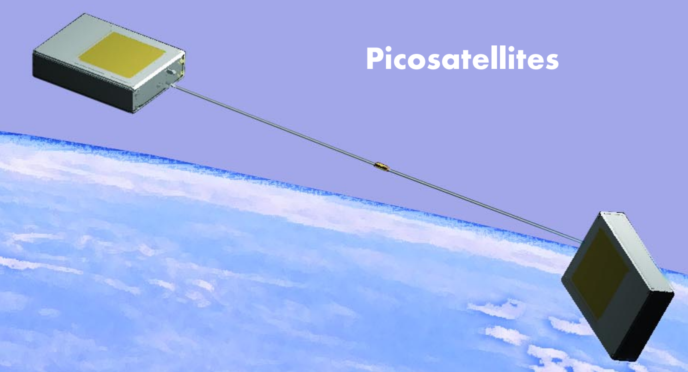
During the early years of spaceflight, remarkable achievements were made in space, even though the rockets available had less thrust than users of space might have liked. How? The payloads were kept as small and as light as possible. America's first artificial satellite, Explorer 1, weighed only 14 kilograms, or 30.8 pounds.

Gravity's Pull



Bigger and more powerful rockets are available today. The Delta IV Heavy generates 8.7 million newton (2 million pounds) of thrust at liftoff. NASA's Saturn V generated 33 million newton (7.5 million pounds); and the space shuttle has about 28 million newton (6.25 million pounds) of thrust.

Sometimes, however, small is still beautiful. Today new designs for "microsatellites" and "nanosatellites" are paving the way for new space applications of very small but capable spacecraft that are easy to launch. The "picosatellite" built by The Aerospace Corporation weighs only 0.275 kilograms (about half a pound) and is the smallest spacecraft to be launched and successfully communicated with while in orbit. Perhaps someday swarms of tiny spacecraft will perform the same functions carried out by heavier space vehicles today.



Picosatellites

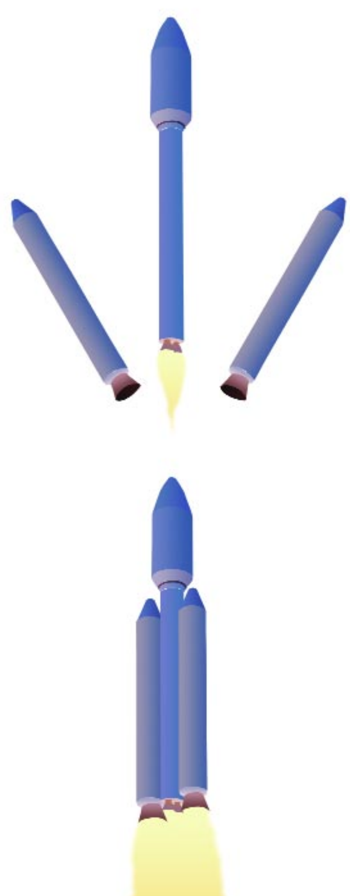
Packages of Energy

To achieve the greater and greater velocities required to send a given mass farther and farther out into space, higher thrust must be exerted or it must be applied for a longer period of time.

The principles of physics tell us the longer thrust is exerted, the faster a rocket will go. For example, providing its mass does not change, a vehicle starting from rest under constant net thrust will be going 100 times faster after 100 seconds than after one second.

For rockets, mass does not remain the same; it decreases. As each kilogram of propellant is burned, the mass of the ascending vehicle becomes one kilogram less, and large rocket engines may burn hundreds of tons of propellant in seconds. As a result, the same thrust has much less mass to accelerate. The decrease in weight allows an increase in acceleration.

Staging



This principle is used in the concept of "staging." A space launch vehicle usually consists of a number of sections known as stages. After the first rocket stage accelerates the entire vehicle and finally burns out, its tanks and motors are discarded because they are no longer needed and add unnecessary weight that slows acceleration. The same happens in the second and subsequent stages. The payload is finally all that remains, having been accelerated to the necessary velocity.

The Titan IV heavylift space launch vehicle looks like three rockets joined together side by side. On the outside are huge solid-fuel motors with a combined thrust of more than 3 million pounds. When these burn out, they fall away from the central core, which then continues the mission. The middle part is itself a two- or three-stage vehicle, but liquid-fueled.

Before the Titan IV booster, a smaller version of the Titan family (Titan III) was used on the Viking spacecraft, which was used to "soft land" instruments on Mars. The Viking spacecraft was mounted on a Centaur rocket, which in turn was mounted on top of a Titan III booster. In this case the solid motors burned and dropped away; then each stage of the Titan III core burned and dropped away until the Centaur and its Viking Mars spacecraft continued alone. At the proper moment, Centaur's own engines were started and imparted the additional thrust to give the necessary velocity for the spacecraft to continue to Mars.

In addition to mass, other factors affect velocities necessary for space operations. The higher a rocket goes from Earth, the thinner the atmosphere becomes, decreasing the amount of friction or drag imparted on the rocket. In space there is very little if any atmosphere and essentially no friction or drag.

The pull of gravity becomes less the farther you move away from Earth's center. This effect is not significant for satellites orbiting a few hundred miles above Earth, but it becomes important if the spacecraft is to be sent thousands of miles into space.

Packaging the energy of a rocket vehicle into stages that can be discarded as they burn out has been the secret of launching into space. The number of stages may vary from two to five or even more.

Solving Problems

In the early days of rocketry many aircraft features were adapted to the new vehicles. Dr. Robert Goddard placed vanes, similar to the tail surfaces of an airplane, on the nozzle section of his early rockets.

Turning these one way or the other deflected a portion of the exhaust gases, pushing the rocket's tail in the opposite direction.

The mere presence of the vanes, however, reduces the efficiency of the rocket. Whatever amount of downward thrust pushes against the vanes cancels out an equal amount of the thrust's upward push inside the rocket.

The solution developed for large rockets and space boosters was to "gimbal" the nozzle. A gimbal is a pivot device that allows the entire nozzle, and the flow of exhaust gases, to be swiveled in any desired direction. This is how the rocket's course in the opposite direction is controlled.

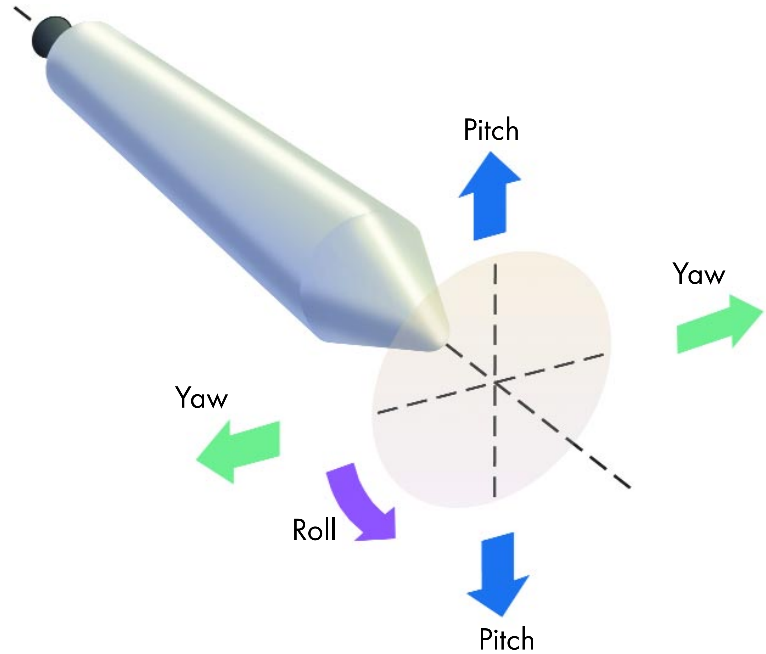
Rockets can be guided by radio signals from the ground or by equipment and prerecorded instructions placed on board.

Inertial guidance is a common form of on-board control. It is an automatic navigation system that senses, through gyroscopic devices and acceleration-measuring devices, the vehicle's position and speed, compares them with the planned flight path, and gives orders for necessary adjustments.

A number of missile and space programs use inertial guidance. Inertial guidance signals cannot be detected outside the vehicle or be disrupted by radio commands.

Another problem is stability in flight. There are three distinct motions to be controlled and corrected quickly before the vehicle begins undesirable tumbling. These motions are "pitch," "yaw," and "roll."

Rocket Motions



Extend your arm straight out in front of you. When you swing your arm up and down, you are describing pitch.

When you swing your arm from side to side horizontally, you are describing yaw.

Keeping your arm straight out in front of you, rotate your arm so that the palm of your hand faces upward then downward. This is roll.

Airplane fins are of no help for controlling roll, pitch, or yaw outside Earth's atmosphere because there is no air to push against in space. Instead, spacecraft have small gimbaled engines or extremely small jets, using the reaction principle, to provide control.

Those small rocket engines are used to produce short bursts of very small thrust in the direction opposing the undesirable motion, damping it out. They are often powered simply by a small supply of cold gas under pressure.

Another method for stabilizing certain unmanned payloads is to make them spin like a gyroscope. The payload spinning at a preplanned rate gives it stability in flight, just as the rifling in a gun barrel spins a bullet for stability.

Reentry into the atmosphere is a critical period in any space vehicle's return to Earth. Shooting stars, or meteors in the night sky, are the most dramatic example of what can happen when an object plunges through Earth's atmosphere at high speeds. As the air becomes thicker, its particles create such friction that the descending body becomes increasingly hotter until it first glows, then burns.

Covered by heat shields, spacecraft can survive their descent through the atmosphere. Three kinds of heat shields prevent fatal heat from reaching astronauts or instruments.

The first type is known as the heat sink. Good examples of heat sink are the early nose cones of the Atlas and Thor missiles, which were made of copper and could absorb and store a large amount of heat without melting. The second type, which is now used instead, is called the ablative type, where special materials coat the forward surface of the vehicle and dissipate the reentry heat by ablation—boiling and bubbling away into vapor, using up the heat energy before it reaches the inside. The third type is a protective surface capable of withstanding high temperatures, such as the ceramic tile used on the space shuttle. The shuttle is built to survive intense heat, while insulation prevents that heat from reaching the internal parts of the spacecraft.

Military Space Systems

Space systems have made an irreplaceable contribution to keeping the peace for more than three decades. They perform many functions important to U.S. military forces and to the nation.

- Communication satellites provide reliable communication for command and control of land, sea, and air forces.
- Meteorological satellites provide up-to-date weather information to Army, Air Force, Navy, and Marine field units.
- Navigation satellites provide accurate positioning (within a few meters) for troops, planes, and ships.
- Space-based surveillance systems provide treaty-monitoring capability during peacetime and essential warning during conflict.

Because of these advantages, space systems are increasingly being used by the military.

Careers in Aerospace

The space industry at 40-plus years is still vigorous. Humans have achieved orbit, landed on and explored the moon, and sent spacecraft on incredibly long exploratory journeys to the planets, the sun, and the stars.

We have achieved marvels with satellites in space: worldwide voice and television communications; precise navigation of planes and ships; weather forecasting; detecting, monitoring and surveying of Earth resources; and various national defense objectives.

Space research has achieved great advances in materials science—light and durable materials; computers and miniaturization; space physics; medical and pharmaceutical applications; and, in a less obvious arena, technical management. There is an ongoing critical need for trained, skilled, imaginative, and dedicated people in all of these fields.

The men and women who work for organizations like The Aerospace Corporation are part of a challenging and rewarding frontier. If you choose to pursue studies in an area of science or engineering, we hope you will consider applying your talent to the national space effort.

Glossary

ablation The process by which heat is removed from a reentry body through the melting, vaporizing, and scouring off of special materials as the body is heated by friction with the atmosphere.

apogee In an object's orbit, the farthest point from Earth.

gimbal A pivot device that allows the entire nozzle and the flow of exhaust gases to be swiveled in any desired direction, steering the rocket's course in the opposite direction.

heat shield Special surface that protects a space vehicle form the heat of reentry.

microsatellite A small but capable spacecraft weighing 10 to 100 kilograms (22 to 220 pounds).

nanosatellite A very small but capable spacecraft weighing 1 to 10 kilograms (2.2 to 22 pounds).

newton The unit of force in the meter-kilogram-second system equal to the force required to impart an acceleration of one meter per second per second to a mass of one kilogram.

nozzle The part of a rocket that accelerates the exhaust gases produced by the burning propellants to produce thrust.

orbit Path of a spacecraft or heavenly body around a parent body where gravity is balanced by inertial forces.

parking orbit The initial orbit achieved for a vehicle that is to be sent into space as a probe, for vehicles to be joined in rendezvous, or for reentry vehicles to be returned to Earth.

payload The load carried by a spacecraft consisting of things (such as instruments) necessary to the purpose of flight.

perigee In an object's orbit, the nearest point from Earth.

picosatellite A tiny satellite weighing less than 1 kilogram (one-half pound).

propellant The solid or liquid fuel and solid or liquid oxidizer of a rocket that are burned to produce the hot gases that flow through the nozzle to provide thrust.

reentry The event that happens when a space vehicle leaves orbit and reenters Earth's atmosphere.

satellite Any body held in an orbit by the gravitational field of another body. Satellites can be artificial or natural.

stack A complete space launch vehicle as assembled on the pad with booster rockets and payload.

stage One unit in a multistage rocket. The stage has its own engines and fuel supply and may have its own guidance system. The booster is the first stage of a multistage rocket.

thrust The amount of push or force generated by a rocket engine measured in pounds or newtons.

throat The smallest part of a rocket nozzle.

The Aerospace Corporation

The Aerospace Corporation is a private, nonprofit company established in 1960 to serve and support U.S. national-security space projects and programs. We operate a federally funded research and development center specializing in space systems and technologies. Aerospace provides systems engineering, architecture and development support to the U.S. government, principally the United States Air Force. We also perform national-security-related work for other agencies in the national interest.

Our primary resource is people. Technical and scientific professionals of the highest caliber are responsible for a corporate tradition of excellence. Nearly half of our employees are members of the technical staff. Two-thirds of the technical staff hold advanced degrees in a broad range of disciplines, and about one-fourth of those staff members hold doctoral degrees.

Our corporate headquarters is located in El Segundo, California, adjacent to Los Angeles Air Force Base. Regional offices exist at Air Force launch sites on the East and West coasts; at Johnson Space Center in Texas; at satellite operations and technology centers in California, Colorado, and New Mexico; and in the Washington, D.C., area.

Visit us on the Web at http://www.aero.org

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THE AEROSPACE CORPORATION

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